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BUSINESS LOGISTICS IN MODERN MANAGEMENT

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C O N T E N T

FOREWORD

It is with great pleasure and anticipation that I welcome you to the Proceedings of the 23rd international scientific conference Business Logistic in Modern Management (BLMM20023) - an event that has become a cornerstone in the world of logistics and supply chain management in this region. As we gather here to reflect on the wealth of knowledge, insights, and innovations presented at BLMM2023 Conference, it is a moment to celebrate the incredible strides made in the field and to look forward to the exciting future of logistics. The field of logistics and supply chain management has never been more pivotal than it is today. It plays a central role in the global economy, influencing the way goods and services move, businesses compete, and societies function. The challenges we face in supply chain management are as diverse as they are complex, from the ever-evolving demands of consumers to the intricacies of global logistics and the imperatives of sustainability.

For the 23rd year in a row, the Faculty of Economics and Business in Osijek, Josip Juraj Strossmayer University in Osijek, has organised the international scientific conference BLMM 2023. On the 5th and 6th October 2023, 85 researchers and academics representing 14 countries (Czech Republic, Egypt, Estonia, Germany, Hungary, Lithuania, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain and Croatia) have convened at this conference to share their expertise, exchange ideas, and engage in discourse that pushes the boundaries of supply chain knowledge.

The Organising committee of the BLMM2023 Conference has received 45 papers, and 36 of them successfully passed the international, double-blind review process and were presented during two days of the Conference. The Conference sessions were characterized by a fruitful and affirmative series of discussions. In coordination with their Editorials, 8 selected papers were sent for publishing process in respectably indexed scientific journals: *Logforum Scientific journal of Logistics* and *Econviews: Review of Contemporary Business, Entrepreneurship*. Consequently, Proceedings of the 23rd international scientific conference Business Logistics in Modern Management consists of 26 papers covering a wide range of supply chain management and logistics topics.

As you explore these proceedings, you will be immersed in the world of supply chain science, where theories are tested, solutions are devised, and innovations are born. Proceedings of 23rd international scientific conference BLMM2023 are divided into six chapters. First five papers form first chapter, titled *Macrologistics performance*, covering different analysis and evaluations of logistics capabilities on national and regional level. Chapter *Reverse green logistics* consists of five papers in quest for sustainability both in downstream and upstream physical flows. The following chapter, *Resilience and risk management,* is this Conference's contribution to very topical questions about how to increase the resilience of the supply chain, mitigate possible risk in the supply chain, and improve performance of especially humanitarian supply chains. The following chapter is focused on different *Optimization methods* in logistics and supply chain management, and it is followed by chapter on *Supply chain solutions implementation* examples. The final chapter of a Proceedings deals with *Digitalization in logistics with* – from blockchain, to logististics softwares and IoT data integrators.

The keynote speaker of BLMM2023 Conference was Dr. Marton Lany. His presentation, drawing from the rich experience of Kuehne + Nagel in the logistics industry, provided a remarkable perspective on the challenges and opportunities that the logistics sector faces in today's dynamic landscape. Ability to articulate complex concepts and trends of intermodality in a clear and engaging manner captivated our audience and left a lasting impression.

While we are sincerely thankful to all authors who decided to participate in BLMM2023 Conference, it is through the collective synergy of reviewers, editors, authors, and the organizational board that made the BLMM2023 Conference possible. Together, we have created a platform for the exchange of ideas, the dissemination of knowledge, and the cultivation of meaningful connections.

In Osijek, October 5th, 2023.

Davor Dujak,
Editor

I. MACRO LOGISTICS PERFORMANCE

EVALUATION OF TRANSPORT AND STORAGE PERFORMANCE OF THE EUROPEAN UNION AND SERBIA BASED ON SF-WASPAS AND WASPAS METHODS

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Abstract

Transport and storage performance research is in principle very challenging, current, significant and complex. Based on that, this paper makes a comparative evaluation of the performance of transport and storage in the European Union and Serbia. The obtained empirical results show that, according to the SF-WASPAS method, out of the five observed countries of the European Union (Germany, France, Italy, Croatia and Slovenia) and Serbia, Germany ranks first in terms of transport and storage performance. Followed by: Italy, Slovenia, Croatia, France and Serbia. Serbia has the worst performance of transport and storage. According to the classic WASPAS method, the top five countries of the European Union in terms of transport and storage performance are, in order: Germany, France, Spain, Italy and Poland. Luxembourg has the worst performance in transport and storage. The performance of transport and storage in Croatia is better than in Slovenia. In Serbia, the performance of transport and storage is poor. By comparison, they are worse than in Croatia and Slovenia. The performance factors of transport and storage are: economic and political climate, economic activity, company size, number of employees, turnover, added value, personal costs, the Covid-19 pandemic and the energy crisis. Effective control of critical factors can significantly influence the achievement of the target performance of transport and storage. Digitization of the entire transport and storage business plays a significant role in this.

Key words: performance, transport and storage, European Union, Serbia, SF-WASPAS method, WASPAS method

1. INTRODUCTION

The problem of evaluating the performance of transport and storage is very challenging, continuously current, important and complex (Kara, 2022; Zhang &Wei,

2023). Because the performance of transport and storage is maintained on the performance of all other sectors. Based on that, the subject of research in this paper is the analysis of the performance factors of transport and storage in the European Union and Serbia. The aim and purpose of this is to investigate the given problem as complex as possible in order to improve performance in the future by taking adequate measures. Recently, in order to evaluate the performance of all managers as accurately as possible, which means both transport and storage, different multi-criteria decision-making methods are increasingly being applied in the literature (Lukić & Hadrovic, 2021, 2022; Tadić *et al.* , 2021; Ulutas *et al.* , 2021; Osintsev, 2021; Saaty, 2008; Popović *et al*., 2022; Iao *et al*., 2022; Đalić *et al*., 2020; Kovač *et al*., 2021; Miškić *et al*., 2021; Puška *et al*. , 2021; Stević & Brković, 2020; Stević *et al*., 2020; Stanković *et al*., 2020; Trung, 2021; Lukić, 2022; Mešić *et al*., 2022). These include the SF-WASPAS and WASPAS methods. Because the multi-criteria analysis ensures, compared to the classical methodology, a more accurate assessment of the performance of transport and storage as a basis for improvement in the future of taking adequate measures (Thanh, 2022; Do Duc Trung, 2022). Continuous analysis of transport and storage performance factors, in the specific case of the European Union and Serbia, is a key assumption for improvement in the future by taking adequate measures (Lukic, 2022a,b,c,2023a,b,c,d,e,f). This manifests the primary research hypothesis in this paper. In the methodological sense of the word, following the given research hypothesis, the application of both SF-WASPAS and WASPAS methods plays a significant role in the evaluation of transport and storage performance (Jafarzadeh Ghoushchi *et al*., 2023). In this paper, they are applied to the case of a comparative analysis of the transport and storage performance of the European Union and Serbia. The necessary empirical data for the research of the treated problem in this paper were collected from Eurostat. They are "manufactured" in accordance with all relevant standards so that there are no restrictions regarding the international comparison of the empirical results obtained in this paper.

2. METHODOLOGY

The primary methodology for researching the transport and storage performance of the European Union and Serbia is the classic WASPAS method. At the same time, the weighting coefficients of the criteria were obtained using the SF-WASPAS method. The methodological process of researching the transport and storage performance of the European Union and Serbia using the classic WASPAS method takes place as follows:

Two methods are used in the research of the treated problem in this paper: the SF-WASPAS method and the classic WASPAS method. We will briefly point out their characteristics.

2.1. SF-WASPAS method

The extended WASPAS (Weighted Aggregated Sum Product Assessment) method with spherical fuzzy sets is a newer method of multi-criteria decision making. MCDM (multi-criteria decision-making) problem it can be expressed as a decision matrix whose elements indicate the evaluation values of all alternatives in relation to each criterion under spherical fuzzy circumstances (Kutlu Gundogdu & Kahraman, 2018, 2019). Suppose that is a $X = \{x_1, x_2, \dots, x_m\}$ $(x \geq 2)$discrete set of m feasible alternatives, $C = \{C_1, C_2, \dots, C_n\}$ is a finite set of criteria, and is a $w = \{w_1, w_2, \dots, w_n\}$weight vector of criteria satisfying the condition that $0 \leq w_j \leq 1$i $\sum_{j=1}^{n} w_j = 1$. SF-WASPAS (Spherical Fuzzy WASPAS) method proceeds through several steps.

Step 1: Decision makers (DMs) evaluate the criteria based on the linguistic terms shown in Table 1.

Table 1 Linguistic terms and their corresponding spherical fuzzy numbers

Linguistic terms	(μ, v, π)
Absolutely more Importance (AMI)	(0.9, 0.1, 0.1)
Very High Importance (VHI)	(0.8, 0.2, 0.2)
High Importance (HI)	(0.7, 0.3, 0.3)
Slightly More Importance (SMI)	(0.6, 0.4, 0.4)
Equal Importance (EI)	(0.5, 0.5, 0.5)
Slightly Low Importance (SLI)	(0.4, 0.6, 0.4)
Low Importance (LI)	(0.3, 0.7, 0.3)
Very Low Importance (VLI)	(0.2, 0.8, 0.2)
Absolutely Low Importance (ALI)	(0.1, 0.9, 0.1

Source: Kutlu Gundogdu, F., Cengiz Kahraman, C. (2019)

Step 2: Aggregating the assessment of each decision maker (DM) using the Spherical Weighted Arithmetic Mean (SWAM).

$$SWAM_w(\tilde{A}_{S1}, \dots, \tilde{A}_{Sn}) = w_1\tilde{A}_{S1} + w_2\tilde{A}_{S2} \dots\dots w_n\tilde{A}_{Sn} = \left\{ \left[1 - \prod_{i=1}^{n} \left(\mu_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n} \upsilon_{\tilde{A}_{Si}}^{w_i}, \left[\prod_{i=1}^{n} \left(1 - \mu_{\tilde{A}_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n} \left(1 - \mu_{\tilde{A}_{Si}}^2 - \pi_{\tilde{A}_{Si}}^2\right)^{w_i}\right]^{1/2} \right\} \quad (1)$$

Step 2.1: Aggregating criteria weights.

In any case, it cannot be assumed that all criteria are equally important. To obtain the weights, all the individual opinions of the decision maker regarding the importance of each criterion should be aggregated.

Step 2.2: Constructing an aggregated spherical fuzzy decision matrix based on the opinion of the decision maker.

Denote the evaluation value of the alternative $x_i(1,2,\dots,m)$with respect to the criteria $C_j(1,2,\dots,n)$ with $C_j(\tilde{x}_i)=(\mu_{ij},\nu_{ij},\pi_{ij})$ and $\tilde{x}_{ij}=\left(C_j(\tilde{x}_i)\right)_{mxn}$ we arrive at a spherical fuzzy decision matrix. For an MCDM problem with SFS (Spherical Fuzzy Set), the decision matrix $\tilde{x}_{ij}=\left(C_j(\tilde{x}_i)\right)_{mxn}$ can be constructed as

$$\tilde{x}_{ij}=\left(C_j(\tilde{x}_i)\right)_{mxn}$$
$$=\begin{pmatrix} (\mu_{11},\nu_{11},\pi_{11}) & (\mu_{12},\nu_{12},\pi_{12}) & \cdots & (\mu_{1n},\nu_{1n},\pi_{1n}) \\ (\mu_{21},\nu_{21},\pi_{21}) & (\mu_{22},\nu_{22},\pi_{22}) & & (\mu_{2n},\nu_{2n},\pi_{2n}) \\ \vdots & & \ddots & \vdots \\ (\mu_{m1},\nu_{m1},\pi_{m1}) & (\mu_{m2},\nu_{m2},\pi_{m2}) & \cdots & (\mu_{mn},\nu_{mn},\pi_{mn}) \end{pmatrix} \quad (2)$$

Also, decision makers evaluate the criteria as shown in Table 2. Decision makers evaluate alternatives in relation to the criteria by assigning higher linguistic terms to the benefit criteria and lower linguistic terms to the cost criteria.

Table 2 Evaluation of criteria by decision makers

Criteria	DM1	DM2	⋯	DMk
C1	$(\mu_{11},\nu_{11},\pi_{11})$	$(\mu_{12},\nu_{12},\pi_{12})$	⋯	$(\mu_{1k},\nu_{1k},\pi_{1k})$
C2	$(\mu_{21},\nu_{21},\pi_{21})$	$(\mu_{22},\nu_{22},\pi_{22})$	⋯	$(\mu_{2k},\nu_{2k},\pi_{2k})$
⋮	⋮	⋮	⋱	⋮
Cj	$(\mu_{j1},\nu_{j1},\pi_{j1})$	$(\mu_{j2},\nu_{j2},\pi_{j2})$	⋯	$(\mu_{jk},\nu_{jk},\pi_{jk})$

Source: Kutlu Gundogdu, F., Cengiz Kahraman, C. (2019)

Step 3: Calculating the value of the score function (score) for each criterion in Table 2 and normalizing their value.

Step 3.1: Defuzzify the aggregated criteria weights using the score function shown below.

$$\omega_j^S=\left(\mu_j-\pi_j\right)^2-\left(\nu_j-\pi_j\right)^2 \quad (3)$$

Keep in mind the following: If less than 0, a small number is added to all criterion weights to provide a number slightly greater than zero.

Step 3.2: Normalize the aggregated criteria weights using the following equation.

$$\bar{\omega}_j^S = \frac{\omega_j^S}{\sum_{j=1}^{n} \omega_j^S} \quad (4)$$

Step 4: Calculating the result of the weighted sum of the WSM (Weighted Sum Model) as shown in the following equation.

$$\tilde{Q}_i^{(1)} = \sum_{j=1}^{n} \tilde{x}_{ij\omega} = \sum_{j=1}^{n} \tilde{x}_{ij}\bar{\omega}_j^S \quad (5)$$

The equation can be split into two parts for easier calculation.

4.1: Calculating the multiplier part of an equation using the following equation.

$$\tilde{x}_{ij\omega} = \tilde{x}_{ij}\bar{\omega}_j^S = \langle\left(1-\left(1-\mu_{\tilde{x}_{ij}}^2\right)^{\omega_j^S}\right)^{1/2}, \nu_{\tilde{x}_{ij}}^{\omega_j^S}, \left(\left(1-\mu_{\tilde{x}_{ij}}^2\right)^{\omega_j^S} - \left(1-\mu_{\tilde{x}_{ij}}^2-\pi_{\tilde{x}_{ij}}^2\right)^{\omega_j^S}\right)^{1/2}\rangle \quad (6)$$

4.2: Calculating the additional term in the equation using the following equation.

$$\tilde{x}_{i1\omega}\otimes\tilde{x}_{i2\omega} = \langle\left(\mu_{\tilde{x}_{i1\omega}}^2+\mu_{\tilde{x}_{i2\omega}}^2-\mu_{\tilde{x}_{i1\omega}}^2\mu_{\tilde{x}_{i2\omega}}^2\right)^{1/2}, \nu_{i1\omega}\nu_{i2\omega}, \left(\left(1-\mu_{\tilde{x}_{i2\omega}}^2\right)\pi_{\tilde{x}_{i1\omega}}^2 + \left(1-\mu_{\tilde{x}_{i1\omega}}^2\right)\pi_{\tilde{x}_{i2\omega}}^2 - \pi_{\tilde{x}_{i1\omega}}^2\pi_{\tilde{x}_{i2\omega}}^2\right)^{1/2}\rangle \quad (7)$$

Step 5: Calculating the results of the Weighted Product Model (WPM) as shown in the following equation.

$$\tilde{Q}_i^2 = \prod_{j=1}^{n} \tilde{x}_{ij}^{\bar{\omega}_j^S} \quad (8)$$

The equation can be divided into two parts for easier calculation.

Step 5.1: Calculating the exponential part of the equation using the following equation.

$$\tilde{x}_{ij}^{\omega_j^S} = \langle\mu_{\tilde{x}_{ij}}^{\bar{\omega}_j^S}, \left(1-\left(\nu_{\tilde{x}_{ij}}^2\right)^{\bar{\omega}_j^S}\right)^{1/2}, \left(\left(1-\nu_{\tilde{x}_{ij}}^2\right)^{\bar{\omega}_j^S} - \left(1-\nu_{\tilde{x}_{ij}}^2-\pi_{\tilde{x}_{ij}}^2\right)^{\bar{\omega}_j^S}\right)^{1/2}\rangle \quad (9)$$

Step 5.2: Calculating the multiplier term in the equation using the following equation.

$$\tilde{x}_{i1}^{\omega_1^S} \otimes \tilde{x}_{i2}^{\omega_2^S} = \langle \mu_{\tilde{x}_{i1}^{\omega_1^S}} \mu_{\tilde{x}_{i2}^{\omega_2^S}}, \left(\nu^2_{\tilde{x}_{i1}^{\omega_1^S}} + \nu^2_{\tilde{x}_{i2}^{\omega_2^S}} - \nu^2_{\tilde{x}_{i1}^{\omega_1^S}} \nu^2_{\tilde{x}_{i2}^{\omega_2^S}} \right)^{1/2}, \left(\left(1 - \nu^2_{\tilde{x}_{i2}^{\omega_2^S}} \right) \pi^2_{\tilde{x}_{i1}^{\omega_1^S}} + \left(1 - \nu^2_{\tilde{x}_{i1}^{\omega_1^S}} \right) \pi^2_{\tilde{x}_{i2}^{\omega_2^S}} - \pi^2_{\tilde{x}_{i1}^{\omega_1^S}} \pi^2_{\tilde{x}_{i2}^{\omega_2^S}} \right)^{1/2} \rangle \quad (10)$$

Step 6: Determining the threshold number λ and calculating as in the following equations.

$$\lambda \tilde{Q}_i^{(1)} = \langle \left(1 - \left(1 - \mu^2_{\tilde{Q}_i^{(1)}} \right)^{\lambda} \right)^{1/2}, \nu^{\lambda}_{\tilde{Q}_i^{(1)}}, \left(\left(1 - \mu^2_{\tilde{Q}_i^{(1)}} \right)^{\lambda} - \left(1 - \mu^2_{\tilde{Q}_i^{(1)}} - \pi^2_{\tilde{Q}_i^{(1)}} \right) \right)^{\lambda} \rangle \quad (11)$$

$$1 - \lambda \tilde{Q}_i^{(2)} = \langle \left(1 - \left(1 - \mu^2_{\tilde{Q}_i^{(2)}} \right)^{1-\lambda} \right)^{1/2}, \nu^{\lambda}_{\tilde{Q}_i^{(2)}}, \left(\left(1 - \mu^2_{\tilde{Q}_i^{(2)}} \right)^{1-\lambda} - \left(1 - \mu^2_{\tilde{Q}_i^{(2)}} - \pi^2_{\tilde{Q}_i^{(2)}} \right) \right)^{1-\lambda} \rangle \quad (12)$$

Step 7: The sum of the previous equations gives the following equation.

$$\tilde{Q}_i = \lambda \tilde{Q}_i^{(1)} + (1 - \lambda) \tilde{Q}_i^{(2)} \quad (13).$$

Step 8: Defuzzify the score function (using the equation shown in step 3.1).

The alternatives are arranged according to the decreasing value of the score. If the score values for two alternatives are equal, the accuracy of their value function is considered as in the following equation.

$$Accuracy(\tilde{A}_s) = \mu^2_{A_s} + \nu^2_{A_s} + \pi^2_{A_s} \quad (14)$$

2.2. WASPAS method

WASPAS (Weighted Aggregates Sum Product Assessment) was proposed by Zavadskas *et al*. (2012). It respects the unique combination of two well-known approaches of multi-criteria decision making (MCDM - Multi-Criteria Decision Making) : the method of weighted sums (WS - Weighted Sum) and the method of weighted products (WP - Weighted Product). The WASPAS method is used to solve various complex problems in multi-criteria decision-making (for example, production decision-making) (Chakraborty & Zavadskas, 2014; Zavadskas et al., 2013). An advanced fuzzy WASPAS method was developed for solving complex problems under uncertainty. The procedure of the WASPAS method consists of the following steps (Urosevic et al., 2017):

Step 1: Determining the optimal performance rating for each criterion.

The optimal performance rating is calculated as follows:

$$x_{0j} = \begin{cases} \max\limits_{i} x_{ij}; & j \in \Omega_{max} \\ \min\limits_{i} x_{ij}; & j \in \Omega_{min} \end{cases}, \quad (15)$$

where: x_{0j} denotes the optimal performance rating of the *i*- th criterion, Ω_{max} indicates the benefit criterion (the higher the value, the better), Ω_{min} means a set of cost criteria (the lower the value, the better), *m* denotes the number of alternatives (*i*= 0,1,..., *m*), and *n* indicates the number of criteria (*j*= 0,1,..., *n*).

***Step 2* :** Determination of the normalized decision matrix.

The normalized performance rating is calculated as follows:

$$r_{ij} = \begin{cases} \dfrac{x_{ij}}{x_{0j}}; & j \in \Omega_{max} \\ \dfrac{x_{0j}}{x_{ij}}; & j \in \Omega_{min} \end{cases}, \quad (16)$$

where: r_{ij} denotes the normalized performance rating of the *i*- th alternative in relation to the *j* - th criterion.

Step 3: Calculation of the relative importance of the *i*- th alternative based on the WS method.

The relative importance of the *i*- th alternative, based on the WS method, is calculated as follows:

$$Q_i^{(1)} = \sum_{j=1}^{n} w_j r_{ij}, \quad (17)$$

where: $Q_i^{(1)}$ denotes the relative importance of the *i*- th alternative in relation to the *j* - th criterion, based on the WS method.

Step 4: Calculating the relative importance of the *i*- th alternative, using the based WP method.

The relative importance of the alternative, based on the WP method, is calculated as follows:

$$Q_i^{(2)} = \prod_{j=1}^{n} r_{ij}^{w_j}, \quad (18)$$

where: $Q_i^{(2)}$ denotes the relative importance of the *i*- th alternative in relation to the *j* - th criterion, based on the WP method.

Step 5 **:** Calculating the overall relative importance for each alternative.

The total relative importance (common generalized criterion of weight aggregations of additive and multiplicative methods) (Zavadskas, 2012) is calculated as follows:

$$Q_i = \lambda Q_i^{(1)} + (1-\lambda)Q_i^{(2)} = \lambda \sum_{j=1}^{n} w_j r_{ij} + (1-\lambda) \prod_{j=1}^{n} r_{ij}^{w_j} \quad (19)$$

wherein: λ coefficient and $\lambda \in [0, 1]$.

When decision-makers have no preference for the coefficient, the value is 0.5, and equation (5) is expressed as:

$$Q_i = 0.5Q_i^{(1)} + 0.5Q_i^{(2)} = 0.5 \sum_{j=1}^{n} w_j r_{ij} + 0.5 \prod_{j=1}^{n} r_{ij}^{w_j} \quad (20)$$

3. DISCUSSION AND RESULTS

The research of the treated problem in this paper will be carried out in two parts. In the first part, we will analyze the transport and storage performance of selective countries of the European Union (Germany, France, Italy, Croatia and Slovenia) and Serbia based on the SF-WASPAS method. The second part is dedicated to the evaluation of the transport and storage performance of the European Union and Serbia using the classical WASPAS method. Table 3 shows the relevant data for 2020. (The data for 2021 and 2022 are not available on the Eurostat website.)

Table 3 Key performance indicators of transport and storage in the European Union and Serbia

		Enterprises - number	Persons employed - number	Turnover or gross premiums written - million euros	Value added at factor cost - million euros	Personnel costs - million euros
		C1	**C2**	**C3**	**C4**	**C5**
A1	**Belgium**	18,830	218,830	45,853.9	15,969.6	10,858.1
A2	**Bulgaria**	22,422	168,136	8,046.2	2,617.8	1,364.3
A3	**Czechia**	42,430	286,554	22,425.1	7,431.7	4,816.4
A4	**Denmark**	11,353	137,619	57,370.2	15,492.9	7,518.3

A5	**Germany (until 1990 former territory of the FRG)**	98,486	2,217,268	311,077.3	106,327.2	77,499.6
A6	**Estonia**	5,905	39,599	4,743.8	1,318.9	781.5
A7	**Ireland**	24,127	104,443	14,736.8	3,226.3	3,485.0
A8	**Greece**	58,701	179,576	12,011.7	4,524.8	3,356.3
A9	**Spain**	218,298	927,491	100,798.9	39,493.8	26,583.5
A10	**France**	163,436	1,493,629	197,130.9	69,264.2	62,384.4
A11	**Croatia**	12,878	90,165	4,362.3	1,893.5	1,325.1
A12	**Italy**	115,293	1,123,402	139,235.1	51,623.3	38,553.6
A13	**Cyprus**	3,094	17,400	3,073.7	652.0	441.5
A14	**Latvia**	8,085	70,145	4,577.9	1,279.1	932.9
A15	**Lithuania**	24,240	157,937	11,839.4	3,670.1	2,072.7
A16	**Luxembourg**	1,028	50,644	6,743.0	2,705.5	1,401.9
A17	**Hungary**	36,266	252,736	16,163.5	4,083.7	3,759.6
A18	**Malta**	1,944	12,967	2,020.8	396.5	307.0
A19	**Netherlands**	55,622	426,141	87,875.0	29,982.9	20,349.2
A20	**Austria**	13,799	211,110	40,976.6	14,269.3	9,733.9
A21	**Poland**	170,508	946,314	65,548.7	20,023.7	10,676.7
A22	**Portugal**	34,237	186,628	17,485.8	5,339.5	4,416.7
A23	**Romania**	58,022	383,438	18,934.4	5,871.8	3,800.0
A24	**Slovenia**	8,674	53,831	6,028.4	2,239.6	1,208.4
A25	**Slovakia**	22,909	114,556	9,853.5	3,003.8	1,817.3
A26	**Finland**	19,719	136,164	19,097.0	6,541.4	5,060.7
A27	**Sweden**	29,134	264,172	43,185.5	14,671.8	11,025.9
A28	**Serbi**	6,315	105,622	4,389.0	1,455.4	1,090.2

Source: Eurostat

3.1. Measurement and analysis of transport and storage performance of selective countries of the European Union and Serbia based on the SF-WASPAS method

The selected criteria for the analysis of the transport and storage performance of the European Union and Serbia are C1 - Enterprises - number, C2 - Persons employed - number, C3 - Turnover or gross premiums written, C4 - Value added at factor cost and C5 – Personnel costs. According to Eurostat statistics, they are key indicators of transport and storage performance. The alternatives are selected countries of the European Union and Serbia: A1 - Germany, A2 - France, A3 - Italy, A4 - Croatia, A5 - Slovenia and A6 - Serbia. They were chosen according to the criteria of the leading countries of the European Union, countries in the region of Serbia and Serbia. Table 4 shows the evaluation of the criteria by the decision makers.

Table 4 Evaluation of criteria

Decision Makers	**Importance**	**Criteria**	**DM1**	**DM2**	**DM3**
DM1	**0.40**	**C1**	**WE**	**HI**	**EI**
DM2	**0.30**	**C2**	**HI**	**LI**	**LI**
DM3	**0.30**	**C3**	**VHI**	**VHI**	**HI**
		C4	**SMI**	**HI**	**HI**
		C5	**EI**	**HI**	**EI**

	DM1			**DM2**			**DM3**			**Weight of Criteria**			**Score Function**	**Normalized Weights**
	0.40	**0.40**	**0.40**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**	**0.30**					
	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1 st	2nd	3rd		
C1	0.19	0.10	0.18	0.51	0.30	0.42	0.75	0.50	0.50	**0.78**	**0.23**	**0.27**	**0.267**	**0.381**
C2	0.51	0.30	0.42	0.91	0.70	0.82	0.91	0.70	0.82	**0.53**	**0.50**	**0.31**	**0.012**	**0.017**
C3	0.36	0.20	0.32	0.36	0.20	0.32	0.51	0.30	0.42	**0.77**	**0.23**	**0.23**	**0.298**	**0.425**
C4	0.64	0.40	0.48	0.51	0.30	0.42	0.51	0.30	0.42	**0.66**	**0.34**	**0.34**	**0.105**	**0.150**
C5	0.75	0.50	0.50	0.51	0.30	0.42	0.75	0.50	0.50	**0.58**	**0.43**	**0.44**	**0.018**	**0.026**
												SUM	**0.701**	**1.000**

Source: Author's calculation

In the specific case, therefore, the most important criterion is C3 – Turnover or gross premiums written. This means, in other words, that the target profit of transport and storage can be realized by more efficient management of this criterion.

Table 5 shows the initial aggregated matrix.

Table 5 Initial Aggregated Matrix

Initial	0.381	0.381	0.381	0.017	0.017	0.017	0.425	0.425	0.425	0.150	0.150	0.150	0.026	0.026	0.026
Aggregated Matrix	**C1**			**C2**			**C3**			**C4**			**C5**		
A1	0.78	0.23	0.27	0.63	0.37	0.37	0.77	0.23	0.23	0.55	0.46	0.40	0.48	0.54	0.42
A2	0.40	0.60	0.40	0.71	0.30	0.32	0.65	0.35	0.36	0.58	0.43	0.44	0.57	0.43	0.43
A3	0.56	0.45	0.41	0.80	0.20	0.20	0.77	0.23	0.23	0.65	0.35	0.36	0.37	0.63	0.38
A4	0.64	0.36	0.36	0.66	0.34	0.34	0.53	0.50	0.31	0.40	0.61	0.41	0.53	0.50	0.32
A5	0.70	0.30	0.30	0.62	0.38	0.39	0.53	0.49	0.38	0.57	0.43	0.43	0.75	0.26	0.26
A6	0.55	0.45	0.40	0.56	0.45	0.41	0.48	0.53	0.38	0.60	0.40	0.36	0.61	0.43	0.29

Source: Author's calculation

Table 6 shows the weighted normalized matrix for WSM .

Table 6 Weighted Normalized Matrix for WSM

	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5
Weighted Normalized Matrix for WSM	**C1**			**C2**			**C3**			**C4**			**C5**		
A1	0.55	0.57	0.23	0.09	0.98	0.07	0.57	0.53	0.20	0.23	0.89	0.19	0.08	0.98	0.08
A2	0.25	0.82	0.27	0.11	0.98	0.06	0.46	0.64	0.29	0.24	0.88	0.22	0.10	0.98	0.09
A3	0.36	0.74	0.30	0.13	0.97	0.04	0.57	0.53	0.20	0.28	0.85	0.19	0.06	0.99	0.07
A4	0.43	0.67	0.27	0.10	0.98	0.06	0.36	0.74	0.22	0.16	0.93	0.18	0.09	0.98	0.06
A5	0.48	0.63	0.23	0.09	0.98	0.07	0.36	0.74	0.28	0.24	0.88	0.21	0.15	0.96	0.06
A6	0.36	0.74	0.29	0.08	0.99	0.07	0.32	0.77	0.28	0.26	0.87	0.18	0.11	0.98	0.06

Source: Author's calculation

Table 7 shows the calculation for WSM.

Table 7 Calculation for WSM

Calculation for WSM	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)	1-(μ*μ)	ν	1-(μ*μ)-(π*π)
	C1			**C2**			**C3**			**C4**			**C5**		
A1	0.70	0.57	0.64	0.99	0.98	0.99	0.68	0.53	0.64	0.95	0.89	0.91	0.99	0.98	0.99
A2	0.94	0.82	0.86	0.99	0.98	0.98	0.79	0.64	0.71	0.94	0.88	0.89	0.99	0.98	0.98
A3	0.87	0.74	0.78	0.98	0.97	0.98	0.68	0.53	0.64	0.92	0.85	0.88	1.00	0.99	0.99
A4	0.81	0.67	0.74	0.99	0.98	0.99	0.87	0.74	0.82	0.97	0.93	0.94	0.99	0.98	0.99
A5	0.77	0.63	0.72	0.99	0.98	0.99	0.87	0.74	0.79	0.94	0.88	0.90	0.98	0.96	0.97
A6	0.87	0.74	0.79	0.99	0.99	0.99	0.90	0.77	0.82	0.93	0.87	0.90	0.99	0.98	0.98

			λ	0.5	
Q1i			**λQ1i**		
0.75	0.26	0.27	0.58	0.51	0.24
0.57	0.44	0.39	0.42	0.67	0.31
0.69	0.32	0.32	0.52	0.57	0.27
0.57	0.45	0.35	0.42	0.67	0.28
0.62	0.39	0.35	0.46	0.62	0.29
0.53	0.48	0.39	0.39	0.69	0.30

Source: Author's calculation

Table 8 shows the weighted normalized matrix for WPM.

Table 8 Weighted Normalized Matrix for WPM

	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5
Weighted Normalized Matrix for WPM	**C1**			**C2**			**C3**			**C4**			**C5**		
A1	0.91	0.14	0.17	0.99	0.05	0.05	0.90	0.15	0.15	0.91	0.19	0.18	0.98	0.09	0.09
A2	0.71	0.40	0.30	0.99	0.04	0.04	0.83	0.23	0.25	0.92	0.17	0.20	0.99	0.07	0.08
A3	0.80	0.29	0.28	1.00	0.03	0.03	0.90	0.15	0.15	0.94	0.14	0.15	0.97	0.11	0.08
A4	0.85	0.22	0.24	0.99	0.04	0.05	0.76	0.34	0.22	0.87	0.26	0.21	0.98	0.09	0.06
A5	0.87	0.19	0.19	0.99	0.05	0.06	0.76	0.33	0.28	0.92	0.17	0.19	0.99	0.04	0.04
A6	0.80	0.29	0.28	0.99	0.06	0.06	0.73	0.36	0.28	0.93	0.16	0.16	0.99	0.07	0.05

Source: Author's calculation

Table 9 shows the calculation for WPM.

Table 9 Calculation for WPM

	1	1	1	2	2	2	3	3	3	4	4	4	5	5	5
Calculation for WPM	μ	1-(ν*ν)	1-(ν*ν)-(π*π)	μ	1-(ν*ν)	1-(ν*ν)-(π*π)	μ	1-(ν*ν)	1-(ν*ν)-(π*π)	μ	1-(ν*ν)	1-(ν*ν)-(π*π)	μ	1-(ν*ν)	1-(ν*ν)-(π*π)
	C1			**C2**			**C3**			**C4**			**C5**		
A1	0.91	0.98	0.95	0.99	1.00	0.99	0.90	0.98	0.95	0.91	0.96	0.93	0.98	0.99	0.98
A2	0.71	0.84	0.76	0.99	1.00	1.00	0.83	0.95	0.88	0.92	0.97	0.93	0.99	0.99	0.99
A3	0.80	0.92	0.84	1.00	1.00	1.00	0.90	0.98	0.95	0.94	0.98	0.96	0.97	0.99	0.98
A4	0.85	0.95	0.89	0.99	1.00	1.00	0.76	0.89	0.84	0.87	0.93	0.89	0.98	0.99	0.99
A5	0.87	0.96	0.93	0.99	1.00	0.99	0.76	0.89	0.81	0.92	0.97	0.93	0.99	1.00	1.00

A6	0.80	0.92	0.84	0.99	1.00	0.99	0.73	0.87	0.79	0.93	0.97	0.95	0.99	0.99	0.99

			(1-λ)	0.5	
Q2i			**(1-λ)Q2i**		
0.73	0.29	0.29	0.56	0.54	0.26
0.53	0.48	0.40	0.39	0.69	0.31
0.65	0.37	0.35	0.49	0.60	0.29
0.55	0.47	0.35	0.40	0.69	0.28
0.60	0.41	0.36	0.45	0.64	0.30
0.53	0.48	0.39	0.39	0.70	0.30

Source: Author's calculation

Table 10 and Figure 1 show the results of the SF-WASPAS method.

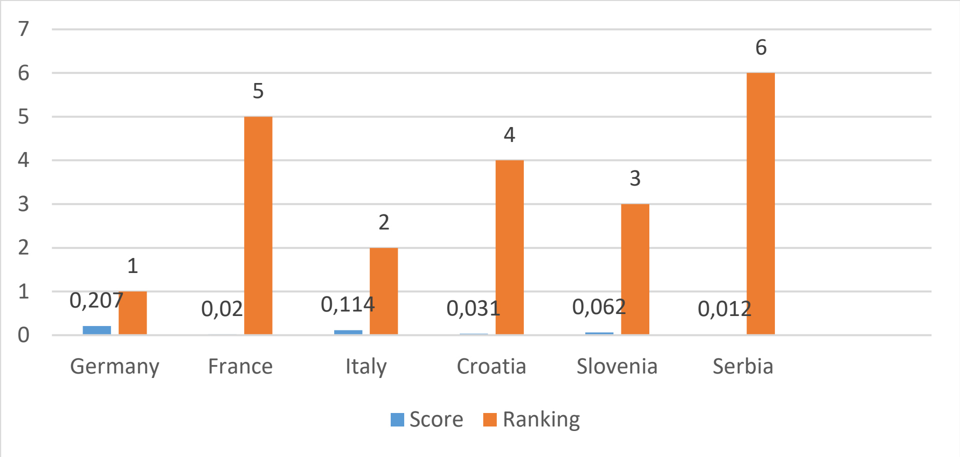
Table 10 Results of the SF-WASPAS

	Results of SF-WASPAS	**Q1i**			**λQ1i**			**Q2i**			**(1-λ)Q2i**			**Qi**			**Score Function**	**Score**	**Ranking**
Germany	**A1**	0.749	0.259	0.274	0.581	0.509	0.244	0.727	0.293	0.293	0.560	0.541	0.256	0.738	0.275	0.284	0.207	**0.207**	**1**
France	**A2**	0.566	0.444	0.390	0.419	0.666	0.313	0.531	0.481	0.395	0.390	0.694	0.313	0.549	0.462	0.393	0.020	**0.020**	**5**
Italy	**A3**	0.686	0.322	0.319	0.522	0.568	0.271	0.653	0.365	0.346	0.493	0.605	0.289	0.670	0.343	0.332	0.114	**0.114**	**2**
Croatia	**A4**	0.567	0.449	0.348	0.420	0.670	0.278	0.548	0.473	0.350	0.404	0.688	0.277	0.558	0.461	0.349	0.031	**0.031**	**4**

Slovenia	**A5**	0.620	0.390	0.353	0.464	0.624	0.290	0.602	0.414	0.363	0.449	0.643	0.295	0.611	0.402	0.358	0.062	**0.062**	**3**	
Serbia	**A6**	0.534	0.476	0.385	0.393	0.690	0.305	0.528	0.483	0.386	0.388	0.695	0.304	0.531	0.480	0.385	0.012	**0.012**	**6**	

Source: Author's calculation

Figure 1 Ranking of alternatives according to the SF-WASPAS method



Source: Author's picture

According to the empirical results obtained using the SF-WASPAS method, out of the five observed countries of the European Union (Germany, France, Italy, Croatia and Slovenia) and Serbia, Germany ranks first in terms of transport and storage performance. Followed by: Italy, Slovenia, Croatia, France and Serbia. Therefore, Serbia has the worst performance of transport and storage. In order to achieve the target profit of transport and storage, it is necessary, among other things, to manage the company, human resources (training, rewards, advancement, health and social insurance), turnover or gross premiums written, value added at factor cost and personnel costs as efficiently as possible.

3.2. Measurement and analysis of transport and storage performance of the European Union and Serbia based on the classic WASPAS method

When measuring and analyzing the transport and storage performance of the European Union and Serbia based on the classic WASPAS method, the same criteria are used (C1 - Enterprises - number, C2 - Persons employed - number, C3 - Turnover or gross premiums written, C4 - Value added at factor cost and C5 - Personnel costs) as for SF - WASPAS methods. Alternatives are all member states of the European Union and Serbia. Table 11 shows the initial matrix.

Table 11 Initial Matrix

Initial Matrix					
weights of criteria	0.381	0.017	0.425	0.15	0.026
kind of criteria	1	1	1	1	-1
	C1	**C2**	**C3**	**C4**	**C5**
A1	18,830	218,830	45,853.90	15,969.60	10,858.10
A2	22,422	168,136	8,046.20	2,617.80	1,364.30
A3	42,430	286,554	22,425.10	7,431.70	4,816.40
A4	11,353	137,619	57,370.20	15,492.90	7,518.30
A5	98,486	2,217,268	311,077.30	106,327.20	77,499.60
A6	5,905	39,599	4,743.80	1,318.90	781.5
A7	24,127	104,443	14,736.80	3,226.30	3,485.00
A8	58,701	179,576	12,011.70	4,524.80	3,356.30
A9	218,298	927,491	100,798.90	39,493.80	26,583.50
A10	163,436	1,493,629	197,130.90	69,264.20	62,384.40
A11	12,878	90,165	4,362.30	1,893.50	1,325.10
A12	115,293	1,123,402	139,235.10	51,623.30	38,553.60
A13	3,094	17,400	3,073.70	652	441.5
A14	8,085	70,145	4,577.90	1,279.10	932.9
A15	24,240	157,937	11,839.40	3,670.10	2,072.70
A16	1,028	50,644	6,743.00	2,705.50	1,401.90
A17	36,266	252,736	16,163.50	4,083.70	3,759.60
A18	1,944	12,967	2,020.80	396.5	307
A19	55,622	426,141	87,875.00	29,982.90	20,349.20
A20	13,799	211,110	40,976.60	14,269.30	9,733.90
A21	170,508	946,314	65,548.70	20,023.70	10,676.70
A22	34,237	186,628	17,485.80	5,339.50	4,416.70
A23	58,022	383,438	18,934.40	5,871.80	3,800.00
A24	8,674	53,831	6,028.40	2,239.60	1,208.40
A25	22,909	114,556	9,853.50	3,003.80	1,817.30
A26	19,719	136,164	19,097.00	6,541.40	5,060.70
A27	29,134	264,172	43,185.50	14,671.80	11,025.90
A28	6,315	105,622	4,389.00	1,455.40	1,090.20
MAX	218298	2217268	311077.3	106327.2	77499.6
MIN	1028	12967	2020.8	396.5	307

Source: Author's calculation

Table 12 shows the normalized matrix.

Table 12 Normalized Matrix

Normalized Matrix					
weights of criteria	0.381	0.017	0.425	0.15	0.026
kind of criteria	1	1	1	1	-1
	C1	**C2**	**C3**	**C4**	**C5**
A1	0.0863	0.0987	0.1474	0.1502	0.0283
A2	0.1027	0.0758	0.0259	0.0246	0.2250
A3	0.1944	0.1292	0.0721	0.0699	0.0637
A4	0.0520	0.0621	0.1844	0.1457	0.0408
A5	0.4512	1.0000	1.0000	1.0000	0.0040
A6	0.0271	0.0179	0.0152	0.0124	0.3928
A7	0.1105	0.0471	0.0474	0.0303	0.0881
A8	0.2689	0.0810	0.0386	0.0426	0.0915
A9	1.0000	0.4183	0.3240	0.3714	0.0115
A10	0.7487	0.6736	0.6337	0.6514	0.0049
A11	0.0590	0.0407	0.0140	0.0178	0.2317
A12	0.5281	0.5067	0.4476	0.4855	0.0080
A13	0.0142	0.0078	0.0099	0.0061	0.6954
A14	0.0370	0.0316	0.0147	0.0120	0.3291
A15	0.1110	0.0712	0.0381	0.0345	0.1481
A16	0.0047	0.0228	0.0217	0.0254	0.2190
A17	0.1661	0.1140	0.0520	0.0384	0.0817
A18	0.0089	0.0058	0.0065	0.0037	1.0000
A19	0.2548	0.1922	0.2825	0.2820	0.0151
A20	0.0632	0.0952	0.1317	0.1342	0.0315
A21	0.7811	0.4268	0.2107	0.1883	0.0288
A22	0.1568	0.0842	0.0562	0.0502	0.0695
A23	0.2658	0.1729	0.0609	0.0552	0.0808
A24	0.0397	0.0243	0.0194	0.0211	0.2541
A25	0.1049	0.0517	0.0317	0.0283	0.1689
A26	0.0903	0.0614	0.0614	0.0615	0.0607
A27	0.1335	0.1191	0.1388	0.1380	0.0278
A28	0.0289	0.0476	0.0141	0.0137	0.2816

Source: Author's calculation

Table 13 shows the weighted normalized matrix.

Table 13 Weighted Normalized Matrix

Weighted Normalized Matrix					
	C1	**C2**	**C3**	**C4**	**C5**
A1	0.0329	0.0017	0.0626	0.0225	0.0007
A2	0.0391	0.0013	0.0110	0.0037	0.0059
A3	0.0741	0.0022	0.0306	0.0105	0.0017
A4	0.0198	0.0011	0.0784	0.0219	0.0011
A5	0.1719	0.0170	0.4250	0.1500	0.0001
A6	0.0103	0.0003	0.0065	0.0019	0.0102
A7	0.0421	0.0008	0.0201	0.0046	0.0023
A8	0.1025	0.0014	0.0164	0.0064	0.0024
A9	0.3810	0.0071	0.1377	0.0557	0.0003
A10	0.2852	0.0115	0.2693	0.0977	0.0001
A11	0.0225	0.0007	0.0060	0.0027	0.0060
A12	0.2012	0.0086	0.1902	0.0728	0.0002
A13	0.0054	0.0001	0.0042	0.0009	0.0181
A14	0.0141	0.0005	0.0063	0.0018	0.0086
A15	0.0423	0.0012	0.0162	0.0052	0.0039
A16	0.0018	0.0004	0.0092	0.0038	0.0057
A17	0.0633	0.0019	0.0221	0.0058	0.0021
A18	0.0034	0.0001	0.0028	0.0006	0.0260
A19	0.0971	0.0033	0.1201	0.0423	0.0004
A20	0.0241	0.0016	0.0560	0.0201	0.0008
A21	0.2976	0.0073	0.0896	0.0282	0.0007
A22	0.0598	0.0014	0.0239	0.0075	0.0018
A23	0.1013	0.0029	0.0259	0.0083	0.0021
A24	0.0151	0.0004	0.0082	0.0032	0.0066
A25	0.0400	0.0009	0.0135	0.0042	0.0044
A26	0.0344	0.0010	0.0261	0.0092	0.0016
A27	0.0508	0.0020	0.0590	0.0207	0.0007
A28	0.0110	0.0008	0.0060	0.0021	0.0073

Source: Author's calculation

Table 14 shows the exponentially weight matrix.

Table 14 Exponentially Weight Matrix

Exponentially Weighted Matrix					
	C1	**C2**	**C3**	**C4**	**C5**
A1	0.3931	0.9614	0.4432	0.7525	0.9115
A2	0.4202	0.9571	0.2115	0.5737	0.9620

A3	0.5358	0.9658	0.3270	0.6709	0.9309
A4	0.3242	0.9538	0.4875	0.7491	0.9202
A5	0.7384	1.0000	1.0000	1.0000	0.8661
A6	0.2527	0.9339	0.1690	0.5176	0.9760
A7	0.4321	0.9494	0.2736	0.5920	0.9388
A8	0.6063	0.9582	0.2508	0.6228	0.9397
A9	1.0000	0.9853	0.6194	0.8620	0.8905
A10	0.8956	0.9933	0.8238	0.9377	0.8710
A11	0.3402	0.9470	0.1631	0.5465	0.9627
A12	0.7841	0.9885	0.7106	0.8973	0.8819
A13	0.1976	0.9209	0.1405	0.4657	0.9906
A14	0.2849	0.9430	0.1665	0.5153	0.9715
A15	0.4328	0.9561	0.2493	0.6035	0.9516
A16	0.1298	0.9378	0.1962	0.5766	0.9613
A17	0.5047	0.9638	0.2845	0.6133	0.9369
A18	0.1655	0.9163	0.1176	0.4323	1.0000
A19	0.5940	0.9724	0.5844	0.8271	0.8967
A20	0.3492	0.9608	0.4225	0.7399	0.9141
A21	0.9102	0.9856	0.5159	0.7785	0.9119
A22	0.4937	0.9588	0.2942	0.6385	0.9330
A23	0.6036	0.9706	0.3043	0.6476	0.9367
A24	0.2926	0.9387	0.1871	0.5604	0.9650
A25	0.4236	0.9509	0.2306	0.5857	0.9548
A26	0.4001	0.9537	0.3055	0.6582	0.9297
A27	0.4643	0.9645	0.4321	0.7430	0.9111
A28	0.2593	0.9496	0.1635	0.5254	0.9676

Source: Author's calculation

Table 15 and Figure 2 show the ranking of alternatives.

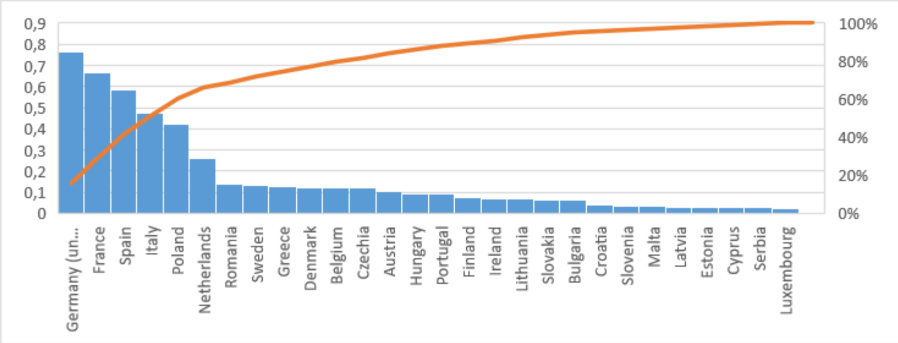
Table 15 Ranking

	Ranking						
					λ	**0.5**	
	Alternatives	**Qi1**	**Qi2**	**Qi**	**Qi**		**Ranking**
Belgium	**A1**	0.1205	0.1205	0.1205	0.1205		**11**
Bulgaria	**A2**	0.0610	0.0610	0.0610	0.0610		**20**
Czechia	**A3**	0.1190	0.1190	0.1190	0.1190		**12**
Denmark	**A4**	0.1222	0.1222	0.1222	0.1222		**10**
Germany (until 1990 former	**A5**	0.7640	0.7640	0.7640	0.7640		**1**

territory of the FRG)						
Estonia	**A6**	0.0292	0.0292	0.0292	0.0292	**25**
Ireland	**A7**	0.0699	0.0699	0.0699	0.0699	**17**
Greece	**A8**	0.1290	0.1290	0.1290	0.1290	**9**
Spain	**A9**	0.5818	0.5818	0.5818	0.5818	**3**
France	**A10**	0.6639	0.6639	0.6639	0.6639	**2**
Croatia	**A11**	0.0378	0.0378	0.0378	0.0378	**21**
Italy	**A12**	0.4731	0.4731	0.4731	0.4731	**4**
Cyprus	**A13**	0.0287	0.0287	0.0287	0.0287	**26**
Latvia	**A14**	0.0313	0.0313	0.0313	0.0313	**24**
Lithuania	**A15**	0.0687	0.0687	0.0687	0.0687	**18**
Luxembourg	**A16**	0.0209	0.0209	0.0209	0.0209	**28**
Hungary	**A17**	0.0952	0.0952	0.0952	0.0952	**14**
Malta	**A18**	0.0328	0.0328	0.0328	0.0328	**23**
Netherlands	**A19**	0.2631	0.2631	0.2631	0.2631	**6**
Austria	**A20**	0.1026	0.1026	0.1026	0.1026	**13**
Poland	**A21**	0.4234	0.4234	0.4234	0.4234	**5**
Portugal	**A22**	0.0944	0.0944	0.0944	0.0944	**15**
Romania	**A23**	0.1405	0.1405	0.1405	0.1405	**7**
Slovenia	**A24**	0.0336	0.0336	0.0336	0.0336	**22**
Slovakia	**A25**	0.0630	0.0630	0.0630	0.0630	**19**
Finland	**A26**	0.0724	0.0724	0.0724	0.0724	**16**
Sweden	**A27**	0.1333	0.1333	0.1333	0.1333	**8**
Serbia	**A28**	0.0272	0.0272	0.0272	0.0272	**27**

Source: Author's calculation

Figure 2 Ranking of alternatives according to the WASPAS method



Source: Author's picture

The top five countries of the European Union in terms of transport and storage performance according to empirical results obtained using the classic WASPAS method are, in order: Germany, France, Spain, Italy and Poland. Luxembourg has the worst performance in transport and storage. The performance of transport and storage in Croatia is better than in Slovenia. As far as Serbia's transport and storage performance is concerned, they are bad. They are worse than in Croatia and Slovenia.

Transport and storage performance was influenced by a number of factors. In addition to the economic and political climate, economic activities, the Covid-19 pandemic and the energy crisis stand out among them recently. Significant factors also include the number and size of companies, number of employees, turnover, added value by factor costs and personnel costs. Effective control of critical factors, among them especially today's energy crisis, can significantly influence the achievement of the target performance of transport and storage. Digitalization of the entire transport and storage business certainly plays a significant role in this.

For the sake of the treated issue, we will present a sectoral analysis of the key indicators of transport and storage in the European Union for 2020. Table 16 and figure 3 shows the given indicators.

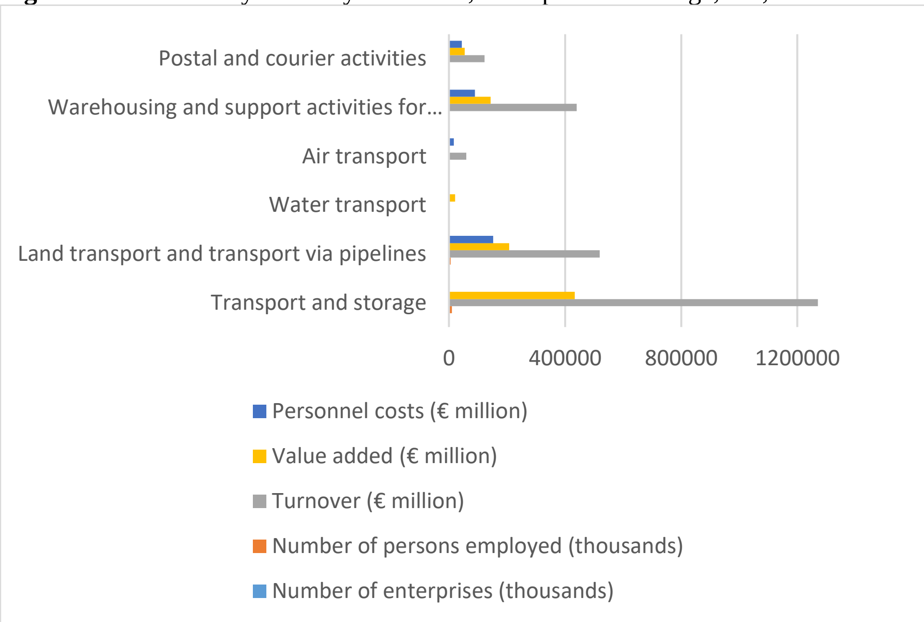
Table 16 Sectoral analysis of key indicators, Transport and storage, EU, 2020

	Number of enterprises (thousands)	Number of persons employed (thousands)	Turnover (€ million)	Value added (€ million)	Personal l costs (€ million)
Transport and storage	1279.4	10270.9	1271195.2	433914.8	315.530.4
Land transport and	966.4	5682.2	519836.0	207372.7	152584.6

transport via pipelines					
Water transport	:	:	:	21607.1	:
Air transport	:	300.0	59854.1	:	16954.0
Warehousing and support activities for transportation	144.0	2440.0	440000.0	144000.0	90000.0
Postal and courier activities	145.1	1629.2	123188.3	54600.4	44738.2

Note: Not avallable
Source: Eurostat

Figure 3 Sectoral analysis of key indicators, Transport and storage, EU, 2020



Source: Author's picture

The data in the given table show that land transport and pipeline transport is the most significant in the framework of the sectoral findings of the key indicators of transport and storage in the European Union. Thus, for example, land transport and pipeline transport participate in the total additional value of transport and storage of the European Union with 47.79%. This means, in other words, that effective management of the number and size of companies, human resources, traffic, added value and personnel costs in the sector of land transport and pipeline transport can significantly influence the achievement of the target performance of transport and storage in the European Union.

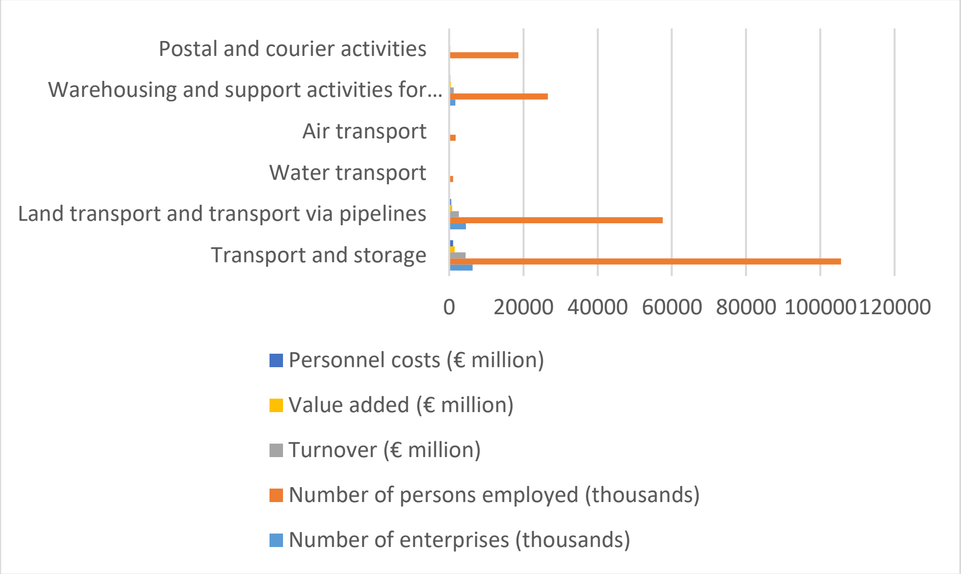
The situation is similar with regard to the sectoral analysis of the key indicators of transport and storage in Serbia (Table 17 and Figure 4). For example, land transport and pipeline transport participate in the total added value of transport and storage in Serbia with 53.77%.

Table 17 Sectoral analysis of key indicators, Transport and storage, Sebia, 2020

	Number of enterprises (thousands)	Number of persons employed (thousands)	Turnover (€ million)	Value added (€ million)	Personal costs (€ million)
Transport and storage	6315	105622	4388.9	1455.3	1090.2
Land transport and transport via pipelines	4496	57548	2578.2	782.6	541.7
Water transport	68	1043	132.4	24.1	12.7
Air transport	33	1787	184.2	36.2	54.0
Warehousing and support activities for transportation	1665	26587	1208.5	414.4	319.3
Postal and courier activities	53	18657	285.4	197.9	162.3

Note: Author's conversion in euros. The conversion was made according to the middle exchange rate for 2020, 1 EUR = 117.5777 dinars.
Source: Statistical Yearbook of the Republic of Serbia 2022

Figure 4 Sectoral analysis of key indicators, Transport and storage, Serbia, 2020



Source: Author's picture

4. CONCLUSION

Based on the obtained empirical results of the research of the problem treated in this paper, the following can be concluded:

(1) According to the SF-WASPAS method, out of the five observed countries of the European Union (Germany, France, Italy, Croatia and Slovenia) and Serbia, Germany ranks first in terms of transport and storage performance. Followed by: Italy, Slovenia, Croatia, France and Serbia. Serbia has the worst performance of transport and storage.

(2) The top five countries of the European Union in terms of transport and storage performance according to the classic WASPAS method are, in order: Germany, France, Spain, Italy and Poland. Luxembourg recorded the worst performance in transport and storage. The performance of transport and storage in Croatia is better than in Slovenia. The performance of transport and storage in Serbia is unsatisfactory. They are worse than in Croatia and Slovenia.

There are numerous determinants of transport and storage performance. These are: the economic and political climate, economic activity, the Covid-19 pandemic and the energy crisis. Significant factors also include the number and size of companies, number of employees, turnover, added value by factor costs and personnel costs. Effective control of critical factors can significantly influence the achievement of the target performance of transport and storage. Digitalization of the entire transport and storage business certainly plays a significant role in this.

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AN ANALYSIS OF THE RELATIONSHIP BETWEEN ROAD FREIGHT TRANSPORT AND ECONOMIC GROWTH IN THE EUROPEAN UNION: A PANEL DATA APPROACH

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Abstract

The objective of this study is to examine the relationship between road freight transport and economic growth in the European Union (EU) using a panel data approach. The study will use data from Eurostat for the period 2012 - 2021 and employ fixed effects regression models to estimate the causal effect of road freight transport on economic growth. The study will also examine the role of road infrastructure investment and transport employment in promoting economic growth in the EU. The results of this study will provide important insights into the factors driving economic growth in the EU and support policy decisions to promote sustainable economic development. The study will contribute to the literature on the relationship between transport infrastructure and economic growth and provide a basis for future research in this field.

Keywords: Road freight transport, Infrastructure investment, Economic growth, European Union, Panel data analysis

1. INTRODUCTION

The transport sector plays a crucial role in promoting economic growth and development by enabling the movement of goods and services between regions and facilitating trade. In the European Union (EU), road freight transport is an important part of the transport system and forms the backbone of the supply chain for various industries. The efficient and reliable movement of goods over road freight networks has a significant impact on the overall economic performance of European Union member states.

The relationship between road freight transport and economic growth has attracted considerable attention from policy makers, researchers and practitioners alike. Understanding the dynamics of this relationship is crucial for devising effective strategies to promote sustainable economic development in the European Union. This study aims to contribute to the existing literature by analysing the relationship between road freight transport and economic growth in the European Union using a panel data approach. Road freight transport involves the movement of goods by lorries on the road network. It provides the flexibility, accessibility and reliability necessary to meet the diverse needs of different industries, including manufacturing, retail and agriculture. As European Union markets continue to integrate and trade activities expand, road freight transport has become an integral part of regional and international supply chains. Consequently, the performance and efficiency of road freight networks have a direct impact on the competitiveness and productivity of EU economies. Economic growth, characterised by an increase in the production and consumption of goods and services, is a priority objective of EU policy makers. Increasing economic growth promotes job creation, improves living standards and enables countries to effectively address social and environmental challenges. Given the significant contribution of road freight transport to the overall transport sector, it is essential to assess its relationship to economic growth in the EU context.

The panel data approach used in this study allows for a comprehensive analysis by taking into account both cross-sectional and temporal variations across European Union member states. The study was conducted over a ten-year period (2012-2021). By using data from Eurostat, which contains an extensive dataset on various economic indicators, road freight transport statistics and infrastructure investments, this study aims to shed light on the relationship between road freight transport and economic growth.

Investment in road infrastructure is a key determinant of the efficiency of road freight transport. Adequate infrastructure, including well-maintained roads, bridges and intermodal facilities, is critical for reducing transport costs, minimising delays and improving connectivity. Consequently, well-functioning road infrastructure supports the smooth movement of goods, leading to improved logistics operations and higher economic productivity.

In addition to infrastructure investment, employment in the transport sector is another important factor to consider when analysing the relationship between road freight transport and economic growth. The transport sector offers employment opportunities at various levels, from lorry drivers to logistics specialists and maintenance personnel. The availability of skilled and efficient labour in the transport sector contributes to the overall performance of road freight transport and consequently to the economic growth of European Union member states.

By analysing the relationship between road freight transport, investment in road infrastructure, employment in the transport sector and economic growth in the EU, this study aims to provide valuable insights for policy makers, industry stakeholders and researchers. The results of this study can help policy makers formulate strategies to improve the efficiency of road freight transport, allocate resources effectively and promote sustainable economic growth in the EU.

The relationship between road freight transport and economic growth in the European Union is a topic of great importance. This study uses a panel data approach to comprehensively analyse this relationship, taking into account the crucial factors of road infrastructure investment and employment in the transport sector. By providing insights into the dynamics of this relationship, this study aims to contribute to the literature and assist policy makers in formulating effective strategies to promote sustainable economic development in the EU.

2. LITERATURE REVIEW

The literature review in this article aims to provide a comprehensive overview of existing research and academic contributions on the relationship between road freight transport and economic growth in the European Union. By examining relevant studies, theoretical frameworks and empirical evidence, this section aims to summarise the current state of knowledge in this area. Key themes, methodologies and findings are examined and gaps in the literature are identified, which this study seeks to address. The literature review provides a comprehensive synthesis of existing research on the relationship between road freight transport and economic growth in the European Union.

A large amount of literature has investigated the correlation between transportation and economic growth (Saidi, 2018). Whether the development of transportation promotes economic development or vice versa is still a matter of debate. A number of studies suggested transportation system development has a positive impact on economic growth (Khadaroo, 2008 and Beyzatlar et. al. 2014).

Research suggests that economic growth should be linked to freight demand (Bennathan et al., 1992). Their study on tonne-kilometres as an indicator supports the linear hypothesis between economic growth and freight demand. In his research paper Rothengatter (2011) believes that the prerequisite for economic recovery is the adjustment of the economic and transport structure, making transport more sustainable and environmentally friendly. Study from Moschovou (2017) investigates the relationship between tonne-kilometres and GDP and the study confirmed that transport services promote economic growth. The research results show that the economic crisis has had a negative impact on Greek road freight transport. Beyzatlar et al. (2014) analyses GDP per capita of domestic freight transport turnover per person and petrol consumption per capita in the road sector of 15 EU countries from 1970 to 2008 and concludes that there is a bidirectional relationship between GDP and freight transport.

As this study is based on panel data, we found other examples of research in the literature that reached conclusions based on similar (panel) data. For example, Feige (2007) uses an econometric analysis to test the relationship between GDP growth, transport costs and trade volumes. Some authors use time series data, for example Verny (2007), to test the relationship between freight, transport distance and economic growth. Some authors like Vilke et al. (2021) conducted a panel analysis for CEE countries and concluded that changes in the overall economy (value added and employment) have a significant and measurably strong impact on the freight transport industry. Paper from Sun et al. (2018) provided research in which they concluded that there is no significant relationship between transport investment and the national economy. The quantitative correlation between transport construction investment and GDP growth was analysed, but the study was unable to show the direct effect of regional lead industry through transport construction investment. In his research conducted by Shanshan (2021) using data for 31 provinces and cities in China from 1993 to 2018, he concludes that there is a co-integration relationship between GDP and freight transport volume, and national GDP increases by 0.954% for every 1% increase in freight transport turnover. Research by Alises et al. (2014) covering the period from 1999 to 2011 in Spain and the UK confirmed that the transition to more service-oriented economies brings with it a much lower demand for transport.

3. METHODOLOGY AND DATA

The aim of this research work is to investigate the relationship between economic growth and road freight transport. The objective of this work had determined the variables and methodology of the scientific research. To achieve this goal, and after a theoretical analysis of the research field, it seems appropriate to use regression analysis in the empirical part of the work. Regression analysis consists of using different methods to study the dependence of one variable on another or more variables, which is the case in this research. It is used for analytical and often predictive purposes and is applied in almost all professional and scientific fields. The regression model used to study the impact of road freight transport on economic growth is structured as follows:

$$GDP_{it} = \beta_0 + \beta_1 GTR_{it} + \beta_2 LMO_{it} + \beta_3 EIT_{it} + \beta_4 IME_{it} + \mu_{it}$$

where is:

- GDP – gross domestic product in euros
- GTR – total road transport in thousands of tons
- LMO – length of the road network (motorway) in kilometres
- EIT – number of persons employed in the transport industry
- IME – investments and maintenance costs in euros
- $\beta_0 - \beta_4$ – coefficients that need to be calculated by the regression model
- μ - residual deviations
- i – a country of the European Union
- t - year of observation.

The regression model was calculated using the software package STATA 18. All data used to calculate the regression coefficients are publicly available and can be downloaded from the Eurostat website (https://ec.europa.eu/eurostat/). The study includes data on 27 member states of the European Union for the period from 2012 to 2021. Economic growth is defined by the variable of gross domestic product (GDP) and set as the dependent variable in the regression model. The independent variables used to determine the impact on the dependent variable are determined by road freight transport. Total road transport in thousands of tonnes (GTR) as the independent variable represents the annual amount of goods transported by road. By reviewing previous research, this variable is expected to have a positive impact on the economic growth of the country. Thus, based on previous scientific findings, we predict the coefficient $\beta_1 > 0$. The independent variable length of road network in kilometres (LMO) is closely related to the volume of freight transport, and we predict it to have a positive influence on the country's economic growth. Therefore, we predict that the coefficient $\beta_2 > 0$. The number of employees in the transport sector as the third independent variable is defined by the movement in the number of employees in enterprises whose activity is the transport of goods. This variable is related to the variable for total road transport. Firms can be expected to employ more workers when total traffic grows. Therefore, we can predict that the coefficient $\beta_3 > 0$. Investment and maintenance costs (IME) in the road network have a direct impact on the economic growth of a country. As is well known in the economic literature, the growth of investment also affects the growth of GDP, and we predict the coefficient $\beta_4 > 0$. Therefore, we assume that all independent variables have a positive impact on the economic growth of the country.

After we have set up the regression model, we must decide between using the fixed effects model and the random effects model. Which model we will use, and which is more appropriate depends on what kind of panel data we have. If we can consider each individual as a randomly selected representative of the total population and they do not differ significantly from other individuals in all their characteristics, then the random effects model would be more appropriate. The fixed effects model describes each individual and is well suited when we need information about each individual because it is specific to itself. By analysing the panel data, we can very easily conclude that this model is applicable in our study. To test this assumption, we conducted the Hausman test. This test is one of the most important tools to determine which panel model is the best for us, i.e. with which panel model we obtain a more efficient result. The null hypothesis of the Hausman test assumes that there is no significant difference in the estimated coefficients, i.e. in this case the random effects model should be applied. The Hausman test was calculated using the STATA 18 software package and the results are shown below.

Figure 1 Hausman test

```
. hausman fixed random, sigmamore

                 ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |     fixed        random       Difference       Std. err.
-------------+----------------------------------------------------------------
         gtr |   -.3935429    -.2396064      -.1539366        .0442238
         lmo |    233.7772     73.85131       159.9259        54.08836
         eit |    904.2792     1022.314      -118.0352        119.8072
         ime |    53.10527     52.33073       .7745458        2.993629
------------------------------------------------------------------------------
                          b = Consistent under H0 and Ha; obtained from xtreg.
           B = Inconsistent under Ha, efficient under H0; obtained from xtreg.

Test of H0: Difference in coefficients not systematic

    chi2(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
            =  16.59
Prob > chi2 = 0.0023
```

Source: Author's calculation using STATA 18 software

The result of the Hausman test for the panel data used in this study confirmed our expectations and showed that the fixed effects model was more appropriate. The previously defined regression model was calculated using the fixed effects model and the results and analysis of the regression coefficients are presented in the following title.

4. RESEARCH RESULTS AND DISCUSSION

The study is based on panel data for a ten-year period (2012 – 2021) for 27 member states of the European Union. To be able to analyse the available data more easily and more precisely, descriptive statistics of the secondary data were first presented before the regression analysis with the fixed effects model was carried out.

Figure 2 Descriptive statistics of regression variables

Variable	*Mean*	*Std. Dev.*	*Min.*	*Max.*
GDP	474 473	749 667	7 364	3 601 750
GTR	498 721	692 326	14 402	3 208 232
LMO	2 781	4 213	0	15 860
EIT	376	482	9	2 141
IME	3 377	5 177	8	36 387

Source: Author's calculation with the software STATA 18

The dependent variable (GDP) is the only variable in the study for which we have all the data (27 countries for ten years is a total of 270 observations). Its average value is 474 billion euros. Malta has the lowest value of GDP of 7.3 billion in 2012, while Germany has the highest value of 3 601 billion euros in 2021. This variable shows the smallest variation between ranks in EU member states. When we look at the ranking of countries according to the value of GDP, we can see that Germany has the largest amount of GDP in all ten observed years, followed by France, Italy, Spain, and the Netherlands. All the first five countries in the ten-year period maintain their ranking. Total road transport (GTR), expressed in thousand tonnes, has a mean value of 498 721 and is lowest in Cyprus (2015), while it is highest in Germany in 2019. The variable length of the road network (LMO) refers to the length of motorways. This variable is related to the degree of economic development, the population density and the size of the territory of a particular country (similar to GDP). Its mean value is 2 781 kilometres, but it should be noted that its smallest value is zero. The member state of the European Union that has the longest highways is Spain. In 2021, the length of their highways is 15 860. The independent variable number of employees in the transport industry (EIT) is expressed in thousands of persons and its mean value is 376 thousand persons. It should be noted that this variable includes all persons working in transport companies. Therefore, this variable is not limited to road transport only, as accurate data on road transport for individual EU member states are not publicly available. The largest number of employees in the transport industry is in Germany, while the smallest is in Estonia. Road infrastructure investment and maintenance costs (IME) are expressed in millions of euros. The highest value of this variable was recorded in the Czech Republic in 2012 and amounted to 36 billion euros while the lowest value is reserved for Bulgaria in year 2012.

By applying the regression model presented in the methodology section, regression coefficients were calculated to explain how a single independent variable affects the dependent variable. The results of the calculated coefficients are shown in the table.

The values of all calculated coefficients are statistically significant, the p-values of all coefficients are smaller than 0.05. This was also confirmed by the test (F), which checks whether all coefficients of the model are different from zero. The results obtained are only partially as expected. All the coefficients obtained are positive, which means that they have a positive impact on economic growth, except for the coefficient explaining the impact of goods transported (GTR) on the independent variable. The results surprised us, because based on previous research that was mentioned in the literature review, we expected the effect to be positive. The coefficient β_1 has a value of -0.39, indicating a decrease in GTR of 393,000 euros when road freight transport increases by one thousand tonnes. We are 95% confident that the interval (-0.5961, -0.19099) includes the mean of total road transport in thousands of tons in research period. There is a 5% chance that this inference is incorrect, i.e. that this range of values does not include the population mean. The reason for this result can be found in the consequences of the Corona virus pandemic. During the pandemic, the flow of goods was interrupted for a greater relative amount than other economic activities, which affected obtained result.

Figure 3 Value of regression coefficients

Coefficient	Value of coefficient	Standard error	p-value	95% conf. interval	
β_1	-0.39354	0.10236	0.000	-0.5961	-0.19099
β_2	233.777	54.766	0.000	125.41	342.14
β_3	904.2792	198.082	0.000	512.34	1296.22
β_4	53.1052	8.0964	0.000	37.08	69.125
β_0	-572557	158834	0.000	-886839	-258275

Source: Author's calculation using STATA 18 software

The coefficient β_2 of the model is 233.77, implying a positive impact on the dependent variable. An increase in the length of motorways by one kilometre has a positive impact on the gross domestic product, which increases by 233 million euros. The independent variable, the number of employees in the transport sector, has the greatest influence on the dependent variable. This result should be interpreted with caution, because the variable refers to all persons working in the transport industry and not only to those working in road transport. The value of the coefficient defining the influence of this variable on the country's economic growth is $\beta_3 = 904$. Increasing the number of people employed by one lead to an increase in gross domestic product of 904 million euros. The variable that has the smallest positive impact on the dependent variable is investment and road infrastructure maintenance costs (β_4 = 53.1). The gross domestic product will increase by 53 million euros if investments and maintenance costs increase by one million euros.

5. CONCLUSION

The shortcomings of the research are the absence of values for certain variables, and we highlight the absence of data for persons employed in the road freight transport industry. These are variables that were not publicly available, which certainly had an impact on the outcome of the research. Although there are shortcomings, the model is statistically significant, the confidence level is set at 95%.

The results of the research do not fully correspond to our expectations that we had before the creation of this paper. From four variables, three have a positive impact on economic growth, while the variable of road freight transport has a negative impact on economic growth. This result can be partially explained by the impact of the corona virus pandemic, as we have already pointed out. It should also be taken into consideration the fact that the European Union is increasingly investing in the transport of goods by rail, even though most of the cargo in the European Union is currently transported by road (almost 77% of the total cargo). Obviously, the desire to reduce carbon in the freight transport sector has had an impact on road freight transport. The European Union is trying to shift cargo from more polluting road transport to rail and inland waterways. The European Commission has set goals, but they are not binding, so the countries of the European Union follow their own goals that are not aligned with those of the European Union. The European Union currently wants to double rail traffic and increase the use of waterways by 50% by 2050. Efforts to reduce road freight are hampered by, among other things, outdated regulations. It is to be expected that in the future in the European Union, most of the cargo transportation will be transferred from road to railway and waterways, which foreshadows the result we reached in the research.

Therefore, in future research, the time period of the research should be increased, and the research should include variables from the domain of rail freight transport and freight transport by inland waterways.

While the present study has its limitations, including the absence of certain variables and the unavailability of data on those engaged in road freight transport, it has produced statistically significant quantitative results. Although the results are not entirely in line with our initial expectations, they highlight the complex dynamics at play, which may be influenced by factors such as the ongoing COVID pandemic and the EU's focus on transitioning to more sustainable modes of transport. Therefore, this study lays the groundwork for further research and encourages further research on the multi-layered relationship between freight modes and economic growth. By broadening the analysis and taking into account new trends and policy initiatives, future research can contribute to evidence-based decision-making and the formulation of effective strategies to promote sustainable economic growth in the European Union and beyond.

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HOW LOGISTICS PERFORMANCE RESHAPES THE MOVEMENT OF STOCKS IN THE CONTEXT OF CLIMATE CHANGE?

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Abstract

Supply chains networks are at risk due to the climate change in terms of reputation, functionality, and safety. Increasing regulations, market forces, and stakeholder demands are paving over the decarbonization of supply chains, which has evident consequences for supply chain management. Therefore, the motivation of this research is to use logistics performance indicators to analyse the financial effects on the stock market. A case study of the Seven Leading Industrial Countries was used for this purpose. Autoregressive Distributed Lag (ARDL) model was used. The research sample was selected based on the industrial stock indices for these countries during the time period from the beginning of 2006 to the end of 2022. It is found that the logistics policy regulations indicators account for 26.28% of the impact on the returns of the industrial indicators, while the performance results of logistics services indicators contribute to 38.35% of the impact on the returns of industrial indicators. As originality, the current study succeeded in confirming that the importance of these countries is not only due to the fact that they are described as the Seven Leading Industrial Countries, but rather in how they deal with logistical challenges and developed them during the study period.

This research adds to the literature on climate change's financial effects and sheds light on the intricate linkages between two separate fields which are Finance and Supply chain, and also between logistics performance, supply chains, and stock market returns. Using indirect way to illustrate how the impact of climate change can reach financial markets.

Keywords: Climate Change, Logistics Performance Index, Stock markets

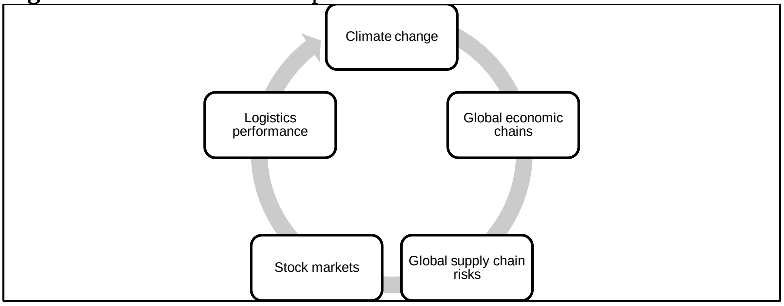
1. INTRODUCTION

Regarding the 2015 Paris Climate Change Agreement, the stock markets of the seven major industrialised nations (Canada, France, Germany, Italy, Japan, United States, and United Kingdom) had to adapt to the climate change considering the industrial sector's global supply chain, which had an impact on their stock prices and returns. This has increased the risks of climate change for companies and attracted the attention of several stakeholders such as institutional investors, banks, accounting firms, government agencies and consumers (Eleftheriadis et al. 2015). In contrast, economic expansion in developing nations has the reverse effect, increasing global emissions and hastening global warming (Hjort, 2016). One of the economic sectors most affected by climate change is the banking system. This is especially true for industrial supply chains that are exposed to the economic effects of climate change and are globally interconnected.

The initial economic effects of climate policy are expected to be below the effects of uncontrolled climate change, in other word climate change and the economic impacts resulting from it or followed that phenomenon are only a small part that has been revealed, but there is other a greater part that has not been revealed yet and is still within unknown of the unknown Risk. This phenomenon also has an impact on logistical performance, which has been addressed through its indicators and needs to be improved, there may be undiscovered effects. Carbon pricing initiatives, which include fees and cap and trade systems, are a key tool for economic experts to reduce emissions and promote technological development (Hjort, 2016). National carbon, energy tariffs, and technology benchmarks are currently in use in several countries**.** If the authorities do not implement regulatory and fiscal measures quickly, this could trigger a disruptive transition to a carbon-neutral society, leading to the obsolescence of certain economic activities and wasted assets (Lagarde, 2020). Businesses must provide comprehensive information about climate risks related to their operations in order to conduct a careful risk analysis. However, the transition to a carbon-neutral economy can offer the financial sector the opportunity to develop into an influential force that delivers greater benefits (Stern, 2022).

Climate change in one place can affect the global economic chains as shown in figure 1, where a global strategy is needed rather than local policies and plans (Levermann, 2014). This is why a global supply chain risk assessment is needed, and capturing accurate information is required about every economic activity within the chains. Country risk analysis has gained importance as businesses work to define the possibility for these risky events as a result of the expansion of global supply networks. The level of logistics risk linked with important suppliers in the global economy was evaluated using the Logistics Performance Index (LPI) data (Lockamy III, 2019).

Figure 1 The research conceptual framework



Source: developed by the authors

The LPI measures logistics efficiency, which is now generally acknowledged as being essential for trade and growth. Access to international freight and logistics networks is necessary for a country's traders to engage in cross-border commerce. While some facets of a country's domestic economy rely on how well its supply chain performs in terms of cost, timeliness, and dependability. Better overall logistical performance and trade facilitation are strongly connected with increased commerce, export diversification, economic growth, and attractiveness to foreign direct investment. According to Narlikar et al. (2012), the six LPI indicators fall into two main categories:

- Policy-regulatory areas that highlight the major supply-chain inputs (customs, infrastructure, and services).
- Supply chain performance results (equivalent to LPI metrics of time, cost, and dependability, timeliness, international shipments, and tracking and tracing).

Hence, this research has addressed the following research question:

How logistics performance reshapes the movement of stocks in context of climate change?

Thereof, the following hypotheses will be investigated in this paper:

H1: There is no statistically significant effect of the logistical performance indicators (Customs, Infrastructure, Logistics competence, Tracking and tracing, international shipments, Timeliness) on the returns of stock market indices in the context of climate change.

H2: There is no statistically significant effect of the areas for policy regulations of logistics represented by the indicators: (Customs, Infrastructure, Logistics competence) on the returns of stock market indices in the in the context of climate change.

H3: There is no statistically significant effect of service delivery performance outcomes of logistics represented in the indicators (Tracking and tracing, international shipments, Timeliness) on the returns of stock market indices in in the context of climate change.

2. LITERATURE REVIEW

The precarious industrial sector is deemed to be one of the prime victims of the daunting financial consequences of climate change (Carney, 2015). The emergence of the Paris Agreement in 2015 has further spurred a growing unease about how the stock markets of major industrial countries would cope with this unfolding disaster. In this section, the related literature of the stock markets' financial impacts in the world's top seven industrial countries has been reviewed.

2.1 Climate Changes and the Financial Impacts

Recent research has identified climate change as a brand-new source of risk for the financial system, raising significant concerns among investors and financial institutions everywhere. The financial sector has not yet created methodologies that allow for an efficient analysis of the threats that climate change poses to financial stability (Battiston, 2021).

Traditional approaches to macroeconomic and financial risk analysis face significant difficulties as a result of the distinctive characteristics of climate risks, including their high degree of uncertainty. Therefore, it is essential to include cutting-edge viewpoints that integrate climate change into macroeconomic and financial analysis in order to achieve a more thorough understanding of the macro financial relevance of climate change (Hallegatte & Rentschler, 2015).

It has come to attention that specific central banks have taken the initiative to conduct an inquiry into the potential impact of climate change and the shift towards low carbon, primarily owing to their responsibility in financial regulation and supervision. Failure to act on climate change may lead to considerable physical and economic losses. This presents a significant matter that demands immediate consideration and critical assessment to avert possible crises (Authority, 2015; Gradwell et al. 2016).

The surge in climate-induced physical hazards like heat waves, floods, and storm surges could potentially trigger a direct impact on insurance providers responsible for covering such risks. In scenarios where such risks remain uninsured, the gradual deterioration of the balance sheets of affected households and corporations may consequently result in losses for their corresponding lending banks. This presents a worrying possibility that demands urgent attention and extensive deliberation, given the potential magnitude of the ensuing financial impacts (Tanaka & O`Neill, 2018).

A shift to a carbon-free economy is ultimately necessary to prevent physical damages and the related financial instability. The risks of economic disruption and stranded assets, however, could increase as a result of the transition itself. For instance, maintaining current oil, gas, and coal reserves underground will likely be necessary to meet the 2 °C temperature threshold (Vogel, 2019; McGlade and Ekins, 2015). At the end, climate change has been identified as a significant source of risk for the financial system, raising concerns among investors and financial institutions globally.

As a result, when making investment choices, insurance firms and other institutional investors must consider the possible financial risks presented by climate change and the transition to a low-carbon economy. Many players in the private sector have pledged to cut deforestation out of their global supply chains.

2.2 Climate Changes and the Global Supply Chain

Managing risks imposed by a climate change requires firms to coordinate and collaborate with their supply chain partners and stakeholders through three different approaches (Dahlmann and Roehrich, 2019), including information gathering, where firms collect information about any climate change and its consequences; Information processing, that aims to collect and analyse information at product level to understand the impacts of climate changes; and Information transferring, where a feedback is shared with all supply chain partners. To achieve the previous three approaches of collaboration, sustainable supply chain management is needed to manage global supply chains. The related literature clarified that focus on the sustainability dimensions was by (29%), on the environmental and social dimensions jointly was by (27%), where a less focus on environmental and economic dimensions jointly was by (9%) (Koberg and Longoni, 2019).

If global warming rises to 1.5°C, it will inevitably lead to an increase in numerous climatic disasters and multiple threats to ecosystems and people. Numerous terrestrial, freshwater, coastal, and marine habitats will face extremely high risks of biodiversity loss due to near-term warming. As results of climate changes, Pörtner et al. (2022) addressed seven projected global supply chain risks, including ecosystems, food security, water security, health and well-being, migration security, infrastructure security, and economic security.

In a supply chain context, buyer decision-making about supplier openness may aid in reducing risks related to suppliers' greenhouse gas (GHG) emissions (Villena and Dhanorkar, 2020; Blanco, 2021). Pankratz and Schiller (2021) focused on two different weather shock heat waves and floods, to determine whether businesses alter their supply chain networks in response to perceived changes in their suppliers' susceptibility to physical climate risks. They claimed that heat and flooding catastrophes have a detrimental impact on suppliers' financial performance and demonstrate how these shocks' financial repercussions spread to customers via the already-existing supply chain links.

In a globalization context, fast transportation and advanced communication technologies changed the way how companies turned from a classical pattern of operating and competing into a strategic pattern to integrate with their supply chain partners (Kano et al. 2020). This has led to global commodity chains (GCCs), global value chains (GVCs) or global supply chain (GSC), global production networks (GPNs), or global factories. Antràs (2020) defined a GVC as a process that involves a number of steps in the creation of a good or service that is sold to customers, each of which adds value and at least two of which are created in different nations. In addition to being environmentally friendly, Maranesi and Giovanni (2020) claimed that the circular economy (CE) can also offer businesses a viable commercial opportunity and a means of integrating into the industrial supply chain network.

2.3 LPI Drivers Review in Seven Leading Industrial Countries

Climate change poses risks to supply chain networks in terms of safety, functionality, and reputation. The decarbonization of supply chains is being paved over by escalating regulations, market forces, and stakeholder pressures. The effects of climate change on supply chains should be of particular concern to supply chain managers, and researchers should continue to investigate how supply chain operations and design are related to climate change (Dasaklis and Pappis, 2013). These risks impose financial impact on companies, governments, and associations.

The Logistics Performance Index (LPI) data (Lockamy III, 2019) was used to assess the degree of logistical risk associated with significant suppliers in the global economy. LPI has six drivers, including customs, infrastructure, international shipments, logistics quality and competence, tracking and tracing, and timeliness.

- As Customs elucidates, a fresh World Bank investigation espouses the prospect of expediting customs procedures and curbing trade obstacles, to engender a higher rate of economic growth and job creation (Ojala & Celebi, 2015; Ekici et al. 2016).
- Infrastructure is an essential pillar of the Logistics Performance Index (LPI), wields a significant impact on the financial markets of industrial countries (Ehlers, 2014).
- International shipments are a pivotal component of the Logistics Performance Index (LPI), are subject to intricate regulations and procedures.
- Logistics quality and competence cannot be overemphasized in the Logistics Performance Index (LPI) and can trigger a seismic shift in the financial markets of industrial countries (Ekici et al., 2019; Nguyen and Huynh, 2023).
- Tracking and tracing is one of the preeminent pillars of the Logistics Performance Index (LPI) and is believed to have an outsized impact on the financial markets of industrial countries (Yu et al. 2023; Wei et al. 2023; Kafetzopoulos et al. 2023; Naghshbandi, 2023).
- Timeliness is a critical pillar of the Logistics Performance Index (LPI) and can have significant impacts on the financial markets of industrial countries (Qazi, 2022; Azadegan et al., 2021).

3. RESEARCH METHODOLOGY

3.1 Research Variables

In order to study markets' climate change financial impacts in the world's top seven industrialised nations, there was a need to identify the independent and dependent variables that significantly impact the efficiency and effectiveness of supply chains. The independent variables that affect supply chains service delivery are as follows:

- Customs: Customs procedures and regulations can impact the speed and ease of goods moving across borders.

- Infrastructure: The quality of infrastructure, such as roads, ports, and airports, can affect the speed and reliability of transportation.
- Logistics quality and competence: The ability of logistics providers to manage the movement of goods efficiently and effectively can impact the speed and reliability of the supply chain.
- International shipments: Shipping goods across international borders involves navigating complex regulations and procedures.
- Timeliness: Timely delivery of goods is essential to keeping the supply chain running smoothly.
- Tracking and tracing: The ability to track and trace shipments throughout the supply chain can improve visibility and transparency, allowing for better inventory management and more efficient resolution of any issues that arise.

While, the dependent variables in this research are the reliable stock exchange indices for measuring industry and energy in the seven major industrial countries. These variables are as follows:

- S&P/TSX Capped Energy Index for Canada: This index tracks the performance of 50 energy companies listed on the Toronto Stock Exchange in Canada.
- CAC 40 for France: This index tracks the performance of the 40 largest companies listed on Euronext Paris, including many industrial and energy companies.
- DAX 30 for Germany: This index tracks the performance of the 30 largest companies listed on the Frankfurt Stock Exchange, including many industrial and energy companies.
- FTSE MIB for Italy: This index tracks the performance of the 40 largest and most actively traded companies listed on the Borsa Italiana in Italy, including many industrial and energy companies.
- Nikkei 225 for Japan: This index tracks the performance of the 225 largest companies listed on the Tokyo Stock Exchange in Japan, including many industrial and energy companies.
- FTSE 100 for the UK: This index tracks the performance of the 100 largest companies listed on the London Stock Exchange, including many industrial and energy companies.
- S&P 500 for the United States: This index tracks the performance of 500 large-cap companies listed on the New York Stock Exchange and NASDAQ in the United States, including many industrial and energy companies.

3.2 Research Sample

The research sample was selected based on the inclusion of the seven largest industrial countries in the world. Industrial stock indices for these countries were determined during the time period from the beginning of 2006 to the end of 2022. The research sample is illustrated in Table 1.

Table 1 The Research Sample

No.	Industrial Countries	Index	Index Components
1	Canada	S&P/TSX Capped Energy	50
2	France	CAC 40	40
3	Germany	DAX 30	30
4	Italy	FTSE MIB Investing	40
5	Japan	Nikkei 225	225
6	United Kingdom	FTSE 100	100
7	United States	S&P 500	500

Source: data obtained from: https://www.investing.com/indices/

In addition, LPI values for the seven leading industrial countries were collected as shown in Table 2.

Table 2 The Values of (LPI) of the Research Sample Countries

No.	Country	2007	2010	2012	2014	2016	2018	2022	Average Periods
1	Canada	3.920	3.870	3.850	3.855	3.931	3.730	3.810	3.852
2	France	3.760	3.840	3.850	3.847	3.901	3.840	3.860	3.843
3	Germany	4.100	4.110	4.030	4.122	4.226	4.200	4.190	4.140
4	Italy	3.580	3.640	3.670	3.691	3.755	3.740	3.730	3.687
5	Japan	4.020	3.970	3.930	3.915	3.970	4.030	3.990	3.975
6	United Kingdom	3.990	3.950	3.900	4.015	4.070	3.990	4.010	3.989
7	United States	3.840	3.860	3.930	3.918	3.992	3.890	3.920	3.907

Source: Sreedevi et al., 2023

The above table shows the average logistics performance index of the seven major industrialised countries during the period from 2007 to 2022. According to the results, Germany ranked first with an average logistics service performance of 4.14, followed by the United Kingdom with a performance rate of 3.989, then Japan with a performance rate of 3.975, and the United States with a performance rate of 3.907. Canada ranked fifth with a performance rate of 3.852, followed by France with a performance rate of 3.843, and finally Italy with an average logistics performance rate of 3.687. These results are important for understanding how the major industrialised countries have tackled logistics challenges and developed logistics services during the mentioned period.

3.3 Research Methodology

In order to study the impact of logistics Performance Indicators on stock indices in Industrial Countries, the Autoregressive Distributed Lag (ARDL) model was used (Pesaran and Shin, 1999; Pesaran et al. 2001), as an alternative to test cointegration of Engel and Granger (1987) and Johansen (1988, 1991).

This approach allows us to test the long-term relationship using variables that may not be integrated of the same order I (0) or (1). Additionally, the ARDL approach provides unbiased estimates of the long-run relationship (Harris and Sollis, 2003), and it is suitable for small samples (Narayan, 2005). The optimal number of lags for the dependent variable and the independent variable is determined using the Akaike Information Criteria (AIC). The ARDL model equation could be formulated using abbreviated terms for the logistics performance indicators as follows:

Y = Stock index (dependent variable)
C = Customs
I = Infrastructure
LC = Logistics competence
TT = Tracking and tracing
IS = International shipments
T = Timeliness
L = Lag operator

Thus, our ARDL model is given by the following equations:

H1: $Y = \beta 0 + \beta 1C + \beta 2I + \beta 3LC + \beta 4TT + \beta 5IS + \beta 6T + \beta 7C (L) + \beta 8I (L) + \beta 9LC (L) + \beta 10TT (L) + \beta 11IS (L) + \beta 12T (L) + \varepsilon$ (1)
H2: $Y = \beta 0 + \beta 1C + \beta 2I + \beta 3LC + \beta 4C (L) + \beta 5I (L) + \beta 6LC (L) + \varepsilon$ (2)
H3: $Y = \beta 0 + + \beta 1TT + \beta 2IS + \beta 3T + \beta 4TT (L) + \beta 5IS (L) + \beta 6T (L) + \varepsilon$ (3)

where:

$\beta 0$ is the intercept term.

$\beta 1, \beta 2, \beta 3, \beta 4, \beta 5, \beta 6$ are the coefficients corresponding to the current values of the logistics performance indicators, representing the short-term impact of each indicator on the stock index.

$\beta 7, \beta 8, \beta 9, \beta 10, \beta 11, \beta 12$ are the coefficients corresponding to the lagged values of the logistics performance indicators, representing the long-term impact of each indicator on the stock index.

C, I, LC, TT, IS, T are the current values of the abbreviated logistics performance indicators (customs, infrastructure, logistics competence, tracking and tracing, international shipments, timeliness).

C(L), I(L), LC(L), TT(L), IS(L), T(L) are the lagged values of the abbreviated logistics performance indicators up to k lags, representing the long-term impact of each indicator on the stock index.

ε is the error term or residual, capturing the unexplained variation in the stock index that is not accounted for by the logistics performance indicators.

The null of non-existence of the relationship is defined by:

H0: $\beta 1=\beta 2=0$. (Null, i.e., the relationship does not exist).
H1: $\beta 1\neq\beta 2\neq 0$ (Null, i.e., the relationship does exist).

4. FINDINGS AND DISCUSSION

4.1 Descriptive Statistics of Research Variables

Table 3 presents the descriptive statistics of the cumulative returns of the indices of seven industrialized countries in the world, where the returns from the previous year and the current year were collected for the periods of seven issues of logistic performance indicators during the years 2007, 2010, 2012, 2014, 2016, 2018 and 2022. With the aim of analysing and evaluating the performance of the indicators of the markets of industrialised countries over these periods, the table is as follows:

Table 3 Descriptive Statistics Market Indicators

No.	Countries	Index	Years	Mean	Min	Max	Std. Dev.
1	Canada	S&P/TSX	(2006+2007)	16.58%	-41.47%	110.47%	46.43%
2	France	CAC 40	(2009+2010)	14.14%	-1.23%	24.31%	9.50%
3	Germany	DAX 30	(2011+2012)	21.03%	-6.60%	42.40%	16.84%
4	Italy	(invit40) Investing	(2013+2014)	6.80%	-11.91%	20.36%	9.90%
5	Japan	Nikkei 225	(2015+2016)	14.62%	-1.52%	57.38%	18.95%
6	UK	FTSE 100	(2017+2018)	12.48%	-4.80%	32.82%	10.88%
7	USA	S&P 500	(2021+2022)	19.99%	5.97%	38.44%	12.07%

Table 4 includes descriptive data and statistics for six logistical dimensions: customs, Infrastructure, logistics competence, tracking and tracing, international shipments, and timeliness. The data was collected from Panel Data and it includes 49 views of logistic issues data over 7 time periods, including 7 industrialised countries as follows:

Table 4 Descriptive Statistics of Logistic Performance Indicators

Dimensions Independent	Logistic Indicator	Mean	Min	Max	Std. Dev.
Areas For Policy Regulations	Customs	3.726	3.19	4.123	0.208
	Infrastructure	4.051	3.52	4.439	0.187
	Logistics competence	3.936	3.625	4.31	0.163

Service Delivery Performance Outcomes	Tracking and tracing	4.021	3.66	4.265	0.134
	International shipments	3.6	3.21	3.91	0.157
	Timeliness	4.211	3.93	4.48	0.135

Based on the provided data, it appears that the logistics operations are generally performing well in terms of infrastructure, tracking and tracing, and timeliness, as these indicators have relatively higher mean scores (4.051, 4.021, and 4.211, respectively). This suggests that the quality and availability of infrastructure, effectiveness in tracking and tracing shipments, and punctuality in delivering shipments according to schedule are areas of strength in the logistics operations.

However, there may be room for improvement in other areas. The logistics competence indicator has a mean score of 3.936, indicating that there may be some room for enhancement in the competence and expertise in managing logistics processes such as planning, organizing, and coordinating shipments.

The customs indicator has a mean score of 3.726, which suggests that there may be some opportunities to improve the performance and effectiveness in managing customs-related processes in the logistics operations, which may involve customs clearance, documentation, and compliance with international trade regulations.

The international shipments indicator has the lowest mean score of 3.600, indicating that there may be some room for improvement in managing international shipments, which may involve customs clearance, documentation, and compliance with international trade regulations.

Overall, these results highlight both strengths and areas for improvement in the logistics operations, and further analysis and action may be needed to address any identified areas of improvement and enhance overall logistics performance.

4.2. Testing Hypothesis

In order to determine the optimal number of delays for the ARDL models, the Akaike information criterion (AIC) was applied in this research. The data was analysed for hypotheses and the results were discussed in the following part.

4.2.1 Testing the First Hypothesis

To investigate the impact of all dimensions of logistics indicators (customs, infrastructure, logistics competence, tracking and tracing, international shipments, and timeliness) on the industrial sector index in the major industrialised countries, ARDL analysis was performed and provided the following results:

Table 5 Testing the First Hypothesis

VARIABLE	LAG MODEL	COEFFICIENT	T-STATISTIC	PROB.	R^2	DURBIN-WATSON	Prob.
C		0.197	0.142	0.888			
CUSTOMS	1	-0.545	-1.487	0.015			

INFRASTRUCTURE	0	0.587	1.296	0.204	54.29%	1.78	0.005
LOGISTICS COMPETENCE	1	1.251	2.871	0.007			
TRACKING AND TRACING	2	1.244	3.686	0.001			
INTERNATIONAL SHIPMENTS	0	0.325	1.285	0.208			
TIMELINESS	2	-1.053	-3.388	0.002			

According to Table 5, the results indicate a significant effect of changes in the dimensions of logistical indicators on the industrial sector index in major industrial countries, with a coefficient of determination of 54.29%. This suggests that these indicators are able to explain approximately two-thirds of the changes that occur in the industrial index.

It is important to note that the logistical indicators of infrastructure and international shipments did not show a significant effect on the cumulative returns of the industrial sector index in the industrialized countries, as the values of the determination coefficients (t) were lower than the significance level (0.05).

Furthermore, the Durbin-Watson test yielded a value of 1.78, indicating no autocorrelation issue in the model. The significance level of the model was 0.005, which is less than the significance level (0.05), leading to the rejection of the null hypothesis and acceptance of the alternative hypothesis in relation to the first hypothesis.

4.2.2. Testing the Second Hypothesis

To investigate the effect of Areas for Policy Regulations on the logistics services indicators (customs, infrastructure, and logistics competence) on the industrial sector index in the major industrial countries. ARDL analysis was performed and provided the following results:

Table 6 Testing the Second Hypothesis

Dimensions	Lag Model	Coefficient	T-Statistic	Prob.	R2	Durbin-Watson	Prob.
C		-0.850	-0.929	0.359	26.28%	1.67	0.008
Customs	0	-0.057	-0.136	0.049			
Infrastructure	2	1.000	2.777	0.008			
Logistics Competence	1	0.634	1.595	0.119			

Based on Table 6, the results indicate a significant effect of changes in the areas of logistics policy regulations on the cumulative returns of the industrial sector index in major industrial countries, with a determination coefficient of 26.28%. This suggests that these policy regulations can explain a significant portion of the changes in the returns of the industrial index.

However, the Logistics competence index did not show a significant effect on the cumulative returns of the industrial sector index in the industrialized countries, as the null hypothesis was rejected, and the alternative hypothesis was accepted in relation to the second hypothesis.

4.2.3 Testing the third hypothesis

To investigate the effect of Service Delivery Performance Outcomes represented by tracking and tracing, international shipments, and timeliness indices on the industrial sector index in the major industrial countries. ARDL analysis was performed and provided the following results:

Table 7 Testing the Third Hypothesis

Dimensions	Lag Model	Coefficient	T-Statistic	Prob.	R^2	Durbin-Watson	Prob.
C		-0.122	-0.105	0.917	38.35 %	1.95	0.011
Tracking And Tracing	2	1.269	3.614	0.001			
International Shipments	0	0.096	0.398	0.693			
Timeliness	2	-1.031	-3.105	0.004			

Based on Table 7, the results indicate a significant effect of changes in the Service Delivery Performance Outcomes on the cumulative returns of the industrial sector index in major industrial countries. The determination coefficient is 38.35%, which suggests that these performance indicators can explain a significant portion of the changes in the returns of the industrial index. However, the international shipments index did not show a significant effect on the cumulative returns of the industrial sector index in the industrialised countries, as the null hypothesis was rejected, and the alternative hypothesis was accepted in relation to the third hypothesis.

4.3. Robustness Check

The ARDL models were assessed for robustness using several diagnostic tests of residuals, including the Breusch-Godfrey serial correlation LM test for autocorrelation, the Breusch Pagan-Godfrey heteroskedasticity test, the Jarque Bera test for normality of residuals, and the CUSUM stability test. Based on the results of these tests, our models were found to be robust, with no evidence of autocorrelation, heteroskedasticity, or departure from normality in the errors. This ensures the validity and reliability of the estimated coefficients and the soundness of our conclusions.

5. CONCLUSION

The results of this study support the hypothesis that logistics performance plays a significant role in influencing the performance of the industrial sector. The findings indicate that the combined effect of various logistics service indicators when considered collectively, can explain up to 54.29% of the changes observed in the cumulative returns of the industrial indicators. Furthermore, the logistics policy regulations indicators account for 26.28% of the impact on the returns of the industrial indicators, while the performance results of logistics services indicators contribute to 38.35% of the impact on the returns of industrial indicators.

These results underscore the significance of logistics services as a critical factor in achieving favourable industrial performance. The aggregated indicators reveal that the interaction among various logistics service indicators can elucidate a substantial proportion of the changes observed in the cumulative returns of the industrial indicators. Furthermore, the specific performance outcomes of logistics service delivery, such as tracking and tracing, international shipments, and timing, also exert a significant impact on industry index returns.

Based on these findings, it can be inferred that logistics services play a pivotal role in industrial performance, as they account for a significant portion of the changes in the cumulative returns of industrial indicators. Enhancements in logistics policy regulations and performance outcomes of logistics services can lead to improved industrial performance.

The results of the study highlight both strengths and areas for improvement in the logistics operations, and further analysis and action may be needed to address any identified areas of improvement and enhance overall logistics performance.

To advance future research, it is advisable to explore additional measures that can potentially enhance the impact on industrial indicators. These measures may include optimizing the organization of shipments, improving the management of timing, streamlining customs procedures, enhancing supply chains, and ensuring the provision of efficient transportation services.

The significant question is how can logistics policy regulations and performance outcomes of logistics services be optimized to maximize their impact on industrial indicators and improve overall industrial performance?

Furthermore, climate change can be used as testable variable by using an event study to investigate the impact of Climate change on both LPI and Financial market indices` returns before and after Paris agreement 2015.

It is claimed that the study provides empirical evidence supporting the hypothesis that logistics performance significantly influences the performance of the industrial sector, as demonstrated by the significant impact of logistics service indicators on the cumulative returns of industrial indicators.

As limitation, the Logistics Performance Index (LPI) serves as a valuable tool for benchmarking logistics performance, but one of the primary limitations of the LPI is its narrow focus on only six dimensions. The LPI neglects various other dimensions that are equally critical for evaluating logistics performance. This narrow scope may lead to an incomplete assessment, failing to capture the holistic complexities of logistics operations. In addition, the LPI's standardized framework might not fully capture the nuances and dynamics of local contexts. Different regions and countries have unique logistical challenges, regulations, and infrastructural constraints that can significantly impact performance.

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AN ANALYSIS OF THE LOGISTICS MARKET AND THIRD-PARTY LOGISTICS PROVIDERS

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Abstract

Over the past 15 years, there have been many shocks that have significantly affected international trade and supply chains. All these shocks affect the operations of businesses, especially those operating on the international stage. Logistics companies such as Third-party logistics (3PL) are an important link in the smooth transportation of goods from the point of production or sale to the point of consumption, offering numerous related activities in addition to the predominant transportation services. The purpose of this article is to examine and present the latest findings on the role of 3PL in global supply chains, to investigate the services provided by 3PL, and to analyse and compare the activities of the largest global 3PL operators. The analysis is based on the secondary statistical data available for 3PL logistics market. Main findings show that global logistics industry is continuously growing. Among all services provided by the 3PLs, the most outsourced are transportation, especially domestic transportation, warehousing, customs brokerage and freight forwarding. The limitation of this research lies in the fact that the analysis is based on the secondary data, and therefore the suggestion for the further research is to run primary research on services of 3PLs. This work contributes to the valorisation of 3PL and logistics services as one of the most important factors of the competitiveness of global supply chains.

Keywords: logistics industry, Third-party logistics (3PL), international trade, global supply chains

1. INTRODUCTION

The global business world involves many activities, parties, and risks, and therefore it is often difficult for a company to manage all these aspects by itself. International logistics is an important element of international business. Given the complexity of supply chains and all the necessary logistical elements that need to be fulfilled for the supply chain to run smoothly, many companies tend to eliminate ancillary activities by transferring them to specialized companies. The transfer of a company's logistics activities to a specialized company is referred to as "3PL" services, also known as Third-party logistics. Logistics companies such as 3PL providers are an important link in the smooth transportation of goods from the point of production or sale to the point of consumption, offering numerous related activities in addition to the predominant transportation services.

Over the past 15 years, there have been many shocks that have affected international trade and international supply chains. All these shocks affect the operations of businesses, especially those operating on the international stage. The Covid-19 pandemic and the growth of e-commerce have made supply chains even more complex and demanding, posing significant challenges to all logistics activities. Logistics and 3PL service providers gained prominence during the outbreak of the Covid-19 pandemic. As a result, e-commerce grew, and most companies could not handle the complex logistics requirements and high demand. Even the specialized 3PL providers faced the challenge of meeting the demands of businesses on one side and customers on the other. More and more international companies operate without internal logistics departments. In this way, they are able to pool financial and human resources to develop their main business activities and flexibly combine services as business requirements change. The 3PL market is a growth market, and outsourcing 3PL services is beneficial in most cases for companies operating in international markets within complex supply chains. Therefore, the main objective of this article is to examine and present the latest evidence on the role of 3PL in global supply chains. The aim of this article is to examine the services provided by 3PL and to analyse and compare the activities of the largest global 3PL providers.

The research questions that arise in this research are: Who are 3PLs and what is their role in international business? Who are the leading 3PL companies and why do they hold this position? What are the main services they provide and what are the main challenges they face in their business. Finally, what are the most required and used technologies in the 3PL business? The analysis is based on secondary statistical data available for the 3PL logistics market. The main research method used in this paper is a literature review and secondary data analysis. Although the secondary data provides a clear insight into the 3PL business, it does not include information on individual companies or regions. Therefore, it would be beneficial for further research to analyse the primary data obtained from the survey in a specific region or the case study of a specific company.

This paper consists of four main parts. After the Introduction, the second part, the literature review, presents the existing literature on third-party logistics providers (3PLs) and their role in international business and supply chains. The third part contains an analysis of the global logistics market and the main 3PL companies operating in this market. The fourth part contains concluding remarks, limitations of the research and suggestions for further research.

2. LITERATURE REVIEW

Topics in third party logistics or 3PLs are increasing in the academic literature. According to Qureshi's (2022) bibliometric analysis of articles published annually in the Scopus database on the topic of 3PLs from 2001 to 2022, the number of publications more than doubled in the second decade compared to the first decade from 2001 to 2010, peaking in 2020. Moreover, the Scopus database index contains 2057 articles related to the keywords “3PL”, “outsourcing" and “logistics service provider" (Qureshi, 2022). Although the topics of logistics market and third-party providers have been present in academic literature for decades, there is still no standard definition to describe third-party providers in logistics. According to the Council of supply chain management professionals, 3PL is a “firm that provides multiple logistics services for use by customers which include services integrated or bundled together by the provider” (Midgley & Bak, 2022, p. 1739). Terms contract logistics and logistics outsourcing are sometimes used as synonyms in the literature. Different definitions attempt to emphasize different aspects of outsourcing contracts (Selviaridis & Spring, 2007). The general idea behind third-party logistics is that a company (e.g., a manufacturing company) allows a specialised company to assign it one or more logistics functions, such as transportation, warehousing, distribution, etc. (Waters, 2003; Murphy & Knemeyer, 2018). 3PLs offer services carried out for a shipper, at the very least managing and carrying out transportation and warehousing. Due to a lack of time, resources, expertise, or understanding, companies frequently employ the services of 3PLs (Berglund et al., 1999). 3PLs are the most common type of logistics provider used today, coordinating freight forwarders, logistics intermediaries and other service providers (Pavlić Skender, Host & Nuhanović, 2016).

Companies are increasingly encouraged to use one-stop logistics services provided by 3PLs to increase the efficiency of their supply chains so they can focus on their core competencies (Vaidyanathan, 2005, Choi, Wallace & Wang, 2016). With the increasing complexity of business units and company processes in international trade, it is becoming more and more difficult to manage all operations by oneself (Pavlić Skender, Host & Nuhanović, 2016). The primary goal of using 3PLs is to facilitate the organization of the shipment and/or delivery of goods for companies involved in international purchasing and sales. 3PLs take care of a wide range of activities, from delivery of goods, warehousing, assembly, loading/unloading, labelling, packing/repacking, and distribution of goods (Batarlienė & Jarašūnienė, 2017). Transportation, warehousing, packaging, inventory management, order fulfilment and quality information system are the main logistics tasks that 3PLs can perform. As logistics service providers, 3PLs take care for the goods during delivery between different parties and other related transformation operations (Schramm, 2012). According to Hickson et al. (2008) 3PLs perform multiple physical logistics functions on behalf of the customer and focus more on freight movement than supply chain management and efficiency, although they may or may not own physical assets and their resources are primarily knowledge-based.

Companies outsource certain operational tasks to third-party logistics providers - 3PLs to reduce costs and increase revenue (Pavlić Skender, Mirković & Prudky, 2017). Furthermore, to prevent the occurrence of mistransactions, financial institutions typically need to use professional logistics service providers (3PLs) to monitor the commodity transactions of upstream and downstream companies in the supply chain to prevent potential collusion between those companies from causing risks to the financial system (Wen et al., 2019). Designing and implementing a supply chain that aligns with the company's business strategies is one of the most difficult tasks in a company's global expansion (Pavlić Skender, Mirković & Dobrilovich, 2019). The role of 3PLs is essentially to manage the logistics of supply chains to ensure the smooth flow of goods and information between companies within a supply chain, from raw material supply through production and consumption to recycling.

It is a common 3PL practice not to outsource individual logistics activities, but to outsource multiple activities from a strategic company perspective. 3PL providers today exhibit characteristics such as integrated or multimodal logistics service providers, contract-based service providers, and consulting service providers (Tezuka, 2011). While integrated service providers usually offer complete logistics services and own assets such as transport vehicles and warehouse facilities, consulting service providers more often do not own assets but offer consulting services to companies to optimize supply chain logistics.

The 3PL industry is incredibly complicated, and 3PL providers must always maintain a pricing structure that is increasingly competitive and build skills to improve their services (Marchet et al., 2017). Considering the ever-changing environment, especially after the Covid-19 pandemic, 3PL companies have to train their managers and hire skilled labour to manage the complexity and changes in relationships in modern global supply chains. Moreover, management and relationship skills are important for 3PL and freight forwarding managers (Midgley & Bak, 2022). To complement logistics business and satisfy customer service expectations, 3PLs are increasingly expected to be inventive, and frequently provide new solutions and more sophisticated and better value-added logistics services (Large, Kramer & Hartmann, 2011). To speed up the shipping process once customers have placed an order, many retailers, especially those operations in online business choose to stock their products in 3PL distribution facilities (Zhang, Nault & Tu, 2015). Modern 3PL companies try to influence the market behaviour of other companies and create a suitable structure for value creation in logistics processes (Deepen et al., 2008; Kmiecik, 2022). 3PLs are a crucial component of the majority of businesses that are expanding and becoming more significant. The competencies, capabilities, and logistics expertise are what make 3PLs valuable. According to Zacharia, Sanders, and Nix (2011), the function of 3PLs has changed from that of a provider of logistics services to that of an orchestrator within the supply chain. According to Bitran, Gurumurthi and Sam (2006), orchestration refers to the control of supply chains by a group of actors, or "hub" company, whose responsibility it is to provide the required services and take over a section of the supply chain. Thus, the reasons to outsource 3PLs are not only to minimise costs or improve access to a broader range of resources, but also to benefit from 3PL relationships. The importance of the study of 3PLs and their role in international business is clearly emphasised, therefore the rest of this paper analyses the business of 3PLs using available data sources.

3. METODOLOGHY AND DATA

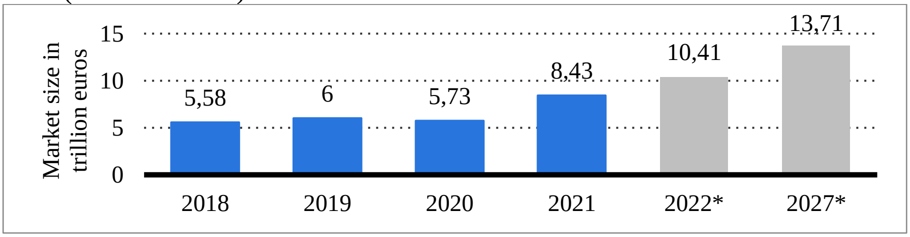
The analysis of the main theoretical and empirical findings on third-party logistics providers is based on the review of the available literature. The literature is drawn from the Proquest (2023) database. In addition to the literature review, the analysis is also based on the review of secondary statistical data on the global logistics market, the third-party logistics market, the most successful global 3PL providers, their services, the technology they use, and the challenges they face in international business. The statistical data comes from Statista's 2023 database and was gathered from various sources such as Research and Markets, Armstrong & Associates, and Inbound Logistics. To analyse the literature and data and achieve the research objectives, the method of analysis, synthesis, induction, deduction, and comparison is used.

4. GLOBAL LOGISTICS MARKET AND 3PLS

Logistics is one of the factors that affects the development of economic sectors key to the development of the country, including the efficiency of international trade (Górecka, Pavlić Skender & Zaninović 2022). Through B2B, B2C, or C2C supply chain networks between various participants in the transportation, storage, and delivery of goods, the logistics industry facilitates trade-related operations (Placek 2023). The global logistics industry is incredibly dynamic. Technological adaptation and development of the industry is advancing rapidly, especially with the Covid-19 pandemic. The global logistics industry has grown rapidly over the past five years (Figure 1) and will continue to grow in the coming period. This part of the paper analyses the available statistical data on the logistics industry and the size of the logistics market, as well as on the 3PL industry, the major 3PL companies, and the 3PL services offered.

The analysis is based on secondary statistical data from the Statista database (2023). Figure 1 shows data on the size of the global logistics industry from 2018 to 2021, with forecasts through 2027. The data show that the global logistics industry continues to grow, despite the Covid-19 pandemic and other global political and economic issues that currently exist. According to the latest available data, even during the pandemic, the logistics market grew from €5.73 trillion in 2020 to €8.43 trillion in 2021, and the industry is expected to continue to grow at that rate over the coming period through 2027. The logistics market follows international trade, so the growth of trade stimulates the logistics industry. With the growth of e-commerce, logistics companies are needed even more and face the challenge of providing adequate logistics services. The logistics industry is expected to become even more efficient thanks to innovative logistics solutions.

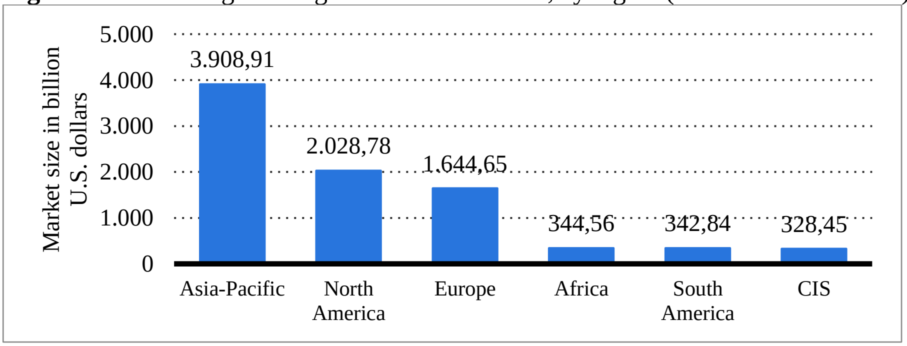
Figure 1 Size of the global logistics industry from 2018 to 2021, with forecasts until 2027 (in trillion euros)



Source: Research and Markets, 2022 in Statista 2023

The size of the global logistics market in 2020, by region is presented in Figure 2. The Asia-Pacific region has the largest logistics market in the world, with an estimated value of US$3.9 trillion. The region's importance in delivering most of the world's required trade goods could be an important factor explaining why it holds the top spot in the logistics sector. The majority of companies now have all their facilities operated in Asian countries, as it has been extremely cost-effective for Western companies to move all manufacturing of goods to less developed countries in Asia. The relocation of industrial production to Asian countries has greatly boosted the growth of the logistics industry. However, the largest companies are headquartered outside of Asia when looking at the distribution of the largest logistics companies by country of origin (Figure 4). In addition, the world's largest ports are located in the Asia-Pacific region.

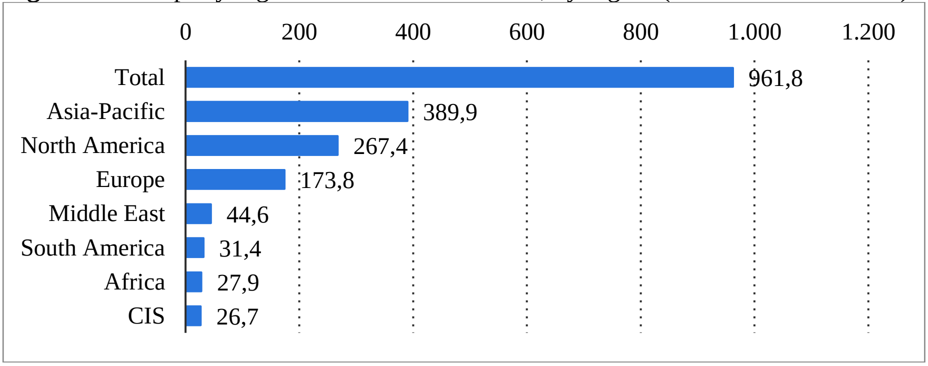
Figure 2 Size of the global logistics market in 2020, by region (in billion U.S. dollars)



Source: Statista, 2023a

The size of the 3PL logistics market in 2020, by region is presented in Figure 3. The largest size of the 3PL logistics market (measured in billions of USD) is in the Asia-Pacific region, driven primarily by China, the leading country in manufacturing, supply chain engagement, and shipping and logistics activities. After China, the second largest 3PL logistics market is in North America, primarily in the United States. The European region ranks third in terms of 3PL logistics market size. The 3PL market has witnessed significant growth in recent years owing to increasing globalization and e-commerce and the resultant rise in demand for logistics and supply chain management services. Moreover, the 3PL industry is expected to grow further owing to technological developments.

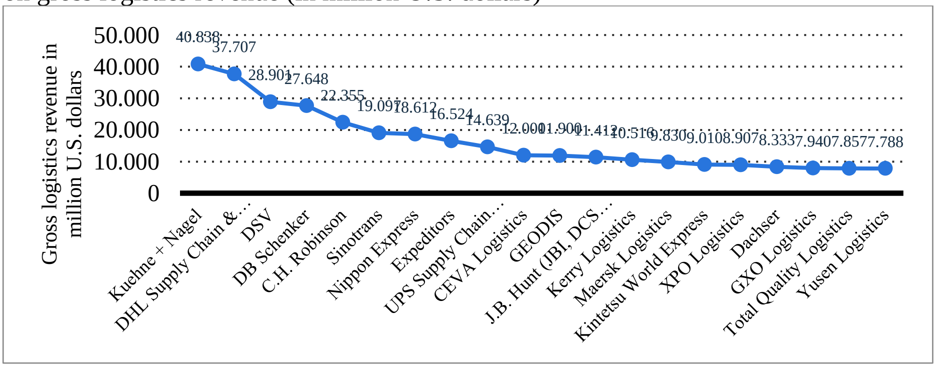
Figure 3 Third-party logistics market size in 2020, by region (in billion U.S. dollars)



Source: Armstrong & Associates, 2021 in Statista 2023

Figure 4 shows the rank of the world's leading 3PLs in 2021, based on their gross logistics revenue. The world's leading 3PL companies operate globally. The top three 3PL companies are Kuehne + Nagel, DHL Supply Chain and Global Forwarding, and DSV, all three of which were founded and headquartered in Europe. Kuehne + Nagel started as a shipping company and today offers various logistics and supply chain management solutions. DHL is a leader in freight forwarding and supply chain management. DSV is a Danish company that recently acquired and merged with Panalpina World Transport in 2019. Most leading 3PLs have acquired and merged with other freight forwarding and logistics companies. Although European companies rank first based on gross logistics revenue, the top 20 in third-party logistics include also developing Asian companies (Figure 4).

Figure 4 The world's leading 20 third-party logistics (3PLs) providers in 2021, based on gross logistics revenue (in million U.S. dollars)

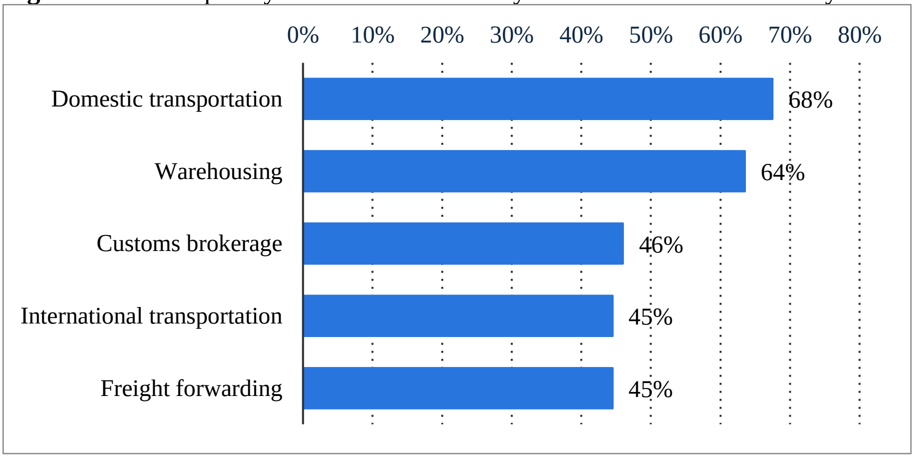


Source: Armstrong & Associates, 2022 in Statista 2023

Looking at the websites of the aforementioned global 3PLs, one finds that they offer a wide range of services, starting with transportation services, within which they offer transportation in all modes of transport: sea, air, rail, road transport, regardless of whether it is transport with only one mode of transport or, more often in practice, multimodal transport, services that also refer to LTL, LCL, FCL, FTL services, groupage or general cargo shipments. In addition to transportation services, they also offer warehousing and distribution services, inventory management, project logistics, customs brokerage, cargo insurance, e-commerce, integrated logistics, supply chain management/network design and supply chain services, reverse logistics, temperature-controlled logistics, and numerous others that can be seen on their web pages. They operate in various market segments and industries such as: Automotive, Chemical, Aerospace, Consumer Goods, Healthcare, High Tech, Industrial, Perishables, Energy, Retail/Fashion, Sports and Events, and many others.

The most commonly outsourced services by 3PL users globally in 2021 are presented in Figure 5. The most frequently outsourced service is domestic transportation (68%), followed by warehousing services, which is outsourced at 64%. The least outsourced services are customs brokerage (46%), international transportation and freight forwarding with a share of 45%.

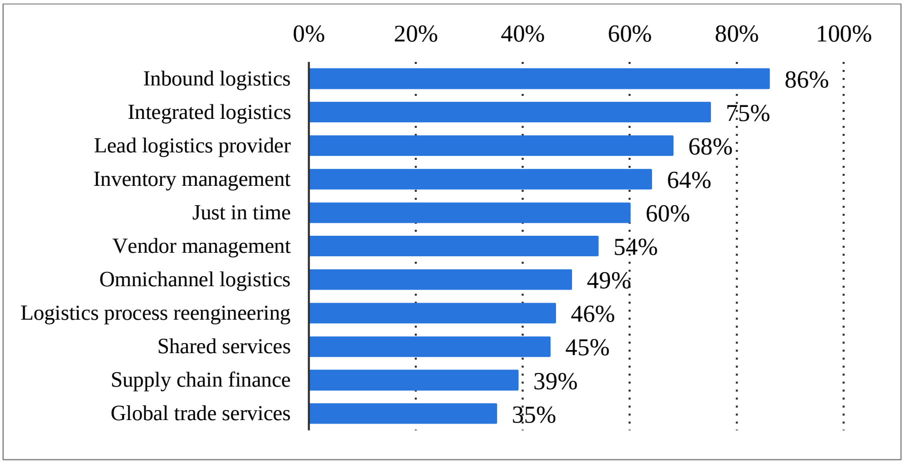
Figure 5 Most frequently outsourced services by 3PL users worldwide in July 2021



Source: Statista 2023b

The results of the survey conducted by Inbound Logistics (2022a) and presented in Statista (2023) regarding logistics services offered by Third-party logistics providers, challenges faced by providers of third-party logistics services and technology services offered by providers are presented in figures 6, 7 and 8. The figures 6 illustrate the logistics services offered by 3PLs worldwide in 2022. In the survey, 86% of 3PL providers surveyed indicated that their company offers inbound logistics services (Figure 6). This makes it the most common logistics service offered. Integrated logistics comes next, with 75% of 3PL providers surveyed indicating that their company offers integrated logistics services. This is followed by Lead logistics provider services, Inventory management, Just in time and Vendor management. Below 50% of logistics service offered is omnichannel logistics, which is typically important for e-commerce. The 3PL service least offered by respondents is global trade services.

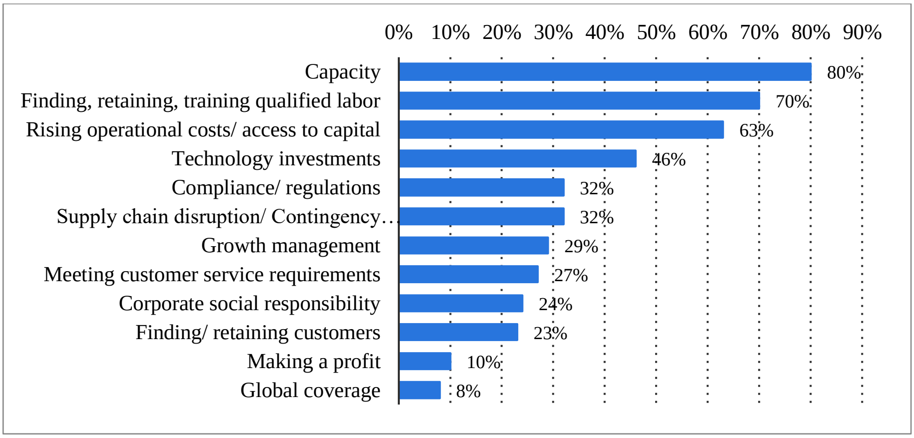
Figure 6 Logistics services offered by third-party logistics providers worldwide in 2022



Source: Inbound Logistics, 2022a in Statista 2023

The logistical challenges facing 3PLs in 2022 are shown in Figure 7. According to the Inbound Logistics (2022a) survey, 80% of respondents stated that among all the challenges facing 3PLs is the capacity problem. Second is the problem of finding, retaining, and training a skilled workforce. 70% of respondents stated they are grappling with this problem. Third is the problem of rising operating costs or access to capital, as stated by 63% of respondents. In part, these challenges can be attributed to the Covid-19 pandemic and e-commerce, where demand for capacity was high. The labour problem is seen in all industries, not just logistics. In the EU, for example, there is a major shortage of truck drivers. Finally, the Covid-19 pandemic and inflation, partly supply and partly demand driven, have led to rising operating costs.

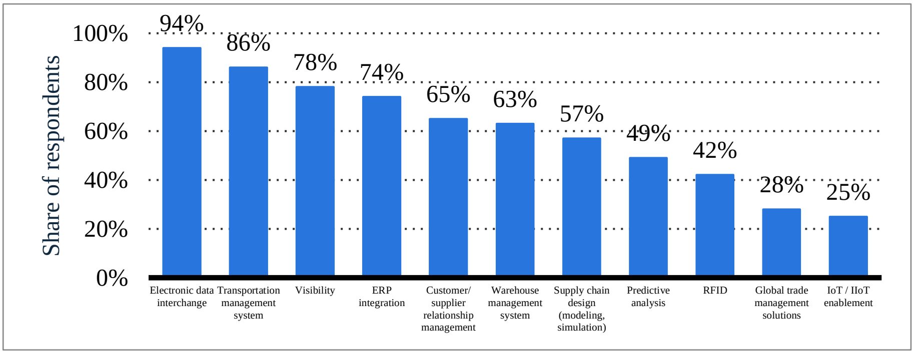
Figure 7 Top challenges faced by providers of third-party logistics services worldwide in 2022



Source: Inbound Logistics, 2022b in Statista 2023

Figure 8 shows the technology services offered by 3PLs worldwide in 2021. In the survey, 94% of 3PLs surveyed indicated their company offers electronic data interchange (EDI) services, making it the most common technology service offered. The transportation management system (TMS) is in second place, namely 86% of 3PLs surveyed stated their company offers transportation management system service. Visibility and enterprise resource planning (ERP) integration services are in second and fourth place, while the Internet of Things (IoT) and Industrial Internet of Things (IIoT) are in the last place. Only 25% of 3PLs surveyed indicated their company offers IoT and IIoT services.

Figure 8 Technology services offered by third-party logistics providers worldwide in 2022



Source: Inbound Logistics, 2022c in Statista 2023

All presented data shows how important not only the 3PLs are, but the entire logistics market. Despite the various challenges that companies face in the international market, it is extremely important to have the right partner, or rather, a link in the global chain that enables the smooth fulfilment of contractual obligations at the right time, in good quality and at minimal cost. And this is what makes the difference between supply chains: the quality of service, measured not only by cost, but also by reliability in meeting the "7Rs" in logistics. Both small and large companies benefit from using 3PL services when, due to lack of experience, time, capacity or knowledge, they are unable to take care of the logistical aspects involved in fulfilling obligations related to the safe, fast and efficient delivery of goods themselves. Although the cost of a logistics intermediary's services is often the primary consideration when making a decision, it should not be the only criterion. In addition to cost, other factors should also be taken into account, such as: the range of services they offer to their customers, the capacity they have in terms of infrastructure, locations, network of logistics centres or branches covering different regions, the technology they have, but also the previous experience of other users in terms of quality of service execution, communication and trust (Pavlić Skender, Host, Nuhanović 2016).

Good relationships between links in the chain, especially between the shippers and 3PLs, are critical to successful business. Research presented in the Third-Party

Logistics Study (Langley & NNT data 2023) shows that both shippers and 3PLs generally view their relationships successful. 83% of shipper respondents agree with this statement, in contrast to 3PL, where 99% of 3PL respondents also agree that their relationships are successful. However, although the percentage of satisfaction is high on both sides, shipper satisfaction is still 7% lower than in 2022, when 90% agreed with the statement. The reasons for the lower satisfaction are due to the challenges they faced, which were reflected in their relationships with 3PL. Nevertheless, 71% of shippers agreed with the statement that using 3PL services has helped improve customer service and claimed that 3PLs have provided new and innovative solutions that have improved logistics efficiency and reduced logistics costs.

Therefore, it is understandable that the demand for 3PL services and the overall logistics market is expected to continue to grow. Logistics activities are the area most often outsourced to logistics intermediaries. These specialize in these areas so that participants in global supply chains can focus on their core business and leave the logistics issues to them.

5. CONCLUSION

Although the importance of logistics intermediaries such as 3PLs has been researched for decades, the topic of their role in everyday business is still relevant. Without their knowledge, expertise and dedication, many companies would not be able to succeed in the market. This is especially true for companies that operate in the global scene, buying and selling, importing, or exporting all over the world. Doing business in the international market requires a good knowledge of numerous processes. The international environment is complex and intertwined with numerous legal, economic, political, financial, and other challenges. This was particularly evident during the pandemic caused by COVID-19, when the already complex processes were complicated by numerous constraints in terms of both capacity and human capability to carry out the processes of shipping and delivering goods between the various players in the international markets. In such a complex environment, logistics operators such as 3PLs are a great help. The main 3PL companies such as Kuhne+Nagel, DHL and DSV have held their position for a long time. These are the companies headquartered in Europe that have bought up and merged with other freight forwarding and logistics companies. Considering the size of the Asian market and the fact that most of the world's production is concentrated in Asia, among the main 3PL companies are Asian companies. Most of these 3PL companies provide various and comprehensive logistics services and have different departments specializing in specific services beyond transportation and warehousing activities. The main challenges they face are capacity issues, a shortage of skilled labour, and rising operating costs. They employ advanced technological solutions. With their knowledge, experience, capabilities, and capacities, they enable their partners to achieve their business goals. Although the market has been shaken by both the pandemic and political reasons, it shows that the market for 3PLs is continuously growing and that their role in the international market will constantly increase. And the data on the global logistics market, of which 3PLs are a part, is growing. The services required still fall into the segments of transportation, warehousing, inventory management, project logistics, order fulfilment, and the implementation of information and communication solutions to efficiently manage the supply chain.

Having a reliable partner to monitor and enable the achievement of goals is critical for all companies that buy and sell in the international market. Therefore, the contribution of this work lies in the valorisation of the role of 3PL in the international market and determining the services that can help their partners. This research offers valuable suggestions for practitioners in the field. From the scientific point of view, these research shows the importance of the logistics industry and 3PLs in global economy as well as the vulnerability of the industry due to the challenges the 3PL industry is dealing with. There is much more space for the further research to explore the possibilities to face the challenges that might last for a longer period of time.

This study relies heavily on the aggregate secondary data, and although the secondary data provide clear insight into the 3PL business, they do not include data on individual companies or regions. This is also the major limitation of this study. For future research, it is suggested that both qualitative and quantitative research be conducted on the quality of services and the impact on business performance, both among companies using 3PL services and among 3PLs themselves on the challenges they face and predictions on the direction of global logistics process development. For further research, it would be beneficial to analyse the primary data obtained from the survey in a specific region or the case study of a specific company to avoid limitations of the aggregated information.

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PROJECTED AND EXPECTED COMPETENCES IN LOGISTICS AND SUPPLY CHAIN IN SLOVENIA

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Abstract

Technological development requires constant adaptation and new work approaches, which also applies to logistics and supply chains. In this field, innovation and instant adaptation are understood as key competitive advantages. The aim of this study was to identify which competences employers in 2020 projected to be needed in the future in the field of logistics and supply chain management and which competences employers expected from employees to have in 2023. For research, a quantitative survey of 435 employers in logistics and supply chains was conducted in 2020 to determine which competences employers projected their employees to need in the future in logistics and supply chain. To analyse the competences expected in 2023, a qualitative analysis of 50 job advertisements from the field of logistics and supply chain was conducted. So, this article presents the results of two different surveys, so a combination of quantitative study from 2020 and qualitative study from 2023. The results of the surveys show that communication skills, coordination and social skills are currently mostly expected competences for logistics jobs, but there is ate the moment not yet an important need for skills in robotics, the Internet of Things (IoT) and blockchain.

Keywords: competences, job advertisements, logistics, supply chain

1. INTRODUCTION

Recently major changes in workspace in logistics and supply chains and in general in various areas, one of which is digital transformation, have been made. (Sapper et al., 2021). The field of logistics and supply chains has undergone many changes in the last 20 years, which have contributed to an increased demand for knowledge as a result of the introduction of technology and international cooperation. While in the last century, lower-level positions in logistics (e.g., truck drivers, warehousemen) required a basic level of qualification, nowadays, due to advanced technology (e.g., barcode and RFID systems, truck fleet management or tolling and truck steering concepts), it is the level of qualification required considerably higher than in the past century. This is also the case for many higher-level positions in logistics and supply chains in fields such as logistics information technology, contract logistics and innovative supply chain concepts. (Klumpp, 2015)

The standard of living is constantly rising and people's demand for diversity and personalisation is expanding (Wu, 2022). Supply chain is becoming increasingly complex and implies the continuous development of value-added logistics services (Cavusoglu et al., 2022). One of the big changes that is taking place is the globalisation of business, which means more transport needs and consequently more environmental pollution (Zhang et al., 2020). On the other hand, customers expect companies to be more environmentally friendly (Letnik et al., 2022).

To meet customer needs, be environmentally friendly and competitive, companies need to include the employees with right competences in their working environment and processes. The results of the study by Closs and Mollenkopf (2004) confirm that supply chain competences lead to improved performance and that supply chain competences are used in different ways to create different performance advantages in different business environments in logistics and supply chains. The importance of competency development is also shown in a study by Mageto and Luke (2020), which shows a growing trend in publications on competences in supply chains management. The importance of equipping employees with specific competences is confirmed by studies that find that competences, among others, impact the resilience of supply chains (Wieland & Wallenburg, 2012). Studies also point to a gap between the competences needed or expected by employers in field of supply chain management and logistics and the competences possessed by potential employees (Closs, 2000; Wong et al., 2011; Lutz & Birou, 2013; Sinha et al., 2016; Cvetić et al., 2017).

This paper aims to present which competences employers in logistics and supply chain organisations in Slovenia in 2020 identified as being needed in the future and which competences or skills employers in logistics and supply chain organisations in Slovenia expect from their employees in the present. The paper shows and explains the need to develop and build competences from a time perspective, i.e., the speed of the requirement for new skills and to clarify which skills are needed and which competences will be relevant when companies have more advanced processes and tools to do the effective and efficient work in field of logistics and supply chains. The purpose of this research was to review the current competence needs based on the predictions of the logistics sector and supply chain managers in the past. The research assesses whether the predictions of the expected competences in 2020 are already a reality in 2023. The results of the survey will help to identify the rapidity with which new competences are required. The research question of the study is:

RQ: Which competences do employers in field of logistics and supply chains expect from their employees in the future, based on past projections?

This research question will be researched according to findings from quantitative research in 2020 among Slovene logistics and supply chain companies and from qualitative analysis of published job advertisements.

First, the following chapters include an overview of the research on logistics and supply chain competences; second, a description of the data sources and the research method is explained; third, a discussion of the presented results will follow; fourth, the gaps between predicted and expected competences will be discussed; and finally, conclusions and suggestions for future research will end this article.

2. LITERATURE REVIEW

First, we will define competences, explain why competences are important in working environment in general and then define and explain the specific competences needed in the logistics and supply chain field.

Competences can be in general understood and defined as the interaction between the individual and the workplace (Derwik et al., 2016). Bouri et al. (2018) defines competence as a polysemic concept that leads to different definitions because it is a multidisciplinary concept that involves several fields such as human resource management, educational sciences, psychology, quality, industrial engineering and supply chain management.

One of the most general definition of competences, that is also being considered in this article, define competences as “knowledge, skills and abilities that are associated with high performance on the job at an individual level” (Barnes & Liao, 2012).

Having employees whose competences match the requirements of the jobs they do is an essential criterion for a company's success (Flöthmann et al., 2018). Individual job fit is positively related to job performance and job satisfaction (Caldwell & O’Reilly, 1990).

2.1 Competences in logistics and supply chains

In the field of logistics and supply chains, the importance of competences is being increasingly researched and discussed.

Several different authors explain that skills and competences in logistics and supply chains are despite all technological development extremely important for the performance and future development of business. (Cottrill & Rice, 2012; Ellinger & Ellinger, 2014; McKinnon et. al. 2017)

"To take supply chain performance to the next level, companies will have to tap into this human element more intensively. Many companies have pushed hard on technological and infrastructure improvements and investments. The next wave of improvements and investment should center on the people who manage and operate the supply chain." (Daugherty et al., 2000)

Different authors have identified various competences as the most important in the field of logistics and supply chain management at different times. Prajogo and Sohal (2012) identified in their research as the most important (1) competence’s ability to work effectively with individuals and groups/teams, (2) ability to manage relationships in diverse contexts, (3) ability to manage risks in supply chain and their associated issues, (4) ability to make use of numerical techniques for decision making and project management skills and (5) ability to lead major projects.

Bals et al. (2019) listed as important competences for purchasing following skills, abilities and knowledge: (1) analytical skills, (2) basic knowledge on purchasing and supply management role & processes, (3) communication skills, (4) cross-functional abilities & knowledge, (5) interpersonal communication skills, (6) ability to negotiate, (7) stakeholder relationship management knowledge, (8) strategic sourcing, (9) strategic thinking and (10) knowledge in field of sustainability.

Katiniene et al. (2021) identified working with people as the most important social competences in field of logistics and supply chain management. Since logistics and supply chain management are despite all technology still service oriented this can be seen as really generally evident and important. For the analytical competences, the competences needed to do the specific job came first, so no general analytical competences were listed, but the competences connected to the specific workplace in logistics and supply chain were mentioned. The most important personal competences were perceived the competences needed for self-management.

Sapper et al. (2021) explored the competences needed for the future in logistics and supply chain filed and listed and rated the willingness to learn as the most important personal competence. This is very important especially in fast developing industries and services where also logistics and supply chain have a significant role. General understanding of the process was perceived as the most crucial in the group of professional competences Sapper et al. (2021). According to Sapper et al. (2021) interdisciplinarity will be the most significant in the future in the group of methodological competences. The same study shows that communication skills are considered to be the most valuable in the group of social competences.

From the previous researches and competences listed above, it can be summarised that the most important competences in field of logistics and supply chain are knowledge of logistics processes, working with people and communication skills. The technological and technical knowledge related to the specific workplaces will be needed as well. And this is closely connected to the willingness of employees to learn and develop in the future and adjust to new ideas, strategies and technologies.

3. METHODOLOGY

The research is based on a survey questionnaire (among companies in field of logistics and supply chain) which was conducted in 2020 and an analysis of job advertisements in field od logistics and supply chain management from 2023. The survey from 2020 aimed to obtain a set of competences extracted from previous researches and scientific articles in the field of logistics and supply chains management on the topic logistics and supply chain of the future, competences needed for the future and in the context of industry 4.0. Respondents in companies rated these according to previous researches found and listed competences on a Likert scale from 1 to 5, indicating how relevant they thought the competences would be for them in the future. To compare the competences projected to be relevant and the competences actually acquired in 2023, 50 job advertisements that were published in Slovenia in

2023 were analysed. So, first, research in 2020 is based on quantitative data from questionnaire and the second from year 2023 is due to analysis of online advertisement performed on qualitative way.

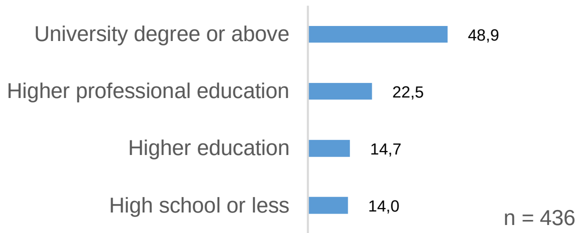
So, this article presents the results from mixed research techniques: qualitative and quantitative ones, and both data and prepared results (according to quantitative and qualitative research) present additional added value to this research. Data from both researches will pre combined and results also compared.

3.1 Research methodology of projected competences for the future (conducted in 2020)

The quantitative survey in 2020 was conducted online between June and August 2020. The questionnaire was prepared for to employees in leading positions in the logistics sector (logistics managers, warehouse managers, purchasing managers, purchasing specialists, transport organisers, etc.) who have the experience, knowledge, overview and insight into the necessary competences needed by employees in this field. The relevant companies and their contacts were obtained with the help of the Bizi.si (business assistant online system) and selected according to the standard classification of the activity, so companies that are fully or partially involved in logistics activities or supply chains. The appropriate contacts for selected companies were also found on companies' websites od LinkedIn profile. S, the whole population in our research were all the companies that are officaly classified in Slovene business system under classification of logistics and supply chains

The sample consisted of 435 respondents, of which 42 % were women and 58 % were men. Most respondents were in the 36-45 age group (36 %), followed by the group age 46 and more (33 %), the group age between 26 and35 (28 %) and the under 25 group (3 %). Almost half of the respondents have a university degree or higher education (Figure 1).

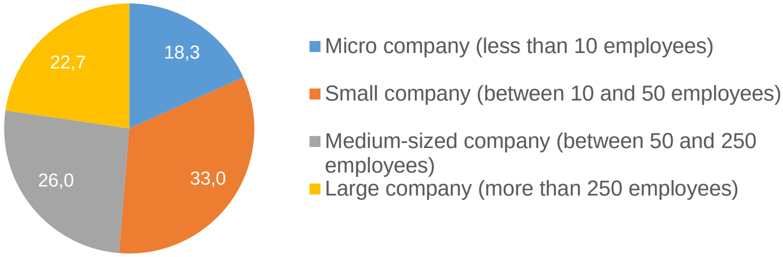
Figure 1 Education (2020)



Source: own source

Most of participants in research come from companies with up to 50 employees (Figure 2) which means mostly small companies. The questionnaire consisted of 24 questions and listed competences related to logistics and supply chain competences relevant for the future.

Figure 2 Company size



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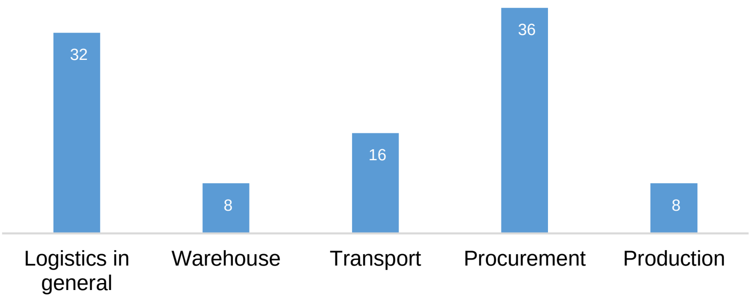
3.2 Research methodology of research about expected competences in 2023

The second part of the research is based on qualitative analysis of 50 job advertisements from the logistics and supply chains sector posted in Slovenia in April 2023. The job advertisements were posted on Mojedelo.com, which is one of the major recruitment platforms in Slovenia, and have been filtered into the "Transport, procurement and logistics" work area. Positions requiring at least a high school education or more were included into research. Job advertisements have been posted for jobs such as logistics associate, director of logistics, (strategic) purchaser, head of department in transport, supply chain developer, logistics coordinator, warehouse analyst, warehouse manager, logistics planner, etc. The highest number of job advertisements was for procurement position (Figure 3).

Figure 3 Percentage of job positions (and related different areas) in job advertisements included in the research



Source: own source

The most often required qualification was at least a bachelor's degree (42 %). This was followed by a high school education or higher (20 %). 10 % required a master’s degree, and 8 % a specific university degree. In 20 % of the job advertisements, the required level of education was not specified. Out of the 50 job advertisements, 26 % specified a logistics degree, while 44 % mentioned a degree, but not specifically in logistics, but in a more general field, e.g. a technical degree. 30 % respondents did not mention the required field of education.

4. RESULTS

Here, the results and findings from both, qualitative and quantitative research, will be presented. The research results show and present the competences that are projected for the future by Slovene companies according to quantitative and qualitative researches made in 2020 and 2023.

Figure 4 shows the results of average ranking of the listed competences on scale from 1 (strongly disagree) to 5 (strongly agree) according to how respondents that are working in field of logistics and supply chains in 2020 predicted the competences in logistics and supply chains will be important in the future.

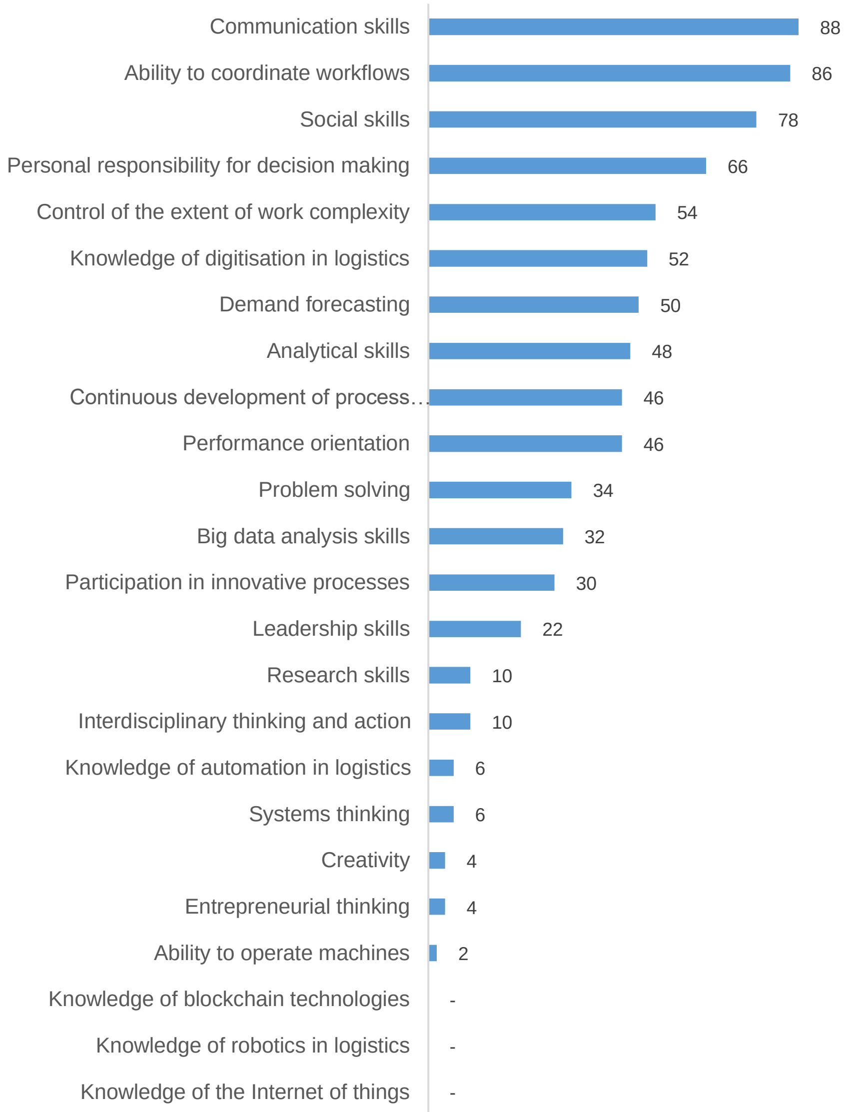
Problem solving, ability to coordinate workflows, communication skills, performance orientation and knowledge of digitalisation in logistics were marked as the most important competences for the future in logistics and supply chain sector. They were in average marked extremely high (average of all more than 4.5).

Figure 4 Projected future competences in logistics and supply chains companies in 2020

Source: own source

Furthermore, these mostly predicted competencies from research performed in 2020 were also mostly found in qualitative analysis of job advertisements (connected to Slovene logistics and supply chain sector) analysed in 2023. So, figure 5 shows the results of the frequency of expected competences in job advertisements in 2023 among those that were predicted in quantitative research before in 2020.

Figure 5 Expected competences in logistics and supply chain sector in 2023



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The figure 5 shows the percentage of analysed online advertisement where mentioned skills, abilities and knowledge (that were found in research in 2020 as the mostly predicted) were found. As presented in figure 5, communication skills, ability to coordinate workflows, social skills, personal responsibility for decision making, control of the extent of work complexity and knowledge of digitalisation in logistics were found the most frequently in analysed online job advertisements in field of logistics and supply chain in Slovenia. These mentioned competences were found in more than 50 % of analysed online advertisements in logistics and supply chain sector.

5. DISCUSSION

The results from 2023 underline the increasing importance of several key competences in the logistics and supply chain industry that were already projected in 2020. The ability to coordinate workflows (mean 4.65 in research performed in 2020 and 86 % share of expectation in analysed online job advertisements in 2023) indicates the need for individuals who can efficiently manage and coordinate tasks to ensure operations without complications. A similar study analysing job advertisements has been conducted in Serbia in 2014 and confirms "Planning and organising of the tasks" as the second most expected competency in the set of fundamental competences, after communication (Cvetić, 2017).

Highly ranked in quantitative research in 2020 and now in qualitative research in 2023 is communication skill (mean 4.65 in research in 2020 and 88 % share of expectation in analysed online job advertisements in 2023). This competence emphasizes the significance of clear and effective communication in facilitating collaboration, reducing errors, and improving overall efficiency. The importance of communication as a core competence in logistics and supply chains was also confirmed before in some other researches by the research of Cvetić et al. (2017), Bals et al. (2019) and Sapper et al. (2021).

The following competences that are according to our two researches very important are social skills (mean 4.27 in research in 2020 and 78 % share of expectation in analysed online job advertisements in 2023). These skills hold considerable importance, reflecting the recognition of the need for strong interpersonal abilities to build relationships, promote teamwork, and effectively interact with stakeholders in the logistics field. The high importance of social skills was also confirmed before in a studies by Derwik et al. (2016) and Kotzab et al. (2018), which analysed 280 competences in the field of logistics and supply chains.

Another competence projected in quantitative research and now expected in online job advertisements in logistics and supply chain companies is personal responsibility for decision-making (mean 4.43 in research in 2020 and 66 % share of expectation in analysed online job advertisements in 2023). This signifies the importance of individuals (in logistics and supply chain sector) who can take ownership of their decisions, make quick and important choices, and be accountable for the outcomes in the dynamic logistics and supply chain environment. This was also confirmed in the findings of the study Mangan and Christopher (2005) and Derwik et al. (2016).

Figure 6 Comparison of predicted (2020) and expected (2023) competences

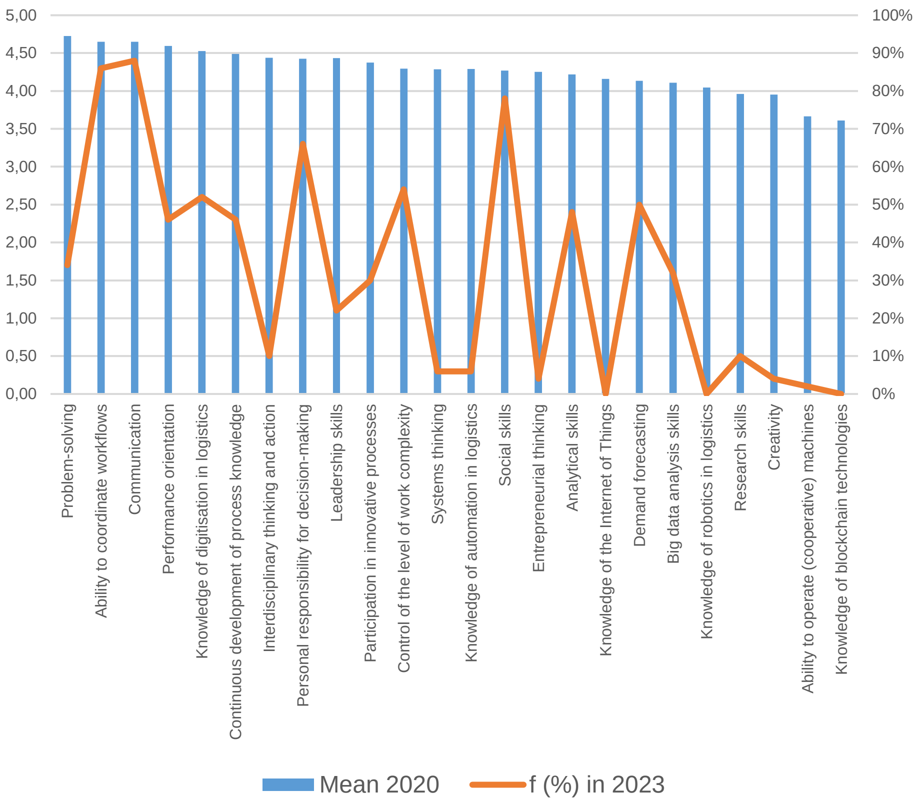

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Figure 6 shows a combination of results of both, qualitative and quantitative researches conducted in 2020 and 2023 in Slovene logistics and supply chain sector. If we combine both results, we can conclude, that ability to coordinate workflows, communication skills, social skills and personal responsibility for decision making were in both researches found as really important for successful work in supply chain and logistics field. Research skills, creativity, ability to operate with machines and knowledge of blockchains technologies were found according to both researches (conducted in 2020 and 2023 in Slovene logistics sector) as the less important for appropriate and good work in companies in logistics and supply chain sector.

Although researches have been made on Slovene logistics and supply chain sector and on limited sample, we still think that these results can be a good starting point for further planning of knowledge, skills and abilities needed for good and successful employees in logistics and supply chains.

6. CONCLUSION

Companies in general and especially in service sector (where in general also logistics an supply chains are classified) continue to highlight the need for soft competences in particular. The focus is according to different researches (Derwik et al. (2016), Kotzab et al. (2018), Cvetić et al. (2017), Bals et al. (2019), Sapper et al. (2021)) mainly on the competences needed for teamwork, emphasising the autonomy of employees and a basic working knowledge of a specific area (e.g. purchasing procedures, warehouse processes, etc.).

Despite the rapid development of new technologies in the world in logistics and supply chain sector, it is interesting and a bit surprising that according to our research findings in Slovenia organisations in this field companies are still looking for employees with only basic knowledge in the field of technology. It is possible that, although the need for these competences is high in companies in logistics and supply chain sector, companies do not mention these expectations in their job advertisements and simply take them for granted.

So, the research results show the importance of soft skills and competences, connected to soft skills, as really important of successful work in logistics and supply chains. Among them, the ability to coordinate workflows, communication skills, social skills and personal responsibility for decision making were marked as most important for future employees in companies related to supply chains and logistics.

There is also a great potential for further research in field of competences, so skills, knowledge and abilities, needs and understood as important in companies in logistics and supply chain sector. It would be interesting to research further on (according to our research results) what are not only expected but also the actual competences that companies expect from their employees that are already included in working environment in logistics and supply chain sector.

To provide companies with the most competency-matched employees, job advertisements should be more specific about the expected competences. In this way, potential employees, who are, to a large extent, students from this field, could also be given information by companies about what they expect from candidates for specific jobs and already strengthen their skills according to this information during the study. There is in general also a great potential to renew study curriculums according to new fast developing logistics and supply chain companies.

For further research, it is proposed to conduct in-depth interviews (according to quantitative research results in 2020 and qualitative analysis results in 2023) with managers in logistics and supply chain workplaces in Slovenia and so to prepare further qualitative analysis and list and closely and precisely describe the competences needed at the moment in companies in Slovene supply chain and logistics sector.

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II. GREEN LOGISTICS

SUSTAINABILITY MODEL FRAMEWORK FOR ESTONIA THROUGH INTEGRATION OF REVERSE LOGISTICS: LITERATURE REVIEW

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Abstract

During the last decades, the environmental trend was steadily moving towards sustainability through control of gas emissions, switch to electrical vehicles, recycling in every industry and every European state. Being ranked 10th globally according to the Sustainable Development Report, Estonia has ambitious plans for its sustainability development for the upcoming 20 years. Implementing alternative supply chain models is vital to cover all routes to achieve a sustainable yet effective supply chain strategy. Reverse logistics can offer a solution to optimize the supply chain through recycling used goods on the one hand and rerouting defective products to prevent spoilage on the other hand. Creating a model based on reverse logistics will provide an opportunity to use the full capacity of existing supply chains by simply reversing product flow backward.

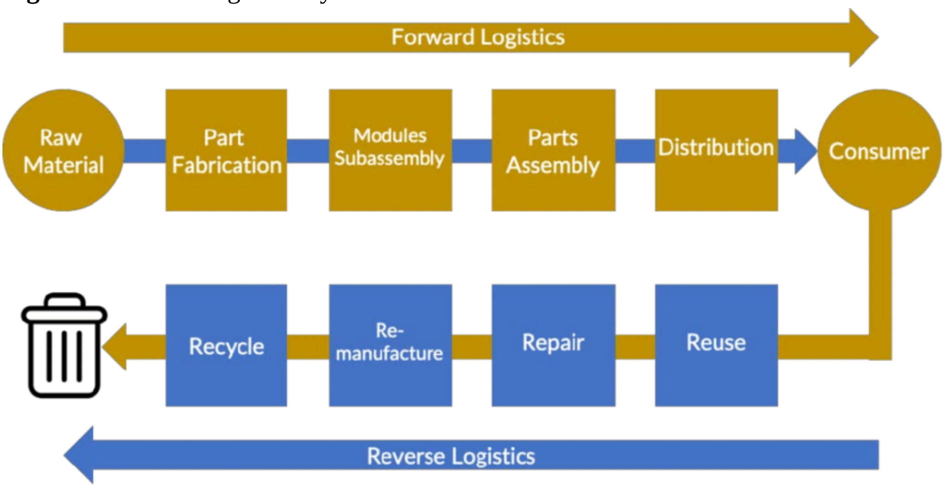
This paper seeks to analyze existing research and synthesize the current state of reverse logistics models against the background of the methodological approach, which will form an initial framework for further research in this direction. By conducting a deep theoretical overview and summarizing previous experience author seeks to create a strong theoretical basis and a corresponding starting point for the development of a successful sustainable reverse logistics model for Estonia, which has a lack of studies in this field both practical and theoretical, hence requires a strong framework for the future sustainability model based on reverse logistics practices that can have not only theoretical, but also practical implementation.

Keywords: sustainability model framework, reverse logistics, supply chain model framework, Estonian sustainability model

1. INTRODUCTION

The concept of sustainability has gained significant attention due to growing environmental concerns and the need for efficient resource management. Due to the shortening life cycles of almost every product on the consumption market, the amount of waste is snowballing. If this waste is not handled properly, significant damage to the ecosystem can be done (Hanafi et al., 2008). Countries now recognize the importance of adopting sustainable practices to mitigate the negative impacts of excessive consumption and industrialization and promote a circular economy to reduce waste. Governments and public administrations are forced to approve new initiatives to reduce environmental impact, extend the product life cycle and recycle raw materials where possible (Prakash and Barua, 2016). In a situation such as this, companies have to adopt sustainable policies (García-Arca et al., 2017) and product recovery reverse flows (Ravi et al., 2005) in extremely short time frames to correspond with newest agenda and legislation, meet society's expectations and at the same time increase the economic value of its product and manufacturing process where possible (Steeneck and Sarin, 2013; Pokharel and Mutha, 2009; Barker and Zabinsky, 2010). To summarize, companies from different industries must adopt various sustainable initiatives, including reverse logistics, to enhance their reputation, stay competitive, and stimulate economic growth (Shankar et al., 2008). Hidayat et al (2019) described a system that connected Forward Logistics and Reverse Logistics in one flow with diametrically opposite parts of the supply chain (Figure 1).

Figure 1 Reverse Logistics Cycle



Source: Hidayat et al. (2019)

Reverse logistics can be identified as a form of management and configuration of the supply chain that allows products or materials to move not only from distributors or manufacturers to the consumers but also to move backward- from consumers to distributors to ensure the final disposal of the product, whether it is recycling, renewal or resale (Shekarian, 2020). The ultimate aim of this process, or strategy, is to return the product's value, maximize the value, or dispose of the product. According to Krstev and Krstev (2022), due to the growth of e-commerce, the yearly profitability of reverse logistics in the consumer goods market is estimated at almost a trillion dollars.

In the constant search for a universal solution to the current waste problem, the Triple Bottom Line (3BL) balance must be considered: social, economic, and environmental (Arnette et al., 2014). From a social point of view, sustainability assists in improving the labor and health conditions of the employees, increasing motivation, and reducing turnover and recruitment costs. From an economic perspective, sustainability helps reduce energy and labor costs and provides wider availability of resources. And finally, from the environmental point of view, sustainability efforts are constantly aimed at preserving the planet by reducing waste and pollution generation (Singhry, 2015). Sustainability programs in Estonia at this point are mostly aimed at waste recycling and gas emission reduction, hence need a systematic 3BL approach. Before economic and social factors will be considered, a strong environmental policy must be implemented.

This research seeks to start creating a framework for a strong sustainability model through the integration of reverse logistics in Estonia, which has a weak basis for practical and theoretical studies in this field.

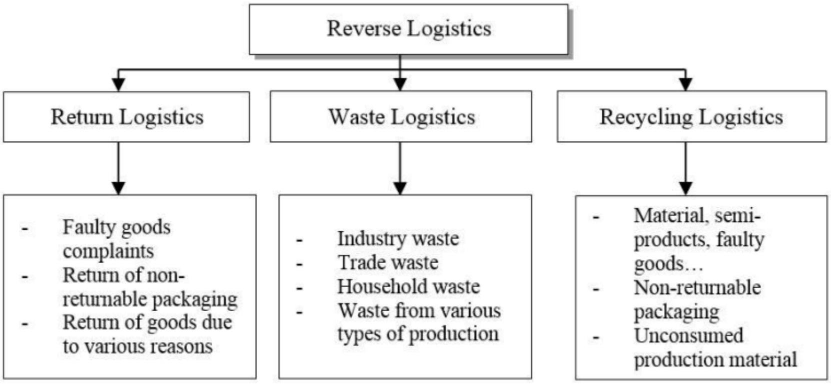
2. METHODOLOGY

For a preliminary literature review qualitative research method was applied to analyze and summarize previously published articles. Most relevant articles were selected and sorted according to the year of publication, as the author aimed to research the evolution of such specific waste and recycling management methods as reverse logistics in the perspective of enhancing sustainability on various levels.

Even though Estonia is one of the most digitalized countries in the European Union and ranked 10th globally according to the Sustainable Development Report, Estonia's environmental sustainability is significantly under-researched on its territory, especially from the perspective of reverse logistics. This paper aims to build a framework for future deeper studies of the Estonian sustainability model in connection with reverse logistics, as this is one of the most sufficient ways of resolving waste and recycling issues.

Figure 2 illustrates a scheme of division of reverse logistics. The division consists of three types of specific logistic subsystems that are usually a part of a larger logistic system.

Figure 2 Division of Reverse Logistics



Source: Tomkova (2015)

The research questions:

1. In which ways was the sustainability model, through the integration of reverse logistics, formulated, shaped, and developed over the last two decades according to the three dimensions of reverse logistics?
2. What have been the main similarities and differences in relevant research?
3. What are the main theoretical models and theories on sustainability model through the integration of reverse logistics today?

The main goal of the research is to locate scientific articles on topics close to reaching sustainability in logistics by applying reverse logistics practices. Deeply analyze and highlight the main research paths and ideas. Gather all similarities and disagreements and conclude the current state of sustainability through reverse logistics. Moreover, the researcher aims to suggest how described theories can be applied to Estonian supply chain practices and make a strong basis for future studies.

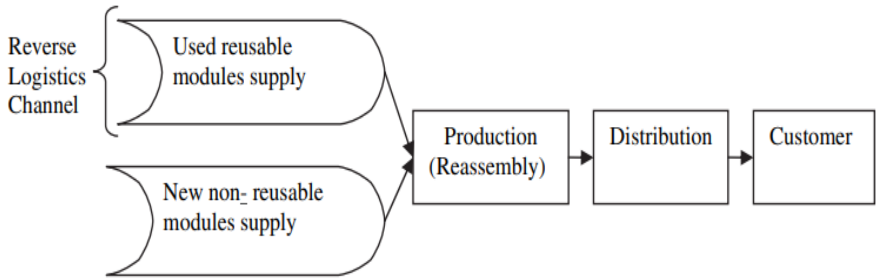
3. SUSTAINABILITY MODEL THROUGH REVERSE LOGISTICS

Reverse logistics is a concept that has been formulating and changing shapes for a few decades. According to Kerr and Ryan (2001), a system of remanufacturing end-of-life products has had several economic, social, and environmental benefits, even though it requires a product to fit specific remanufacturing standards (Sundin and Bras, 2005). An impact on the supply chain system is even more significant, requiring the product to be collected, remanufactured, and remarketed (El Korchi and Millet, 2011). At this point, the researchers decided to design a reverse supply chain system; additional research is required to create a systematic approach to business instead of narrow optimization research of local optimization (Guide and Van Wassenhove, 2009). Remodeling the supply chain to integrate reverse supply chain elements enormously impacts the whole value chain.

3.1 Reverse logistics studies conducted between 2010 and 2020

El Korchi and Millet (2011) established the main difference between the reverse supply chain and forward supply chain as the presence of a Reverse logistics channel (RLC) within the reverse supply chain as it is illustrated in Figure 3. This channel provides a way to return the reusable used products to the manufacturer to reassemble them. Other logistic flows of the reverse supply chain bringing non-reusable products, production, and distribution, generally use the same ways as the forward supply chain.

Figure 3 Reverse Supply Chain



Source: El Korchi and Millet (2011)

According to Dowlatshahi (2005), Fleischmann et al. (2001), and Guide and Van Wassenhove (2009), the demand for an integrated approach in the design and implementation of reverse logistics practices has been steadily increasing. To answer this demand, a framework that integrates relevant economic factors of reverse logistics was proposed by Dowlatshahi (2005). Managerial guidelines for designing and applying reverse logistics practices were presented within the framework. El Korchi and Millet (2011) moved in the same direction in their research. They offered a framework to integrate with other stages of the remanufacturing system and product design stages. This specific design of the framework allows managers to have a broad view of all stages of production that impact RLC sustainability and make weighed decisions in creating their reverse supply chain. Using a case study on remanufacturing electric-and-electronic equipment study created 18 different frameworks for building an RLC. It compared the results from economic, social, and environmental points of view. The main idea of the study is that a strategic approach to creating a framework provides an opportunity to create a more complex yet effective framework that can be adapted to the specific needs of a supply chain. Reverse logistics or reverse supply chain systems proved effective in achieving a certain level of sustainability, depending on the company's goals. This can also be reflected in the choice of a specific framework.

Sustainability through the integration of a reverse supply chain was studied from the perspective of digitalization by Cullinane et al. (2017). The researchers explained the choice of this perspective by the increase of e-commerce, especially in the consumer goods area. The growth of e-commerce inevitably leads to a rise in returns.

A study conducted by Cullinane et al. (2017) provided an example of two Nordic companies with different marketing approaches, but similar return logistic chains, where product return numbers were presented and compared by country (Table 1).

Table 1 Returns by country and brand, 2016.

	Brand A (low fashion)		Brand B (high fashion)	
Country	% returns (on an item basis)	Items returned	% returns (on an item basis)	Items returned
Finland	24.5	126,000	45	51,700
Sweden	15.6	248,000	31.6	176,000
Denmark	13.9	44,000	25.7	10,000
Norway	14.2	74,000	25.3	7,500

Source: Cullinane et al. (2017)

On the contrary, outward logistics is well organized and executed; the return process, directly related to reverse logistics, must be better organized and significantly under-researched. Reaching a sustainable business model through the integration of reverse logistics with major appliances of digital tools is studied from the perspective of social media, apps, electronic data interchange (EDI), and customer profiling was the main purpose of the research.

The research results were controversial. On the one hand, implementing some technologies such as virtual reality helped to improve visualization, allowing consumers to make weighed decisions on the purchase. On the other hand, making the return process easier by using EDI encouraged consumers to make more frequent returns. In conclusion, the authors suggest appealing to consumers' conscience and environmental responsibility through digital channels. The goal of improving sustainability can be reached using two main paths, by reducing the number of returns and by improving reverse logistics efficiency through deep integration of digital tools that are currently available.

Companies can generate additional profit and sustain the business long-term by implementing sustainable principles (Székely and Knirsch, 2005). This makes achieving a competitive advantage through adopting sustainable practices a crucial goal for every organization (Hart, 2005; Pfeffer, 2010).

Banihashemi et al. (2019) conducted a deep overview of existing articles aimed at analyzing product disposition as a key feature in reverse logistics and its impact on sustainability from the perspective of 3BL- economic, social, and environmental, mentioned in previous articles. The research group found a significant correlation between implementing a reverse logistics system and improving environmental sustainability. Several relevant papers were studied and evaluated based on the 3BL dimensions. Table 2 demonstrates the analysis of articles that investigated the sustainability performance of firms from economic, environmental, and social perspective performed by Banihashemi et al (2019).

Table 2 Reverse logistics and sustainability performance from the perspective of Green supply chain management (GSCM).

Author	RL Economic	RL Environmental	RL Social
Wu *et al.* (2015)	✓	✓	✓
Govindan, Khodaverdi and Vafadarnikjoo (2015)	✓	✓	
Azevedo *et al.* (2011)	✓	✓	✓
Eltayeb *et al.* (2011)	✓	✓	✓
Diabat *et al.* (2013)	✓	✓	✓
Laosirihongthong *et al.* (2013)	✓	✓	✓
Govindan *et al.* (2014)	✓	✓	✓
Geng *et al.* (2017)	✓	✓	✓
Younis *et al.* (2016)	✓	✓	✓
Eltayeb *et al.* (2010)	✓	✓	✓
Abdel-Baset *et al.* (2019)	✓	✓	

Source: Banihashemi et al (2019)

The research team concluded that previous research needed more attention to the disposition decision in reverse logistics and their influence on sustainability results. A deeper analysis of the potential impact of disposition options as a way of extending product life and hence impacting an organization's sustainability performance was suggested using the 3BL approach to measure sustainability performance.

Considerable interest in recycling and reusing the materials was indicated in Europe due to the limited number of dumping sites and strict regulations regarding removing the product's packaging and handling outdated products (Skrucany et al., 2018; Dolinayova and Loch, 2015). The research conducted by Zitricky et al. (2019) aimed to create an optimal way to collect a specific recycled type of waste within a case study.

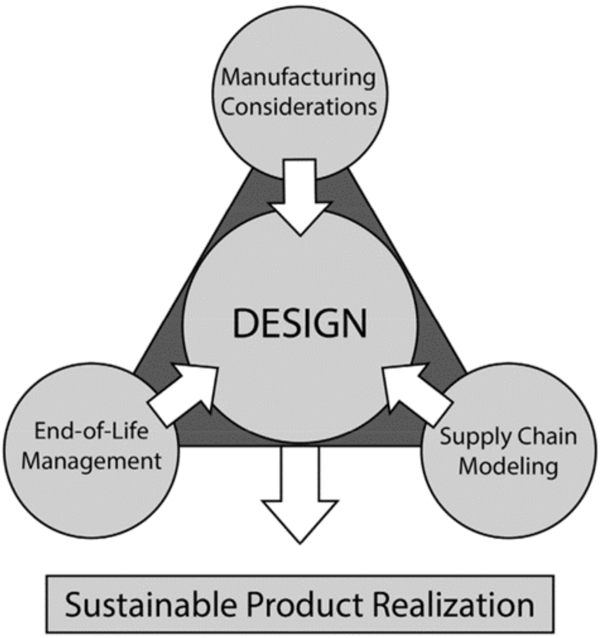
Because no society can function without producing a considerable amount of waste, ways to reduce this must be treated with great attention (Caban et al., 2018). Even though reverse logistics is a relatively new direction in supply chain management, its role in achieving sustainability is undeniable. The use of reverse logistics to achieve sustainability is mostly applied in European states; here, it is considered one of the few means for utilizing waste generated by the previous stages of the supply chain.

The research calculated certain methods of gathering recycling for a certain type of waste. For plastic containers, which appear to be the most frequent type of waste- the Clarke-Wright method of organizing circular transport issues is the most suitable. The Nearest Neighbourhood Method was found to be most efficient for the second type of container. Glass haulage was only possible to gather and recycle with current routes. Calculating these methods allowed researchers to make calculations on annual savings and labor cost savings. However, the environmental and reputational positive impact was a lot more considerable. The study based on a specific case study showed that applying reverse logistics principles can lead the company towards sustainable operation and save costs. One of the main tasks of modern society includes various methods of reducing waste. It is the task of businesses and citizens to start saving the environment in any way available (Torok, 2017).

Increased consumption in the production market has considerably influenced the amount of waste (Raja Ghazilla et al. 2015). The population has pressured their governments to adopt regulations to resolve the issue of disposal of post-consumer waste and make manufacturers responsible (Afroz et al. 2013; Borthakur and Govind 2018; Choong et al. 2018) even though the traditional approach was known for total ignorance of the post-production waste disposal. A post-consumption lifecycle approach has been adopted in the framework of Extended Producer Responsibility (EPR) (Chari et al. 2014; Cheung et al. 2015).

Keeping this in mind, it was suggested to prioritize sustainability at all stages of product design and distribution. Along with traditional approaches, new ideas such as 3BL mentioned in previously discussed papers (Singhry 2015; Thomé et al. 2016; Ma and Kremer 2016) and EOL (End of Life Management) (Amelia et al. 2009; Ramani et al. 2010; Shevtshenko et al. 2012; Subramanian et al. 2014; Ziout et al. 2014) were proposed. According to the newest theories, a product lifecycle can be divided into five stages; pre-production, production, distribution, use, and disposal. An early design approach can significantly impact sustainability by affecting the choice of material and production processes and the product lifecycle, including distribution, transportation, and recycling. Figure 4 shows aspects that must be considered during the early stages of product design to achieve sustainable product development on early stages.

Figure 4 Design decisions that impact every stage of a product's lifecycle



Source: Ramani et al. (2010)

3.2 Newest reverse logistics studies conducted between 2020 and 2023

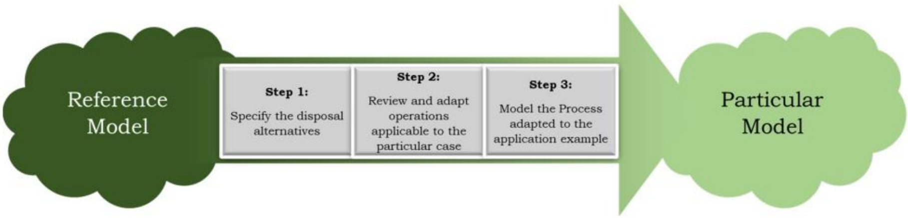
The systematic Review Protocol was used in the research conducted by Melo et al. (2021) to choose the most relevant publications and exclude irrelevant studies. The group analyzed previous publications from the perspective of the newest theories based on several Research Questions. They managed to identify a correlation between reverse logistics and sustainable design in the present business environment. Integration between reverse logistics and sustainable design needed to be further researched. Even though this conclusion opens several possibilities for further research, the researchers found it surprising that reverse logistics processes were not included in the end-of-life cycle and other stages of sustainable product design, considering there is a proven relationship between the two.

Several researchers point out the inevitable problem that corporations around the world are facing- the shortened product life cycle, which increases the amount of waste exponentially and forces governments to enforce laws to minimize environmental impact and focus on the reuse and recycling of raw materials (Prakash and Barua, 2016).

Reverse logistics have become the answer to increasing pressure companies face to make their business processes sustainable yet financially acceptable. In other words, efficiently managing returns have become a crucial success factor for many companies (Autry, 2005).

In the pursuit of creating a reference RLP (Reverse logistics processes) model that companies could use as a starting point to increase supply chain sustainability, research conducted by Alarcón et al. (2021) three-step methodology based on selecting or eliminating basic activities in the reference model according to each company’s specific needs. The research group also presented an example to demonstrate the proposal's effectiveness. Figure 5 shows the methodology consisting of three main steps to adapt the Reference Model-Reverse Logistics Process based on a particular case.

Figure 5 Graph of the methodology to adapt the RM-RLP.



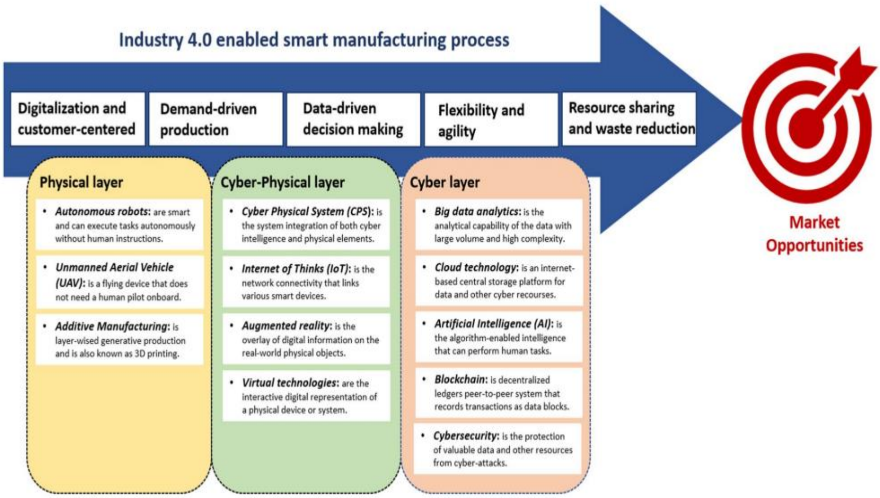
Source: Alarcón et al. (2021).

The authors concluded that reverse logistics processes have become crucial in achieving sustainability within the supply chain, mostly because of managing product disposal and recycling. They also managed to create a reference model that can be adapted to the company's specific needs. The reference model includes three stages: collection and transport, inspection and evaluation, and product disposition. The reverse logistics processes must be informal to bend and adapt to a specific market requirement easily. The research group points out that the proposed model suits any business moving towards sustainability. A case study was used as an example to prove this point. Even though the research results in terms of the practical implementation were sufficient, the authors still point out the need for more relevant studies on the topic and suggest further research from theoretical and practical perspectives.

Nowadays, companies are forced to take responsibility for the whole product lifecycle, the new reality in which reverse logistics is used to maximize the remaining value of end-of-life products through various processes such as product design, operations, control, and organizing effective and efficient flows from consumers to suppliers (Rogers and Tibben-Lembke, 2001). Ramos et al. (2014) point out that a properly designed and operated reverse logistics system must always balance economic, environmental, and social sustainability. The concept of Industry 4.0 (Fourth Industrial Revolution) and other state-of-the-art technologies has provided an opportunity to create Logistics 4.0 (Wang 2016; Winkelhaus and Grosse 2020). Integrating technologies like the Internet of things (IoT), big data analytics, and artificial intelligence (AI) with a cyber-physical system (CPS) a Logistics 4.0 can potentially start a new era of actual real-time monitoring and decision-making, systematic and timely information update and effective product flow, a lack of which has always been an obstacle on the way to effective supply chain. These tools can also considerably impact improving reverse logistics systems' economic, environmental, and social sustainability.

Figure 6 reflects three categories: the physical, cyber, and cyber-physical layer of Industry 4.0 major technologies. Manufacturing system created with the use of Industry 4.0 consists of an enormous amount of interconnected devices, which are constantly in connection with one another in real-time (Sun et al. 2022).

Figure 6 Industry 4.0 enabled smart manufacturing process.

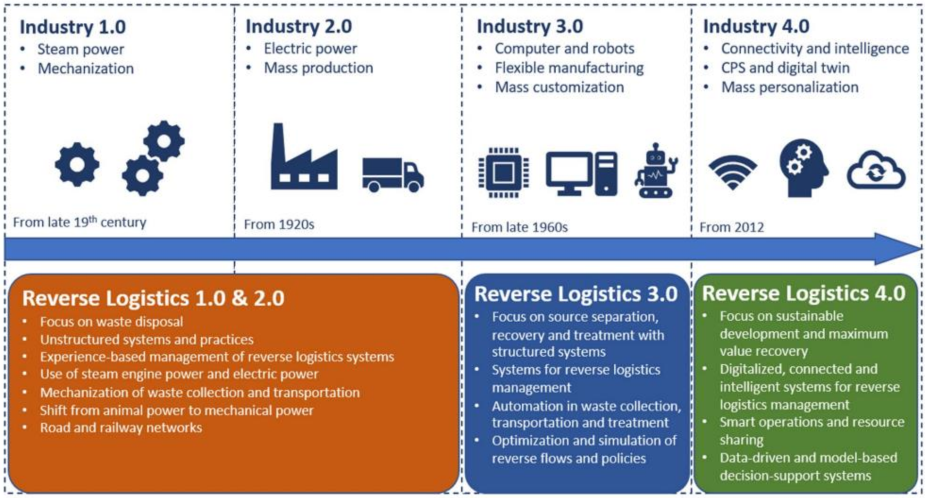


Source: Sun et al. (2022)

The research conducted by Sun et al. (2022) sets an ambitious goal of developing a conceptual approach and research agenda on transforming conventional reverse logistics into Reverse Logistics 4.0 as an analogy to Industry 4.0 using theoretical and practical tools.

The authors present a fresh approach to integrating technology into reverse logistics systems. The major difference is how they see the industry or logistics system and incorporate this vision into their study. Extending the idea of Industry 4.0 to the supply chain allows us to see the big picture from a technological angle and develop the principles to achieve sustainability by systematically integrating technology. Figure 7 demonstrates the evolution of reverse logistics keeping in mind four industrial revolutions. The concept of reverse logistics was widely used before the early 1990s, even though its basic rules were not written yet.

Figure 7 Reverse logistics evolution compared to the four Industrial Revolutions.



Source: Sun et al. (2022)

In conclusion, the authors highlight opportunities to combine conventional elements of reverse logistics and state-of-the-art technology, such as data, autonomous technologies, internet- and cloud-based connectivity, etc. However, a lack of systematic approach prevents the transition of reverse logistics into Reverse Logistics 4.0. The paper contributed to developing a definition and conceptual direction of Reverse Logistics 4.0 and created a general framework for future transformation to achieve sustainability from the perspective of the previously discussed 3BL. The researchers also underline the need for additional research to deeply investigate service innovation and the role of humans as a major influencing factor.

4. RESEARCH RESULTS AND RECOMMENDATIONS FOR BUILDING ENVIRONMENTAL SUSTAINABILITY IN ESTONIA

2018 Estonia held the Presidency of the Council of the European Union for the first time. On the verge of its Presidency, Estonia established priorities based on four major themes, two directly connected to environmental issues. Another step towards ecological sustainability was the establishment of an Interministerial Sustainable Development Working Group to guarantee coordination among all ministries involved (www.consilium.europa.eu/media).

According to statistical data, 32 out of 231 global indicators are currently measurable in Estonia. The country shows good results in achieving a high proportion of renewable energy in overall energy consumption and rich biodiversity protection. The main challenges lie in reducing CO2 emissions and creating a point- and resource-efficient economy (UN DESA, 2020).

Estonia has shown good results in implementing new programs nationwide in a concise time frame. It was proven by «Tiigrihüppe» which can be translated as «Tiger Leap» the governmental program of developing and integrating computers and networks (https://kompass.harno.ee/tiigrihupe/). In just a few years, computers and networks were integrated into every household, a first step toward E-Government that we can see today. This is a promising example of well-organized and delivered teamwork. Even though the Estonian government pays close attention to the environmental sustainability topic from different angles, some issues still need to be uncovered. One of them is integrating reverse logistics principles into the supply chain model to reach greater sustainability.

Over the last two decades, reverse logistics have moved from a concept that allows companies to control the backward flow of the product to maximize profit through recycling and reuse of materials to a vital part of creating environmental, social, and economic sustainability. It has grown to have various frameworks that can be used to develop a sustainable model within any company and any business area. Reverse logistics is now moving towards becoming a state-of-the-art technological system, with autonomous, interconnected devices working independently.

Studied papers showed similar views on environmental issues and ways to solve them. Excessive consumption and waste produced as a result of it is a major issue all over the world. Reverse logistics is considered one of the most logical steps toward responsible supply chain management. However, all researchers point out insufficient studies on the topic, which is a major obstacle to building a strong theoretical basis with the goal of future practical implementation of reverse logistics principles to build a sustainable supply chain model. Major differences are detected in choosing an approach. While some researchers focus on building a specific framework, others try to create a strong yet universal model that any company can implement. Finally, one research group has taken a step forward and tried to create a whole ecosystem analogical of yet to come Industry 4.0.

Reverse logistics is a relatively easy way to achieve sustainability in the supply chain, which does not require drastic measures like switching to electric vehicles or biofuel. Its principles can be integrated at any level, whether in single companies, corporations, or even governmental groups. However, the evidence from all papers studied during this research showed that the topic needs to be more researched in every country. The lack of data and practical case studies prevent the concept from developing faster. Estonia has limited resources and has yet to start toward environmental sustainability compared to other European states. Integrating Industry 4.0 principles would be most appropriate in a functioning E-government that Estonia has built over the years. E-government principles have many similarities with Industry 4.0 principles. Building an interconnected system of state-of-the-art technology based on conventional reverse logistics methods would be much easier in a country such as Estonia, which already has a strong technological base that can be extended further to create a sustainable model. An idea with such potential will surely get more attention from public authorities soon. This article will set a trend for future studies in this field.

One thing that all studies have in common is the fact that the world has changed. Companies must bear responsibility for the whole product lifecycle and try to make the best of it. Social, environmental, and economic approaches have become social, ecological, and economic responsibilities. Adopting a new philosophy would give companies an advantage from a financial and reputational perspective. And, of course, save the planet.

5. CONCLUSION

The world is moving toward sustainability in every major aspect, such as the economy, labor safety, and environmental protection. This study has gathered papers from Asia, Europe, the USA, etc., proving this point. We are facing issues like air and land pollution due to excessive consumption, which has taken over the world with the rise of e-commerce. Almost every government now recognizes the strong need to adopt sustainable initiatives to bend this flow backward (Prakash and Barua, 2016).

Logistics has been the source of pollution as it is a significant part of almost every business. The most popular answer to this issue is to switch to electric vehicles and biofuel. Even though these measures might lead to a promising result, some undeniable obstacles prevent this from happening soon. Reverse logistics has a strong advantage over the conventional approach to reaching environmental sustainability. It can be applied to existing supply chain systems or added to an extent. It can be extended to Reverse Logistics 4.0 or add a few changes to the supply chain. Reverse logistics is flexible and significantly under-researched. With all the studies discussed in this article, we „only scratched the surface” of it. All studies discussed in this paper indicate the need for further research, additional data, and case study collection. Estonia is even more under-researched when it comes to reaching sustainability through the integration of reverse logistics practices, from which it follows that the next logical step would be:

- to collect practical cases within the country,
- analyze and systemize cases using one of the proposed approaches,
- suggest a sustainability model that ideally will have a practical use in the nearest future.

Keywords for the future study development would be sustainability in Estonia, reverse logistics, recycling in Estonia, and waste management in Estonia.

Estonia has a promising tendency to move toward environmental sustainability. Its ability to adopt new practices within a very short time frame was proven by the «Tiger Leap» the governmental program of developing and integrating computers and networks. Keeping this in mind, the fact that the right steps toward environmental sustainability would be enforced within very short time frames is unquestionable.

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OPTIMISATION OF THE REVERSED SUPPLY CHAIN OF WOOD BIOMASS IN THE PERSPECTIVE OF ITS EMISSIVITY - CASE STUDY

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Abstract

Evaluating the carbon footprint level is critical when deciding on the shape of supply chains. The efficiency index of logistic processes referring directly to their emissivity may also indicate their technological and organisational advancement level. Such an approach is present in Green Supply Chains (GrSC) and Sustainable Supply Chains (SSC). Elements of these approaches can be applied to reversed supply chains of wood biomass. In this study, the differences in carbon footprint emissions for different shape variants of reversed supply chains of wood biomass are analysed. Based on the conducted research, a set of recommendations and identified dependencies between the elements of the process and its effectiveness were developed. The case study part of this paper was devoted to calculations of the carbon footprint related to the logistic service of wood biomass. Based on calculations of the carbon dioxide equivalent (kgCO2e) level, an attempt was made to indicate the most favourable setup of the reversed supply chain of wood biomass.
The research results may be considered when modelling reversed supply chains of wood biomass.

Keywords: carbon footprint, reverse logistics, carbon accounting, wood biomass, efficiency

1. INTRODUCTION

The potential of increasing transport processes' efficiency thru their decarbonization is a burning issue (Chaabane et al., 2012; Chen et al., 2017; Farm Europe, 2019; Herrador et al., 2022; ITF, 2018a, 2018b; Ku et al., 2021). The legal framework within Europe enforces the motivation to reduce transportation carbon footprint (European Commission, 2020). Simultaneously, vital out of the EU's international environmental policies are present (UN, 2015; UNFCCC, 1997). Carbon footprint mitigation solutions that lead signatories to international climate protection agreements to view emissions as a finite resource. Hence its proper evaluation and management have to be introduced within sustainable supply chains. According to this approach, emissions trading schemes or management methodologies have been proposed – In Europe: French Bilan Carbone, EU Emission Trading Scheme, Dutch Energy Covenant, and The Carbon Trust Standard. In North America, US EPA GHG Rule, US GHG Protocol Public Sector Standard, US EPA Climate Leaders Inventory Guidance, US Regional Greenhouse Gas Initiative, and US Securities and Exchange Commission Guidance (Dubisz et al., 2021). However, regardless of the chosen method, each supply chain participant involved in the carbon footprint evaluation is obliged to measure and report its carbon footprint properly. A practical approach for seeking an opportunity to minimize the anthropological impact on the environment is the 3R concept (Golinska-Dawson, 2020) The Circular Economy (CE) aims to maximize the use of once-processed resources. The processing of wood biomass of various origins can be an executive tool of this concept (Danish et al., 2018). Reusing once-obtained resources supports the reduction of the anthropological impact on the environment (Golinska-Dawson et al., 2020).

Additional support for this concept and verification of potential efficiency increase can be provided by assessing the environmental performance of transport processes from the perspective of the carbon footprint level expressed as kgCO2e (Acquaye et al., 2014).

2. LITERATURE REVIEW

The need for improvement in the efficiency of wood biomass supply chains has been the subject of attention in the available literature. Numerous supply chain control parameters have been identified as having a direct impact on supply chain efficiency. An important approach highlights the particular importance of solving supply chain organization problems in terms of distance - Maximum Allowable Travel Distance (MATD). The use of tools such as multiple linear regression (MLR) helps to identify cost effectiveness correlations (Lam et al., 2023). The significant dynamics of change in the handling of wood biomass from different origins indicate the need for the implementation of mechanisms that allow for spatial and temporal variability in supply chains handling wood biomass. Inadequate modelling of supply chains may lead to an underestimation of the actual costs of biomass handling. This highlights the importance of optimizing reverse wood biomass supply chains (Roni et al., 2023). The role of selected capacity parameters of the supply chain participants and their location, which have an influence on the change of the cost efficiency level, is recognised. The verification of the efficiency can be carried out by modelling a simulation under different scenarios. Both raw material flow efficiency and level of financial benefits achieved can be assessed (Kim et al., 2011). The growing role of forest wood biomass supports the reduction of anthropogenic environmental impacts. There is a direct impact on economic, social and environmental aspects of the long-term use of wood biomass. The combination of selected areas, such as economic efficiency and environmental performance, is the focus of efforts to optimise processes for handling wood biomass flows. The proper modelling and optimisation of reverse wood biomass supply chain processes is supported by environmental indicators oriented towards the measurement of greenhouse gas emissions (Cambero et al., 2014).

A literature review was conducted to identify factors influencing the efficiency of reverse supply chains of wood biomass. In the first research step, an attempt was made to identify factors influencing the carbon performance of the transport fleet. It was recognized that the degree of filling of vehicles(Korpinen et al., 2019), vehicle age (Dubisz et al., 2022), total weight (Brown, 2021) allowed and fuel type (McDowall, 2014; Parra et al., 2019) are the main factors determining the carbon performance of a heterogeneous fleet (Dubisz et al., 2022). Another crucial factor is the driver's style of driving(Zamboni et al., 2015). An urban transport study showed that each bus driver following the same route using the same type of vehicle has a unique carbon footprint(Zarkadoula et al., 2007). Route planning itself and the routing of points along the route are also important (Sar et al., 2023). For this purpose, advanced route modelling algorithms can be used, but such a universal tool that applies to the different types of routes might be challenging to implement (Lee et al., 2016). The effectiveness of route modelling tools in the case of linehaul transports between fixed points is lowered (Melo et al., 2006). The available literature also verifies the influence of the degree of filling of vehicles. It was pointed out that many studies indicate the importance of this parameter while improving the efficiency of transport processes (Brown, 2021; Kogler et al., 2020; Korpinen et al., 2019; Wong et al., 2018). Therefore, it was determined to verify the types of transport units present within reversed supply chains of wood biomass. The loading unit types identified for handling wood biomass were mainly big bags, pallets, and cage containers (Do et al., 2022; Hogland et al., 2018; Keefe et al., 2014). According to the identified packaging types, an idea for each packaging type environmental efficiency evaluation in the case study part was extended. Hence efficiency assessment in alternative transport of wood biomass scenarios was proposed. Simultaneously impact of increasing the volume of wood biomass within the supply chain on its efficiency was verified (Kogler et al., 2018). Another study verified the mutual dependencies between control parameters that affect the change in efficiency while handling various materials within the supply chain (Ghosh et al., 2022). Other studies indicate the need to properly correlate the demand-supply model in order to guarantee its proper effectiveness. This approach can also be applied to the handling of wood biomass within reversed supply chains (Al-Babtain, 2010). Simultaneously it was noticed that the efficiency of transport processes within the reverse supply chains in terms of usage of alternative packaging types needs to be analysed. Identified research gap was a motivation for conducting further research outlined within a case study research stage. In o order to assess changes in efficiency, the case study section of the study further simulated the efficiency of handling woody biomass in reverse supply chains.

3. RESEARCH METHODOLOGY

A literature study was carried out in the field of identifying control parameters affecting the effectiveness of reverse supply chains. At the same time, the available types of bulk packaging suitable for use in forming loading units of post-production wood biomass were verified. The simulation was carried out for the identified types of packaging, and the results were presented in scenarios. The proposed approach made it possible to compare the results and indicate the best solution. Based on the conducted research, answers to the research studies were formulated. According to the scope of the research's importance, it was decided to conduct research into improving the environmental efficiency of transport processes within the reverse supply chains of wood biomass.

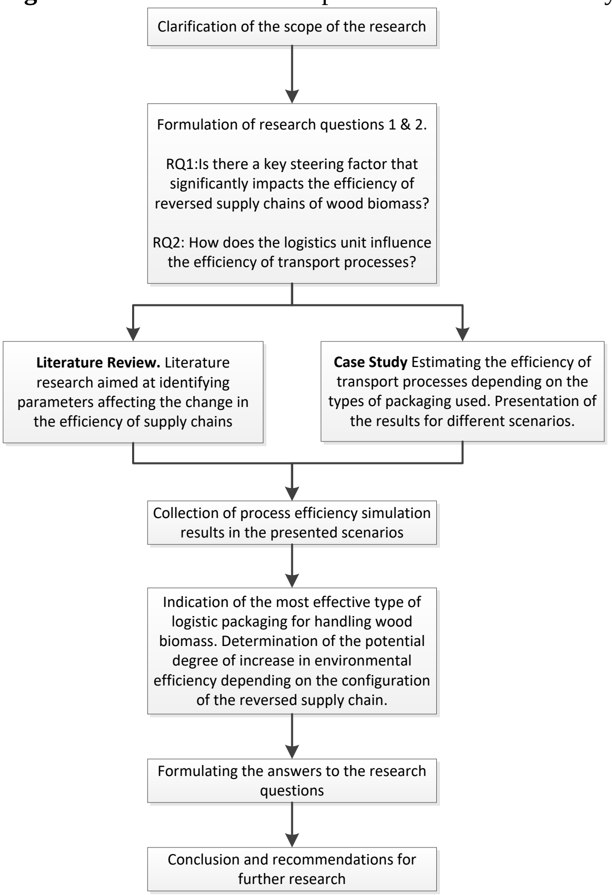
The following research questions were outlined:

Research Question 1: Is there a key steering factor that significantly impacts the efficiency of reversed supply chains of wood biomass?

Research Question 2: How does the logistics unit influence the efficiency of transport processes?

The conducted study is an attempt to answer the research questions proposed. The logic of the research is shown in **Error! Reference source not found.**.

Figure 1 Research method implemented within this study

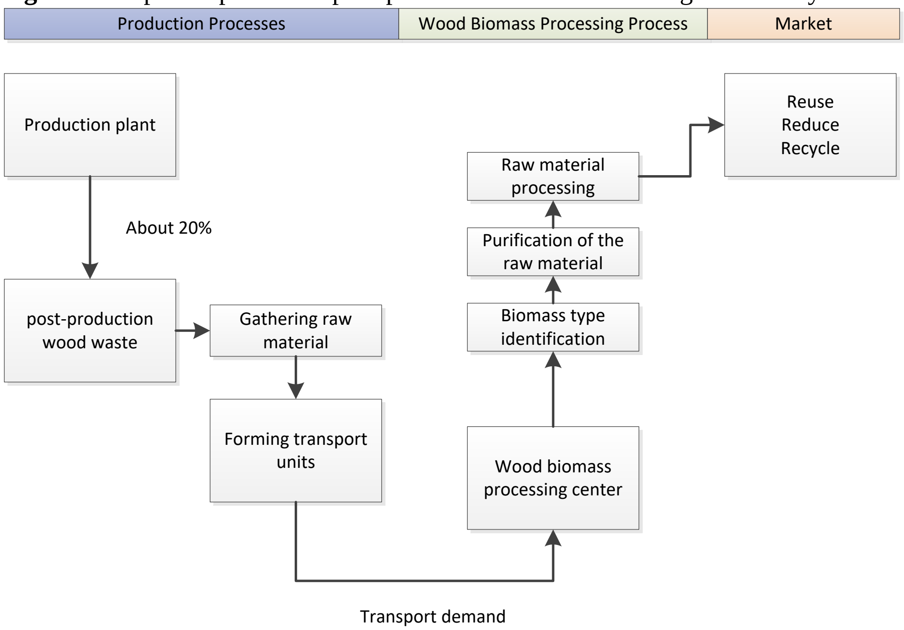


Source: own elaboration

3. CASE STUDY

The case study research was conducted using basic data of a manufacturing company in the furniture industry. The information on the company's internal flows included in the data allowed to estimate the overall level of post-production waste. Anonymized basic data of a company involved in the production of wooden furniture was used in the simulation. For this purpose actual production data of 25379 indexes was used for further calculations within scenarios. Gathered data describes production volumes for 2021. It has been observed that during the production process about 20% of production waste is turned into wood biomass. Based on the indicators developed, the level of production waste was estimated by product group. The processed waste feeds into the reversed supply chain of wood biomass. Once the waste material is obtained and loaded onto the trucks is transferred to proper processing centres. The general functional scope of the reverse supply chain is presented in the **Error! Reference source not found.** below.

Figure 2 Simplified process of post-production biomass handling in the analysed case



Source: own elaboration

The reverse supply chain has identified three main areas: Production Processes, Wood Biomass Processing Processes, and Market. The primary participant in the supply chain is the production plant which generates post-production wood biomass. It has been outlined in **Error! Reference source not found.** that about 20% of the v olume is post-production waste. This is a very high waste indicator that forces proper raw material management. The formation of logistic units precedes the grouping of biomass within the production plan premises. However, there are no standardized transport units in the current logistics model. Therefore, the shape of the formed logistics units is difficult to assess and classify. This results in the allocation of only 40-ton vehicles with a capacity of up to 33 pallets. The wood biomass processing centre is another essential participant within the reverse supply chain of wood biomass. The distance between the participants in the supply chain is 134 km; therefore, sending additional transports will significantly increase the emissivity of the reversed supply chain of wood biomass. The main tasks of the biomass processing centre include identifying the type of biomass, sorting, separating undesirable residues, purifying the raw material, and further processing depending on its further destination and utility purposes. The market is the last area within the supply chain, which determines the method of processing wood biomass waste. The entire functional course of the supply chain is consistent with the 3R concept (reuse, reduce, recycle) and is in line with the assumptions of the circular economy (Krstić et al., 2022; Stahel, 2016).

Based on the packaging types dedicated to wood biomass handling indicated during the literature research, the effect of standardised packaging types on the change in the emissivity level of reversed supply chains of wood biomass was verified. For this purpose, the six packaging types indicated in Table 1 were implemented in simulation scenarios. For each of the defined types of packaging, basic parameters have been indicated. Including width, depth and height. During the verification of types of packaging, the focus was put on weight, volume and capacity. These parameters directly affect the filling level of the vehicles and the environmental performance of the entire reversed wood biomass supply chain presented in further scenarios.

Table 1 Packaging types implemented for wood biomass handling in alternative distribution scenarios.

	Capacity		Dimensions & Specification				
Packaging type	Maximum weight [kg]	Maximum cbm [litres]	Packaging weight [kg]	Packaging cbm [m3]	width [cm]	depth [cm]	height [cm]
Big Bag A	1 000,00	480,00	30,63	0,48	1,11	0,71	0,61
Big Bag B	1 000,00	250,00	14,38	0,26	0,74	0,54	0,64
Big Bag C	1 000,00	820,00	41,90	0,83	1,11	0,91	0,82
Cage Container A	1 000,00	960,00	26,20	0,96	1,20	0,80	1,00
Cage Container B	1 000,00	760,00	24,20	0,77	1,20	0,80	0,80
Cage Container C folding window	1 000,00	1 152,00	32,90	1,15	1,20	0,80	1,20

Source: own elaboration

The efficiency of the logistic units implemented to handle the raw material, indicated in Table 1, was demonstrated through further simulation of alternative handling methods. Six scenarios were created and the result of each scenario was compared with the current model. In this way, a number of outcome parameters were demonstrated on the basis of which the level of efficiency was verified. The level of savings resulting from a reduction in the number of means of transport, the number of kilometres was indicated on this basis. It also showed a number of control parameters that were modelled for simulation in alternative operating scenarios. Means of transport characteristic is presented in **Error! Reference source not found.**.

Table 2 Packaging types implemented for wood biomass handling in alternative distribution scenarios.

Truck type	40 tonns lorry
Max. payload [kg]	25 000
Max. volume [m3]	91
kgCO2/km	0,633
Linehaul distance between Production Plant and Wood Biomass processing location [km]	134

Source: own elaboration

The characteristics of the logistic units implemented to handle the post-production wood biomass are indicated in Table 1. Each solution's efficiency is demonstrated in the further simulation of alternative logistics unit types. In order to conduct a valid comparison of efficiency between six logistics units, four scenarios were created. The result of each scenario was compared according to its emissivity level expressed in kgCO2e units. Apart from the number of trucks engaged with transportation tasks, the overall emissivity level was calculated and shown in **Error! Reference source not found.**.

Based on the conducted estimation, the emissivity level of each alternative scenario was evaluated. The methodology used for the evaluation was to measure the carbon footprint according to the GHG Protocol and the ISO 14064 standard (Crippa et al., 2021). To calculate the emissivity within each scenario, the available sets of emission factors were used as a dedicated data source. For this purpose, the emission sets published by UK DEFRA were used, mainly due to reliable information on the kgCO2e emissions factors of the different modes of transport, taking into account their GVM and the degree of filling of the cargo space. The result of the simulation is presented in **Error! Reference source not found.**.

Table 3 Emission efficiency evaluation for each packaging type dedicated to wood biomass handling.

	Amount of packaging units per its type [Pcs]					
Month	Big Bag A	Big Bag B	Big Bag C	Cage Container A	Cage Container B	Cage Container C folding window
Jan	1 442	2 870	907	714	864	570
Feb	763	1 520	480	378	458	302
Mar	697	1 387	439	345	418	276
Apr	1 753	3 490	1 103	868	1 051	693

May	3 304	6 576	2 079	1 636	1 980	1 306
Jun	1 750	3 483	1 101	867	1 049	692
Jul	3 077	6 124	1 937	1 524	1 844	1 216
Aug	1 637	3 258	1 030	811	981	647
Sep	821	1 634	517	407	492	325
Oct	624	1 241	392	309	374	247
Nov	667	1 327	420	330	400	264
Dec	337	671	212	167	202	133

	Amount of routes of 40 tonnes GVM trucks according to packaging unite type [Routes]					
Month	Big Bag A	Big Bag B	Big Bag C	Cage Container A	Cage Container B	Cage Container C folding window
Jan	7,62	8,06	8,26	7,53	7,29	7,22
Feb	4,03	4,27	4,37	3,99	3,86	3,82
Mar	3,68	3,90	3,99	3,64	3,53	3,49
Apr	9,26	9,81	10,04	9,16	8,87	8,77
May	17,45	18,48	18,93	17,26	16,71	16,54
Jun	9,24	9,79	10,02	9,14	8,85	8,76
Jul	16,26	17,21	17,63	16,08	15,56	15,40
Aug	8,65	9,16	9,38	8,55	8,28	8,19
Sep	4,34	4,59	4,70	4,29	4,15	4,11
Oct	3,29	3,49	3,57	3,26	3,15	3,12
Nov	3,52	3,73	3,82	3,48	3,37	3,34
Dec	1,78	1,89	1,93	1,76	1,70	1,69

	Carbon footprint of transportation processes - Production plant to Wood biomass processing center [kgCO2e]					
Month	Big Bag A	Big Bag B	Big Bag C	Cage Container A	Cage Container B	Cage Container C folding window
Jan	646	684	700	638	618	612
Feb	342	362	371	338	327	324
Mar	312	330	338	309	299	296
Apr	785	831	851	776	752	744

May	1 479	1 566	1 604	1 463	1 416	1 402
Jun	783	830	850	775	750	742
Jul	1 378	1 459	1 494	1 363	1 319	1 305
Aug	733	776	795	725	702	694
Sep	368	389	399	364	352	348
Oct	279	296	303	276	267	265
Nov	299	316	324	295	286	283
Dec	151	160	164	149	145	143
Total carbon footprint [kgCO2e]	7 554	7 999	8 191	7 471	7 233	7 157

Source: own elaboration

4. RESULTS

As a result of the simulations, it was shown that changing a logistics unit type for handling wood biomass may increase the overall efficiency of transportation processes. The obtained results showing the number of vehicles necessary for transport were deliberately left with the values after the decimal point. According to those results, it has been outlined that there are months in which 40-ton vehicles were not used effectively. It has been indicated that linehaul transports may be reduced between the production plant and the wood biomass processing centre due to the usage of alternative logistics unit packaging. The introduced change in the type of packaging contributed to minimizing the total number of kilometers travelled. Simultaneously the obtained result can be related to the supply chain's emissivity level using different types of transport packaging. The lowest emissivity level was obtained using Cage Container C with a folding window. The highest emission factor, expressed as kgCO2e, was obtained while using Big Bag type C. The difference in the demand for means of transport is as much as 12 trucks per year, depending on the packaging type. In response to research question 1, it was concluded that the key steering factor influencing the environmental performance of reverse wood biomass supply chains is the physical form of the transported volume. The aim to minimise its weight by changing its moisture content can positively influence the minimisation of the carbon footprint of transport processes as a result of the reduced need for transport resources. This approach is consistent with research conducted by Ungureanu et al. (2018). Regarding research question 2 it has been identified that the efficiency of the wood biomass supply chain is directly affected by the packaging type used. Transport demand can increase significantly if inappropriate types of packaging are applied. Conversely, choosing the right type of packaging can have a major impact on efficiency. This parameter should be considered as crucial while modelling reverse wood biomass supply chains.

5. CONCLUSION

Conducted research indicated the importance of logistic units in determining the efficiency level of transport processes of reversed supply chains of wood biomass. In order to improve the efficiency of transport processes and minimise their carbon footprint, the correct type of logistics units needs to be matched to the exact type of wood biomass. The identified potential increase in efficiency can translate into a significant reduction in logistics organisation costs. Thus it is essential to carry out further research into reducing the physical parameters of the raw material in terms of its volume and weight. Wood biomass may be reprocessed in order to reduce its moisture and volume. The conclusions of the literature study are confirmed by the simulation carried out using standardised types of packaging for the transport of wood biomass. Increasing transport efficiency is closely linked to the appropriate utilisation of transport unit loading space. The predictability of the physical form of the transported volume was increased by using standardised types of packaging. Through the use of several types of packaging, it is possible to select the appropriate loading unit for the quantity of wood biomass being transported. The method identified by Lam et al. (2023) for identifying the trade-off between cost and the level of efficiency achieved enables the efficiency of reverse wood biomass supply chains to be improved by introducing additional loading units, depending on the current needs of the supply chain. In line with the approach presented in the Cambero et al. (2014) stydy, the implementation of environmental indicators for the evaluation of the efficiency of the execution of distribution processes is considered to be feasible and can be used for the modelling and optimisation of supply chains. The idea of reducing cargo moisture content and changing its volume using hydraulic presses is also related to the approach outlined in other studies (Ungureanu et al., 2018).

The research has shown that using a standard of packaging dedicated to different types of wood biomass impacts the emissivity of reverse supply chain transport processes. It has been shown that the proper choice of suitable packaging is crucial to ensure standardisation of loading and unloading of the means of transport in production plants and wood biomass processing centres. Another critical factor that has to be analysed in further research is the time spent in the warehouse at loading and unloading trucks carrying logistics units of wood biomass. This could be an area of further research into the efficiency of handling woody biomass within reverse supply chains. However, the efficiency of warehouse processes can be assessed based on their energy consumption and related to the carbon footprint emission factors (kgCO2e).

The research also outlined that in periods of reduced demand for transport tasks, using vehicles with a lower capacity may be beneficial. The use of vehicles with lowered GVM will reduce the emissivity resulting from the implementation of transport routes and contribute to generating financial savings.

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FUTURE OF TRANSPORT AND GREEN DEAL

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Abstract

The transport system is crucial to European businesses, global supply chains and the movement of people. Transport employing more than 10 million people in Europe and contributing around 5 % to EU GDP. At the same time the huge challenge for transport and our society are: greenhouse gas and pollutant emissions, noise, road crashes and congestion.

The average of the transport emissions is on 25% of the European Union total greenhouse gas emissions with tendency of increasing over recent years. European Union and hers institutions (first of all European Commission) in coordination with Member State of the European Union has goal of being the first climate-neutral continent by 2050 requires ambitious changes in transport. For the achieve to goal of 90% reduction in transport-related greenhouse gas emissions by 2050. To achieve the goal of 90% reduction of transport-related greenhouse gas emissions by 2050, it is necessary to ensure financial capacity, knowledge, infrastructure and human resources. In addition to the above, the European Commission adopted a set of proposals to make the EU's climate, transport, energy and taxation policies fit for reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.

The aim of this paper is to research the literature about transport and Green Deal, hers providing efficient, safe and environmentally friendly transport. Based on these results, the author(s) will contribute to the new knowledge about the transport and Green Deal and offer recommendations for a sustainable, efficient, safe and environmentally friendly transport.

For the purposes of this work, the author(s) used secondary data, analyzing them using the following methods: descriptive research methods, deductive research methods, analysis methods and compilation methods.

Keywords: Green Deal, sustainability, environmentally friendly transport, alternative fuels

1. INTRODUCTORY CONSIDERATIONS

The paper is structured through 7 chapters, three sub-chapters and literature review. First chapter is introduction and view of the structure of the paper. Second chapter was structured by the author(s) through three sub-chapters. The first sub-chapter relates to the Research subject, in which the author(s) introduce readers to the routes of Trans European Transport Network (TEN-T), number of recharging stations and refueling station for alternative fuel vehicles across the European Union. The second sub-chapter relates to the Research goals, in which the author(s) introduce readers to the main goals of this paper. Author(s) are focused on presenting the current situation around installed recharging stations, hydrogen refueling stations, liquefied methane refueling points and other supporting infrastructures and the third sub-chapter relates to the Research methodology. Third chapter refers to the Literature review. Fourth chapter refers to The Green Deal: A game changer for transport. The Green Deal is conceived as a sustainable concept of the modern economy and society. A concept that, with the help of new technologies, knowledge and human resources, will mitigate the impact of industry, transport and breeding of domestic animals (primarily livestock breeding) on climate change and mitigate the consequences of climate change. Significant role in achieving the set goals it has a Directive 2014/94 EU of the European Parliament and of the Council. In addition to the above-mentioned institutions, Member States also play a significant role in the implementation of the Directive, which they should ensure with their national policy frameworks. Author(s) are focus on the researching of the main pollutants in the transport sector and the possibilities of reduction of using fossil fuels as a cause and the consequence to reach climate neutrality by 2050. The challenge is to provide the appropriate number of recharging points and alternative fuel refueling points in the EU for the cars, planes and ships that use them.In this chapter, the author(s) focused their research on the needs in Road transport, Aviation and Ports. Fifth chapter refers to Infrastructure: Building a sustainable trans European transport network (TEN-T). In this chapter the author(s) emphasize the importance of TEN T as crucial transport infrastructure, which includes roads, railways, waterways and airports with the aim of improving transportation efficiency and environmental sustainability across Europe. Under this chapter author(s) presented a detailed view of the old (TEN-T) and new (TEN-T) corridor in table and with the help of maps.

The sixth chapter refers to the Intelligent Transport Systems (ITS). These are advanced applications that, without embodying intelligence in the strict sense, aim to provide innovative services related to different modes of transportation and traffic management and enable different users to use traffic networks in a "smarter" and safer way. Their contribution is ultimately reflected to reduced travel time, reduced travel costs, reduced negative impacts on the environmental performance, energy efficiency, road safety, public safety and the mobility of people and goods, but at the same time and higher level of competitiveness and employment. In this chapter author(s) focused on researching of the implementation of level ITS on the total length of the TEN -T in certain European countries. In this chapter, the author(s) focused on researching of the implementation of level ITS on the total length of the TEN -T in certain European countries, number of Electricity recharging points, number of BEV&PHEV vehicles by type category, number of hydrogen (H2) recharging points (number of H2 vehicles by type category), number of natural Gas CNG & LNG recharging points (number of CNG & LNG vehicles by type category), number of LPG vehicles by type category.

Last chapter in this paper are refers to research limitations, suggestions for further research and concluding remarks.

2. RESEARCH METHODOLOGY

2.1 Research subject

This research focuses on the implementation of fuel sources that will bring about changes, in the transportation system across Europe. It aligns with the goals outlined in the European Green Deal, (European Commission, COM/2021/559 final, 2021), goals outlined in Directive 2014/94 EU of the European Parliament and of the Council, goals outlined in Proposal for a Regulation of the European Parliament and of the Council on the deployment of alternative fuels infrastructure, and repealing Directive 2014/94/EU of the European Parliament and of the Council which aims to create a future. The Trans European Transport Network corridors (TEN-T) are crucial in facilitating this transition. Will serve as a foundation for establishing infrastructure that supports alternative fuel options such, as electricity, hydrogen, CNG&LNG and LPG.

2.2. Research goals

The aim of this paper is to research the literature about Green Deal and and his influence on transformation of transport. The focus of this paper are primarily on alternative fuel infrastructure in road transport. Based on research, the author(s) will contribute to the new knowledge about the Green Deal and green transformation of transport and offer recommendations for a sustainable green transport in the future.

2.3. Data analysis

The data used for this research is primarily divided into two categories; data and policy documents. Secondary data is gathered from publicly accessible sources such, as databases, academic articles, reports on alternative fuel infrastructure and industry publications. This includes information on the number of vehicles using fuels, the availability and distribution of charging stations and the implementation levels of Intelligent Transport Systems (ITS) in selected Member States. Additionally to gain a understanding of the effectiveness of the infrastructure the authors also calculated the ratio of alternative fuel vehicles per charging station. The study examines National

Policy Frameworks (NPFs) and National Implementation Reports (NIRs) provided by EU Member States. These documents are publicly available. Provide insights into government commitments, targets and performance metrics related to adopting alternative fuels. Furthermore additional data was extracted from publications by organizations like the European Commission and other international bodies that produce reports on sustainable transport and energy. It is important to note that all utilized data is publicly available without involving any sensitive information ensuring integrity in conducting this research while offering a comprehensive perspective, on how alternative fuels are influencing European transportation network particularly focusing on TEN-T corridors.

The constraints of the paper is predominantly quantitative and relies on statistical methods, which inherently carry assumptions that may not fully capture the complexities of the real scenarios and target goals.

3. LITERATURE REVIEW

The European Green Deal was lunched by European Commission (European Council, EUCO 29/19, 2019) in December 2019. Under the Green Deal (European Council & Council of the European Union, European Green Deal, 2023). European Union declared very optimistic goal of becoming the first carbon-neutral region by 2050.

The first reasonable definition of the “Green New Deal” was the idea that with "green" (clean and sustainable) technologies and products, a thorough structural change of the global economy that could prevent dangerous climate change and mitigate the consequences of climate change (Galvin & Healy, 2020).

The concept of the Green New Deal was formulated on the basis of a figurative rhetorical question: "Do we want to justify overcoming the crisis by reviving the existing 'brown' global economy, or do we want to promote global revitalization toward a 'green' economy that avoids ecological damage in the first place?“ (Barbier, 2010).

Reducing the use of fossil fuels in transport is key if the EU is to reach climate neutrality by 2050. In order to achieve this goal, there needs to be enough recharging points and alternative fuel refueling points in the EU for the cars, planes and ships that use them (European Council & Council of the European Union, Infographic - Fit for 55: towards more sustainable transport, 2023).

Significant role in achieving the set goals it has a Directive 2014/94 EU of the European Parliament and of the Council. This Directive establishes a common framework of measures for the deployment of alternative fuels infrastructure in the Union in order to minimize dependence on oil and to mitigate the environmental impact of transport. This Directive sets out minimum requirements for the building-up of alternative fuels infrastructure, including recharging points for electric vehicles and refueling points for natural gas (LNG and CNG) and hydrogen, to be implemented by means of Member States national policy frameworks, as well as common technical specifications for such recharging and refueling points, and user information requirements (European Commission, Directive 2014/94/EU, 2014).

In implementing the Directive major roll has the Member States. Member States shall ensure, by means of their national policy frameworks, that an appropriate number of recharging points accessible to the public. Also, Member States which decide to include hydrogen refuelling points accessible to the public in their national policy frameworks shall ensure that, by 31 December 2025, an appropriate number of such points are available, to ensure the circulation of hydrogen-powered motor vehicles, including fuel cell vehicles, within networks determined by those Member States, including, where appropriate, cross-border links. Member States shall ensure, by means of their national policy frameworks, that an appropriate number of refuelling points for LNG are put in place at maritime ports, to enable LNG inland waterway vessels or seagoing ships to circulate throughout the TEN-T Core Network by 31 December 2025. Also, Member States shall cooperate with neighbouring Member States where necessary to ensure adequate coverage of the TEN-T Core Network (European Commission, Directive 2014/94/EU, 2014).

A detailed description of the influence of traffic types (road, aviation: ships, trains, others) on the amount of greenhouse gases produced is presented in the next chapter.

4. GREEN DEAL: A GAME CHANGER FOR TRANSPORT

Most research on new energy vehicles in transportation focuses on small and medium–sized vehicles, although heavy trucks are responsible for most cargo transportation. Heavy trucks generally use diesel engines, which emit high levels of nitrogen oxides and particulate pollutants during operation, posing a threat to human health, contributing to global warming, and negatively impacting ecological sustainability. Therefore, it is necessary and meaningful to include heavy–duty electric trucks to participate in the study of cargo transportation (Lu & Shuang, 2023).

Picture 1 The European Green Deal

Source: Author(s) processed and adapted to: (DNV, 2020) (accessed 04.07.2023.)

According to Picture 1. The European Commission has a plan to provide numerous benefits to its citizens and the next generation in mind:

✓ fresh air, clean water, healthy soil and biodiversity

✓ renovated, energy efficient buildings

✓ healthy and affordable food

✓ more public transport

✓ cleaner energy and cutting-edge clean technological innovation

✓ longer lasting products that can be repaired, recycled and re-used

✓ future-proof jobs and skills training for the transition

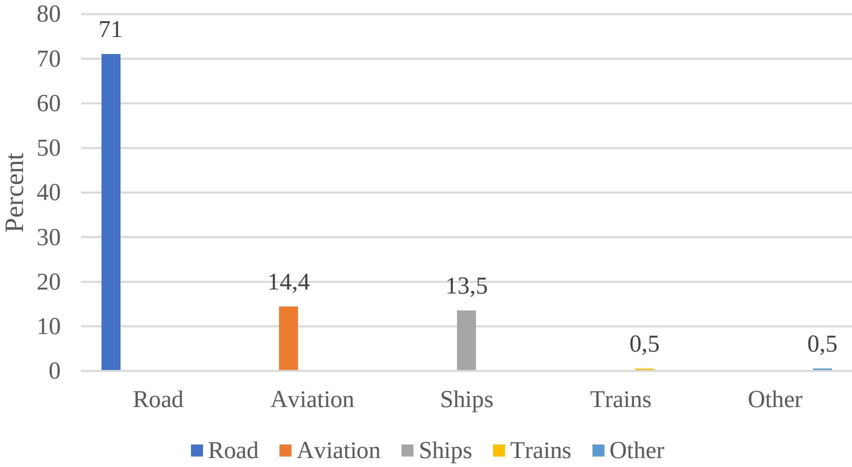
✓ globally competitive and resilient industry (European Commission, 2019)

In order to ensure the above, the European Union and its institutions, together with the national institutions of the Union Member States, work diligently in each of the above areas.

For the purpose of this paper author(s) are focus on transport as as a significant factor of negative effects on environment and direct consequences of the generally occurring climate changes.

According to the available information transport is responsible for almost 25% of greenhouse gas (GHG)[1] emissions in the EU. If we look the Figure 1. we can se the share of emissions per transport type.

Figure 4 Share of emissions per transport type



Source: Author(s) processed and adapted to: (European Council & Council of the European Union, Infographic - Fit for 55: towards more sustainable transport, 2023), *(accessed 04.07.2023.)*

Share of emissions per transport type the road transport (71%) has most negative effects on nature. Under the road transport the most polution in 2019. year of GHG coming from the cars (60.6%), heavy duty trucks (27.1%), light duty trucks (11%), motorcycles (1.3%) (European Parliament, CO2 emissions from cars: facts and figures (infographics), 2019). On the second place is aviation with 14.4% and ships with 13.5% of GHG. Trains and other type of transport have the least impact on the environment (0.5 %).

For example the cars and vans represent the biggest share of CO_2 emissions in transport in absolute terms, and average emissions from internal combustion engine cars are rising. The rollout of charging and refuelling infrastructure for alternative drive systems, in conjunction with the new CO_2 emission standards, and in particular the ramping up of electro-mobility, to be a key condition for achieving the climate targets at European, national and regional level. the transformation of the European automotive industry towards zero-emission vehicles is the most comprehensive structural change in the sector to date, with a multitude of impacts on workers, suppliers and car manufacturing groups in Europe. Necessity of establish, by the European Commission, European Mechanism for a just transition of the automotive sector and regions" which should draw on European funds and make sure it addresses

[1] GHG = Greenhouse gases (also known as GHGs) are gases in the earth's atmosphere that trap heat. Available at: (National Grid, 2023)

challenges in the regions most affected by the transformation and reaches all SMEs in the supply chain to adapt to the changes in the automotive value chain (European Commitee of the Regions, 2022).

One of solution for the future sustainability of transport and minimizing impact of GHG for sure are more vehicles powered by electricity and alternative fuels. According to the available information in the EU there are over 13.4 million alternative fuel cars and vans. Today, it's less than 5% of total fleet but it is estimated that the percentage of all cars and vans in the EU that run on alternative fuels will grow tenfold by 2050 (European Council & Council of the European Union, 2023).

In addition to the electric vehicles, it is necessary to provide the accompanying infrastructure, there needs to be enough recharging points and alternative fuel refueling points for the cars, planes and ships that use them.

The needs in *Road transport* are reflected in recharging stations. The EU plan is to install at least one recharging stations on every 60 km on the main roads (core TEN-T[2] network) for passenger cars and trucks below 3.5 tonnes by the end of 2025 and for trucks heavier than 3.5 tonnes by the end of 2030. Every year, the total power output provided through recharging stations grows with the number of registered cars. For trucks above 3.5 tonnes at least two recharging points in each safe and secure parking area (end of 2027) and four by end of 2030 (European Council & Council of the European Union, 2023).

Plan for the hydrogen refuelling stations is at least every 200 km on main roads (end of 2030), at least one refuelling station in every urban node. Every refuelling station will have a designed capacity to provide 1 tonne of hydrogen per day, at 700 bar (European Council & Council of the European Union, 2023).

Also the plan for liquefied methane refuelling points is at least one along main roads to allow vehicles using methane to circulate throughout the EU (European Council & Council of the European Union, 2023).

The new infrastructure will have to: allow ad-hoc charging, accept electronic payments and clearly inform users about pricing options (European Council & Council of the European Union, 2023).

The needs in *Ports* (especially in the busiest sea ports) are reflected in at least 90% of container ships and passenger ships to have access to shore-side electricity supply (European Council & Council of the European Union, 2023).

In most of the inland waterway ports at least one installation providing shore-side electricity (by 2030) (European Council & Council of the European Union, 2023).

The needs in *Aviation* are reflected in electricity supply for all aircraft stands next to the terminal by 2025 and all remote stands by 2030 with an exception for the

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[2] „along the TEN-T road network' means:

(a) with regard to electric recharging stations: that they are located on the TEN-T road network or within 3 km driving distance from the nearest exit of a TEN-T road; and

(b) with regard to hydrogen refuelling stations: that they are located on the TEN-T road network or within 10 km driving distance from the nearest exit of a TEN-T road“. (11454/23, p.60 https://data.consilium.europa.eu/doc/document/ST-11454-2023-INIT/EN/pdf) (2021/0223(COD) 11454/23, 2023), (accessed 02.07.2023.)

airports with fewer than 10 000 flights per year may use a derogation for remote stands (European Council & Council of the European Union, 2023).

5. INFRASTRUCTURE: BUILDING A SUSTAINABLE TRANS-EUROPEAN TRANSPORT NETWORK (TEN-T)

The Trans European Transport Network (TEN-T) is a transportation infrastructure network designed to connect all regions of Europe in a way that supports travel. It includes roads, railways, waterways and airports with the aim of improving transportation efficiency and environmental sustainability across the continent.

The role of TEN-T, in the success of the Green Deal cannot be overstated. By promoting transportation methods and reducing reliance on fuels TEN-T plays a vital part in achieving the goals outlined by the Green Deal. A connected and sustainable transport network has the potential to reduce congestion, lower emissions and enhance quality of life for citizens.

As we strive to lessen our dependence on fuels alternative fuels are becoming increasingly important. Fuels like biofuels, electricity and hydrogen offer benefits such as reduced emissions and enhanced energy security.

However there are challenges associated with adopting these fuels. One major obstacle is the lack of infrastructure to support their use. This includes having charging stations for vehicles as well as refueling stations, for hydrogen powered vehicles. Additionally issues related to production and distribution need to be addressed in order to facilitate adoption and utilization of these fuels.

The updated Trans European Transport Network (TEN-T) takes an approach, to the transportation infrastructure in Europe. Unlike the version, which mainly focused on connecting cities and ports the new TEN-T aims to establish a network that covers all regions of Europe effectively. The framework consists of two layers; the network and the core network.

The core network consists of nine corridors that support modes of transportation. These corridors, listed in the Table 1 and Pictures 1 and 2 below play a role in achieving the objectives of the TEN-T network, such as improving connectivity reducing congestion and promoting friendly transportation methods. They seamlessly integrate road, rail, air and maritime transport systems to facilitate movement between member states.

Table 4 TEN-T Network of Corridors

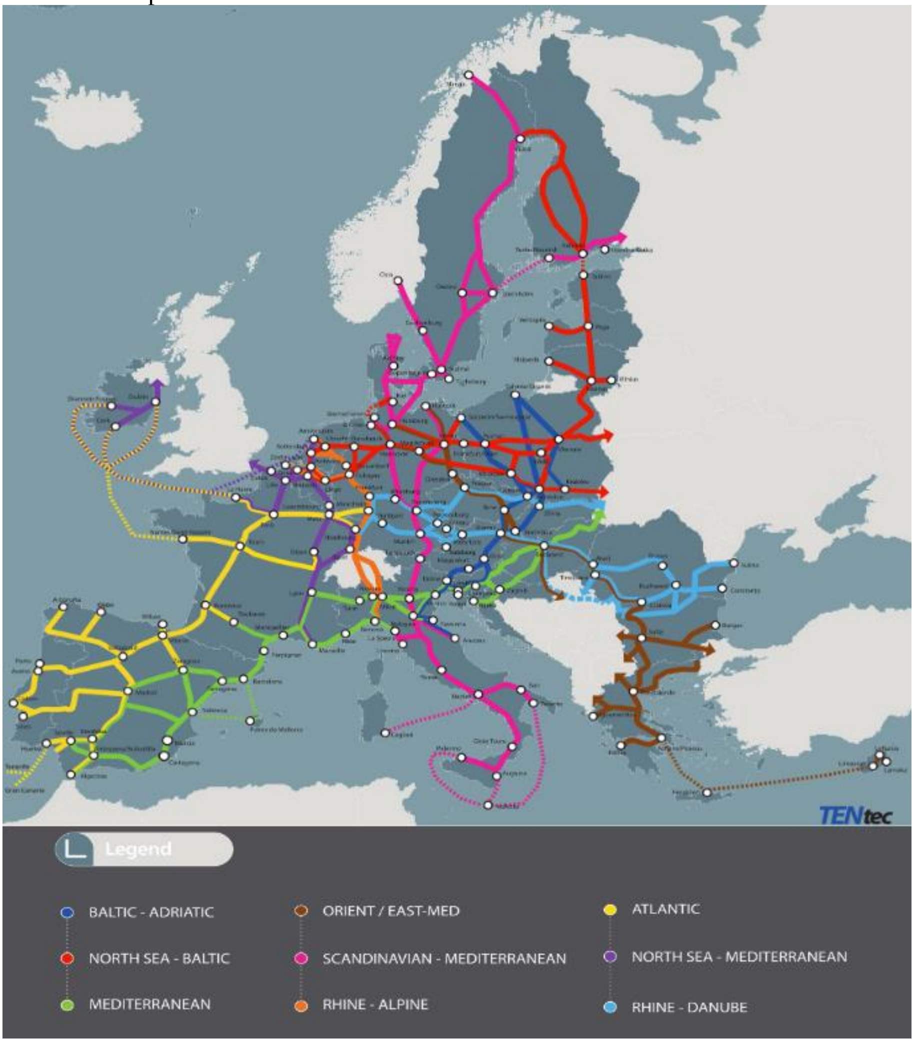
TEN-T Network Corridors	New TEN-T Network Corridors
1. Atlantic	1. Atlantic
2. Baltic-Adriatic	2. Baltic-Adriatic
3. Mediterranean	3. Mediterranean
4. North Sea-Baltic	4. North Sea-Baltic
5. North Sea-Mediterranean	5. North Sea-Rhine-Mediterranean
6. Scandinavian-Mediterranean	6. Scandinavian-Mediterranean
7. Rhine-Danube	7. Rhine-Danube
8. Orient/East-Med	8. Western Balkans-East Mediterranean
9. Rhine-Alpine	9. Baltic sea-Black sea-Aegean sea

Source: (European Commission, Mobility and Transport, 2023), (accessed 04.07.2023.)

Each corridor is meticulously planned to incorporate modes of transport and connect hubs, ports and cities within the European Union. Serving as the backbone of the TEN-T network these corridors are expected to be fully operational by 2030.

The Comprehensive Network goes beyond the core network by ensuring that remote regions are well integrated into Europes transportation landscape. This comprehensive network is projected to be completed by 2050 and aims to provide high quality connections, for all modes of transport while preventing any region from being isolated.

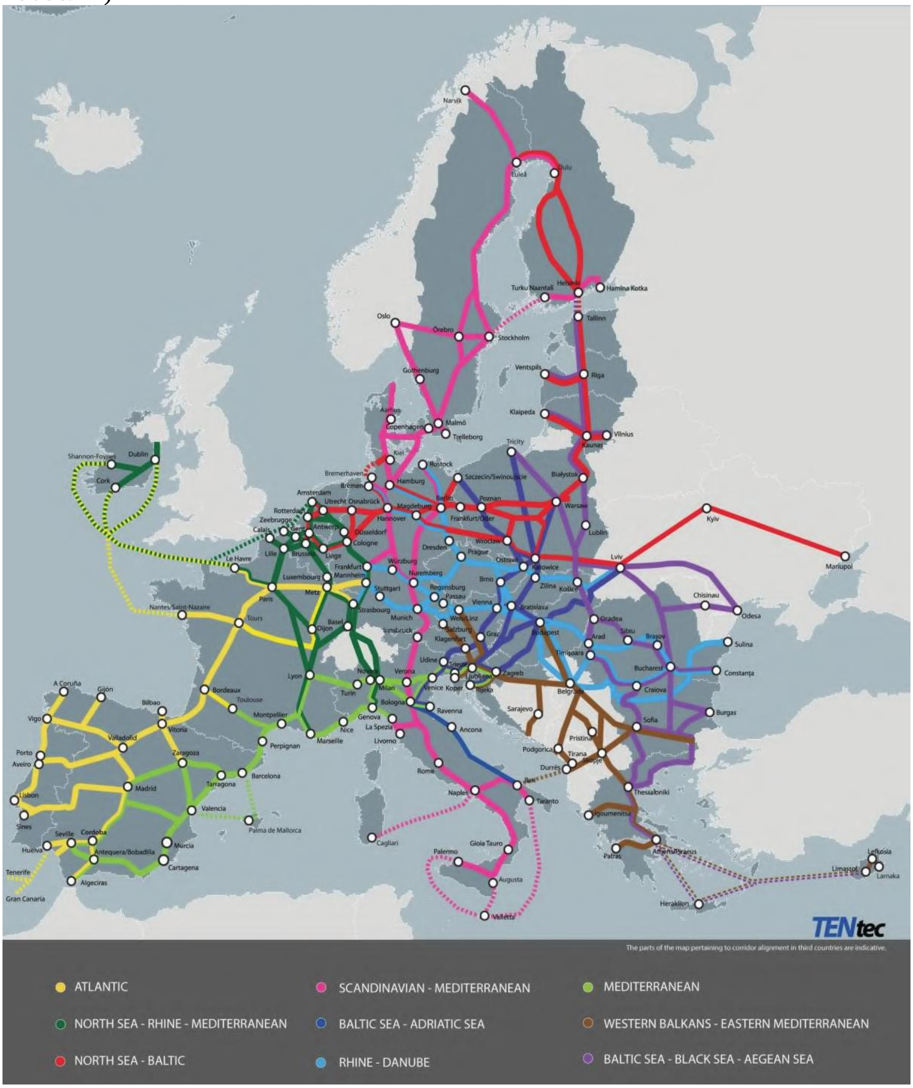
Picture 2 Map of TEN-T Core Network Corridors



Source: (European Commission, TEN-T Interactive Map Viewer, 2023), (accessed 04.07.2023.)

According to the Picture 2. TEN-T Core Network Corridors it is made up of ninen strategic transport corridors (Baltic -Adriatic, North sea – Baltic, Mediterranean, Orient/Est-Med, Scandinavian – Mediterranean, Rhine – Alpine, Atlantic, North sea – Mediterranean, Rhine – Danube).

Picture 3 Map of TEN-T Core Network Corridors as adopted by the Transport Council for the revision of the TEN-T Regulation on 5 December 2022 (ST 15058/22)



Source: https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/729314/EPRS_BRI%282022%29729314_EN.pdf (accessed 05.07.2023.)

According to the Picture 3. Map of TEN-T Core Network Corridors as adopted by the Transport Council for the revision of the TEN-T Regulation some changes have been made compared to Picture 2. TEN-T Core Network Corridors. Corridor Orient/East-Med has been replaced by the Western Balkans-East Mediterranean and corridor Rhine-Alpine has been replaced by the Baltic sea-Black sea-Aegean sea. The changes made in the corridors contributed to the strengthening of the traffic importance of the eastern and southern parts of Europe.

6. INTELLIGENT TRANSPORT SYSTEMS (ITS)

The term Intelligent Transport Systems (ITS) has been introduced in transport and traffic engineering during the 1990s (Mandžuka et al., 2013).

Due to the increase in road traffic in the Member States of the European Union in the context of economic growth and mobility needs of citizens is the main cause of increasing congestion of road infrastructure and energy consumption, as well as a source of environmental and social problems, was introduced the need for intelligent transport systems (ITS).

Intelligent Transport Systems (ITS) are advanced applications that, without embodying intelligence in the strict sense, aim to provide innovative services related to the different modes of transport and traffic management, and to allow the different users to be better informed and to use transport networks in a safer, more coordinated and "smarter" way.

ITS integrate telecommunications, electronics, and information technologies with transportation engineering to plan, design, operate, maintain, and manage transportation systems. The application of information and communication technologies to the road transport sector and its interfaces with other transport modes will make a significant contribution to improving environmental performance, efficiency, including energy efficiency, road safety, including the transport of dangerous goods, public safety and the mobility of people and goods, while ensuring the functioning of the internal market and a higher level of competitiveness and employment. However, the applications of ITS should not affect matters related to national security or necessary in the interest of defence.

Progress in the application of information and communication technologies to other modes of transport should now be reflected in developments in the road transport sector, particularly with regard to greater integration between road transport and other modes of transport.

In some Member States, these technologies are already being deployed at national level in the road transport sector (Directive 2010/40/EU).

The improvements associated with the use of ITS usually manifest themselves in reduced travel time, reduced travel costs, reduced incidents, reduced negative impacts on the environment, increased pedestrian comfort and satisfaction, increased capacity, and industry development. (Šimunović et al., 2009)

This indicator describes the deployment of Intelligent Transport Systems on the Pan European Road Network. The values show in Figure 2. the proportion of the road network equipped with different levels of ITS. The levels range from Level 0 to Level 4 as shown below and are based on the Easy Way Deployment Guidelines.

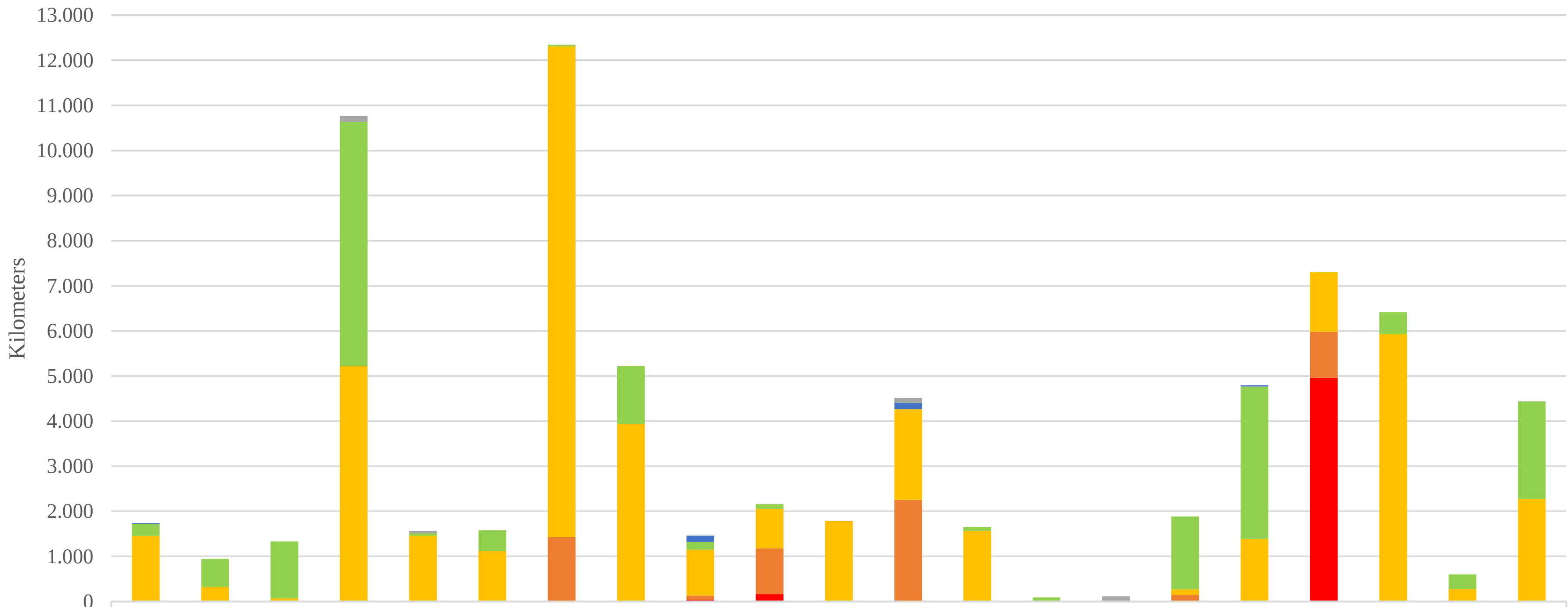
Table 5 Levels of use Intelligent Transport Systems based

Level 0	None
Level 1	Monitoring system (e.g. real-time data about traffic/weather conditions is collected by or on behalf of the road administration)
Level 2	Traffic information system (road administration passively manages the network e.g. information about traffic/weather conditions is provided to road users)
Level 3	Traffic management system (road administration actively manages the network e.g. variable speed limits, dynamic lane management, ramp metering)
Level 4	Cooperative ITS (i.e. vehicle-to-vehicle or infrastructure-to-vehicle information)

Source: *(Pettersson, et al., 2022),* (accessed 04.07.2023.)

The implementation of level ITS on the total length of the TEN-T network for 2021 shows that most countries have implemented level 2 with 43,036 km or 60% of the total length, followed by level 3, which has been implemented with almost 24.5% 17,807 km and is longest in absolute terms in Denmark with 5,415 km, Norway with 3,380 km, England with 2,159 km and the Netherlands with 1,615 km. Luxembourg has 89 km of fully covered level 3 roads ITS, while Switzerland has 94.6% coverage. Poland has the highest number of roads with no ITS system implemented, 4,958 km, and 1,024 with Level 1. Significant investments are expected to be made in the implementation of ITS. Interestingly, only four countries have implemented Level 4: Italy, Hungary, Austria, and Norway, with the relatively highest percentage in Hungary at 9.9% (Figure 2).

Figure 5 Length of the Pan European Road Network Featuring Different Levels of ITS in 2021



	AT	BE (Flanders)	CH	DE	DK	ES	ES	FI	HU	IE	IS	IT	LT	LU	MT	NL	NO	PL	SE	SI	UK (England)
No Data	0	0	0	127	49	0	0	0	0	6	0	102	0	0	114	0	0	0	0	0	3
Level 4	25	0	0	0	0	0	0	0	144	0	0	148	0	0	0	0	21	0	0	0	0
Level 3	261	623	1261	5415	49	465	39	1278	167	108	0	0	84	89	0	1615	3380	0	490	324	2159
Level 2	1454	325	72	5225	1461	1116	10880	3939	1019	868	1786	2009	1568	0	0	125	1389	1319	5927	275	2278
Level 1	0	0	0	0	0	0	1429	0	91	1015	0	2255	0	0	0	146	0	1024	0	0	0
Level 0	0	0	0	0	0	0	0	0	41	166	0	0	0	0	0	0	0	4958	0	0	0

Level 0 · Level 1 · Level 2 · Level 3 · Level 4 · No Data

Source: Author(s) adopted to: *(Pettersson, et al., 2022)* 2021 Pan European Road Network Performance Report p. 74, (accessed 04.07.2023.)

Table 6 Electricity recharging points, number of BEV&PHEV vehicles by type category

	AC	DC	Total	Number of BEV&PHEV vehicles per charging station	Number of BEV&PHEV vehicles	Number of BEV vehicles	Number of PHEV vehicles	Passenger cars (M1)		Light Commercial Vehicles (N1)		Buses (M2 & M3)		Trucks (N2 & N3)	
								BEV	PHEV	BEV	PHEV	BEV	PHEV	BEV	PHEV
2012	*	*	10,507	3.75	39,424	35,712	3,712	25,891	3,712	9,527	-	286	-	8	-
2013	*	*	17,850	7.27	129,781	68,805	60,976	52,130	60,880	13,175	-	2,756	96	744	-
2014	*	*	26,536	7.07	187,637	103,236	84,401	79,899	84,304	19,374	-	3,052	97	911	-
2015	*	*	49,363	6.31	311,295	160,514	150,781	127,194	150,582	29,249	-	3,192	199	879	-
2016	*	*	77,038	5.78	445,590	230,404	215,186	184,431	214,811	41,704	1	3,332	335	937	39
2017	*	*	109,896	5.62	617,742	338,629	279,113	278,066	278,613	55,808	1	3,131	459	1,624	40
2018	*	*	123,727	6.58	813,578	444,624	368,954	365,924	368,380	72,372	1	3,918	533	2,410	40
2019	*	*	133,947	8.86	1,186,314	698,587	487,727	600,394	487,004	89,503	117	5,328	568	3,362	38
2020	156,779	18,267	175,046	12.46	2,181,432	1,220,208	961,224	1,098,849	959,584	111,237	1,054	6,909	557	3,213	29
2021	279,838	23,340	303,178	12.81	3,883,156	2,088,952	1,794,204	1,928,307	1,790,873	146,961	2,733	9,432	554	4,252	44
2022	400,913	46,186	447,099	13.54	6,052,598	3,302,829	2,749,769	3,063,203	2,743,867	224,214	4,909	11,673	878	3,739	115
2025	N/A	N/A	1,000,000 T	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2030	N/A	N/A	6,800,000 T	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

*Data counting methodology until 2019 did not did not take into account the type of charging station
T- Target value
Source: Author(s) adopted and calculated to: EAFO (accessed 15.07.2023.)

Battery electric vehicles (BEVs) are fully electric meaning they don't have an internal combustion engine. They solely rely on their batteries, which you can charge from a power source. On the hand plug in hybrid electric vehicles (PHEVs) have both a motor and a conventional combustion engine. They can operate using electricity for distances and switch to the internal combustion engine for trips. Like BEVs PHEVs can charge their battery either from a power outlet or, by using the internal combustion engine. The main differences between these two types of vehicles lie in their range capabilities refueling infrastructure options and CO2 emissions. When it comes to range BEVs generally offer an all driving range compared to PHEVs. However PHEVs have the advantage of range thanks, to their gasoline engines. In terms of refueling infrastructure options BEVs rely on electric charging stations for recharging their batteries. On the hand PHEVs have the flexibility of being able to use both charging stations and conventional gasoline fueling stations. One important distinction is that when powered by electricity BEVs are considered zero emission vehicles since they do not produce any emissions during operation. However it's worth noting that PHEVs may still generate emissions when their internal combustion engines are running. To charge the batteries of vehicles efficiently with current (DC) converters are required to convert alternating current (AC) into DC power. Typically AC chargers are used at home overnight for charging your vehicle. They have some characteristics, including a price and a slower charging speed compared to DC chargers. DC chargers on the hand charge the vehicles battery faster and are typically used while, on the road. This can pose challenges due to time constraints and the limitations of infrastructure and power grid. The dominance of passenger cars in the category of BEV highlights the shift in consumer preference towards vehicles for use. Data indicates an adoption of both BEVs and PHEVs with a focus on passenger cars. While BEVs are gaining popularity across all vehicle categories PHEVs are commonly found in passenger cars suggesting patterns of adoption for these two types of electric vehicles. Based on data until 2022 the usage of battery vehicles in N2 and N3 categories is still at an early stage but shows signs of growth potential. By 2022 there will be an increase in BEV trucks within these categories. 206 trucks compared to 4 in 2016. Despite starting from a base this growth reflects increasing interest and investment in electrifying heavy duty vehicles. Electric trucks within these categories offer benefits such as reduced operating costs, lower emissions and compliance, with regulations. While the figures may not be as high, as those seen in vehicle sectors it seems that the logistics and heavy duty industries are gradually embracing environmentally friendly energy choices. As sustainability and reducing emissions become more important we can anticipate these numbers to keep growing in the future. This growth will be fueled by advancements, in battery technology and the development of charging infrastructure (Table 3).

Table 7 Hydrogen (H2) recharging points, number of H2 vehicles by type category

	High pressure (700 bar)	Low pressure (350 bar)	H2 vehicles per stations (high pressure)	H2 vehicles per stations (low pressure)	Number of H2 vehicles				
						Passenger cars (M1)	Light Commercial Vehicles (N1)	Buses (M2 & M3)	Trucks (N2 & N3)
2016	20	15	28.20	37.60	564	366	162	32	4
2017	24	15	31.83	50.93	764	531	186	41	6
2018	24	15	43.46	69.53	1,043	718	280	40	5
2019	100	13	15.10	116.15	1,510	1,182	280	41	7
2020	105	19	21.39	118.21	2,246	1,842	303	92	9
2021	108	28	29.55	113.96	3,191	2,706	306	165	14
2022	132	44	34.55	103.64	4,560	3,993	306	206	55
2025	300[T]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2030	1,000[T]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

T- Target value
Source: Author(s) adopted and calculated to: EAFO, (ACEA, 2021), (accessed 15.07.2023.)

The analysis of hydrogen fueling station infrastructure, between 2016 and 2022 reveals growth. Pressure (700 bar) stations have experienced a compound growth rate (CAGR) of around 37% increasing from 20 to 132 stations. Additionally there has been a CAGR of 24% for low pressure (350 bar) fueling stations indicating a deliberate effort to expand the infrastructure. Based on the vehicle to station ratio high pressure stations are moderately utilized while low pressure stations are in demand suggesting a need for expansion in the latter.

Some countries have set more specific targets related to production volume or share of fuel cell vehicles (Belgium, Czechia), share of fuel consumption (Germany, Hungary, Italy, Slovakia, Slovenia) or number of refuelling stations (Czechia, France). In general, specificity implies a low degree of comparability (Wolf & Zander, 2021).

The penetration of hydrogen vehicles has seen an increase across all categories. The highest penetration is observed in passenger cars (M1) accounting for 3,993 out of the total of 4,560 hydrogen vehicles in 2022. There is also promising growth in vehicles (N1) buses (M2 & M3) and trucks (N2 & N3) albeit at a slightly slower pace. This suggests that hydrogen vehicles are not gaining popularity among consumers but also making their way, into the public transport sectors (Table 4).

Table 8 Natural Gas CNG & LNG recharging points, number of CNG & LNG vehicles by type category

	CNG stations	LNG stations	Total CNG& LNG station	Natural gas vehicles per natural gas refuelling point	Number of CNG & LNG vehicles				
						Passenger cars (M1)	Light Commercial Vehicles (N1)	Buses (M2 & M3)	Trucks (N2 & N3)
2015	2,957	63	3,020	401.63	1,212,936	1,058,992	132,072	17,242	4,630
2016	3,091	80	3,171	391.84	1,242,530	1,089,608	126,082	20,809	6,031
2017	3,111	110	3,221	425.64	1,371,001	1,113,587	226,450	21,457	9,507
2018	3,216	133	3,349	399.52	1,337,997	1,160,998	136,735	22,680	17,584
2019	3,490	237	3,727	375.71	1,400,254	1,201,812	157,914	20,078	20,450
2020	3,642	332	3,974	363.49	1,444,506	1,233,197	163,146	22,119	26,044
2021	3,778	421	4,199	343.29	1,441,483	1,224,651	163,244	23,523	30,065
2025	5,579^{T}	396^{T}	5,975^{T}	N/A	N/A	N/A	N/A	N/A	N/A
2030	7,257^{T}	1,335^{T}	8,592^{T}	N/A	N/A	N/A	N/A	N/A	N/A

T- Target value
Source: Author(s) adopted and calculated to: EAFO, (Prussi, Julea, Lonza, & Thiel, 2021), (accessed 15.07.2023.)

The use of gas has seen growth particularly in the development of CNG refueling stations. As of 2021 there are 3,778 CNG fueling stations compared to 421 LNG stations. This indicates a focus, on expanding the CNG infrastructure possibly due to its range of applications and lower costs for implementation. When it comes to vehicles passenger cars (M1) dominate the CNG market with 1,224,651 units in 2021. This accounts for a portion of the number of CNG vehicles which stands at 1,441,483. Light commercial vehicles and buses have also experienced growth with figures reaching 163,244 and 23,523 units respectively in the year. Furthermore there has been an increase in the number of trucks powered by gas which is expected to reach 30,065 units in 2021. This suggests a growing acceptance within the logistics and heavy duty vehicle sectors. Overall there has been an expansion in the natural gas infrastructure accompanied by growth across all vehicle categories. CNG fueling stations dominate the infrastructure landscape while passenger vehicles lead in terms of adoption. The decreasing ratio between vehicles and fueling stations indicates scaling of infrastructure. These trends collectively confirm the maturity and diversity, within the natural gas ecosystem (Table 5).

Table 9 Liquefied Petroleum Gas LPG recharging points, number of LPG vehicles by type category

	LPG Refuelling stations	Number of vehicles per LPG refuelling stations	Number of LPG vehicles				
				Passenger cars (M1)	Light Commercial Vehicles (N1)	Buses (M2 & M3)	Trucks (N2 & N3)
2014	28,263	252.89	7,147,532	6,924,669	210,366	799	11,698
2015	28,723	254.87	7,320,633	7,084,604	224,224	788	11,017
2016	28,959	257.70	7,462,713	7,225,795	224,696	825	11,397
2017	30,264	249.66	7,555,775	7,258,780	284,601	801	11,593
2018	31,286	253.42	7,928,357	7,625,967	289,701	1,010	11,679
2019	32,710	246.21	8,053,482	7,749,321	291,456	780	11,925
2020	31,541	253.40	7,992,641	7,690,119	289,725	799	11,998
2021	30,744	259.74	7,985,303	7,685,643	286,659	798	12,203
2025	N/A	N/A	N/A	N/A	N/A	N/A	N/A
2030	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Remark: The member states different approaches make it impossible to obtain the target values.
Source: Author(s) adopted and calculated to: EAFO (accessed 18.07.2023.)

The total count of LPG stations has generally gone up over the years. It reached its point in 2019 with 32,710 stations. Slightly decreased to 30,744 stations in 2021. When it comes to vehicle categories, passenger cars (M1) take the lead with a

7,685,643 vehicles in 2021. They make up the majority of the LPG vehicles at 7,985,303. These numbers have consistently increased over time showing that consumers strongly prefer using LPG for their transportation needs. In terms of vehicles (N1) they set a record breaking number. Are not as numerous, as passenger cars. In 2021 there were 286,659 vehicles. As for buses (M2 & M3) and trucks (N2 & N3) these categories are relatively smaller in comparison. In 2021 there were a total of 798 buses and 12,203 trucks. Although the number of refueling stations has been relatively stable recently the increasing ratio of vehicles, to refueling stations indicates that existing infrastructure is being utilized efficiently and effectively. While passenger cars make up the majority of LPG usage other vehicle categories also show stability to some extent (Table 6).

7. RESEARCH LIMITATIONS, SUGGESTIONS FOR THE FUTURE RESEARCH AND CONCLUDING REMARKS

7.1 Research Limitations

The examination of National Policy Frameworks (NPFs) and National Implementation Reports (NIRs) is limited to the documents that are currently accessible and publicly available. It's important to note that these documents may not offer an overview of all the initiatives or future plans.

7.2 Suggestions for Further Research

Adding a perspective, to the research, which includes analyzing the Return on Investment (ROI) for the private, public and state stakeholders, would provide another valuable dimension to the study.

7.3 Concluding remarks

The transportation industry finds itself at a crossroads with both possibilities and daunting challenges particularly in the shift, towards electric and hydrogen powered cars and trucks. One major hurdle is the need for infrastructure investment in the form of electric and hydrogen charging stations. Achieving this objective will require efforts from governments, businesses and other stakeholders to ensure the development and expansion of this infrastructure. Another challenge lies in influencing consumer behavior to embrace these modes of transportation. Accomplishing this transformation will necessitate targeted campaigns and incentives that make electric and hydrogen options more appealing and accessible to the public.

The transition to electricity and hydrogen as fuels is creating opportunities for innovation while giving rise to new business models within the transportation sector. The European Green Deal is already driving advancements in charging infrastructure. Moreover both the EU, as a whole and its member states are allocating resources towards promoting eco logistics presenting companies with an opportunity to overhaul their supply chain operations.

However it's important to acknowledge that transitioning to these fuels comes with complexities. At present it takes three hours for a truck to fully charge while hydrogen refueling takes even longer.

These extended refueling durations have consequences, for logistics, impacting areas such as inventory control, route mapping and the overall efficiency of supply chains. To ensure a transition, to energy sources companies must incorporate these logistical considerations into their planning.

To sum up as we focus on utilizing electricity and hydrogen to power vehicles it is crucial to adopt an multifaceted strategy. This strategy should prioritize enhancing infrastructure addressing obstacles and capitalizing on the opportunities presented by this shift towards a more sustainable transportation network.

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ANALYSIS OF LAST-MILE LOGISTICS IN SHORT AGRI-FOOD SUPPLY CHAINS

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Abstract

The purpose of this paper is to analyse and describe empirically the practices of Last Mile Logistics (LML) in Short Agri-food Supply Chains (SASC) of fruit and vegetable sector in south-east Spain, and their contributions to sustainability.

For this objective, a case study methodology was used, to study a Agri-food Supply Chains (ASC) in the South Spain that has developed SASC with LML. The case study was focused in a successful SASC that commercialize a box of fruits and vegetables in collaboration with the LML operator. Their ecommerce and integration with their LML supplier were analyses through stakeholder meetings to develop a co-creation process. Semi-structured interviews were also conducted with LML operator to identify the requirements and particularities needed for successful deliveries, which add sustainability and proximity to the end market, helping towards healthier consumption, and avoiding food waste

The paper offers a novel perspective by identifying and analysing the positive and negative contributions of LML to each of the dimensions of sustainability of SASC. The limitations that can be found in the study derive from the fact that it was focused on a fruit and vegetable cluster with very particular characteristics. The specificity of the context may restrict the generalization of LML recommendation in other Food Supply Chains such as meat, fish, oils and fats, and dairy products. On the other hand, this study analyses LML in an unexplored sector due to the novelty of the business model recently implemented in SASC.

Keywords: last mille logistics, e-commerce, sustainability, agri-food short supply chain

1. INTRODUCTION

Traditionally, Agri-food Supply Chain (ASC) has been considered as separate models from Short Supply Chain (Chi Ffoleau and Dourian, 2020). While the first ones are usually oriented towards mass distribution, the second ones tend to focus on distributing agricultural products directly to consumers on a small scale. Recently, advances in information and communication technologies, as well as the development of economic, social and environmental sustainability practices, have driven the evolution of these models so that they can take advantage of synergies between them (Thomé *et al.*, 2021). Along these lines, in Spain (Navarro-del Aguila and de Burgos-Jiménez, 2022) have identified synergies between the two in the distribution of fruit and vegetables using a box model.

Spain is the main European exporter of vegetables, with a high concentration of agricultural companies in south-east Spain. This has led to the development of a strong Agri-food cluster with specialized research and transfer centers. In this agri-food cluster of fresh fruit and vegetables in south-east Spain traditional agri-food chains have a structure of farmers' associations that perform the functions of handler and marketer (Perez-Mesa and Galdeano-Gomez, 2010). In the last decade, some fresh fruit and vegetable producer organizations have created parallel short channels through which they also sell their products directly to the final consumer by their ecommerce. Deliveries to the consumer by short chains require specific capabilities that traditional marketer do not have developed yet and rely on specialised LML operators. However, the development of the SASC of fresh fruits and vegetables is constrained for the LML of these products. LML have to adapt to working with highly perishable, refrigerated (positive cold) and fragile products.

According to (Peppel and Spinler, 2022), LML refers to logistics operations at the final part of the delivery between the recipient and the final processing location, i.e. warehouses, depots, sorting centers or dark stores. This LM sector, including courier and parcel companies and new operators, has experienced tremendous growth, driven by the rise of e-commerce, which has also accelerated during the COVID-19 pandemic. LML is considered to be a resource-intensive process that requires continuous coordination between stakeholders. In addition, LML can also suffer from problems such as urban congestion and unattended deliveries by the consumer. In some cases they can lead to high returns, which can have environmental consequences (Mangiaracina *et al.*, 2015). There is also a perception that there are sometimes safety risks in this sector, and low labor wages (Verheyen and Kołacz, 2022).

In SACs, this type of logistics can contribute to healthier consumption by bringing the product to the final consumer faster and in better conditions. In this article it was analyzed the characteristics and contributions of LML to SASCs integrated in large exporting traders in the agri-food sector, thus providing a new perspective on the development of LML, which contributes with solutions that solve some of the problems that appear when operating in other sectors.

During the study, it was tried to answer the research question on how LML practices associated with the delivery of fresh fruit and vegetables are configured to improve the sustainability of SASC.

Sustainability is understood in this paper as an extension of the concept of sustainable development (WCED, 1997) which encompasses three dimensions (Munasinghe, 1993): social (including aspects such as culture, poverty or quality of life), economic (efficiency, growth, profitability) and ecological/environmental (natural resources, pollution, carbon footprint).

Although in these ASCs the volume of business in their short channel is very low compared to the traditional channel, they are developing the strategic capabilities necessary to meet the needs of the final consumer of fresh fruit and vegetables.

The characteristics and peculiarities of the LML operation are of special interest because they should have to facilitate the emergence of hybrid chains (conventional supply chains of fresh fruit and vegetables which are developing a SASC).

The SASC allow consumers' needs to be addressed in a more direct way without the need for many intermediaries that increase the prices paid by customers and reduce farmers' margins. The customer wants a variety of fresh products (fruit and vegetables) from the greenhouses. However, direct delivery from the farmer to the consumer presents a number of difficulties: food safety controls, the variety of products the customer wants, and the match between farmers' production and consumer demands. For all these reasons, a grouping of several farmers/producers is required, to which conventional chains respond (Jiménez-Guerrero *et al.*, 2018). The provisioning of the SASC have been resolved by conventional chains with a network of establishments close to the farmer where agricultural products are received and prepared for marketing (washing, calibration, packaging, residue analysis, etc.). However, the customer delivery logistics are required to enable the development of the SASCs, in which integration with the LML provider plays a fundamental role.

It was reviewed the growth of this paradigm in the sector within the specific fruit and vegetable agri-food cluster in which it was located, exploring whether this trend could be replicated in the rest of the agri-food industry and thus extrapolated to other agri-food clusters

2. MATERIALS AND METHODS

2.1 Theorical Background

Improved agricultural production and transport systems have shaped the current ASC model, characterized by mass production and distribution. The dominant ASC model is an extensive network of interconnected operators comprising specialized farmers, warehouses, handling companies, intermediaries, wholesalers and retailers that bring the product to the final consumer. This has led to the development of local agglomerations of enterprises, known as agri-food clusters (Simboli *et al.*, 2015).

Supply Chain (SC) according to (Flynn *et al.*, 2010) can be defined as a series of operations that ensure the production and distribution of goods in the right quantities, delivered to selected locations at the required time, to meet the needs of consumers.

In traditional ASC, large-scale distribution exercises a dominant position, which leads to a narrowing of margins at source and a distancing from the consumer (Thomé *et al.*, 2021). In order to provide a solution to this ASC model in which there is an inadequate distribution of added value, ASSC are being developed in these organizations, giving rise to Hybrid Supply Chains (Navarro-del Aguila and de Burgos-Jiménez, 2022).

SASC can be defined as a ASC made up of a limited number of economic actors committed to cooperation, local economic development and socio-economic relations between producers and consumers in a close geographical area (Elghannam *et al.*, 2017), and with as few intermediaries as possible. This achieves greater sustainability and interaction between farmers and consumers and changes the relationship in the construction of value in these chains.

According to (Navarro-del Aguila and de Burgos-Jiménez, 2022) the hybrid fresh fruit and vegetable SCs that are emerging in south-east Spain on the supply side can benefit from economies of agglomeration, scale and scope that contribute to the sustainability of the agricultural model. These chains facilitate the fight against food waste by providing an outlet for sizes or products that at a given moment do not meet certain standards (e.g. size, color) established by the large distributor in the long chain but which are in perfect nutritional and physical condition.

Concentration in agricultural production allows effective and efficient access to advanced technologies. Mass production for large export-oriented SCs requires homogeneity and compliance with standards, which facilitates the reduction of production costs. However, SASCs are better adapted to the variability of agricultural production, as their product specifications can be more flexible and change rapidly. The flexibility and agility of short chains allows access to customer segments that particularly value certain product attributes (freshness, taste, smell, size). Most use e-commerce with deliveries made by LML operators with systems such as food boxes.

This new paradigm of hybrid chains in which short and long fruit CSs coexist is a sustainable innovation and is starting to set a clear trend in long fruit and horticultural CS, as there are clear advantages from synergies in common processes.

In order to realize the SASC objective, there has to be close collaboration and coordination with the LML provider, as well as coordination with the other stakeholders in the SC.

LML takes place from the point of order penetration (referring to an inventory location (e.g. cooperative handling center) where a fulfilment process is triggered by a consumer order to the final recipient's preferred destination point.

Due to the difficulty of service differentiation in the LML sector, prices are similar, margins are low, and competition is often achieved through improving cost efficiency (Peppel *et al.*, 2022). Innovation is central to this process, allowing them to improve processes and develop new tools. To do so, they can employ different methods by first trying to increase delivery factors (number of parcels delivered) per stop, while minimizing consumption, delivery time and kilometers travelled. In addition, they try to minimize the stop factor by grouping many parcels per route. Secondly, digitization allows a higher level of automation to be achieved, thus reducing personnel costs. Thirdly, using new AI functions to optimize both routing and internal processes in sorting centers. The last dimension is quality. Finally, it is essential to take care of security as it is crucial to maintain the quality of LML services. This is also where the packaging used plays an important role, as it can improve the performance of the supply chain, helping to avoid food waste, and enabling efficient logistics and transport operations, as well as reducing packaging waste. It is important to avoid lost or damaged packages, and to take care to manage personal data such as location and preferred delivery options.

It should be noted (Hjort *et al.*, 2019) that one of the aspects that remains to be resolved in the LML is the management of reverse flows of products. However, in agri-food chains, especially for highly perishable products such as fresh fruit and vegetables, returns are not appropriate due to the very nature of the products themselves, thus reducing the reverse flow of products.

2.2. Research methodology

2.2.1 Context of the study

The Fresh Fruit and Vegetables sector in Spain accounted for 11.4% of the total agri-food industry in 2022 (Subdirectorate General, 2022). Spain, especially the south-east, on which was focus our study, is currently the main horticultural supplier to Europe through important horticultural supply chains, with a 40% share of fresh vegetables in recent years (Pérez-Mesa *et al.*, 2021). The largest concentration of greenhouses in the world is located in this area (Aznar-Sánchez, Velasco-Muñoz, García-Arca, 2020). Its productivity is 30 times higher than the European average. The Almeria agricultural model is based on the use of simple but efficient technologies, such as plastic greenhouses or crops grown on sandy soils in small family farms of an average size of 2.5 ha. This paradigm has been evolving, concerned with sustainability, improving water use, biodiversity, circular economy, image and identity, focused on technology and knowledge transfer and largely digitized (De Witte *et al.*, 2023). It focuses on vegetable production which takes place mainly in winter, specializing in the cultivation of peppers, tomatoes, courgettes, cucumbers, aubergines, green beans, watermelons and melons (Navarro-del Aguila and de Burgos-Jiménez, 2022). Approximately 80% of fruit and vegetable production is exported (Servicio de Estudios Agroalimentarios de Cajamar, 2022).

The marketing of fruit and vegetables is carried out through handling-marketing companies (usually cooperatives) with which the farmers usually have stable relationships. These marketing companies also carry out basic product preparation tasks such as residue analysis, washing, sizing and/or packaging for delivery to their customers (Navarro-del Aguila and de Burgos-Jiménez, 2022).

2.2.2 Methods

In order to carry out our study, it was conducted a search for fruit and vegetable ASCs that have developed a SASC with home delivery by LML in the selected study area. These chains found were hybrid chains, since they were initially conventional supply chains and have developed a SASC that coexists with the traditional chain (Navarro-del Aguila and de Burgos-Jiménez, 2022), relying on LM operators to develope these new deliveries.

The main hybrid supply chain (in terms of turnover, market share, product variety) of the 9 SASCs identified by (Navarro-del Aguila and de Burgos-Jiménez,

2022) was selected to analyse in detail the LML organisation through a case study. This SC is characterised by its innovative orientation, it is a second-tier cooperative that is interested in studying the improvement of its supply chain in the short term and sustainability, which leads it to participate in research projects on the subject.

It was analysed its e-commerce and its integration with its stakeholders and especially with the LML operator. To this propouse, personal interviews were held in January 2022 with the middle managers appointed by the company's management to organize the study. The first task was to create a working group in which stakeholders involved in all the phases of the value chain were represented. There were 15 stakeholders including 4 suppliers (LML operator, seed supplier, packaging and agricultural technician) 2 consumers, 2 employees, 2 farmers and 5 intermediate managers (logistics, Information technologies, plant, customer service and quality). These stakeholders received methodological co-creation training in order to conduct the group meetings successfully. The first working group meeting of 15 stakeholders from the whole value chain was scheduled for March 2022.

They were previously informed of the required time availability and the content of the process in which they were going to participate in order to foster the collaborative work environment necessary to carry out a cocreation process. During this process, they used techniques proposed by (Nanclares, 2014) to add value, collaboratively design and create innovative and sustainable ideas for products and services, through a group of "experts", in our case belonging to the stakeholders of the value chain composed of customers, suppliers, business or product developers, marketing, last mile logistics operator among others, in order to achieve a high degree of acceptance in the market with their contributions. During the meeting, techniques were used to stimulate the generation of ideas through a Swot process on strengths, weaknesses, opportunities and threats in SASCs. To this culmination, working sub-groups were formed consisting of 2 or 3 people with related functional areas, who were asked to draw up an outline that they would discuss during a word café in which they sought to integrate, share and understand proposals on a given topic. This was followed by a meeting in which the contributions proposed by each working group were synthesised.

Subsequently, from April 2022, telephone interviews were managed with the 9 chains in the sample that have developed a short chain to find out more about the details of the LML operator they work with. Curiously, almost all of them worked with the same operator that offers an affordable level of costs (these are basic products that form part of the shopping basket, not premium products) and speed of delivery, due to the fact that the products are delicate and perishable and if the necessary care and quickness (less than 24 hours) is not taken, the food spoils. In fact, one of the long chains that had developed this short channel with e-commerce has abandoned the activity, due to te inconveniences and complications it was causing, as it was not dedicating the necessary resources and attention to the process of preparing and delivering orders to the short chain.

It was prepared a guide notes with 16 questions. At the beginning of January 2023, a personal meeting was held with the branch manager of the logistics operator in charge of our case study, which is considered the most established in the Agri-food sector. A semi-structured personal interview was conducted on the following topics:

- how the delivery of vegetable crates is carried out with the SASC,
- the procedure followed by the logistics operator,
- challenges and opportunities of fruit and vegetable delivery systems,
- their innovation strategies,
- requirements to be met, internal protocols.
- the company's internal policies to be more sustainable,
- new technologies to be used,
- the role of governments and regulations,
- what is your direct competition.

The details provided about their competitors were used to try to cross-check the information obtained. Telephone interviews were conducted with two of these operators. It was verifye that only one of them actually operates with a certain frequency in the fresh fruit and vegetable sector.

From February 2023, it was analysed the details obtained on the operations necessary to carry out successful deliveries, their interaction with the hybrid chain and the rest of the stakeholders, and the measures they take as a company policy to improve sustainability.

3. RESULTS, DISCUSSION AND LIMITATIONS

3.1 Aspects for improvement in sustainability of SASC

Through our case study, it was verify how this fruit and vegetable ASSC represents an improvement in the sustainability of traditional supply chains by helping to fight food waste through appropriate and innovative logistics supported by LML (Peppel and Spinler, 2022) integrating with its logistics provider. This finding is aligned with the assertions of (Neutzling *et al.*, 2018) on the need for collaboration between SC stakeholders which includes knowledge integration and cooperation that empowers firms to create unique organisational capabilities. Integrated and synergetic collaborative relationships can be developed as in the case study that enables knowledge exchange and the generation of innovative capabilities that lead to improved sustainability throughout the SC.

The contributions proposed by each working group in the Swot process implemented by the selected stakeholders have been synthesised. It can be seen how all members of the short supply chain have to work in close coordination. The main contributions have been schematized in figure 1:

Figure 1 Swot Agrifood Short Supply Chain

Source: Own elaboration

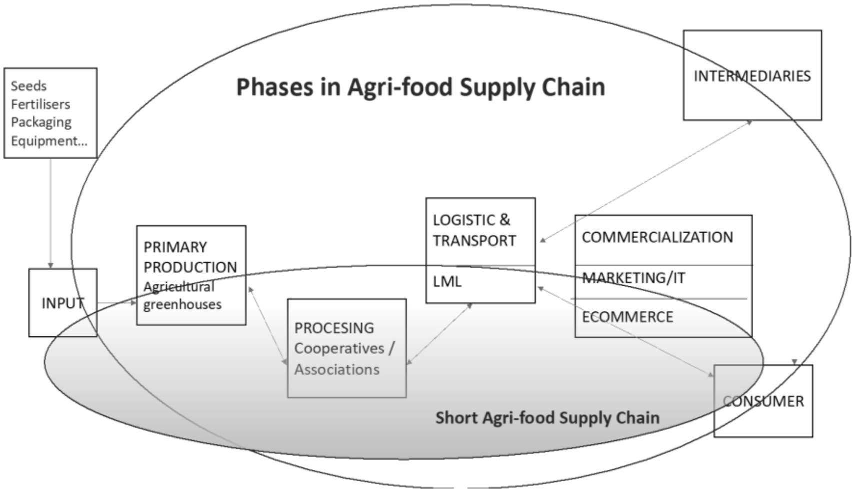
Once the Swot has been analysed, there was a starting point as an overview of the strengths and weaknesses as well as the opportunities and threats that SASC is facing. It can be seen that there is a lot of stakeholder concern in ensuring that the product arrives fresh and with a sustainable delivery to the consumers, as well as that the purchasing and receiving experience were easy and positive.

To continue with the cocreation procedure, the phases of the supply chain defined by (Navarro-del Aguila and de Burgos-Jiménez, 2022) were used to organise the working subgroups.

Figure 2, shows the phases of the CSA in which all stakeholders are involved. It starts with the supply of inputs such as seeds, packaging, etc. by suppliers. These materials are used in the following phases, in primary production, where the farmer produces fruit and vegetables in greenhouses. And subsequently in the processing, e.g. packaging, which is carried out in the handling cooperatives, where the products are processed, prepared for sale and stored in cold storage. Finally, the chain is bifurcated at the marketing level. On the one hand, the traditional chain (ASC) can be seen in the upper part of figure 2. In the ASC, packaged fruits and vegetables are sent to a varied set of intermediaries that use different channels to bring their products directly or indirectly to the final consumer. These intermediaries include wholesalers, brokers, large supermarkets, retailers and other types of stores.

On the other hand, the supply chain is shortened by selling the products through Ecommerce and delivering it directly to the end consumer through the LML (SCSA) This short part of the hybrid chain, which no longer involves intermediaries to reach the consumer, is shaded in the bottom of Figure 2.

Figure 2 Phases in Agri-food Supply Chain (ASC / SASC)

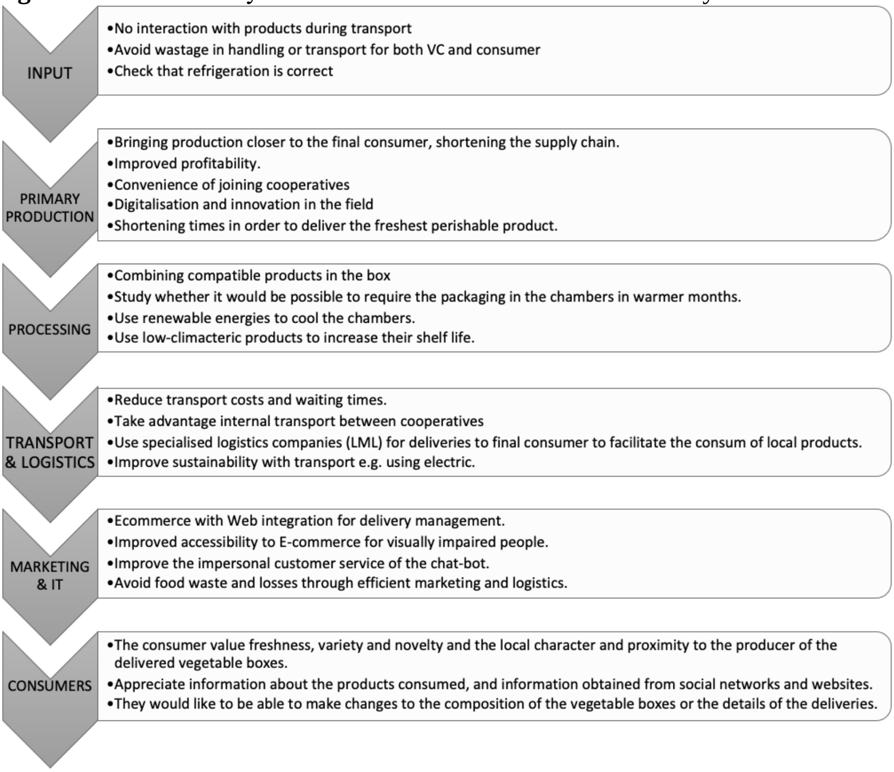


Source: Own elaboration

The special characteristics of highly perishable products (Pérez-Mesa and García-Barranco, 2019) must also be taken into account in order to successfully deliver the vegetable boxes to the final consumer. This particularity marks from the beginning of the phases of how operations will have to be carried out in the chain, for example in the selection of seed varieties, which have to possess certain qualities, not only in terms of taste, appearance and nutrition, but also resistance to transport, the type of packaging used that allows the product not to hit each other, its cold storage in warehouses and its e-commerce and LML.

These results can be seen in figure 3. The left side of figure 3 shows the phases of the SASC from the selection of inputs through primary production (farmers), Processing, Transport & Logistics, and Marketing & Information Technologies to the final consumer. The right hand side shows the contributions to sustainability proposed by the key stakeholders in each of the phases of the SASC.

Figure 3 Phases and key stakeholders' interaction for sustainability in SASC.



Source: Own elaboration

Studying the summary of interactions in the phases that each stakeholder has developed, it could be seen how important was that sustainable actions and innovations were coordinated for successful delivery to consumers. According to (Neutzling *et al.*, 2018), these collaborative relationships between organizations can be sources of competitive advantage, enabling the creation of value for the entire chain.

It also highlights the importance that consumers attached to delivery logistics and the improved sustainability provided by the delivery of these products, thus also helping to avoid food waste. This allows them to consume local produce, through deliveries in less than 24 hours with information available digitally on the status of the delivery. This LML allows them to take advantage of the facilities provided by digitalization and online commerce for direct interaction with the end consumer. It also provides a solution to the need to create value in SC by increasing trade margins and achieving a better distribution (Pérez-Mesa *et al.*, 2021), by reducing the number of intermediaries, and providing a solution to the distance between the consumer and the producer. It is a shortening of the traditional chain by eliminating the figure of the retailer and carrying out the function of supplying the end consumer directly by the SASC.

In this type of chain, the last mile delivery operation requires specific and differential characteristics to adapt to this sector of perishable and delicate products in the fresh fruit and vegetable sector (Wang *et al.*, 2019).

The characteristics of the products handled introduce a novel perspective for the development of LML (Lim and Winkenbach, 2019), which require solutions that solve some of the problems that affect the sustainability of this logistics (Peppel *et al.*, 2022).

3.2. Specific characteristics of the LML of SASC

It was studied in depth how last mile logistics was organized in the case study what considerations need to be considered for it to function correctly. It was reviewed how, in general, these characteristics coincide with the rest of the cases found in our sample of traditional supply chains that are developing a short-term chain (hybrid).

The interviews and group meetings have provided us with a detailed description of the operations between the SC and the LML operator.

It starts with the collection usually by truck from the LML operator, depending on the volume of the goods at the facilities of the ASC processing center at the agreed time, usually fixed and in the afternoon, of the vegetable crates. The boxes are pre-marked with the logistics operator's labels, palletized and suitably refrigerated. Here the boxes are grouped with goods from other customers (of the logistics operator) according to the destination of the package on domestic routes. For this purpose they employ the cross-docking in LML operator’s facility (crossdocking warehouse) in which according to (Mejia *et al.*, 2017) the materials are received by the suppliers of the distribution center and are not stored, but are managed for their next shipment reducing unproductive inventory, shipping times and distribution costs. This type of practice shortens the handling time and extends the shelf life of the products, which is why it is widely used for perishable products. In other words, transport is optimized according to the destination, not according to the product (looking for cost efficiency).

These boxes of vegetables are loaded (along with the rest of the goods from other customers of the logistics operator) in conventional vans, not refrigerated, as at the moment, the incorporation of refrigeration is not viable and would entail a high cost in places, although they do try to keep the products in cool places for better preservation. The boxes travel at night to each destination, thus avoiding crowded hours and maintaining a better temperature. They must be at the destination delegation of the LML operator at first time of the morning, then, the vegetables boxes are unloaded. Finally, the boxes are prepared for dispatch, normally together with third party goods, to be delivered to the end customer before 2 p.m. on the day after collection. In this way, delivery is made in less than 24 hours after collection of the product (time without refrigeration). This delivery will be made according to the characteristics of the local delegation, and the destination requested by the customer, and can be made in a normal delivery van, electric, or walkers.

The sale of boxes is concentrated in the cooler months, which facilitates the possibility of transporting the boxes without refrigeration with little loss of product quality, since in the summer, which are the hottest months of the year, the marketing of boxes is suspended because there is no local production.

In addition, the LML operator has to comply with an internal protocol with this very delicate merchandise that is treated as a priority delivery and fragile product, which helps to avoid food waste (Yetkin Özbük and Coşkun, 2020) by always placing the boxes on the top, without knocking them or turning them upside down. Packaging (Pålsson and Sandberg, 2021) also plays a fundamental role in this good preservation of the product, which must be appropriate and sustainable, for which they must be resistant, ventilated, insulating, recyclable and reusable, with the minimum possible presence of single-use plastics, normally cardboard is used. In addition, with the possibility of compartmentalization, so that fruit and vegetables are not mixed or moved, which is already prepared from origin with the heaviest products at the bottom and the most delicate ones on the surface or in specific compartments.

This process of LML of boxes of fresh agri-food products by specialised operators allows the geographical scope of product delivery to be extended, but also involves an adaptation to conventional LML.

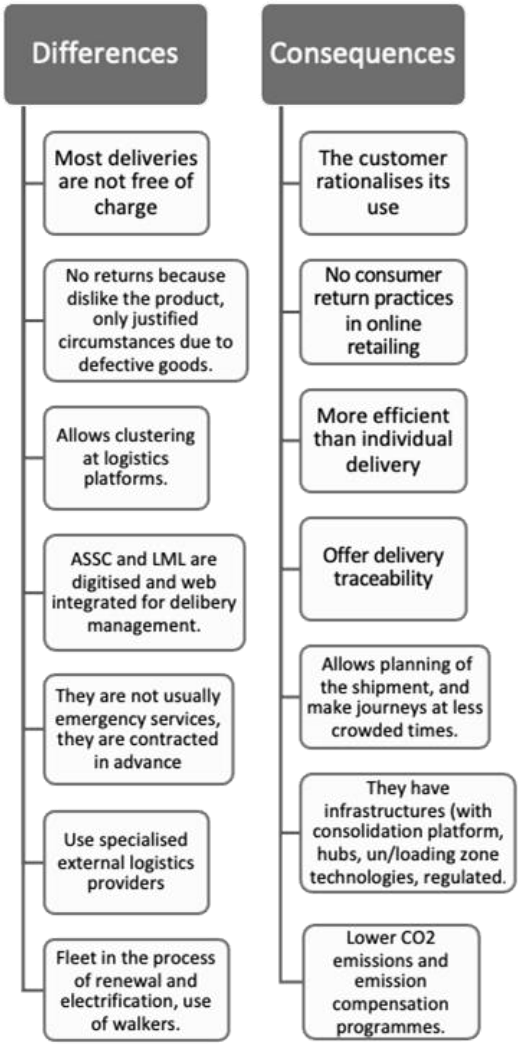
The use of this type of logistics is more efficient than individual deliveries, as it allows groupings in logistics platforms, and organizes the start of deliveries during off-peak hours (at night), avoiding congestion problems.

These are outsourced services, carried out by specialized companies, with infrastructure, a fleet undergoing renewal and electrification, digitized, offering shipment traceability, normally contracted in advance or with a work agreement framework, which allows shipments to be planned. They are able to meet demanding consumer expectations (speed, flexibility, traceability and digital communication, geolocation of the parcel, home delivery) at competitive prices.

They share a concern for sustainability and the environment, with policies to reduce CO2 emissions (consumption of green energies, electrification of fleets, etc.) and offsetting of emissions (Peppel *et al.*, 2022).

Figure 4 shows a summary of the specific characteristics of in SASCs, detailing the differences with respect to conventional LML.

Figure 4 Specific characteristics of LML in SASCs



Source: Own elaboration

These specialized external logistics operators are committed to sustainability and the use of green energies, with a fleet of hybrid and electric vehicles, bicycles and walkers for foot delivery in the most environmentally friendly delegations, and even CO_2 emission compensation programs (e.g. financing projects in some countries to carry out climate protection measures by reducing their resource consumption and associated emissions, or the use of renewable energies in developing countries).

Political markers also have a very important role to play in encouraging and supporting this improvement of sustainability in LML, by making regulations aimed at encouraging investments in green energy consumption, and replacing existing fleets with electric vehicles and installing energy charging points (Galati *et al.,* 2021).

3.3. Limitations and possible extensions

The limitations that can be found in our study derive from the fact that it focuses on a fruit and vegetable cluster with very specific characteristics in terms of agricultural production (small and high-tech greenhouses) and marketing organization (farmers' cooperatives). The specificity of the context may mean that the model of LML use is not directly replicable in other food supply chains such as meat, fish, oils and fats and dairy products (possibly because they are not concentrated, less frequent consumption, more or less demanding preservation systems (meat and fish more, oils less,,,,).

On the other hand, this study analyses LML in a very little explored sector due to the novelty of the business model recently implemented in ASCs (many processes and procedures are not standardized because not enough experience has been gathered yet).

The in-depth interview has been done only with 2 logistics operators who deal with fresh fruit and vegetables on a regular basis. Other (5) LML operators indicated that they only ship on a one-off basis due to the actual unattractiveness and restrictions associated with this type of perishable (agri-food) products. The Spanish case study may work differently in other countries or contexts (all road vs. multimodal...).

It should be noted, however, that this study analyses LML in a sector that has been little explored due to the novelty of the hybrid chain business model recently implemented in ASCs and is therefore subject to natural evolution.

Future research will explore the application of this model to other food products distributed in boxes, such as eggs, pre-prepared and pre-cooked convenience foods and some cold meats. Its development could generate economies of scale and scope in the distribution of fresh food products, both in terms of collection (establishing coordinated routes) and, above all, in terms of delivery to the end consumer (delivering several boxes simultaneously).

Additionally, the incorporation in LMLs of refrigerated areas in their storage and distribution facilities would allow the incorporation of other fresh products that are more sensitive to cold, such as meat, fish and dairy products.

4. CONCLUSION

The characteristics and contributions of LML to SASC (hybrid) have been analyzed showing how they enhance sustainability and proximity to the consumer. LML may facilitate healthier consumption of fresh products through direct product deliveries and helping to avoid food waste.

They provide a solution by bundling existing mobility patterns for parcel delivery with the fresh fruit and vegetable boxes. LML integration in SASC giving rise to new innovative and collaborative business models. Organizations develop capabilities to reduce the negative impact of LML and, at the same time, achieve a sustainable competitive advantage, which offsets the negative impacts of LML practices with the demand for cost-effectiveness and competitive service that encourages the consumption of fresh and healthy products.

LML contributes to the three main pillars of sustainability. On the economic side, it reduces the time and cost of distributing boxes of fresh fruit and vegetables, adapting the infrastructure and distribution systems of conventional products to these fresh products; it provides value to fruit and vegetables that are in perfect condition but do not meet the size or appearance specifications required by large distributors. On the negative side, the lack of refrigeration of the goods leads to an increased risk of deterioration of the fruit and vegetables. Working with perishable fresh produce requires stringent handling protocols (fragile and perishable goods) in LM to avoid complaints and loss of goods; non-compliance with these protocols incurs high claims costs that have caused some LM operators to give up working with this type of goods. In addition, the customer wants a variety of produce in the fruit box, which requires more handling and increases the risk of spoilage. There are climacteric fruits (e.g. avocado) that in certain environments (presence of ethylene) can ripen very early or spoil. For all these reasons, 8% more weight of goods than agreed is included in the box at origin.

In the social dimension, it contributes positively to several aspects: by reducing intermediaries, it simplifies and makes traceability more accurate; by shortening the delivery period to the customer, it facilitates the consumption of healthy products in a better state of conservation; it also reduces food waste and losses both by reducing storage time and by facilitating the marketing of products that are not in demand by wholesalers or large distribution chains. On the other hand, the delivery of the product by a company specialised in LML makes it lose the perception of local product and proximity to the consumer that a short food distribution channel provides. In addition, employment generation in the LML sector tends to have poor working conditions (Kougiannou and Mendonça, 2021)

In the environmental dimension, positive contributions have been identified, such as the fact that the LML carries out logistics operations for the distribution of fruit and vegetables in a more energy-efficient way than the average consumer, as it carries out operations in a grouped way and with specialised fleet and facilities; moreover, thanks to a more accurate information system, it adjusts transport at times with less traffic, avoiding traffic jams and reducing pollution; they also tend to have carbon footprint compensation programmes. Among the negative effects on environmental sustainability, the main problem is the need for the consumer to receive the goods at the agreed place and time of delivery, which causes delivery delays that increase product damage and food waste. In addition, it has been found that packaging material, in order to protect transport and to allow the compatibility of fruit with other goods, is a source of waste. The reuse of packaging in the same circuit presents logistical difficulties, even if it is in a good state of conservation, and other less environmentally sustainable options are used (such as alternative uses or recycling).

Finally, it should be noted that the increase in demand for home-delivered vegetable boxes can also help the sustainability of the LML: on the one hand, by increasing the traffic of goods and enabling the development of economies of scale and scope, and on the other hand, by incorporating values that favour a rational use of the LML (the cost of transport is usually included in the price of the final product but the delivery is not free of charge).

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III. RESILIENCE SIMULATIONS AND RISK MANAGEMENT

COMPARISON OF CRITICAL TRANSPORTATION INFRASTRUCTURE OF FOOD SUPPLY IN HUNGARY AND GERMANY – IDENTIFYING KEY STAKEHOLDERS

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Abstract

The pandemic caused by Covid 19, and the emergence of the Russian-Ukrainian war conflict have generated global implications, but primarily threats the stability in the European context. The key focus of this study is on the critical infrastructures (CI) and how a disruption in it can challenge the stakeholders of the food supply. Critical infrastructures are those systems that provide essential services to society (see defence, management of the economy, public health, and security of people), the failure or even their destruction would have a serious impact on the sustainability of the fundamental infrastructures of a country. The methodology applied is the exploration of the literature and available secondary data about critical infrastructures in Hungary and Germany as well as stakeholder mapping. The aim of this conceptual paper is to identify key stakeholders in case of a disruption in the critical infrastructure relevant for the food supply, especially focusing on the transportation related CI when studying Hungarian and German practices. The findings are compared based on the strong economical dependency of the two countries. Main finding of the study is that a model was used to categorize food supply stakeholders into 4 categories (supportive, marginal, mixed blessing, non-supportive). This categorization along 2 dimensions (stakeholder's potential for threat FSC's CI and stakeholder's potential for cooperation with FSC in CI) was developed and carries an important message for policy makers about who and in what processes can be involved in case of disruption. The research limitations include the number of examined critical infrastructures and the possibility of non-reachable information connected to topic hidden by the governments. The authors aim to continue the research and involve more European countries to the analysis.

Keywords: food supply chain, critical infrastructure, transportation, stakeholder analysis

1. INTRODUCTION

The Covid-19 pandemic and the Russian-Ukrainian war have global implications, particularly threatening stability in Europe. The study focuses on critical infrastructures, specifically the challenges for the food supply. Critical infrastructures are vital systems that provide essential services. Failure or destruction of these infrastructures would have a significant impact on the sustainability of society.

The methodology employed involves exploring literature, websites and other available secondary data on critical infrastructures in Hungary and Germany to reveal the most important stakeholders who have meaningful impact on the operations of the CI or the damage of the CI may affect them seriously. The research compares the critical infrastructures of Hungary and Germany, emphasizing their strong economic dependency, and aims to identify best practices in food supply.

The goal of this conceptual paper is to identify and determine the power of the key stakeholders of critical infrastructure in food supply, especially critical transportation infrastructure, which is indispensable when disruptions happen. Therefore, the main research question is when comparing German and Hungarian approaches about food supply as critical infrastructure, what kind of interdependencies exist between stakeholders, and how do they impact the operations? A proper stakeholder map might help decision makers in involving the right authorities and entities to achieve resilience. The methodology used is stakeholder mapping which assesses the stakeholders along two dimensions: concern and power.

The paper is built up as follows. In the next chapters the theoretical background will be introduced defining critical infrastructure and critical transportation infrastructure as well as the German and the Hungarian approach. It will be also pointed out how these affect the food supply. The paper will continue with the methodology introduction, stakeholder mapping and the results of the analysis. In the conclusion the findings will be summarized, the limitations and future plans will be introduced.

2. CONCEPTUALIZATION

Before moving on to the research itself, it is important to gather and define the key concepts related to the topic, such as infrastructure, critical infrastructure and critical transport infrastructure as well as its resilience. In addition, in order to properly link the concept with the food industry, the most important concerns were also collected which may characterise critical infrastructures in food supply.

Starting from the historical basis, the commitment to identify and protect critical infrastructure is not new, as from very early history, networks (e.g. a road or water pipeline network), a range of facilities, equipment, objects, products and services that played a key role in the life of a society were identified (Bonnyai, 2019).

Infrastructure is understood as a "system of interdependent networks" (Bonnyai, 2019: 31) that is "man-made" (Cecei and Mórocz, 2004) and consists of indispensable elements that are indirectly linked to production processes (Cecei and Mórocz, 2004), which already includes both tangible (e.g. a road network) and intangible (e.g. a supply chain that uses the physical infrastructure) assets (Fjäder, 2016). Connected to this, Stone and Rahimifard (2018) define resilience as the speed at which a system resists and returns to its original equilibrium state. However, it is also possible that there are multiple equilibrium states rather than a return to the original state. The concept of adaptive resilience challenges this closed system thinking, recognizing that constant interactions and environmental changes prevent the attainment of a stable equilibrium state (Folke, 2016).

Critical infrastructure types or categories are not independent, they are interconnected and rely on each other. The volume of this interdependency is shown in Table 1. For example, the focus of the paper is food supply which is considered as part of a nation's critical infrastructure (in Germany and in Hungary, too), but it is highly dependent on the critical transportation infrastructure (transporting goods), the critical cyber infrastructure (communication between supply chain members), critical financial infrastructure (payments through banks) etc. From these all, this paper will focus on critical transportation infrastructure from the food supply perspective.

Table 1 Interdependency of critical infrastructures

	Energy	ITC	Transport	Water	Food	Health	Fin.	Industry	Gov.	Pub.Sec
Energy		xx	xxx	xx	xx	xxx	xx	xxx	x	x
ITC			xx	x	x	xx	xxx	xxx	xx	x
Transport				x	xxx	x	x	xx	x	xx
Water					xx	x	x	x	x	xx
Food						xx	x	x	x	xx
Health							x	xx	x	xx
Finance								xx	xx	xx
Industry									x	xx
Legal order - Government										xx
Public Security										

Source: own edition (the growing number of "X"-s means the increasing volume of interdependency

The reviewed critical infrastructure literature deals mainly with energy security (Yusta et al., 2011), cyber security (Linkov et al., 2019) and financial infrastructure security (Langenohl, 2020), but less emphasis is placed on food supply and the food supply chains. This paper aims to fill this gap. The aim of the study is to examine the German and Hungarian critical transport infrastructure from the perspective of the food supply chain and to identify the stakeholders which can contribute to the resilient operations in this economically important sector.

2.1 Critical infrastructure, threats and sectors

In this section, it is worthwhile to interpret the concepts of critical infrastructure (CI) as defined by the EU and at national level. Critical infrastructure, as defined by the EU, is *"those physical assets, services, information technology facilities, networks and property, the disruption or destruction of which would have a serious impact on the health, peace, security or economic well-being of Europeans or on the effective functioning of the EU and its Member States' governments"* (EUR LEX Green Book, 2005). Critical infrastructure, therefore, is understood at EU level as an interdependent network between two or more Member States, not specifically defined for military purposes, but as a definition of unity for the EU, based on principles such as subsidiarity, complementarity, confidentiality, cooperation and proportionality (EUR LEX Green Book, 2005)

At the national level, Brown et al. (2006) argue that critical infrastructure can be defined as infrastructure that represents a significant public investment and where even minor disruptions can degrade system performance and cause significant social harm. According to Barroca et al. (2012), an infrastructure should be considered critical if its failure, disruption, breakdown or damage threatens the security, economy, livelihood, well-being and/or public health of a city, region or even state.

Critical infrastructure is defined at the national level as *"a network of interconnected, interactive and interdependent infrastructure elements, facilities, services, systems and processes that are vital to the functioning of the country (population, economy and government) and play a meaningful role in maintaining a socially required minimum level of legal certainty, public safety, national security, economic viability, public health and environmental condition"* (Hungarian National Legislative Reference Manual, 2008).

The critical infrastructure definitions have similarities as well as differences. The EU's approach has been extended with cyber-security in the recent years, as a reaction to the Covid19-crisis. All in all, the definitions contain the following common components which can be regarded as fundamental characteristics of CI:

- network of facilities or entities
- vital role from the society's point of view
- which in case of demage, could lead to severe econonomic and social consequences.

Even though the CI is interpreted by each nation which all have national strategies, these infrastructure elements are not independent, heavily interconnected and this way the countries rely on each other.

2.1.1 Critical infrastructure's threats

Critical infrastructure threats can be classified in a number of ways, including Bonnyai's (2019) categorisation based on the Green Paper, which classifies threats into three broad categories: "malicious acts", "natural hazards" and "civilisation-originated technological hazards". While the first group includes acts of terrorism, cyber-attacks, riots, wars and various economic and political motivations, the second group includes events that are natural (e.g. a tsunami following a volcanic eruption but we can consider here the climate risks as well), i.e. events that occur independently of human actions. Finally, the third group includes 'civilisation-originated technological hazards', which can be defined as hazards with industrial (e.g. nuclear disruption, disaster, programming errors) or civilisation (e.g. the coronavirus pandemic) sources (Bonnyai, 2019; Government National Legislative Reference Manual, 2008). However, it is also possible to distinguish internal as well as external hazards affecting the critical infrastructure.

2.1.2 Sectors of critical infrastructure

It is also important to identify the sectors, industries and sub-sectors that have critical infrastructure, or are affected by the CI's proper operations. The Hungarian government decision 2080/2008 (30.VI.2008) applies the EU decree and includes the elements of critical infrastructure in each sector, as shown in Figure 1.

Figure 1 Identified sectors of critical infrastructures

I. Energy
II. Information and communication technologies
III. Transport
IV. Water
V. Food
VI. Health
VII. Finance
VIII. Industry
IX. Legal order – Government
X. Public Security – Defence

Source: Hungarian government decree 2080/2008 (30.VI.) in line with EU regulations

Of the sectors listed in Figure 1, critical transport infrastructure will be analysed from the perspective of food supply.

2.2 Critical transport infrastructure

Critical transport infrastructure refers to the physical and virtual systems, facilities, and networks that are essential for the transportation of people, goods, and services. It encompasses a wide range of modes of transport, including road, rail, air, waterways, and pipelines. Critical transport infrastructure plays a vital role in facilitating economic activities, supporting social mobility, ensuring public safety, and maintaining the functioning of a society. According to Pavić et al. (2021) *"a critical transport infrastructure includes the physical elements, services, supply chains, information technology (network and infrastructure) that play a key role in the transport of people and goods, the health of the population, national security and the efficient functioning of the state, society and economy"* (Pavić et al., 2021).

Critical transport infrastructure is characterized by its strategic significance, high dependency, and potential impact on economic stability, public safety, and national security. Disruptions or failures in these infrastructures can lead to serious consequences, including the following (Taylor, 2008; Kiel et al., 2016; Horváth & Csaba, 2015):

- Disrupted supply chains, causing shortages of essential goods and services.
- Economic losses due to reduced productivity, increased transportation costs, and decreased trade.
- Impaired emergency response capabilities during natural disasters, accidents, or public health crises.
- Restricted mobility and limited access to critical services, impacting public welfare and social well-being.
- Compromised national security if transport assets are targeted or compromised by malicious actors or occurring events.

Given the critical nature of transport infrastructure, it is crucial to ensure its protection, resilience, and continuous operation. This involves implementing robust security measures, regular maintenance programs, contingency planning, technology enhancements, and collaborative efforts among various stakeholders, including government entities, transportation agencies, operators, and private sector partners.

2.3 Critical transport infrastructure and food industry

It can be stated that critical transport infrastructure and the food supply chain are closely interconnected and rely on each other for the efficient movement of food products from producers to end consumers. If the vulnerability of the food supply chain is seen and compared to the vulnerability of other networks classified into critical transport infrastructure, it can be concluded that this structure is one of the most vulnerable supply chains from many perspectives. It was proved during the early stages of Covid-19 pandemic, in many cases caused by extreme climate events and now during the Ukrainian-Russian war that disruptions in transportation can cause desperate situations on the market. Therefore, it is necessary to examine the entities of the food supply chain that are likely to be affected by a crisis situation (Horváth, 2013). The whole food supply chain should therefore be examined, from raw material supply to manufacturing and final product distribution, involving the possible stakeholders. The main points to describe are the connection between the critical transport infrastructure and food supply which are the following:

- Supply chain logistics: critical transport infrastructure plays a crucial role in the food industry's supply chain logistics. It enables the transportation of raw materials (for example: from farms, fisheries, and agricultural regions) to food processing facilities, food processing plants. It also facilitates the movement of processed food products to distribution centres, markets, restaurants, and retail outlets for consumers.
- Timely delivery: efficient and reliable transport infrastructure is essential for ensuring the timely delivery of perishable food items. Fresh products (for example: different dairy products, seafood, and other temperature-sensitive goods) require relatively quick transportation to maintain their quality and safety.
- Food safety and quality: reliable transport infrastructure supports food safety and quality standards. Proper transportation conditions, including temperature control, hygienic handling, and compliance with regulations, help prevent contamination and maintain food integrity throughout the supply chain.
- Regional and international trade: transport infrastructure facilitates the import and export of food products, allowing regions to access a diverse range of food items and enabling countries to participate in the global food trade. Ports, airports, and road networks are crucial for transporting food commodities across borders, across the world.
- Accessibility and food security: and adequate transport infrastructure contributes to ensuring food accessibility and availability, particularly in remote or underserved areas. Efficient transportation networks enable the timely delivery of food to areas with limited local food production, enhancing food security and reducing food deserts.
- Emergency response and disaster management: during natural disasters or emergencies, critical transport infrastructure is vital for delivering emergency food supplies, humanitarian aid, and relief materials to affected regions. Accessible and resilient transport systems are crucial for timely response and recovery efforts.
- Sustainability and environmental impact: transport infrastructure in the food industry has implications for sustainability and environmental impact. Efficient logistics planning, optimizing routes, and reducing carbon emissions from transportation contribute to sustainable food systems and the overall environmental footprint of the industry.

Overall, it can be concluded, that critical transport infrastructure is integral to the functioning of the food industry, supporting the efficient movement of food products, ensuring food safety, enabling regional and global trade, and contributing to food accessibility and security, the relevance of the topic is crucial due to the vulnerability and sensitivity of the food supply chain (Horváth, 2013). Collaboration between the transport and food sectors is crucial for addressing challenges, improving efficiency, and promoting sustainable practices throughout the food supply chain.

3. RESEARCH METHODOLOGY

Freeman (1984) contends that in order to accomplish an organization's objectives, it is crucial to acknowledge the impact of all stakeholders, whether they are individuals or groups. The initial stage involves recognizing these stakeholders and evaluating the extent of their influence and involvement. Each organization possesses a unique stakeholder network that evolves dynamically over time, with interests closely tied to different strategic matters. Therefore, decisions should consistently identify the pertinent stakeholders and their interests, considering the particular circumstances of each decision situation.

There are various methodologies to map the relationships between entities (e.g., organizations, industry actors, civil actors, governments… etc.). To map the links between actors, value chain mapping, supply chain mapping or even stakeholder mapping methodologies are suitable.

According to Mehrizi et al. (2009) the actors of the examined complex system are linked together in several forms (Mehrizi et al., 2009). These factors can be the level of interest, internal or external position, degree of relationship power (Styk & Bogacz, 2022), or even the responsibilities, tasks, competencies and motivation can determine the role of a stakeholder. The first step is always to understand their role within the observed system, so mapping their relation power must be prioritised (Nyström et al., 2014).

Factors which influence the stakeholder mapping can be categorised in five ways. *Belonging factors (1)* show information about to which stakeholder group belongs the observed stakeholder. S*takeholder factors (2)* refer to the possible role characteristics e.g.: decision making, consulting, monitoring, supporting, while the *planning stage factors (3)* introduce the phases where the stakeholder group is at the moment of the observation (Zingraff-Hamed et al., 2020, p. 10). The category of *relation to the hazards (4)* should be interpreted specifically in the case of CIs. They tell about how strongly the stakeholder group is affected by the hazards regarding CIs, are they key targets (direct affects) or side participants (indirect affects). At the end the *relation to CIs factor (5)* highlights risk management tasks, it is observed how strongly is the stakeholder group affected by negative events (Zingraff-Hamed et al., 2020). After having collected the required data about the examined stakeholders the visualisation of their relations is the next step.

For presenting a stakeholder there are various ways. An important tool is to collect data using the above listed factors and turn them into variables for quantitative purposes or we can focus on the value-added information competing the links between the actors (Giordano et al., 2018; Walker et al., 2008). Both ways require detailed information about the observed actors, that is what significantly differentiates stakeholder maps from value or supply chain maps (Donaldson et al., 2020; Smith, 2012; Taylor, 2005).

In this study, the stakeholder map of Polonsky (1996) will be used. In every stakeholder mapping, the first step should be the identification of the stakeholders. Everyone – individual or organization – have stake if they have a potential or ability to influence the behaviour of an organization or a company (Polonsky, 1996 p.213).

Organizations can classify stakeholders along to their potential to threat or to cooperate with an organization into 4 categories (Figure 2), along which different strategies can be followed with them (Savage et al., 1991).

Figure 2 Classification of stakeholders

	Stakeholder's potential for threat to organization		
		High	*Low*
Stakeholder's potential for cooperation with organization	*High*	Mixed Blessing stakeholder (iv)	Supportive stakeholder (i)
	Low	Non-supportive stakeholder (iii)	Marginal stakeholder (ii)

Source: Savage et al, 1991 p.65

Organizations aspire to have stakeholders who align with the organization's objectives and initiatives. They prefer stakeholders of this kind, who demonstrate a low potential for posing threats and a high potential for cooperation (i). Marginal stakeholders (ii) are characterized by being moderately involved in the organization, neither highly threatening nor remarkably cooperative. While they may have a stake in the organization and its decisions, they typically display limited interest in most issues. However, specific matters such as product safety, pollution, or greenmail have the potential to mobilize these stakeholders and cause their willingness for either cooperation or posing threats to rise. An organization and its managers find stakeholders who exhibit a high potential for threat but a low potential for cooperation to be particularly distressing (iii). When dealing with non-supportive stakeholders, it is advisable to employ a defensive strategy initially. This defensive approach aims to diminish the reliance that forms the foundation of these stakeholders' interest in the organization. The mixed blessing stakeholder (iv) holds significant importance as the organization deals with an individual or other organization whose potential for both posing threats and cooperating is equally high. Collaborative efforts may be the most effective approach in managing such stakeholders. By maximizing their cooperation, potentially threatening stakeholders will encounter greater difficulties in opposing the organization (Savage et al., 1991; Polonsky, 1996).

Since neither critical transport infrastructure nor food supply chain can be regarded as an organization, the paper interprets to them as systems. So, in this paper Savage's stakeholder map will be applied to discover the entities which have influence on or are affected by the critical transport infrastructure (CTI) system in food supply chains (FSC).

4. RESULTS AND DISCUSSION

In this chapter the authors will present systematically the critical infrastructure approach of Hungary and Germany, the similarities and differences between them. Then food supply's critical infrastructure will be in the focus especially the critical transportation infrastructure dimension. The main findings are introduced in the third sub-chapter whereas the stakeholders of the critical food supply infrastructure are presented and classified.

4.1 Comparison of German and Hungarian CI approach

Based on secondary data (official communication of the governments of Hungary and Germany and related organisations) we conducted an analysis to detect the differences and common characteristics within the management and strategy building of the two observed nations. Table 2 shows the factors and result of the analysis.

Table 2. Comparison of German and Hungarian CI approach

	Hungary	Germany
Definition at a national level	Critical system element: a service, asset, facility or system element belonging to one of the specified sectors, as well as the services provided by them, which are essential for the performance of vital social functions - in particular, health care, personal and property security of the population, provision of economic and social public services, national defence - and the loss of which would have significant consequences due to the lack of continuous performance of these functions (Act CLXVI of 2012, § 1 (j))	Critical infrastructures (KRITIS) are organisations and facilities of vital importance to the state community, the failure or impairment of which would result in lasting supply bottlenecks, significant disruptions to public safety or other dramatic consequences (BSI website, 2023).
Methodology for management	Centralised, outsourced into the hands of disaster management authorities (65/2013 (III. 8.) Government Decree)	Centralised (governmental level) and decentralised both (individual decision-making power of Federal states)
Content (sector)	10 sectors, separated regulations per sector	10 sectors, separated regulations per sector

Content (food as subsector)	Specialisation for food producers and traders, food service Task-responsibility declaration	Specialisation for food producers and traders Task-responsibility declaration
Relation to the EU strategy	Direct (national regulation followed the EU reg. 4 years later) derived from the EU directive (COUNCIL DIRECTIVE 2008/114/EC, 2008)	Direct, completed with resilience questions from 2022
Way of communication	Based on regulations, representatives of some sectors communicate on their own	Derived from EU strategy, centralised through the website of the government and each Federal states, websites from charities
Stakeholders involved	Government, disaster management authority (enabled for management of CIs in Hungary)	Government, Federal states, charities

Source: Hungarian: Act CLXVI of 2012, § 1 (j)), 2012, 65/2013 (III. 8.) Government Decree; German: BSI website, 2023; Both: COUNCIL DIRECTIVE 2008/114/EC, 2008

The Hungarian and the German governmental strategies regarding critical infrastructures can be followed back to the legislation of the European Union from 2008 (Council Directive 2008/114/EC, 2008). Both governments apply the definition from the EU directive and frame it in form of domestic legislatives (BSI website, 2023, 2080/2008. (VI. 30.) legislative, 2008). The first differences appear within the applied methodologies in the management tasks of critical infrastructures. Hungary directly delegates the task to a subordinated public organisation specialised for disaster management (disaster management authority), while the German government selected in addition to the disaster management representatives. This shows that the management tools are differently selected, and this might probably thank to the size and structure specialities of the countries. Germany highlights the importance in IT safety and starts dealing with critical infrastructures from the perspective of IT safety (PWC website, 2023). On the other hand, both governmental organisations established for disaster management deal with the following topics: identification of CI-s, risk management, crisis management (BBK website, 2023a, DMA website, 2023.). Germany allows the Federal states to complete the governmental legislations and strategies on their own. In comparison Hungary gives the decision-making power to one centralised public organisation (controlled by the government), not to the counties.

There is no significant difference within the critical infrastructures, both governments focus on the 10 sectors determined by the European Union (Council Directive 2008/114/EC, 2008). In addition, Germany has given an updated complement to the previous existed legislation since 2022 with a special focus on resilience (Bundestag report, 2023). This effort shows that Germany wants to focus on prevention and resilience not only disaster management (when the disruption has happened). This perspective is rarely applied by the Hungarian government, it behaves mainly reactively in a crisis situation, and rather the procedures come to the fore first.

This pro-, and reactive behaviour also appears in the way of communication of both countries. In Hungary there is no well-structured webpage of the government (or a governmental authority) which tells transparently and in detail the public about the critical infrastructures and the emergency procedures. They mainly communicate in forms of legislations (Act CLXVI of 2012, § 1 (j)), 2012, 65/2013 (III. 8.) Government Decree, BSI website, 2023).

The last factor to be observed is the composition of stakeholders involved. It is seen that the interdependence of critical infrastructures is enormous. They even might cause a domino effect in the case of electricity blackout, natural hazards, epidemics, pandemics, or cyber hazards (BBK website, 2023a, McGee & Penning-Rowsell, 2022). Based on the analysis of the context presented previously, the goal of this paper is to detect the interdependencies between stakeholders with a special focus on the food industrial actors.

4.2. Food supply as critical infrastructure

In this chapter the Hungarian and German approach will be compared, how this two EU member stated handle food supply as part of the critical infrastructure.

Table 3. Critical Infrastructures with a special focus food sector

	Hungary	**Germany**
Sub-legislation	Yes	Yes
Related sub-sectors	Food industry (if production is above the determined limit from the legislative): - Gene bank for the conservation of plant and animal genetic resources, - seed production facility, production of vaccines for animals, - slaughterhouse activities, processing of meat and poultry meat, - keeping livestock (e.g., cattle, pigs, geese, turkey),	Food industry: supply of food to the public, food production, food processing - live animals which may be used to produce food and hatching eggs, - feed, - plants before harvesting that can be used to produce food or animal feed, - seeds, - reproduction material.

	- fruit and vegetable processing, preservation, - dairy processing, - manufacture of grain mill products (e.g., bread, fresh bakery products). Food trade: - logistics facilities for the storage and distribution of food Food service: Cooking kitchen for public services (e.g., schools, hospitals)	Food trade: food supply and trade - placing on the market - trading activities.
Content	List of actors who belong to the critical infrastructures, description of the production limit above they're considered as CI actors, the process for designation as a critical system element	The process for designation as a critical system element, list of actors who belong to the critical infrastructures, providing facilities and equipment for the CI actors, ensuring the basic supply regarding orders concerning the production, handling placing on the market, order the purchase, collection, storage, transportation, distribution or dispensing of products order, prohibit, restrict, or place under sovereign supervision, Application guides of: - machinery - fuels and combustibles for machinery - emergency power supply equipment - secure product - regulations for temporary maintenance,

		taking measures for the sovereign distribution of food to the population.
Responsible organisation(s)	National Food Chain Safety Office	Federal Ministry of Food and Agriculture

Source: own edition, based on BBK website, 2023b; ESVG, 2017; Government Decree 540/2013 (XII. 30.), 2015

Table 3 shows that both Hungary and Germany prepared individual regulations for the food sector. The form of regulations is a governmental legislative (ESVG, 2017; Government Decree 540/2013 (XII. 30.), 2015), but the contents are differently structured. The common characteristics of these regulations are that they describe the actors who is responsible for the management task in the case of a crisis. The decision-making and intervention processes are strongly determined in the legislations, so they can be interpreted as procedural guides. Sub-sectors linked to critical infrastructure also show divergence. While Hungary directly mentions the cooking kitchens (as caterers empowered to supply warm and cold food for public organisations), Germany embedded this service into the term "supply of food to the public) rather focusing on production, processing, and distribution. The content of the regulations differs in some points. Hungary focuses on the production limits from which an actor of the food sector is considered as a CI member. Analysing both documentations, it is seen, that the requirements for being able to manage crisis situations can be categorised as follows. First, the CI members must be determined. Governments should deal with the key stakeholders, who play an important role within the food supply. Second, the naming of the responsible authority and the publication of the rules of procedure are required to be able to track the triad of task-responsibility-competence (Eraut, 1998). The intervention guideline seems to be the most important if an authority has to inform and even lead food sector actors in direction to work resilient and cooperating with other CI members within a crisis.

4.3 Stakeholder mapping of the food supply chain from Critical Transport Infrastructure perspective

The aim of this study is to examine the key stakeholders in critical transport infrastructure, which plays a prominent role in food supply, and their importance for critical infrastructure in the event of a disruptive event. To classify the stakeholders, the work of Savage et al. (1991) has been used (Figure 3).

In food supply, the transport infrastructure is critical to the provision of food to society. The location of food production often does not coincide with the location of its consumption, either locally (e.g. dairy products) or globally (e.g. chocolate), and the same is true for the timing of consumption. In addition, the consumption of products rarely coincides with the time of production (e.g. sugar, flour). These two dimensions (place and time value), which contribute to the creation of customer value, need to be addressed through the transport infrastructure and its stakeholders.

The stakeholders of critical transport infrastructure in this respect can therefore be diverse. The creation of the infrastructure is a public task, a state decision, but the operational implementation itself and then the operational management is typically in the hands of some public authority. Users include food supply chain actors, farmers (worldwide), processors, retailers and wholesalers, and logistics service providers that carry out the actual transport processes. Civil society can also be seen as part of this chain, because they are the ones who go to the retail unit to buy food and also use the CTI. In case of a disruptive event an obstruction of CTI can lead most quickly to social tension.

Critical transport infrastructure has other types of stakeholders, too. NGOs or other charity and social organisations that are involved in e.g. food supply in the event of a disaster, or reverse processes in the food chain to avoid food waste and redistribution. Stakeholders also include chambers and trade associations that represent the professional or interest groups of the above and convey a unified position to the state or the authorities. Disruptive events are often reported by the media, which has a role in informing the public and will be taken into account when drawing up the relevant map.

The listed stakeholders are classified in Figure 3.

Figure 3 Classification of stakeholders of food supply in CTI context

		Stakeholder's potential for threat FSC's CTI	
		High	*Low*
Stakeholder's potential for cooperation with FSC in CTI	*High*	*Mixed Blessing* supply chain downstream and upstream members	*Supportive* EU, State government, operative authorities, NGOs,
	Low	*Non-supportive* news and media, nature, human	*Marginal* trade associations, chambers, civil society

Source: based on Savage et al., 1991 own edition

In their study, the authors identified as "*supportive stakeholders*" primarily those who have a primary influence on the design and operations of the CTI in a crisis situation, who are unlikely to threaten the CTI or the FSC, but who nevertheless play a critical role in a crisis situation. This includes the EU and individual national governments as well as authorities, who develop and operate the infrastructure based on common principles and define the crisis procedures. NGOs are also included here because they are, alongside the former, the most intensively involved in providing for civil society in the event of a disruptive event.

In the "*marginal*" category are those stakeholders who, although important, do not really have any influence or pose a threat. Chambers and professional associations enable other actors to act in a united way, e.g. in crisis management. Civil society has little advocacy capacity at the level of individuals, but the whole system under review works in their interests and seeks to build resilience.

Members of the "*mixed blessing*" group can become supportive or non-supportive. Here, mainly upstream and downstream actors of the FSC were categorised whose cooperation is of paramount importance in the event of a disruptive event in the FSC or CTI, but who may also be the source of a disruptive event themselves. The reactions of FSC members to a crisis event, the way in which a crisis is handled, or even how a member who has dropped out can be replaced.

The last group, the "*non-supportive*" category, includes elements and stakeholders that cannot be influenced externally (natural disasters) or are difficult to predict (terrorist groups), but whose impact can be drastic. The influence of the media in the mass media is of great importance, but distorting or exaggerating the news can cause unnecessary panic among civil society.

The identified stakeholders are therefore all of great importance, and a further option could be the naming of specific governmental organisations and authorities, through which individual states can be aware of the range of organisations and entities that could be involved in the event of a disruptive event, and their potential responsibilities.

5. CONCLUSION

This is a conceptual paper which aims to highlight the importance and applicability of a stakeholder analysis as a particular area of critical infrastructure analysis from a decision maker's perspective. To ensure credible and informative data besides the literature review, websites from the examined governments and the linked stakeholders were analyzed.

The main research question of the paper was to compare German and Hungarian approaches about food supply as critical infrastructure, and to reveal that what kind of interdependencies exist between stakeholders, and how do they impact the operations.

From the analysis conducted it can be seen that there are some stakeholders which may seem obvious, but not all, and there are others that can be key to address consciously (media). The matrix helps to group and assign strategies to them and is also a good indication of who can be involved in what kind of processes during a disruption. Based on the model presented, it is worthwhile in the future to examine each group (supportive, marginal, mixed blessing, non-supportive) in more depth and in more detail, in order to better understand the objectives and conflicts of interest of each group concerned and to propose effective solutions.

NGOs and other social organizations, trade associations and chambers are not an integral part of the system and could play a role. They should be involved in gathering sectoral information, providing credible information, communicating sectoral expectations for CTI development, reaching a broad cross-section of society, involving and mobilizing civil organizations to achieve resilience. They might also have a role in cooperating with similar foreign organization organizing cross-border intervention, sharing information, collect best practices.

Certainly, this research has its limitations. On one hand, the examined critical infrastructures focus on one area (food supply where water is excluded), but the extension would have caused conceptual troubles (e.g., water supply is separated from food in general). Furthermore, the appearance of non-reachable information connected to topic hidden by the governments might not cover all research questions (e.g., Hungary does not provide that detailed and publicly available communication about the critical infrastructures as Germany does). In the future, the authors aim to conduct a bibliometric literature analysis with which the research streams and the thematic evolution could be interpreted. Their aim is to formulate possible practical implications for both decision makers and citizens in form of a collection of best practices which highlights the possible preventing methodologies for both entities.

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SELECTION OF PRODUCTION SOURCING METHOD USING PROCESS SIMULATION

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Abstract

The paper presents an analysis of warehouse and production processes for component sourcing and finished goods receiving using BPMN notation in the iGrafx IT environment. The authors in the paper presented the developed model of how production is sourced and its impact on the production process. The model is the result of optimization work for enterprises carried out within the activities of the Lukasiewicz Research Network - Poznan Institute of Technology and research work at the School of Logistics. In order to accurately depict the processes and their interrelationship between each other, the model also includes the production process for a finished product having a preset structure of the structure. The results of the simulation studies of the model for the following variables are also presented: variances in the handling of supplies for production and receipt of products, allocation of necessary resources for the implementation of processes, and availability of resources. Simulation validation of these variants allows to conclude that the developed model of the production supply process is universal and implementable in business practice for the purpose of conducting efficiency analyses of production supply processes.

Key words: BPMN Notation, iGrafx software, multi-criteria analysis, manufacturing, production procurement

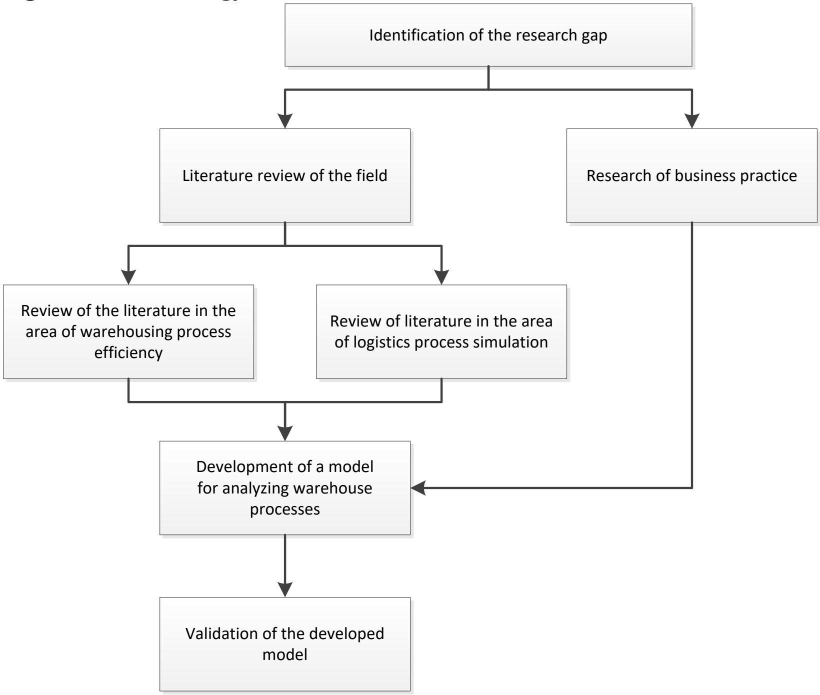
1. INTRODUCTION

The efficiency of warehousing processes in handling production has a major impact on the performance of production systems. The warehousing process includes operational activities related to the storage of goods and all manipulative activities performed in accordance with specific organizational and technological conditions. Manipulative activities include the flow of material goods (receipt, movement within the warehouse, issuance to production, receipt of goods from production) and the collection and processing of goods (picking, preservation). In addition to handling activities, the warehousing process also includes activities involving the flow of information. Particularly at the level of warehousing processes, as well as at the level of production processes, there is a tendency to continuously improve existing processes for optimization purposes. These requirements are forcing companies to implement increasingly efficient processes using organizational and technological solutions. A very important aspect of warehouse process efficiency is currently the implementation of IT systems and innovative technologies. However, as these implementations should be based on optimally organised warehouse processes, a fundamental step in our research is to identify the key operational activities that affect the efficiency of warehouse processes even before the implementation of innovative technologies.

2. RESEARCH METHODOLOGY

The research presented in this paper presents both the literature review on the subject and a consideration of the practical aspects of implementing warehousing processes in supply chains. Therefore, the analyses conducted are the result of research work, concerning the impact of warehousing on the supply processes efficiency, and the observation of business practice, feeding the developed model with reliable data for validation. Figure 1 shows the logic of the ongoing research work in this regard.

Figure 1 Methodology of conducted research



Source: own study

The use of the case study method makes it possible to discover the state of the phenomenon under study, which the results of quantitative research can only suggest. The case study, compared to other research methods, offers a more extensive range of techniques and tools for data acquisition and analysis. Sources of data can include observations, interviews, data and documents from companies, journal papers, surveys. The numerous possibilities for obtaining data mean that the case study method is not methodologically limited in terms of data analysis (George, 2019). A case study should be considered as a single and limited research process that aims at detailed analysis using multiple research techniques over a long period of time (Shani, Coghlan, 2021). In the literature on the verifiability of models through case studies, different views can be found on the number of variants carried out that must be analysed for the study's conclusions to be scientific. The dominant view suggests conducting between four and ten case studies (Eisenhardt, Grabner, 2007; Yin, 2009; Ponelis, 2015). Taking into account the specifics of the efficiency of the warehousing process, the authors considered that conducting a simulation analysis for a minimum of four case study variants would allow validation of the developed model.

The following paper will describe the study of the storage process in a manufacturing company through the implementation of organizational solutions. The organizational solutions consisted of variances in work shifts, the distribution of working hours for handling deliveries and releases, and the appropriate allocation of the necessary resources for the implementation of processes. The main criteria for selecting the most efficient process were:

- handling of assumed commodity flows within 1 day,
- human resource utilization rates of 80%,
- lowest process handling costs.

3. SPECIFICS OF EFFICIENCY OF WAREHOUSE AND PRODUCTION PROCESSES

The peculiarities of warehousing processes make it necessary to focus on those factors that have a key impact on the continuity of material flow in terms of production handling (Zuchowski, 2022). In the scientific research on logistics management, one can find many factors - processes and resources, affecting the overall process of warehousing (Kolinski, Sliwczynski, 2015; Shah, Khanzode, 2017; Md Hanafiah, et. al. 2022). Therefore, it should be concluded that warehouse management should focus on ways to improve the efficiency of processes, both internal and external supply chain, and to continuously monitor and evaluate the results obtained. The research problem identified in the course of literature studies and observations in enterprises, is to carry out an assessment of the efficiency of the warehouse process, taking into account a multidimensional analysis of the dependencies occurring within the process, as well as the connections with other processes that affect the continuity of the flow of materials in the production process.

The efficiency of warehousing processes is an issue of great importance from the point of view of the organization of processes taking place in the enterprise and in the supply chain (Lukinskiy, Lukinskiy, Merkuryev, 2017; Richards, 2021). Increasing efficiency is therefore an important factor in controlling activities.

However, it should be noted that despite the numerous references in the literature regarding efficiency, in business practice efficiency analysis is not used to the extent that it guarantees effective support for decision-making processes taking place in the enterprise. Studies conducted on the identification of difficulties in conducting comprehensive process efficiency analysis confirm the low degree of use of these analytical tools in business practice (Yan, et al., 2019). It should be noted that almost half of the surveyed enterprises do not perform such analysis or are not aware of it. This should be considered an unsatisfactory result and confirms the generally held opinion that efficiency analysis is a complicated process and difficult to use in practice, especially due to the lack of universal analytical tools to support its performance. However, the results also testify to the growing awareness of the need to perform efficiency analysis to improve competitive positions in the market.

Analyzing the literature on the subject, it should be noted that there is no unambiguous analytical method, taking into account a comprehensive analysis of the efficiency of warehouse processes in both financial and technical-organizational aspects, along with the interrelationships and feedbacks that occur.

Analyzing the warehouse process in terms of efficiency, it is necessary to identify the goals and objectives of effective warehouse management, which are presented in Table 1.

Table 1 Goals and objectives of effective warehouse management

Goals	Tasks
Maximizing the use of storage space, achieved through appropriate actions in the design, construction and commissioning of the warehouse, and responding to ongoing changes	Ensuring the availability of adequate technical and personnel resources to achieve the planned level of activity - possible only with close cooperation with the company's management
	Ensuring a flow of goods that meets delivery and shipment requirements - requires cooperation between the warehouse and the procurement and sales departments;
Minimize the use of handling operations - in the first step, unnecessary operations are eliminated, and in the second step, the aim is to reduce the time of performing necessary operations	Constantly planning, controlling and maintaining the use of all resources held - is done at the operational level and can be based on production plans and orders placed with suppliers (in the case of a supply warehouse) or sales plans and orders from customers (distribution warehouse);
	Continuous monitoring, evaluation and improvement of the warehousing process according to established criteria - should be based on selected indicators and metrics reflecting the course of the process

Source: own study based on (Niemczyk, 2016, pp. 73-86)

Granting the validity of the thesis that warehouse management has a significant impact on the operation of the enterprise, it is clear that it is necessary to strive for continuous improvement of warehouse operations. Among the most important factors for increasing the efficiency of warehouse operations are (Kolinski, Sliwczynski, 2015, pp. 178-179):

- adjusting the flow to the capacity of the warehouse - the determination of the capacity of the warehouse should be taken as a starting point. Based on it, working with other departments of the company, the schedule of deliveries and shipments should be set in such a way as to avoid the piling up of work during the day and the excess of cargo units flowing through the warehouse,
- use of storage space - refers to the efficient use of the available height of the storage area,
- rationalization of the paths traveled by employees and goods - this factor is most important for the picking process; besides, efforts should be made to eliminate or shorten the paths traveled by employees without goods,

- use of personnel - when analyzing this factor, it is necessary to pay attention to three criteria: the workload of employees over time, the competencies and powers they possess, and the constancy of employment,
- effective circulation of information - has a key impact on the implementation of all phases of the warehousing process. Any disruption in the flow of information (especially in the picking and issuing phases) can result in delays in the execution of orders.

One of the most widely used methodologies for mapping business processes is that based on the SCOR - Supply Chain Operations Reference Model (Chen, et al. 2020). It should be noted that the necessity to exchange operational data of the process, taking into account the division into operations and transactions, as well as initiating events, documents and output reports, is the basis for the dimensioning and operational preparation of processes in accordance with the BPMN concept (Abouzid, et al. 2022; Stajniak, Guszczak, 2011).

BPMN (Business Process Model and Notation) notation is a graphical notation for describing business processes. It was developed as part of the Business Process Management Initiative and is currently maintained by the Object Management Group consortium. The current version of the standard is 2.0. In earlier versions, the name BPMN was developed as Business Process Modeling Notation. The big advantages of this notation are its unambiguity, its suitability for both ERP and Workflow software process descriptions, and the fact that it is supported by more than 70 tools.

Of the products present on the Polish market, this notation is supported by iGrafx, ADONIS, Borland and IBM tools, among others. One of the most widely used simulation tools in enterprises is iGrafx Process. The iGrafx Process IT environment allows editing of elaborate process diagrams for clear presentation and comprehensible simulation at a later time.

Both in the literature and in business practice, one can find numerous ways of reflecting processes occurring in enterprises, for analytical purposes. Simulation methods take into account the passage of time and the variability of control parameters, and therefore seem appropriate for the presentation of process dynamics (Golroudbary, et al. 2019). They make it possible to analyze the impact of the size and intensity of the flow of materials (parts, components) on load distribution in warehouse systems, analyze constraints (including bottlenecks), critical flow levels for queuing and downtime in the warehouse, as well as the impact on the performance characteristics of warehouse equipment (diagnostics).

Conducting simulations makes it possible to analyze the process in terms of various variants, which are verified in a virtual way, a way that does not affect the real-time operation of the process. However, based on well-developed control parameters that are consistent with the actual state, it is possible to conclude with high probability that the analyzed process variant has a chance to be realized in economic reality. Any simulation requires the definition of basic principles (Dullinger, 2009, p. 3):

- in the case of complex processes subjected to simulation, it is necessary to properly select the simulation tool and model in detail the parameters of the analyzed process and the system in which it operates, define the input data and define the objective,
- in the case of flexible processes subjected to simulation, it is necessary to frequently change the values of control parameters,
- basing the analysis on average parameter values carries the risk of misinterpretations,
- simulation must be carried out in a timely manner to achieve the greatest benefit.

The simulation model design procedure includes the following steps (Mourtzis, 2020):

- identification of the object to be simulated, using one of two approaches: top-down, in which the main process is subject to detailing into sub-processes and activities; bottom-up, which begins by defining all activities to group them into sub-processes and main processes in the next stage,
- development of diagrams of the process being simulated using IT tools (the number of hierarchy levels depends on the detail of the process being analyzed),
- collection of input data and parameters, and then entering them into the simulation model,
- validation of the model, which boils down to comparing the behavior of the simulation model with the actual behavior of the system in question.

Simulation is one of the methods of quantitative analysis of decision-making problems, the main advantage of which is the ability to evaluate solutions without implementing them in market reality. Computer assisted analysis and evaluation of the efficiency of logistics processes in logistics enterprises depends on the reliability of input data, derived from information systems (Anisimov, Anisimov, Saurenko, 2020). The specifics of the warehousing process, makes computer simulation widely used. It should be stated that the choice of the IT environment used during process simulation depends on the complexity of the problem being analyzed. A very common solution is the use of spreadsheets for simulation, which, however, can be used only for simple simulations that do not require graphical depiction of the implementation of the process. Specialized simulation programs allow the execution of simulations over a wide analytical range, and often require the programming of dedicated macro-definitions. The complexity of the storage process makes the construction of simulation models time-consuming and error-prone. However, one can find numerous empirical analyses in the literature, using simulations, that address both the entire process (Szczepański et al, 2019), as well as only a selected, very often complex part of it (Li et al., 2021). One can also find numerous literature references to simulation analyses of processes with different specificities and in different aspects, concerning:

- financial analysis of the cost-effectiveness of the course of the logistics process and prediction of potentially obtained effects (Meade, S. Kumar, A. Houshyar, 2006),
- optimization analysis aimed at reducing resource consumption (Tang, Meng, 2021),
- analysis of operational results of logistics process execution and value stream mapping (Jing et al., 2021).

Process simulation capabilities have a significant impact not only on the implementation of warehouse processes, but also on logistics processes throughout the supply chain. The process integration of the supply chain, as well as the identification of cause-effect relationships and feedbacks, is increasingly reported in the scientific literature (Golinska-Dawson et al., 2023; Dubisz, et al., 2023; Blöchl, M. Schneider, 2016; Trojanowska, et al., 2018; Akpinar, 2021; Kluska, 2021). This demonstrates the growing interest in simulation procedures as transparent research methods, especially in the field of management science.

4. MODEL OF WAREHOUSE PROCESSES FOR PRODUCTION SUPPLY - BASIC ASSUMPTIONS

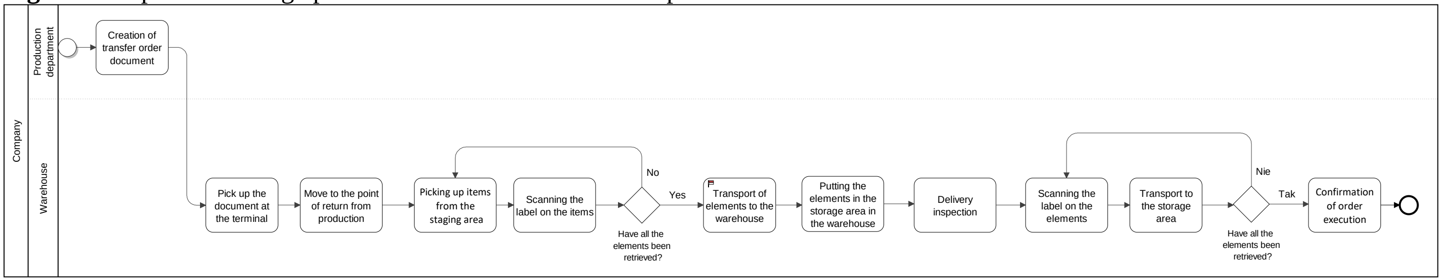
The main research problem of organizational solutions in the warehouse process model for production supply was to analyze its efficiency, taking into account the process configuration, its parameterization based on changes in the volume of material flows related to production, the formation of the demand for human resources and internal transport resources, and its impact on the production process.

As an example of the research process, the process implemented in a post-production warehouse serving the production line of a finished product was taken. The process flow diagrams are shown in Fig.1 to Fig.3.

The research of organizational solutions of storage and production process models was carried out in iGrafx Process 2011 program using simulation. Conducting simulations in iGrafx required transforming process maps into models by parameterizing them, viz:

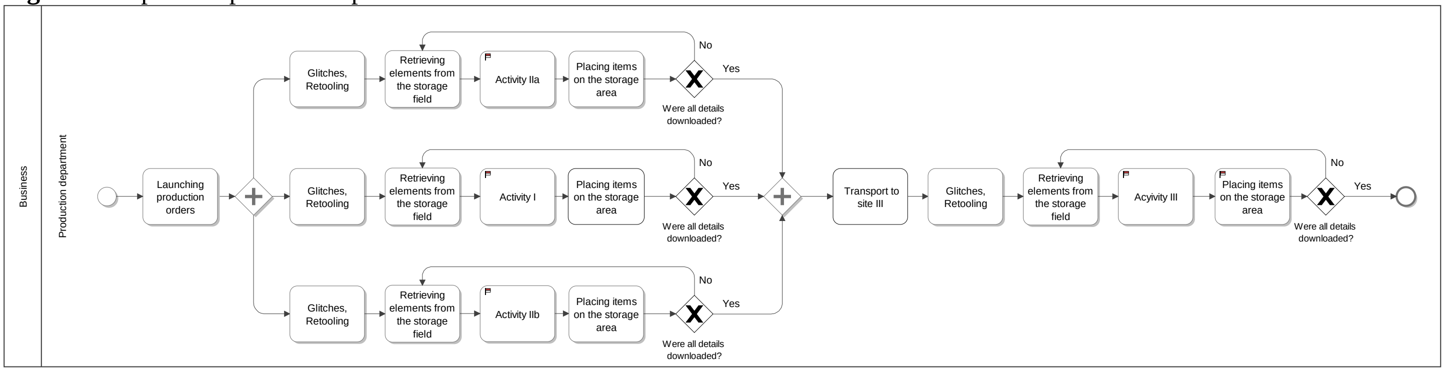
- defining dependencies in the process,
- defining the type of resources and assigning them to execution in individual activities,
- determining the costs of individual resources,
- determining the duration of individual activities,
- determining the work schedules of individual company departments,
- determination of the frequency of service of the production line in terms of delivery and reception,
- definition of transactions (parameters of commodity and information flows processed in process activities),
- defining the type of transaction generator.

Figure 2 Map of the storage process - release of materials for production



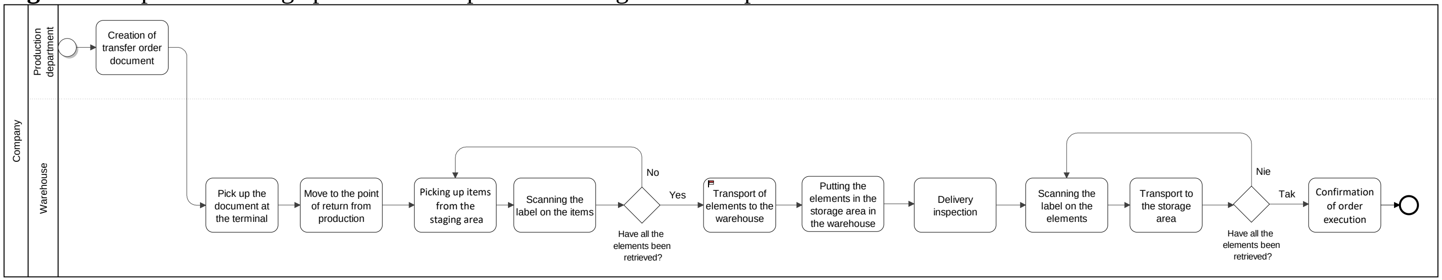
Source: own study

Figure 3 Map of the production process



Source: own study

Figure 4 Map of the storage process - receipt of finished goods from production



Source: own study

Resources

The storage process model defines three types of resources:

- Labor (employees),
- Equipment I (internal transportation equipment),
- Equipment II (positions - production machinery).

Employees carrying out processes were divided according to department into:

- Production worker - production department
- Warehouse worker - warehouse.

Internal transport equipment was divided into:

- lift trucks,
- lift trucks guided.

For each resource, the parameters of cost, work schedule, possible overtime, number of individual resources were determined and then the resources were assigned to individual activities. A summary of the entered data for resources in the processes is shown in Table 2.

Table 2 Resources in the storage and production process

	Resource	Hourly Rate	Cost of use	Schedule	Overtime	Resource Assignment
		[PLN/h]				
1	Production foreman	40	10	Firm	-	Production department
2	Machine operator	30	5	Firm	-	Production department
3	Cart operator	24	5	Firm	-	Production department
4	Position - Machine	0	100	Firm	-	Production department
5	Warehouseman	24	5	Firm	-	Warehouse
6	Forklift operator	24	5	Firm	-	Warehouse
7	Lift truck	0	5	Firm	-	Warehouse
8	Lift truck	0	2	Firm	-	Warehouse/Production Department

Source: own study

A variable number of resources were simulated.

Activity durations

In the developed storage process model, the durations of process activities were divided into two groups:

- fixed, concerning the preparation of editing and approval of documents,

- variable, concerning the execution of cargo handling activities in the process.

Fixed and variable times are introduced at the simulation stage with the help of transaction, scenario attributes. A summary of the introduced sample times in the processes is shown in Table 3.

Table 3 Unit times of activities in the process model

PROCESS PHASE	ACTIVITY	BENCHMARK UNIT	ATTRIBUTE	TIME UNIT [MIN]
Release of materials for production	Create document demand for raw materials and semi-finished products	doc	Ww_t1	2,50
	Edit document Wm	doc	Ww_t2	1,00
	Getting the order to the terminal	doc	Ww_t3	0,30
	Transfer to the storage address	jł	Ww_t4	1,00
	Picking	jł	Ww_t5	1,56
	Picking release carrier	poz	Ww_t6	1,00
	Move to storage address	poz	Ww_t7	1,56
	Pick up and deposit the indicated quantity of goods on the carrier	jł	Ww_t8	2,50
	Transport of goods to inspection area	jł	Ww_t9	1,56
	Control of picking	jł	Ww_t10	1,00
	Complete and improve the order picking	jł	Ww_t11	2,50
	Formation and securing of the delivery unit	jł	Ww_t12	1,50
	Labeling of the delivery unit	jł	Ww_t13	0,50
	Transportation to the production storage area	jł	Ww_t14	1,56
	Confirmation of completion of the doc. Wm	doc	Ww_t15	0,50
	Quantitative control in the production storage area	jł	Ww_t16	0,10
Production process	Putting elements on the storage area	pcs	Pp_t1	0,5
	Picking elements from the storage area	pcs	Pp_t2	3
	Activity I	pcs	Pp_t3	0,5
	Putting elements on the storage area	pcs	Pp_t4	0,5
	Picking elements from the storage area	pcs	Pp_t5	3

	Activity II a	pcs	Pp_t6	0,5
	Putting elements on the storage area	pcs	Pp_t7	0,5
	Picking elements from the storage area	pcs	Pp_t8	4
	Activity II b	pcs	Pp_t9	0,5
	Putting elements on the storage area	pcs	Pp_t10	0,5
	Picking elements from the storage area	pcs	Pp_t11	15
	Activity III	pcs	Pp_t12	0,5
	Putting elements on the storage area	jł	Pp_t13	2,5
Pickup of products from production	Creation of a document transfer order	doc	Dw_t1	2,50
	Downloading the document to the terminal	doc	Dw_t2	0,30
	Move to the point of departure from production	jł	Dw_t3	1,56
	Picking up elements from the storage area	jł	Dw_t4	1,00
	Scanning the label on elements	jł	Dw_t5	0,10
	Transport of elements to the warehouse	jł	Dw_t6	1,56
	Putting elements on the storage area from the storage area at the warehouse	jł	Dw_t7	0,50
	Scanning the label on elements	jł	Dw_t8	0,10
	Checking the delivery	jł	Dw_t9	2,00
	Transport to the storage area	jł	Dw_t10	1,56
	Confirmation of order completion	doc	Dw_t11	0,50

Source: own study

The operations described as activity I, IIa, IIb and II have been deliberately generalised, as they concern production operations that were not the subject of the research carried out. The data used for the simulations are real, but due to the object of the research being warehouse processes, no attempt was made to infer and optimise strictly production processes.

Schedule of work

In the developed storage process model for the study, a standard work schedule was adopted in which the following were defined:

- days of work,
- working hours.

Days of work
The model adopted the company's standard working days of Monday through Friday.
Working hours
The model assumes three-shift operation.
Frequency of production handling
The variability of production service frequency was simulated.

Transactions - parameters of commodity and information flows

In order to determine the basic results of the efficiency of the storage process run during process simulation, transactions were defined parameters of goods and information flows that will feed the developed models. It was assumed that transactions as well as activity durations will be entered into the model using export from an external file. A transaction generator will be used for this, the configuration and working principle of which is described below.
In the developed models, transactions were divided into two groups concerning:

- information flows,
- commodity flows.

A summary of the proposed transactions - parameters of commodity and information flows is shown in Table 4. Transactions - flow parameters will be entered into the model from an external file (Ms. Excel) at the simulation stage using the transaction attributes defined in the models, scenario.

Table 4 Transactions - parameters of commodity and information flows in the process model

No	PHASE OF PROCESS	PARAMETER NAME	ATTRIBUTE
1	Delivery of materials for production	Number of delivered documents	Number of delivered documents
2		Number of items on release documents	Wyd_ number of positions
3		Number of elements on release	Wyd_ number of units
4		Number of homogeneous elements on release	Wyd_ unit number of pieces
5		Number of elements completed on release	Wyd_ number of units set
6	Production	Picking from the staging area	PP1_ number of units
7		Activity I	PP2_ number of units

No	PHASE OF PROCESS	PARAMETER NAME	ATTRIBUTE
8		Putting the elements on the staging area	PP3_ number of units
9		Transport to staging area III	PP4_ number of units
10		Picking from the staging area	PP5_ number of units
11		Activity IIa	PP6_ number of units
12		Putting the elements on the collecting fields	PP7_ number of units
13		Transport to stand III	PP8_ number of units
14		Picking the elements from the staging area	PP9_ number of units
15		Activity IIb	PP10_ number of units
16		Putting the elements on the collecting fields	PP11_ number of units
17		Transport to stand III	PP12_ number of units
18		Picking up elements from the staging area	PP13_ number of units
19		Activity III	PP14_ number of units
20		Putting the elements back on the staging area	PP15_ number of units
21	Picking up products from production	Number of documents in delivery	Dost_ number of doc
22		Number of items on documents	Dost_ number of units
23		Number of items in delivery	Dost_ number of units
24		Number of homogeneous items in the delivery	Dost_ unit number of pieces
25		Number of elements completed in the delivery	Dost_ number of units set

Source: own study

Transaction generator type

A generator that is automatically created and assigned to this starting point will be used to enter transactions into the process model. Of the generators available in iGrafx Process 2011, a sequential generator was selected to enter transactions into the model during simulation:

- unit times of individual process activities,
- transactions resulting from commodity flows in the warehousing and production process.

The magnitude of commodity and information flows results from the design of the finished product, its structural complexity viz:

- the number of details that make up a subassembly,
- the number of subassemblies and details making up the finished product,
- the method of packaging of details, subassemblies in the production and transport processes,
- the adopted daily production volume.

The structure of the construction of the finished product and the method of packing of details and subassemblies in the production and storage process are shown in Table 5.

Table 5 The structure of the structure of the finished product and how the details and components are packed in the production and storage process

50	Number of components or parts per finished product [pcs]	Components	Detail	Number of parts per component [pcs]	Place of the process				Method of packaging in internal transport					
Production volume [pcs]					Stand I	Stand IIa	Stand IIb	Stand III	Components	Quantity in container [pcs]	Number for containers for pjł [pcs]	Detail	Quantity in the container [pcs]	Number of containers for pł [pcs]
Finished product	1	I	Detail 1	4	X			X	I	1	2	Detail 1	50	4
			Detail 2	4	X							Detail 2	50	4
			Detail 3	4	X							Detail 3	50	4
	1	II	Detail 4	4		X		X	II	1	2	Detail 4	20	4
			Detail 5	4		X						Detail 5	20	4
	1	III	Detail 6	3			X	X	III	1	2	Detail 6	10	3
			Detail 7	3			X					Detail 7	10	3
	6	-	Detail 8	-				X	-	-	-	Detail 8	15	4

Source: own study

A summary of transactions - volumes of goods and information flows is shown in Table 6.

Table 6 Transactions - volumes of material and information flows for the process model

NO	PROCESS	ATTRIBUTE	BENCHMARK UNIT	VOLUME OF DAILY FLOWS
1	Delivery of materials for production	Wyd_ number of docs	doc	24
2		Wyd_ number of items	item	8
3		Wyd_ number of items	item	24
4		Wyd_ number of items unit	item	24
5		Wyd_ number of elements set	item	0
6	Production	PP1_ number of pieces	piece	600
7		PP2_ number of pieces	piece	600
8		PP3_ number of pieces	piece	50

No	PROCESS	ATTRIBUTE	BENCHMARK UNIT	VOLUME OF DAILY FLOWS
9		PP4_ number of pieces	item	25
10		PP5_number of pieces	piece	400
11		PP6_number of pieces	piece	400
12		PP7_number of pieces	piece	50
13		PP8_number of items	item	25
14		PP9_number of pieces	piece	300
15		PP10_number of pieces	piece	300
16		PP11_number of pieces	piece	50
17		PP12_number of items	item	25
18		PP13_number of pieces	piece	450
19		PP14_number of pieces	piece	450
20		PP15_number of pieces	piece (item)	50
21	Receiving products from production	Dost_number of docs	doc	24
22		Dost_number of items	Item on doc	1
23		Dost_number of items	item	50
24		Dost_number of unit items	item	50
25		Dost_number of items of sets	item	0

Source: own study

Simulation validation of the developed model

The simulation of the storage process involved changing:
- frequency of production handling,
- the number of available resources assigned to carry out activities in the process,

The following models were adopted for the simulation:
- model 1 - handling production once per shift,
- model 2 - handling production once per shift,
- model 3 - handling production twice per shift,
- model 4 - handling production three times per shift.

For each model, two scenarios were considered with:
- a limited number of resources,
- an unlimited number of resources.

One of the primary objectives of process modeling and simulation is to measure the time
and costs associated with the process and to identify bottlenecks in the process. Simulating logistics processes in iGrafx software allows generating many statistics on process execution times, activity waits and unit costs, number of resources, e.g:

- actual process execution time,
- general statistics of transactions (service time, service waiting time, working time, blocking time),
- detailed statistics of transactions carried out by individual departments,
- resource costs
-

With regard to resource statistics, it is possible to obtain the total time or cost of resources consumed or their average values. Most often they are related to:

- overall resource utilization,
- detailed use of resources in individual departments,
- detailed statistics of activities in the process in relation to resources (service time, service waiting time, working time, blocking time).
-

In turn, statistics on bottlenecks in the process can be presented in the form of, for example:

- the number of transactions that were waiting for resources,
- waiting times for resources if resources are busy or are unavailable,
- waiting times for resources in individual departments.
-

The following parameters obtained from the simulations were selected for further detailed analysis from the process study:

- process service time,
- working time,
- total production time,
- resource waiting time,
- labor time utilization,
- number of resources,
- overall resource utilization,
- resource costs,
- number of finished goods produced.
-

The simulation results for each model and scenario are shown in Table 7.

Table 7 Simulation results of process execution for assumed models and scenarios

Specification		Model 1		Model 2	
		SC1	SC2	SC1	SC2
Operating time [h]		173,35	173,92	172,84	257,21
Operating time [h]		118,48	173,85	167,91	174,08
Total production time [days]		4,93	1,25	7,00	3,16
Resource waiting time [h]		277,88	0	249,67	169,54
Number of pieces of finished product produced.		50	50	50	50
Time utilization [%]	Production worker	38,16	63,84	60,74	24,52
	Warehouse worker	1,95	11,62	2	4,54
	Lift trucks	4,48	11,84	3,14	3,53
	Elevator trucks	1,99	7,88	1,61	2,93
	Machines	40,95	72,11	28,78	25,68
Number of resources	Production worker	18	28	18	26
	Warehouse worker	6	4	6	4
	Lift trucks	2	3	2	4
	Elevator trucks	1	1	1	1
	Machines	4	9	4	10
Costs	Production worker	67 441,00 zł	29 760,00 zł	94 724,00 zł	65 616,00 zł
	Warehouse worker	17 541,00 zł	3 360,00 zł	24 658,00 zł	7 763,00 zł
	Lift trucks	106,00 zł	106,00 zł	106,00 zł	106,00 zł
	Elevator trucks	215,00 zł	215,00 zł	215,00 zł	215,00 zł
	Machines	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł
	Waiting for resources	13 894,00 zł	0,00 zł	12 483,50 zł	8 477,00 zł
	Total	**111 197,00 zł**	**45 441,00 zł**	**144 186,50 zł**	**94 177,00 zł**

Source: own study

Results

The selection of the most effective model and scenario was based on the calculated indicators:

- unit cost of production of 1 piece of finished product,
- service time of 1 piece of finished product,
- production time of 1 piece of finished product,
- cost per hour of department downtime resulting from waiting for needed resources,

using multi-criteria analysis assigning weights to each criterion. The results of the multi-criteria analysis are presented in Table 8.
According to the adopted criteria, the most efficient solutions are models 1 and 2 based on scenario 2 (unlimited number of resources).
The other process implementation models are inefficient compared to the selected ones due to:

- higher unit costs of production of 1 finished product,
- longer handling and production times of the finished product.

Table 8 Results of multi-criteria analysis

Index	JM	Model 1		Model 2		Model 3		Model 4		
		SC1	SC2	SC1	SC2	SC1	SC2	SC1	SC2	
Unit cost of production of 1 unit of finished product	[zl/pcs]	2 223,94 zł	908,82 zł	2 883,73 zł	1 883,54 zł	-	1 900,88 zł	2 303,32 zł	1 632,36 zł	
Handling time of 1 unit of finished product	[h/pcs]	3,47	3,48	3,46	5,14	-	5,50	3,49	5,69	
Production time of 1 unit of finished product	[day]	4,93	1,25	7,00	3,16	-	2,02	5,23	1,64	
		Multi-criteria analysis								Weight criteria
		2,043	5,000	1,576	2,413	-	2,391	1,973	2,784	5
		4,012	3,975	4,000	2,688	-	2,513	3,966	2,428	4
		0,761	3,000	0,536	1,187	-	1,856	0,717	2,287	3
Total points		6,816	11,975	6,111	6,287	-	6,760	6,656	7,498	
Place in the ranking		3	**1**	7	6	-	4	5	2	

Source: own study

In order to identify possible bottleneck processes, delays in the production process resulting from the need for additional changeovers and production machine faults were modelled for the selected model. Delays were simulated separately for each machine/station and collectively for all of them. The sizes of possible delays from 0.5 to 2h were assumed. The obtained results are shown in Table 9.

Table 9 Results of bottleneck analysis

Specification		Model 1					
		SC2					
		No downtime	Machine 1	Machine 2	Machine 3	Machine 4	All
Service time [h]		173,92	190,57	184,87	180,9	192,92	123,1
Operating time [h]		173,85	160,09	155,36	148,19	160,09	75,62
Total production time [days]		1,25					
Resource waiting time [h]		0	3,5	4,51	0,53	2,61	153,36
Number of pieces of finished product produced		50	46	48	46	46	21
Use of working time [%]	Production worker	63,84	67,24	66,24	66,21	67,36	54,57
	Warehouse worker	11,62	11,61	11,62	11,61	11,61	9,19
	Lift trucks	11,84	11,84	11,84	11,84	11,84	6,67
	Elevator trucks	7,88	7,88	7,88	7,88	7,88	6,23
	Machines	72,11	71,63	71,93	71,74	71,65	37,98
Number of resources	Production worker	28	28	28	28	28	28
	Warehouse worker	4	4	4	4	4	4
	Lift trucks	3	3	3	3	3	3
	Elevator trucks	1	1	1	1	1	1
	Machines	9	9	9	9	9	9
Costs	Production worker	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 760,00 zł	29 110,00 zł
	Warehouse worker	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 360,00 zł	3 260,00 zł
	Lift trucks	106,00 zł	106,00 zł	106,00 zł	106,00 zł	106,00 zł	66,00 zł
	Elevator trucks	215,00 zł	215,00 zł	215,00 zł	215,00 zł	215,00 zł	170,00 zł
	Machines	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł	12 000,00 zł	7 700,00 zł
	Waiting for resources	0,00 zł	175,00 zł	225,50 zł	26,50 zł	130,50 zł	7 668,00 zł
	Total	**45 441,00 zł**	**45 616,00 zł**	**45 666,50 zł**	**45 467,50 zł**	**45 571,50 zł**	**47 974,00 zł**
Unit cost of production of 1 unit of finished product	[PLN/pc]	908,82 zł	991,65 zł	951,39 zł	988,42 zł	990,68 zł	2 284,48 zł
Handling time of 1 unit of finished product	[h/pc]	3,48	4,14	3,85	3,93	4,19	5,86
% of finished products produced	[%]	100	92	96	92	92	42

Source: own study

Analysing the results from the above table, it can be concluded that:
- the most critical for continuity are outages at machine /station 1 and 4 which results in:
    - a decrease in production by 8% (from 50 pieces to 46 pieces),
    - an increase in handling time of 1 piece of finished product by about 19% ÷ 20%,
    - an increase in production costs by about 9% ÷ 9.1%
- the occurrence of downtime on all machines/stations results in:

- a decrease in production by 58%,
- an increase in handling time of 1 unit of finished product by about 68.3%,
- an increase in production costs by about 151.3%.

5. CONCLUSION

In this paper, the authors presented simulation validation of the developed model of the production procurement method. Simulation validation also allows for multiple predictive simulations, based on which it was possible to identify dependencies and feedbacks in the processes. Simulation validation was based on multiple case studies, which can be considered representative of the specifics of warehouse processes.

In this paper, the authors presented the problem of analysing the processes taking place in the warehouse at production supply lines. The conducted research dealt with both aspects of operational efficiency and economic efficiency of warehouse processes. This analytical approach allows for a comprehensive analysis of warehouse processes.

The research carried out is characterised by a high level of detail, focused on operational data. The simulation research indicates that the detail of data and attributes simulated should be as high as possible. However, the research does not answer the question of the necessity of such a detailed analysis of operational data, but it does confirm the fundamental importance of analysing warehouse processes at the operational level as a basis for implementing optimisation measures, including the implementation of IT systems and innovative solutions. The direction of further research will therefore be an attempt to simplify the analysis of data subjected to simulation and the introduction of process changes resulting from the implementation of innovative solutions.

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ANALYSIS OF PROBLEMS OF THE PERFORMANCE MANAGEMENT OF HUMANITARIAN SUPPLY CHAINS

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Abstract

The research paper analyzes humanitarian supply chains compared to business chains and addresses performance management. The study employs quantitative and qualitative research methods, literature review analysis, statistical tools, previous research, and grounded theory. The findings consolidate significant issues limiting the performance of humanitarian supply chains and highlight challenges in measuring performance in the humanitarian sector. This study contributes to a better understanding and more effective management of humanitarian supply chains for improved operational outcomes.

Keywords: Humanitarian supply chains, humanitarian logistics, performance management, performance measurement, analysis

1. INTRODUCTION

Performance management is defined as the use of information to influence positive changes in organizational culture, systems and processes, define performance goals, allocate resources, set policies, set targets and share performance results in achieving them (Amaratunga, Baldry, Sarshar 2001). The process consists of selecting performance variables, defining metrics, setting goals, measuring and analyzing the process (Forslund, Jonsson 2007). Sets of performance indicators then provide qualitative and quantitative information on the building elements of success in which firms need to improve performance (Melkers, Willoughby 2005). Organizations that apply performance management perform better than those that do not measure and manage performance (De Leeuw, Van Den Berg 2011). Thus, many organizations implement the system to achieve competitive advantage, to maintain responsiveness to an ever-changing environment (De Waal, Kourtit 2013), or to increase stakeholder support and trust (Anjomshoae et al. 2017).

Performance measurement systems are often recommended to facilitate strategy implementation and improve organizational performance (Davis, Albright 2004). Since the late 1950s, they have been implemented in business, public and military organizations, and more recently in the humanitarian sector, to improve productivity, accountability and service delivery (Abidi 2019). In recent decades, the field of performance measurement has been the focus of many academics and practitioners (Franco-Santos, Lucianetti, Bourne 2012). Performance measurement includes processes for setting targets, designing indicators, and collecting and analyzing data on supply chain performance (Abidi 2019). It enables the transformation of data into information that facilitates control and remediation by reporting the actual level of supply chain performance against a desired level (Melnyk et al. 2014). Performance metrics can have a significant impact on performance by putting things into perspective, focusing attention on what is important, increasing objectivity, improving understanding, decision making and execution, improving consistency of performance over the long term, facilitating feedback, providing early warning signs to management, and helping the organization prepare for the future (Parmenter 2015).

To effectively apply performance management, organizations can coordinate key activities and initiate related performance management practices through performance measurement systems (De Waal 2003). These practices include selecting performance indicators and monitoring and evaluating them regularly to communicate direction, provide feedback on current performance, influence behavior, and stimulate improvement actions (Bourne, Bourne 2011). In modern management, performance measurement goes beyond quantification and accounting. Due to the limitations of traditional financial metrics, academics and practitioners advocate multidimensional performance indicators (typically financial and non-financial) (Chan, Qi 2003). Parmenter then describes four types of indicators (Parmenter 2015):

- key result indicators (KRIs) provide an overall view of how an organization is performing;
- result indicators (RIs) inform management about how teams are coming together to achieve results;
- performance indicators (PIs) tell management what teams are achieving;
- key performance indicators (KPIs) tell management how well the organization is performing on critical factors, and by tracking them, management can significantly improve performance.

However, every performance measure has a dark side, a negative consequence and an unintended action that can lead to poorer performance. Neely and Bourne cite poor system design and difficulty of implementation as the two main reasons for failure (Neely, Bourne 2000). In particular, the difficulty of implementation can be a pivotal issue in the humanitarian sector. In the commercial sector, more than 70 per cent of BSC (Balanced Scorecard) implementations fail (Neely, Bourne 2000), and more than half of the measures encourage unintended negative behaviors (Parmenter 2015), such as linking rewards to metrics (Spitzer 2007). Related to this is the identification of appropriate metrics and their number in a large amount of available data (Monczka 2009). Organizations often fail to distinguish critical success factors (Parmenter 2015). Employees should not be tracking more than a dozen metrics, only half of which should be crucial (Monczka 2009). These problems are exacerbated by big data and new technologies, leading to a regime of ever-increasing reporting of irrelevant indicators (Parmenter 2015). Thus, selecting fewer meaningful indicators is crucial to improving performance (Parmenter 2015). However, over-aggregation can be a mistake which aggregates information to the point that it loses value (Monczka 2009). Conversely, many organizations rely only on short-term indicators, such as financial and operational indicators, or indicators focused on behavior rather than results (Monczka 2009). In order to set up a meaningful performance measurement system, it is necessary to focus on auditable events, strong internal communication of the system and metrics, reduction of bureaucratic burden, and future orientation (Parmenter 2015).

The research goal is to analyse humanitarian supply chains compared to business chains and address aspects of performance management in humanitarian environment (Jambor 2023). As the above suggests, this is a critical part of the logistical optimization of rescue operations. The paper is structured according to answering to each research question. First, the specifics of humanitarian supply chains are defined, then the differences between humanitarian and business supply chains are explored. Next, current approaches and models are analysed, and the challenges needed to overcome are discussed.

2. OBJECTIVES, METHODS AND LIMITATIONS

The research goal is to analyse humanitarian supply chains compared to business chains and address aspects of performance management in humanitarian environment. To fulfil the objective, the following research questions (RQs) were formulated:

- **RQ1:** What are specifics of humanitarian supply chains and its environment?
- **RQ2:** What are differences between humanitarian and business supply chains?
- **RQ3:** Which theoretical approaches and models are used to measure performance in humanitarian environment?
- **RQ4:** What are challenges in measuring performance in the humanitarian sector?

By researching the answers to these questions, the study will contribute to a better understanding and more effective management of humanitarian supply chains for improved operational outcomes. Simultaneously, the findings consolidate significant issues limiting the performance of humanitarian supply chains and highlight challenges in measuring performance in the humanitarian sector.

The study employs mostly qualitative research methods, literature review analysis, previous research, content analysis and grounded theory. The data was collected from various relevant sources, mainly from European Commission, IFRC (International Federation of Red Cross and Red Crescent Societies), and Web of Science.

The research limitation was to use the only open data, publicly available, based on the wide literature review. There was not used internal data from private, public or NGO (Non-governmental organization) organizations.

3. SPECIFICITY OF HUMANITARIAN SUPPLY CHAINS

In the commercial sector, the convention is to use a division of supply chain flows into tangible (material) and intangible (information and financial) flows (Repík 2021). Information flows are the basis on which HSC (Humanitarian Supply Chain) can be designed, shaped and managed (Tomasini, Wassenhove 2009a). When an emergency of the type of earthquakes in Turkey and Syria occurs, information flows flow to different actors around the world to alert them to the need for assistance and define the needs on the ground, i.e. describe and activate material flows. In the reverse flow, information about what material flows are being implemented. Finally, in the next wave, information about the receipt and use of the shipments is sent, and the cycle repeats (Tomasini, Wassenhove 2009a). Financial flows enable the implementation of the whole chain. Without financial flows, it is impossible to function even in the non-profit sector. A prerequisite for the effectiveness of the basic flows is to set up visibility, transparency and accountability (Tomasini, Wassenhove 2009a). It makes it possible to distinguish what resources need to be improved, how needs are being met and who has erred in the event of failure. With large-scale emergencies and a lot of media attention, shipments of tens of thousands of tons of goods are made that would cause extreme logistical bottlenecks without proper setup. In the humanitarian sector, these basic flows are augmented by (Tomasini, Wassenhove 2009a):

- people: representing all the labor available to the chain in each operation;
- knowledge and skills: are particularly important in the humanitarian sector, as each time an HSC is deployed in response to an emergency, skills need to be reconfigured quickly, i.e. each HSC is new and different.

All five flows are equally important in managing the response to the emergency. Disruption to anyone can affect the performance of the entire chain. Under pressure from limited resources (i.e. people, capital and infrastructure) (DG ECHO 2022), there is a need to ensure that all flows in the chain are managed. However, actions in the humanitarian sector are often uncoordinated, spontaneous, unsolicited or unwanted (Tomasini, Wassenhove 2009a). A common problem in humanitarian organizations is the limited amount of trained and coached personnel, as well as the limited ability to train personnel. Moreover, people usually work under uncertainty and time pressure, which can be accompanied by logistical complications (Repík, Foltin 2022a):

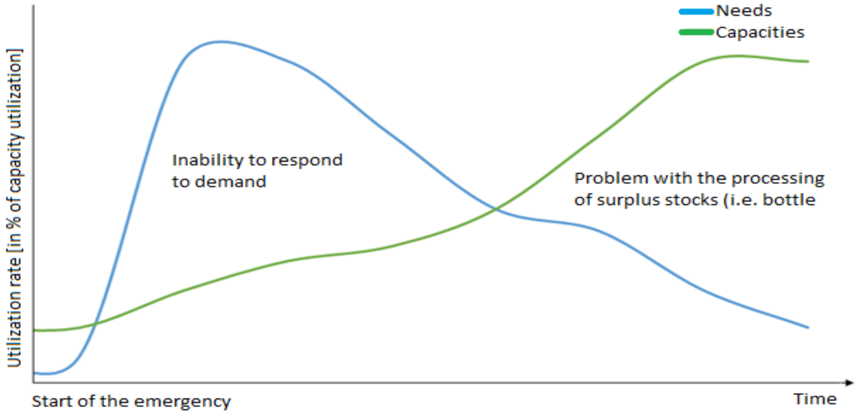
- external origins (e.g. disrupted infrastructure);
- internal (e.g. lack of storage, transport or handling capacity).

Each emergency is different in its course and impact, but the complications have certain characteristics. At the beginning of an operation, organizations face shortages (personnel, material, finance, equipment, etc.) that can quickly turn into surpluses (especially for highly publicized events), see Figure 1. Complications of external origin usually have two possible scenarios of development that reflect on the performance of logistics support (Repík, Foltin 2022a):

- the situation improves over time (e.g., high winds);
- the situation deteriorates over time (e.g. armed conflict).

Based on these specifics, the form of logistic security then changes its character from a push principle at the beginning of the operation to a pull principle after the initial onslaught has been compared (Foltin, 2018). The push principle is generally used for uncertain environments where customer requirements are unknown (Chopra, Meindl 2013). After the first surveys and estimates, it is possible to start adjusting the pull principle according to the demand. The impacts on the supply chain are then mainly influenced by the level of preparation before the emergency and the commitment of the stakeholders. Humanitarian organizations often find themselves in situations that crisis management describes as firefighting (Bohn 2000). There are a lot of examples in the Czech Republic, e.g. the COVID-19 pandemic or the tornado in South Moravia was a major shock to the status quo. For a long time, the humanitarian sector was not prepared, and the response was led by extinguishing one problem after another.

Figure 1 Diagram of the evolution of demand and logistics capabilities during an emergency



Source: (own)

4. DIFFERENCES BETWEEN HUMANITARIAN AND BUSINESS SUPPLY CHAINS

Several models and lessons can be adopted from the private sector for HSC management. However, there are specifics in the humanitarian context that can complicate the application of business sector approaches. Researchers already compared the differences between humanitarian and business supply chains, see (Beamon, Balcik 2008; Abidi 2019). However, our paper considers the major changes in the humanitarian sector in recent years, and our comparison is also more comprehensive than previous analyses, see Table 1. HSC, to be effective, must also exhibit three key characteristics that demonstrate utility in the business sector (Lee 2004):

- agility: the ability to respond quickly to changes in external influences;
- adaptability: the ability to adapt the supply chain, modifying strategies, products/services and technologies provided;
- alignment: creates conditions for better performance and requires information exchange with all relevant partners.

At the same time, the International Red Cross and Red Crescent Movement (RCRC) defines basic humanitarian principles, i.e. humanity, impartiality, neutrality, independence, voluntary service, unity and universality (IFRC 2023). At the European Union (EU) level, humanitarian principles are enshrined in the European Consensus on Humanitarian Aid, signed in December 2007 by the EU Council, the European Parliament and the European Commission (Evropská unie 2008). Based on the provisions of the Consensus, EU countries and institutions have agreed to work in a coordinated and complementary manner and to support the overall coordination role of the United Nations (UN). The UN and the EU have thus adopted the same humanitarian principles based on the IFRC, i.e. humanity, neutrality, impartiality and independence (DG ECHO 2023a). These principles differentiate humanitarian aid from other activities, such as political, religious, ideological or military, and it is essential that the work of the HSC is always based on these principles.

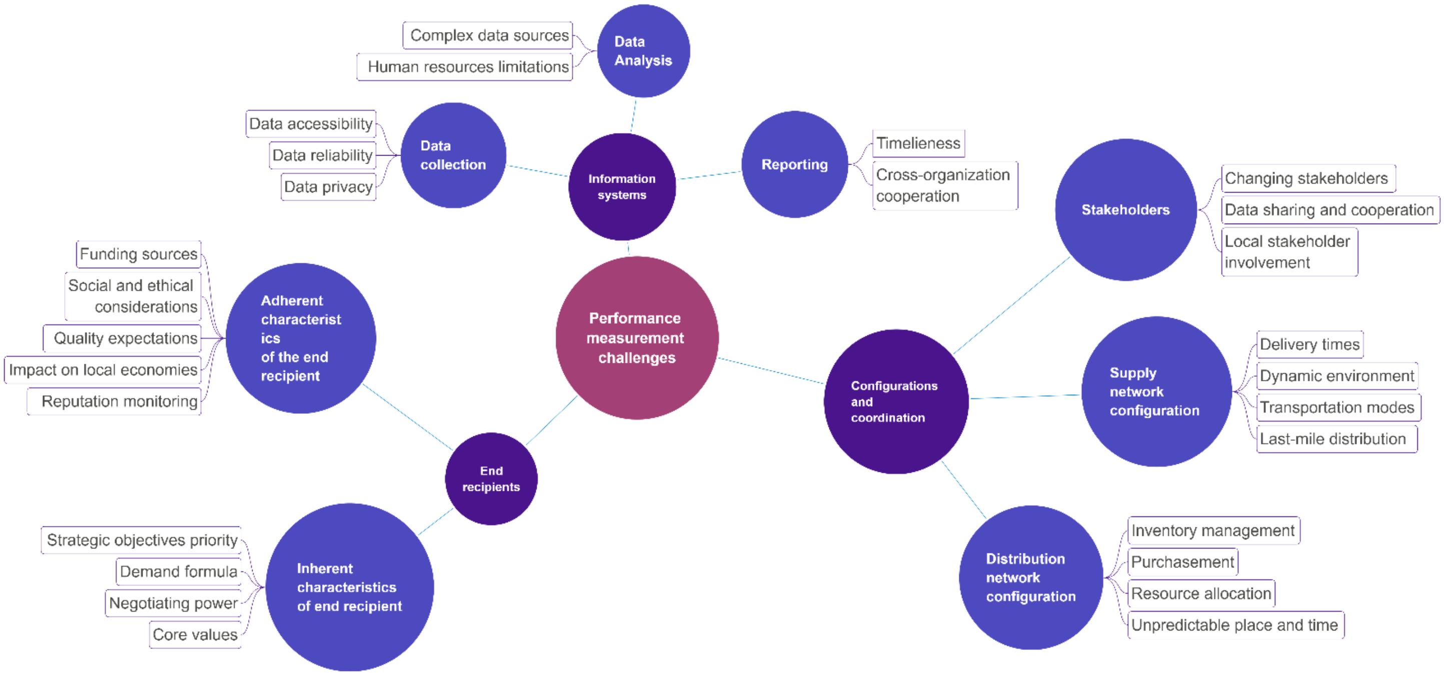
Table 1 Differences between business and humanitarian supply chains

Criterion	Business Supply Chain	Humanitarian Supply Chain
Environment	Dynamic environment (Chopra, Meindl 2013).	Chaotic and uncertain environment (Tomasini, Wassenhove 2009b).
Strategic objectives	Maximising profit, value and high customer satisfaction (Chopra, Meindl 2013).	Minimising loss of life and alleviating suffering (Tomasini, Wassenhove 2009b).
Information system	Generally making good use of advanced technology (Christopher, Peck 2004).	Information is often unreliable, incomplete or non-existent (Christopher, Tatham 2011).
Performance measurement system	Performance management is a common practice (Bititci et al. 2012; Gopal, Thakkar 2012).	Structured and standardised performance management is not a common practice (Abidi, de Leeuw, Klumpp 2014) and lags behind the commercial sector (Lu, Goh, De Souza 2016).
Configuration of actors	A tightly knit network of actors working together to ensure the efficient flow of materials and information throughout the supply chain (Christopher 2005).	Stakeholder groups without clear inter-linkages, predominance of NGOs and government actors (Kovács, Spens 2007).
Configuration of the supply network	Usually a well-structured and organisationally stable supplier base (Chopra, Meindl 2013).	Limited choice, sometimes even undesirable suppliers (Kovács, Spens 2007).
Configuration of the distribution network	Well-defined methods for determining the number and location of distribution centres (Mangan, Lalwanis, Calatayud 2021).	Challenging due to the nature of the unknowns and the risk and urgency context (Gatignon, Van Wassenhove, Charles 2010).
Delivery times	Determines the supply chain on the basis of a preliminary agreement (Pettit, Beresford 2009).	Delivery time requirements are very short and critical to saving lives (Kovács, Spens 2007).
Demand formula	Relatively stable, predictable demand patterns (Beamon, Balcik 2008). Demand emerges from fixed locations in predictable quantities.	Demand arises from unpredictable events (time, place, type and size) (Pettit, Beresford 2009). The demand for goods during these events is also unpredictable (Murray 2005).
Inventory management	Well-defined methods for determining inventory levels based on lead times, demand and target customer service levels (Simchi-Levi, Kaminsky, Simchi-Levi 2000).	Inventory management is challenging due to variables in lead times and demand quantities and locations (Balcik, Bozkir, Kundakcioglu 2016).
Staffing structure	Designed to ensure efficient operation and optimise performance. Staff is developed based on current trends (Kisperska-Moroń 2010).	Largely by volunteers (Repík, Foltin 2022a).
End recipient	A consumer buying a product or service (Gros 2016).	A victim of an emergency (Kovács, Spens 2009).
Output	Products and services (Gros 2016).	A changed human life (Drucker 1994).

Source: (own)

We can identify the main common features and differences between the analysed chains. The objective of both types of supply chain is to deliver goods or services to final recipients. What changes from a technical point of view are the inherent and adherent characteristics of the end recipient. Both types of chains involve the coordination of different actors and stakeholders. However, the stakeholders are changing. HSCs involve a range of stakeholders that business chains do not know. At the same time, stakeholders have a different position and authority in the chain. The configuration of distribution networks is essential for efficient operation. However, it also differs in the humanitarian setting. Although the general principles of tangible and intangible logistics flows are the same, the dynamic and uncertain environment causes complications and differences. Information systems play a vital role in decision-making. Both types of supply chains use information systems. However, HSCs (especially small and medium-sized) are behind the commercial sector. They are not as technologically advanced and lack quality in human capital and data collection. In both types, performance measurement is a necessary prerequisite for data-driven optimization. At the same time, all these aspects play a critical role in performance measurement. Thus, the humanitarian sector will probably never be at the level as the business environment. Therefore, it is crucial to focus on areas we can influence and where we can improve performance.

Figure 2 Performance measurement challenges for humanitarian supply chains



Source: (own)

5. ANALYSIS OF CURRENT THEORETICAL APPROACHES AND MODELS

Research on HSC performance measurement is growing. Despite the growing number of publications, however, a relatively small number of authors have addressed the issue. A keyword analysis of the Web of Science and Scopus databases identified 200 journal articles and conference papers dealing with HSC performance. The analysis was performed by combining the keywords *Humanitarian Supply Chain* and *Performance*, and research areas outside the author's interest were excluded, e.g. energy, meteorology, geology, etc.

Supply chain performance management is no longer based on functional hierarchy, ownership or intra-organisational power but rather on inter-organizational relationships (Forslund 2012). The transformation from organizational competition to supply chains has emphasized the role of managing and improving the performance of supply chains as a whole (Christopher 2005). Managing the performance of the entire supply chain has become a crucial factor in gaining competitive advantage, increasing efficiency and ensuring better execution of objectives (Gunasekaran, Patel, Tirtiroglu 2001). In the last decades, managers have used separate cost, time, and accuracy metrics to manage logistics and supply chain performance (Abidi 2019). As many as 38% of the most widely used metrics between 1995 and 2004 were financial (Gunasekaran, Kobu 2007). However, global supply chains are complex structures in many management areas, and these metrics do not provide insight into areas that are not under the direct control of managers (Shaw, Grant, Mangan 2010). Moreover, HSCs are specific in several characteristics. Thus, such limited metrics may lead to inaccurate or incomplete conclusions (Srimai, Radford, Wright 2011). Therefore, more comprehensive and sophisticated approaches are being explored for planning and managing the supply chain as a whole (Bititci et al. 2011).

Donors are increasingly calling for greater accountability and transparency in the humanitarian sector (Cardoso et al. 2023). A rapid response to a crisis is no longer sufficient. Scrutiny of the effectiveness and efficiency of spending has increased (Anjomshoae et al. 2022). Humanitarian organisations are required to objectively demonstrate positive impacts through sustainable and cost-effective operations (Paciarotti, Valiakhmetova 2021). Several performance measurement standards have been introduced to meet the requirement for greater transparency, e.g. The Red Cross Code of Conduct, The Sphere Project, and The Core Humanitarian Standard. While these initiatives have established standards for humanitarian programmes and projects, they are limited to implementation guidelines and have not been able to fully satisfy the desire for transparency and accountability of HSC (Dufour et al. 2004). Moreover, they are primarily used for reporting purposes and rarely serve as a basis for management decisions to improve performance and resource allocation (Ramalingam et al. 2009). In the absence of rigorous performance measurement systems, donors and the general public are increasingly sceptical of HO (Humanitarian Organization) claims about their impact (Anjomshoae et al. 2022).

Thus, research has begun to focus on more advanced theoretical concepts inspired by commercial supply chain performance. The SCOR (Supply Chain Operations Reference) and BSC models have received the most attention (Behl, Dutta

2019). Both frameworks simplify communication between supply chain actors and lead to increased transparency of supply chain and logistics processes (Gunasekaran, Kobu 2007). SCOR links business processes, metrics, best practices and technologies and has widespread applicability. Successful implementation of the SCOR model can be found in Bölsche's application for WFP (World Food Programme) (Bölsche 2012). The broad applicability of SCOR can create a single reference source for the humanitarian sector (Tatham, Spens 2011). Given humanitarian organisations capacity and knowledge constraints, a unified framework is a strength of this approach. It would allow organisations to partially combat their limitations and provide a uniform standard in the sector. The model has already been partially tested with 13 international HOs (Lu, Goh, De Souza 2016). However, complete testing is hampered by the inadequate state of humanitarian organisations, and the current unpreparedness of the sector may be a drawback.

The BSC considers the financial perspective, the customer perspective, the learning and growth perspective, and the internal process perspective (Kaplan, Norton 1992). One of the earliest applications of BSC in the humanitarian sector was in the final work Davidson did with the IFRC in 2006 (Davidson 2006). A year later, Kyne et al. adapted the BSC to evaluate natural disaster relief projects (Kyne et al. 2007). De Leeuw's research further defined the indicators that can be adopted within the BSC to measure HSC performance (De Leeuw 2010). However, the BSC is also not without its critics. Organizations may want to include social and environmental factors (Epstein, Wisner 2001). Nowadays, these are crucial topics that are also important in the humanitarian sector (notice the link to the SDGs). In humanitarian aid, this is not a priority in the first phase, but the weight of criteria changes over time.

With advances in information technology and data analysis methods, the humanitarian sector has also seen the emergence of innovative and analytical approaches to performance measurement (Anjomshoae et al. 2022). A study by Swaminathan (Swaminathan 2018) provided insights into the types of data streams that could be used to develop big data analytical models to improve the performance of humanitarian operations. Jeble et al. (2020) and Dubey et al. (2019) have developed conceptual models that illustrate the role of big data analytics in improving HSC performance. Agarwal et al. (2019) suggest methods and tools such as analytic hierarchy process, analytic network process, data wrapper analysis, goal programming, rough set theory, and fuzzy approaches to weighting, classification, and aggregation of individual metrics. Researchers have also proposed several other advanced tools for streamlining HSC processes, such as RFID (Radio-frequency identification) (Mukhopadhyay, Roy 2016). However, new technologies have not yet made many inroads in the sector, which relates to HOs limited capacity and skills (Repík, Foltin 2022a), the failure to tie research to the needs of HOs, and other issues identified in this paper.

6. THE CHALLENGES OF MEASURING THE PERFORMANCE OF HUMANITARIAN SUPPLY CHAINS

Setting performance indicators applicable in HSC practice has been a long-standing problem (Anjomshoae et al., 2022; Davidson, 2006). As critical as measuring HSC performance is, it is a complex process and is not consistently performed in most humanitarian organizations (Anjomshoae et al., 2022). Up to 55% of HOs do not track any performance measurement indicators, a quarter uses some indicators and only the remaining 20% measure performance consistently (Blecken 2010). While many performance indicators exist for commercial supply chains, many are invalidated by the nature of the humanitarian sector (Beamon & Kotleba 2006). These differences appear, for example, in the different objectives of commercial and HSCs or the absence of financial indicators as a primary performance measure (Repík, Foltin 2022b). Given the elusiveness of humanitarian services and what constitutes a successful humanitarian outcome, it is even more challenging to translate humanitarian objectives and concepts such as neutrality and impartiality into measurable performance indicators (Anjomshoae et al., 2022).

In the humanitarian sector, it is thus challenging to build a model that ensures the correct performance of flows. In addition to the practical constraints mentioned above, there are also constraints at the conceptual level. It is challenging to link HO's performance (Abidi, de Leeuw, Klumpp 2014) or year-long efforts (Sawhill, Williamson 2001) of a HO to its objectives. Although humanitarian assistance is primarily about alleviating suffering, identifying and quantifying the relationship between HSC performance and alleviation of suffering is challenging (Abidi, de Leeuw, Klumpp 2014). Moreover, it is challenging to consult beneficiaries' views on their assistance due to the unavailability of resources and accurate data (Cardoso et al. 2023; Clarke, Parris 2019). That leads to a discrepancy between the organization's perception of performance and the beneficiaries' perception of the relevance and quality of assistance (Clarke, Parris 2019). There are also problems with the lack of focus on performance indicators for future improvement (Van der Laan, De Brito, Vergunst 2009). Kunz and Reiner point out that HOs cannot fully control the performance of HSC (Kunz, Reiner 2012). In logistics, disaster response is complex regarding tangible and intangible flows. However, HSC as a complex system can be improved by changing the performance of its individual parts (Repík, Foltin 2022a).

After a sudden disaster, the speed of response in the first 72 hours is crucial to save as many lives as possible (Tomasini, Wassenhove 2009b). Speed is the primary criterion for disaster response. However, other specifics of humanitarian operations can limit the speed. Preparation and planning are also critical aspects. However, predicting humanitarian needs' time, place, and scale are challenging. Information is still limited at the beginning of a disaster (Tomasini, Wassenhove 2009b), even if the area has been well monitored before the disaster, which is rarely the case, especially in less developed countries. In logistics performance terms, it is critical to understand the specific impacts and needs and to design and coordinate a response (Tomasini, Wassenhove 2009b). For this, information flows are crucial. They allow structuring the distribution chain around population needs (water, food, medicine, shelter), define the means to meet these needs (storage capacity, access to airports, transport options, telecommunications) and minimize coordination gaps. However, data accuracy and availability may be limited in environments with disrupted information and communication networks (Van der Laan, De Brito, Vergunst 2009). Uncertain and rapidly changing conditions rarely allow the collection of complete and trustworthy data (Kunz 2019). That is also true for the developing sector and long-term conflict areas where security situations hinder assessment and data collection (Anjomshoae et al. 2022). Sometimes only paper is available for data collection, leading to slow, inaccurate, and outdated evidence for logistics planning and supply (Repík, Foltin 2022b). Most HOs use spreadsheet tools to collect and process data. More advanced information systems are a rarity. Thus, one of the reasons for the inefficient use of data is the lack of innovation.

While in the commercial sector, the pressure to perform well comes from the demand side (from customers), in the humanitarian sector, it is usually pushed by the supply side (donors) (Tomasini, Wassenhove 2009b). Aid recipients typically have a weak bargaining position in the chain. In terms of donors' influence on performance, the fact that they may insist that their funds are used for victim assistance and not, for example, for staff training and investment in HO facilities also plays a role (Murray 2005). Some large organizations are known to have high bureaucratic burdens that can limit the speed of disaster response (Thorvaldsdottir, Patz, Eckhard 2021). In addition, highly publicized events are subject to political and marketing pressures (Repík, Foltin 2022b). It can not only put pressure on bottlenecks in the chain but also already limited staff capabilities. However, the human resource problem is broader than limited skills, abilities or knowledge. It is challenging to manage people who are in the organization voluntarily (Repík, Foltin 2022b). HOs have to contend with uncertain availability and workload. A related issue is the absence of performance-based rewards and punishments (Repík, Foltin 2022b). The effectiveness of humanitarian logistics is strongly affected by high turnover and heavy reliance on volunteers (Tomasini, Wassenhove 2009b). High staff turnover results in poor knowledge retention, which creates additional challenges for performance measurement processes (Anjomshoae et al. 2017). In addition, humanitarian missions focused on performance measurement are typically very time and labour-intensive, requiring extensive support (Anjomshoae et al. 2022). In particular, long-term operations can lead to staff burnout or mental exhaustion (Repík, Foltin 2022b).

However, at the heart of the aid effectiveness debate is the recognition that humanitarian action is often driven by short-term objectives. That can lead to unintended negative long-term impacts on society (Anjomshoae et al. 2022). The negative impact can manifest itself, for example, in the form of market distortions and aid dependency (Moyo 2010), damage to the natural environment, or even prolonged conflict (Anderson 1999). Thus, for the above reasons, it is necessary to go beyond cost or time optimization in the humanitarian sector.

8. CONCLUDING DISSCUSSION

The paper discusses the possibilities of measuring the performance of HSC. Due to the factors mentioned above, such as the increasing number of black swan events

(Taleb 2007), climate change (EM-DAT 2023) or armed conflicts (UN 2023), HSC management becomes an elementary discipline for an effective and coordinated response to these emergencies. Academic research is still in its infancy, and in practice, HSCs are still below the necessary resources (Lowcock 2019). For countries affected by natural disasters or conflicts, ensuring rapid and efficient distribution of humanitarian assistance to civilians in vulnerable areas is crucial. The importance of HSC in such situations lies in the ability to correctly identify needs, coordinate different actors, mobilise resources and capital, and ensure safe, rapid and reliable transport, storage and distribution of supplies. As the disparity between humanitarian needs and available financial resources continues to widen (DG ECHO 2023b), there is a need to develop tools and strategies to respond effectively to humanitarian crises.

In a business environment, performance monitoring is a regular practice. Even in the armed forces, evaluations of missions, tasks and projects take place. In the humanitarian sector, however, it is still an emerging innovation that encounters a number of sector-specificities in practical applications (Repík, Foltin 2022b). HSC operates under challenging conditions of uncertainty and time pressure. As a result, performance measurement is often not a priority and is, therefore, less mature than in business supply chains (Anjomshoae et al. 2022). Establishing performance indicators is also problematic due to the differences between operations, long- and short-term interventions, and pre-and post-disaster phases (Repík, Foltin 2022b). For example, while in acute and rapid response environmental aspects may be sidelined, they should be considered in long-term programmes. Such specificities offer the need for future research on dynamic models for performance management, i.e. models that account for changing priorities over time. Measuring HSC performance requires a systematic and impartial examination of humanitarian operations to increase transparency and accountability (Anjomshoae et al. 2022). The problem should be looked at holistically, seeking ways between the trap of over-generalisation, and the specificity of individual operations (Repík, Foltin 2022a).

However, these challenges and limitations do not mean measuring performance in a humanitarian context is impossible. HOs have recognized that measuring HSC performance can facilitate and guide process improvement initiatives (Rongier et al. 2013). However, measurement frameworks with too many indicators can be complicated, costly, time-consuming, and a drain on already limited time and resources in the humanitarian sector (Anjomshoae et al. 2022). A matrix dividing indicators according to the importance and feasibility of implementation (Lu, Goh, De Souza 2016) or dividing indicators according to linkages to results (Parmenter 2015) can suggest the importance of indicator prioritization. HOs have gradually become aware of the need for empirical research that can provide insights into performance measurement systems, and more integrated and analytical approaches to analyzing the effectiveness and efficiency of their efforts are increasingly being explored (Anjomshoae et al. 2022). A possible strategy to overcome these challenges may be research leading to a general framework for implementing performance measurement systems in humanitarian environments.

The application of the performance measurement, frequently used in private business models, are applicable within humanitarian supply chains. There could be proper to focus the consecutive research on the limitations of the direct applications, together with the real availability of the data inputs. In this area, the Big Data approach and application of data-mining tools could bring new insight to proper management of available scare resources under the emergency and disaster relief conditions.

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THE IMPORTANCE OF RISK MANAGEMENT IN THE COLD SUPPLY CHAIN

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Abstract

Risk management within the cold supply chain provides an important part of logistics processes. The cold chain has its many specificities, which consist of a series of activities that must be ensured in order to maintain the required set temperature of the product. For the success of the process in the cold supply chain, it is necessary to minimize every possible risk. In this way, the quality of easily perishable products would be maintained. Standardisation (ISO standards) of the cold chain supplies in this context contributes to its quality and functionality. For the purpose of researching this paper, a survey was conducted on 205 respondents. The main goal of the research was to improve that in the trade of frozen products it is necessary to manage the risks of the cold supply chain in order to ensure the quality of products and services. In the research, it is evident that a large number of consumers encountered products that were under an impermissible temperature that is not set by the standards. 55.1% (113 respondents) confirmed that they encountered a product that was thawed and refrozen. Furthermore, the respondents encountered another problem, damaged packaging of frozen products, which can also have major consequences for the product itself, because the packaging itself has the function of maintaining freshness. Therefore, the problem is not always in the set temperature itself. The survey also mentions problems related to finding damaged goods and broken goods due to poor conditions, as well as the risk of open refrigerator doors, which half of the respondents encountered. In this case, it is necessary to manage risks in the cold supply chain using and applying the requirements of the ISO 28000:2022 standard (risk management in supply chains) as well as using certain risk management tools and analysis.

Keywords: management, risks, supply chain, cold products, quality

1. INTRODUCTION

Supply chain management requires constant challenges. There are several types of supply chains and each of them is inherently different from one another. In this paper, the focus will be on the cold supply chain, that is, the supply chain of products that require low temperatures. This is a very demanding supply chain because it is a commodity that is easily perishable if the given conditions are not met. Such conditions must be met during storage, preservation, transportation, manipulation and other activities within the supply chain. This research paper hypothesizes that there are certain shortcomings of cold supply chain management that can have a bad impact on product quality, business operations and consumer health. Through the conducted research, an attempt will be made to obtain information on whether all the given conditions are respected for the mentioned products and whether the given standards are respected. This work is based on secondary sources that were relevant to the research of the cold regime area, while the research itself, carried out through a survey, is based on primary sources where all valid data were analyzed after the information obtained. The paper aims to reveal the possible risks of the cold supply chain by asking questions. The questions are defined according to possible places of occurrence of a certain risk. The paper used an analysis method that investigated the causes of the market situation and defined possible factors influencing them. After the conducted survey, a deductive method was used, through which conclusions could be reached after the conducted analysis. In the first part of the work, secondary sources of different authors are listed. In combination with the method of comparison, the professional literature of different authors on the subject that the paper deals with was studied. Using the method of compilation and description, all the important points of view of the authors of professional literature were summarized and compared with practice. In the second part, the previously mentioned market research with real data and the conclusion of the research was mentioned. The research of this work was carried out at the level of the entire Republic of Croatia. At the end of the paper, the standardisation (ISO) of the cold supply chain was mentioned in the context of risk reduction, and some of the tools for risk management were listed.

2. COLD SUPPLY CHAIN

A supply chain consists of many different links and activities. It all depends on what kind of chain it is. It also depends on the type of goods that pass through that chain. Certain goods require to be treated in a special way, such as goods that require a certain type of temperature during flow and storage. Such a chain is called a cold supply chain.

Cold chain management refers to the creation of an integrated distribution model focused on three key factors, namely product attributes, performance characteristics, distribution channels, and product origin and destination locations. The product property factor refers to their physical characteristics and special requirements for temperature, as well as humidity during transport, handling and storage. The following are the places of origin and destination of products that describe the place of final production and consumption of products sensitive to temperature fluctuations. Their interaction enables a detailed description of the cold chain by separating its subsequent subdivisions. Industries that use a cold supply chain are fruits and vegetables, meat and seafood, floriculture, dairy products, confectionery and pharmaceuticals. (Brzozowska, et al., 2016.)

Depending on the type of cold products, certain temperatures are required that vary from -30 °C to +14 °C and these are the following types:

- Banana (12 °C to 14 °C), a group characterized by temperature range enabling to monitor ripening of fruit,
- Pharmaceutical (2 °C to 8 °C), for most specialty pharmaceuticals including vaccines,
- Chill (2 °C to 4 °C), products for which the average storage temperature includes fresh fruits and vegetables, dairy products, meat products and similar,
- Frozen (-16 °C to -20 °C), category for frozen products including meat,
- Deep freeze (-28 °C to -30 °C), group with the lowest achievable temperature, designed to transport seafood. (Wojciechowski, 2014.)

We can see that the temperature required to keep cold products varies. Temperatures that exceed accepted standards may cause damage to products or loss of their required value. In cold supply chains, it is important to minimize transport costs and ensure the safety of transported products. Otherwise, there may be a loss of their physical and chemical properties, which leads to irrational material losses. (Brzozowska, et al., 2016.)

Farms and markets are highly fragmented, leading to an increasing number of intermediate products in the chain, resulting in high delivery times, costs, waste, order returns, complaints and customer dissatisfaction (Shashi, et al., 2018.). Such a thing should not be associated with cold products because they are the most sensitive in that part. Time, which is constantly mentioned, is, along with temperature, the most important component of the cold chain. The delivery time of cold products should be minimized with as few waits and stops as possible to the end point of the supply chain.

In the delivery of products to consumers using a cold chain delivery system, the characteristics of the product determine the evaluation and control systems necessary to maintain the freshness and quality of the product during its delivery to the end user. It is also important to monitor the temperature during the entire cold chain process in order to ensure the safety and quality of the cold chain products, and it is also important to know the nature and characteristics of the product for the construction of the cold chain. With products having a short shelf life and requiring special facilities for storage, distribution and sales, the development of cold chain management (CCM) was a natural progression in supply chain management. (Danso, 2021.)

Storage of such products under consistently recommended conditions is essential for their quality. Storage is done by keeping it using pallets, crates, cartons, glass/plastic bottles and other suitable containers. Such preservation extends their life and ensures that their quality is maintained over long shipping periods, while the chances of waste, waste disposal costs and associated emissions are minimized. (Sharma, et al., 2021.) However, it is not enough just to properly store cold products, it is necessary to pack them properly, and only in this combination can we say that such products are properly stored (Ndukwu, 2017.).

Research in Pakistan in 2011 revealed that 32% of food produced in that country is thrown away due to risks related to cold supply chain management (Khan, et al., 2022.). In this segment, it is important to recognize the risks that affect the management of the cold supply chain. They are the reason for possible losses in that chain. Proper risk management reduces their negative impact. Below is a research of the risks that may appear in the cold chain. After that, the ways in which they can be detected and managed will be listed.

3. COLD SUPPLY CHAIN MARKET RESEARCH

In this part of the paper, the research of the market of cold products will be mentioned. The research is based on secondary sources that were relevant to the research of the cold regime area, while the research itself, carried out through a survey, is based on primary sources where all valid data were analyzed after the information obtained. The paper used an analysis method that investigated the causes of the market situation and defined possible factors influencing them. After the conducted survey, a deductive method was used, through which conclusions could be reached after the conducted analysis.

3.1 Research method

Research on the topic of this paper was conducted using the sample method through a survey questionnaire. The necessary data for the research was obtained by conducting an anonymous survey in digital form. 205 respondents (n=205) were surveyed. The respondents are buyers of cold products in stores in the territory of the Republic of Croatia. This questionnaire included the collection of quantitative data. Questions are precisely defined in advance that will serve as a source of information and are necessary for this research and their graphic arrangement. Such research used sampling, which, based on a smaller and carefully selected group of people, tried to estimate the percentage parameter or the real average value of the population, i.e. to determine the framework within which the wider community's opinion on the quality of keeping cold products is likely to move. On the basis of the above, the goal of the research is to be realized, which is to detect possible risks by surveying the citizens of the Republic of Croatia. It should be noted that the questions in the survey were determined in such a way that possible places and ways of occurrence of risks from practice were taken into account. All questions were multiple-choice with the question asked and the answer offered, next to which respondents should put a mark if they agree with any of the answers offered. The questions in the survey were simple, mainly for the reason that the respondents would not get confused and that they could give as concrete an answer as possible in accordance with the hypotheses set in the paper. The research was conducted during the first half of 2022.

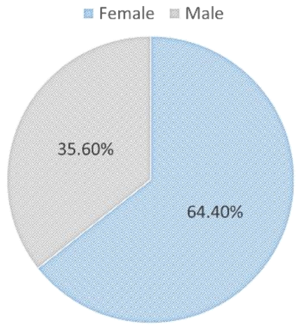
3.2 Research results

The purpose of this research, which was conducted through a survey, is to provide us with answers to the assumptions stated in the paper, and in this way to gain an insight into how the cold chain works in practice, primarily from the consumer's point of view. With the aim of reviewing the conditions and problems in the trade of chilled and frozen products and to obtain a customer rating with the quality of the cold supply chain through product quality assurance.

3.3.1 Graphic display of data

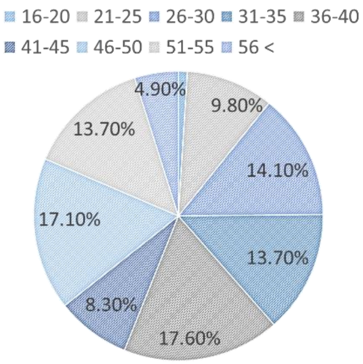
In this part, a graphic presentation of the data obtained by the previously defined survey questionnaire follows. With each graphic representation there is an additional explanation of the results. The information from the obtained data is defined.

Figure 6 Ratio of male and female samples



Source: Authors

Figure 7 Age group of samples

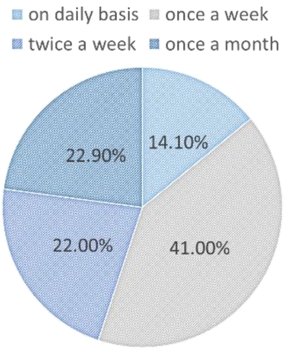


Source: Authors

In Figure 1 one can see the ratio of female and male respondents. In this research, we have a higher proportion of female (64.40%) compared to male (35.60%)

respondents. The graph from Figure 2 shows the age groups of the samples. It can be seen that the age group from 16 to 20 years is in the smallest percentage of only 2 respondents, which is 1%. While the age group from 36 to 40 has the highest percentage of 17.6% (36 respondents).

Figure 8 Frequency of purchase of chilled and frozen products



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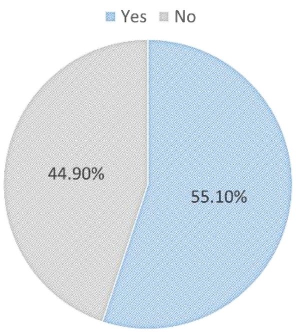
Further questions in the survey were specified in order to gain an insight into which link is the weakest when the product from the cold regime is already placed on the market. When asked how often they buy chilled and frozen products, the largest percentage (41%) answered once a week, 22.9% answered once a month, which is almost equal to respondents who buy twice a week. 14.1% buy products on a daily basis. The above shows us that people have different habits when it comes to buying products from the cold regime. The obtained data can be seen in Figure 3. When looking at the broader picture, it is evident that the vast majority buy chilled or frozen products almost regularly on a daily, weekly or biweekly basis, which speaks volumes about the important function of such a supply chain.

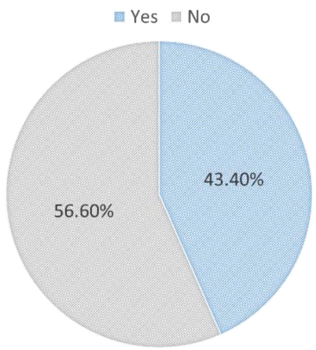
Figure 9 Temperature changes on products observed by customers



Source: Authors

The next question was about whether the customers came across products that were previously thawed and then frozen again. It can be seen in the graph from Figure 4 that out of 205 respondents, 113 of them responded with an affirmative answer, which is 55.1%, while 92 of them (44.9%) responded with a negative answer. Most respondents can recognize if the product has been improperly handled during transport. Such an obtained result is a consequence of an emerging risk in case of inadequate handling, which damaged the quality of the product. Visible signs on the product that indicate changes in the temperature of frozen products are a change in the shape of the product (for example indentations on the product), further wet spots on the packaging (especially on cardboard and paper packaging it is easy to see signs of thawing), the formation of ice crystals inside the closed packaging, stuck to the contents in packaging, product color change (if it is visible through the packaging), etc. A little more than half of consumers have encountered a temperature risk in the cold supply chain, if the temperature of the product is regularly monitored in real time, it is easy to see where the link in the chain has weakened.

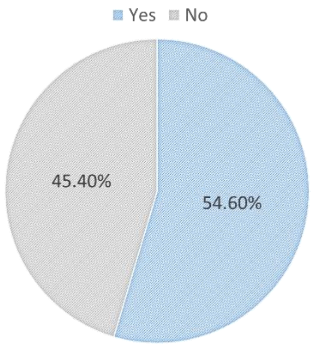
Figure 10 Consumer experiences with damaged packaging of frozen products



Source: Authors

The next question shown in Figure 5 refers to whether consumers had a situation where they bought a product that was damaged (eg its packaging). 56.6% gave a negative answer, while the remaining 43.4% answered that they had encountered the stated condition of the product. This gave us the information that the majority of respondents did not have a negative experience with a damaged product, but still the remaining 43.4% encountered such a situation, and it is certainly not a negligible problem that occurs on the market. Product packaging has a much greater function than that packaging looks nice and attracts the customer. Any damage to the packaging creates the possibility that the customer buys a defective product, which in the extreme case can harm health. It is evident from the research that this problem is present, and when it comes to the fact that this problem is in the cold chain, then there is a double risk. Damaged packaging and the possibility of temperature changes can seriously damage the quality of the product itself.

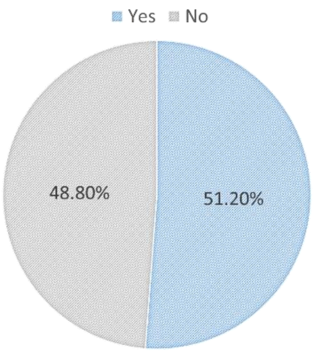
Figure 11 Opened doors of refrigerated shelves



Source: Authors

The next question shown in Figure 6 refers to risks that do not occur within the process, but occur after the products have been placed on the market due to the consequences of human carelessness (trader or customer). According to Figure 6, we see that the majority of respondents (54.60%) had experience with an open refrigerator, while the rest (45.40%) did not have this experience. Due to such cases, it often happens that the door of the refrigerated display case remains open/semi-open, which can also damage the quality of temperature-sensitive products. If the door of the display case on the refrigerator is left open or half-open, the temperature in the refrigerator increases, and the situation occurs where the refrigerated products release rarefied air, and on the other hand, the product becomes hotter. By mixing warm and cold air, moisture is created on the product and the packaging becomes wet, which may indicate problems during storage, improper loading or unloading, but in fact the problem arose in stores due to the human factor. For this reason, it is important to record the temperature at every step in order to accurately determine the place of origin of the mentioned problem.

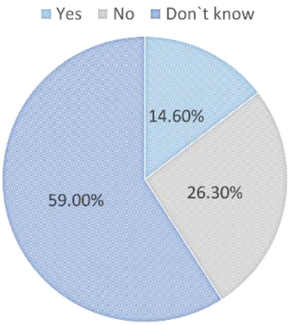
Figure 12 Buying spoiled product



Source: Author

There are products such as meat, fish, milk or eggs that you should definitely pay attention to in their condition because they can dangerously harm the customer's health. The declaration of the expiration date is not the only guarantee that the product is healthy. A problem with the product can also arise when the expiration date is correct, and some part of the process within the cold chain is not respected according to rules, standards and other. Most often this happens in the summer months when the change in temperature easily affects all links of the cold chain from loading, unloading, storage, etc. Some of the solutions can be giving importance to temperature oscillations in warmer months in all stages of the process. On the graph in Figure 7, we can see the worrying fact that almost 51% of the respondents had an encounter with the purchase of a damaged product that had passed its use-by date or was the result of a risk that was not observed within the development of the cold supply chain process. So, it is about the majority of those surveyed. In order to avoid health problems, it is important that customers are careful when buying this type of product despite the expiration date being correct, but on the other hand, it sometimes happens that the expiration date is 'deceptive', which results in unnecessary food waste even though it is still safe for consumption. From this research, data was obtained that the cold chain does not function perfectly and that risks have been observed.

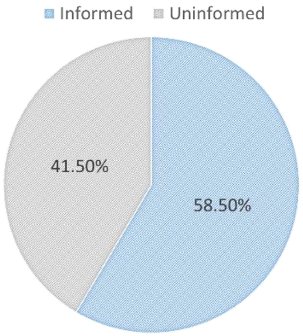
Figure 13 Purchase of products that have subsequently removed from sale



Source: Author

The next question from Figure 8 refers exclusively to products from the cold chain such as meat, fish and other, although the situation with the remove of products from stores for the sake of consumer safety is much more extensive. The situation of removed products from all food categories, not only frozen and semi-frozen products, is becoming more and more frequent. What is worrying is that the vast majority of consumers do not know or are not sure if they have bought and consumed products that were subsequently removed from the market. If we look back at the data obtained through the survey, out of the total number of participants in the survey, even 59% of them responded with *I don't know*, while 14.6% of them responded with an affirmative answer. Only 26.3% of them answered with a negative answer.

Figure 14 Informing customers about the risks of the cold supply chain



Source: Authors

When asked whether consumers are informed about all the risks of improperly stored products from the cold chain, in a survey of 205 respondents, 58.80% answered that they were informed, while 41.50% answered negatively. This indicates to us that there is still a large percentage of consumers who do not take care and are not aware of the risks when buying perishable products.

3.3.2. Research analysis

The research showed that Croatian customers often buy cold products, whether on a daily, weekly or monthly basis. Many respondents encountered products that were thawed and refrozen, which created a risk of product defrosting. This leads to further risks related to the poor quality of the purchased product, and in some cases there are risks related to the health of consumers if such products have been exposed to higher temperatures for too long. If the temperature of the product is regularly monitored in real time, it is easy to see which link in the chain has weakened. The reason can also be various malfunctions in cooling devices, carelessness when monitoring the temperature, etc. In addition to temperature changes, the respondents also had experience with damaged packaging, which leads to risks such as reduced product freshness, reduced shelf life (mostly in the case of fruits and vegetables), microbiological risks, etc. Any damage represents a risk that the customer will buy a defective product. Problems must not only appear in the process of storage, loading or unloading, but also in the part of the supply chain when the product is already available to the customer. For example, respondents in the survey mostly confirmed that they encountered open doors of refrigerated display cases in stores. This leads to an increase in temperature in refrigerated display cases and refrigerators, and the products begin to change their properties, which can affect health safety. Mixing warm and cold air creates moisture on the product. The cause of such problems are malfunctioning display cases or human carelessness, which is the reason in most cases. These are just some of the risks that can occur, and this problem can also lead to risks related to the failure of parts (e.g. the compressor). A good solution can be sound sensors that will warn of the mentioned problem, which can significantly reduce the risks. Half of the respondents encountered defective products, which shows that the risks are active. The most common reason for this may be the expiration date of the product, but the expiration date does not have to be a guarantee of the correctness of the product, as some other problems may arise in the management of the cold supply chain. We asked the respondents if they had encountered a situation where they bought a cold product that was subsequently withdrawn from sale after their purchase. The vast majority of respondents do not know if such a situation has happened to them (probably due to poor consumer information), while the fewest answered that they have (14.6%). This figure should not be neglected because the risks in this case can be dangerous for the health of consumers. That is why good and timely consumer information is important if such a product was available for purchase. This leads to a reduction of further possible risks. Although the majority of respondents answered that they were informed, almost half of the respondents were still not informed about the risks that may arise. Then the risks become even greater and more uncertain.

On the basis of this research, it is concluded that it is necessary to manage risks in the cold supply chain, which will ensure consumer safety, business credibility and ensure a competitive advantage on the market.

4. COLD SUPPLY CHAIN RISK MANAGEMENT

We saw in the previous chapter of this work that the risks in managing the cold supply chain are very present. In order to reduce the mentioned risks, it is necessary to ensure quality management of such a chain. This should be the responsibility of everyone within the chain, and mostly risk or quality managers.

Standard ISO 28000:2022 talks about risk management in the cold supply chain. It is the basis of quality management of such a chain, which reduces numerous risks as well as those mentioned in the previous research. ISO 28000:2022 is an international standard that requires specific qualifications in the safety management system and includes some critical aspects related to the assurance of safety in the supply chain (Huei Ing, et al., 2019.). Safety is ensured by minimizing risk in every segment and link of the supply chain. In this case, the risks of the cold chain must be specifically detected in order to avoid problems for the organization and for the consumer himself. As stated by certain authors (Huei Ing, et al., 2019.), supply chain security management is important for every industry in any field. This is because the level of market demand for products and services must be fully in line with the requirements of the ISO 28000:2022 standard. This standard must help in continuous improvement to achieve a high level of standards, not just small improvements in the company. The characteristics of ISO 28000:2022 are that it has a pragmatic and business-oriented approach to risk management and promotes risk management as a central component of effective management. The standard also ensures that key decisions are made based on an effective risk assessment process, supports overall compliance management and protects the company from liability issues and third-party claims. (Franke, 2013.) Ultimately, this provides greater consumer satisfaction.

The authors (Prasad & Baker, 2020.) state that risk management must have its own strategy. It must be specialized in perceiving and analyzing the possibilities and outcomes of threats and in selecting appropriate strategies to reduce the likelihood of episodes associated with hostile events. It must be aimed at reducing the effect of the observed risk event. For a better risk management process, 4 steps are carried out:

1. Identify the Risk,
2. Assess the Risk,
3. Control risk,
4. Review controls. (Mahmood, 2021.)

Certain tools can be used in risk management, such as BowTie, which represents the basis for ensuring business continuity. Then SWIFT analysis (Structured What-If Checklist Technique) and HAZOP (Hazard and Operability Analysis) can be used, which is a qualitative tool, and the input to the tool is brainstorming. FMEA (Failure Mode and Effects Analysis) is most often used, which, in addition to risk analysis, also serves to define measures. The authors (Kardos, et al., 2021.) state that the FMEA method belongs to the group of basic analytical methods used in the process of risk management, quality management, reliability and safety, and is one of the basic methods used in the risk assessment process. They also state that it applies not only to production processes but also to financial and social processes. The main goal of the FMEA method is to recognize the possibility of failures as soon as possible, identify their possible causes, consequences, assess risks and safely prevent them.

The most common quality management systems are ISO 9001:2015, Six Sigma, LEAN management and Total Quality Management. In addition to the mentioned standard, there is also the ISO 9001:2015 standard that talks about quality management. These two standards can be closely linked in cold supply chain management. The principles of quality management can be defined as a series of fundamental beliefs, standards, rules and values that are accepted as true and serve as a basis for quality management. The key principles mentioned are customer focus, leadership, involvement of all employees, process approach, continuous improvement, fact-based decision making and relationship management. There are three levels at which quality can be observed:

- quality management systems and models,
- quality tools and techniques,
- quality principles and values. (Buntak, et al., 2021.)

During quality management, it is possible and recommended to use certain tools such as the cause/effect diagram - Ishikawa diagram, Pareto diagram, flow diagram - flowchart, test sheet - check sheet, histogram, scatter diagram and control charts.

In this section, we clearly see that there are ways to properly manage risks at all times. All the above tools, standards, methods and risk management strategies are necessary if we want our cold supply chain to function with quality and without problems. Without such risk management and compliance with standards, we cannot ensure the quality of cold products that are available to consumers every day.

5. CONCLUSION

The cold supply chain is one of the riskier chains. It must meet the numerous requirements of the products that pass through it. Frozen or cold products require a certain temperature that preserves them, otherwise their properties change. In addition to transport under special conditions, it is also important to store cold products, which extends their life and ensures the maintenance of their quality during a longer period of shipment, while the chances of waste, waste disposal costs and related emissions are minimized. One of the measures to preserve product quality is constant temperature measurement and record keeping. In order to determine that there are risks in the cold supply chain, a survey was conducted of Croatian customers of cold products who buy them every day. The scientific research showed that risks are present in certain segments. These risks can be affected by a number of situations from defrosting the products to their refreezing, and it has also been established that there is a problem when customers carelessly leave the cooling devices open and thus increase the temperature of the products. Such problems also affect the health of consumers who cannot know if they have bought a defective product. Some products were later withdrawn from sale, but there is a problem of poor information, which creates additional risks. This confirms the hypothesis of the work set out in the introduction, because the mentioned problems revealed by the research can affect the quality of the product, the business of the company and the health of consumers. In order to reduce the mentioned risks, this work recommends quality risk management through the implementation of a clear strategy. Such a strategy must be in accordance with standards (at most ISO 28000:2022 and ISO 9001:2015), certain risk management tools (eg FMEA) and quality management tools must be used. With this, we can ensure better business operations, a more functional cold supply chain and better customer satisfaction. After the research carried out in this paper, an open question arises as to whether this survey of customers can detect risks and see the actual state of their management, or whether other research is needed. Therefore, future research should go in the direction of risk detection by research conducted on other stakeholders of the supply chain who are responsible for the storage and handling of cold products. This would reveal whether there are any deviations from the survey conducted on customers and the one conducted on other responsible stakeholders.

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ALLOCATION MEASURES IN A VOLATILE MARKET A STUDY CASE FOR SEMICONDUCTORS

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Abstract

This paper, motivated by the experiences of a major automotive company in Romania and has the purpose to analyze why the components enter in allocation to find the root cause to propose further improvement solutions.

This paper represents a study case regarding the process that it's followed by raw materials which enter an allocation.

This paper will focus on analyzing and answering one question, regarding the main cause for components to end in allocation process. The target is to define, which situation creates more challenging situations: poor planning or capacity constrains. The main questions that remain to be answered are regarding the definition of the steps to be taken for each of the scenarios analyzed: poor planning and capacity issues.

Keywords: allocation, inventory management, demand fluctuations, uncertainty

1. INTRODUCTION

The semiconductor crisis which affected over 169 countries worldwide, made us understand that we are currently in a volatile market where uncertainty is a decisive factor into taking decision regarding inventory management.As the crisis continues, companies around the world have developed different strategies to overcome the challenging situations, one of them being the allocation of critical devices in order to support different customers and not interrupt the production flow Starting with the definition of the allocation process, this is the action to distribute an amount of a resource assigned to a particular recipient.

Due to the crisis of semiconductors this was one of the strategies used by some suppliers of this devices to support the demands of more customers. Nevertheless, the allocation processes it is a two-sided sword, as it may support and help the manufacturing companies of semiconductors, and it may support the major customer, but for the small players, this approach may jeopardize their business.

As stated by Mallik and Harker (2004), we can define the allocation process with the liniarity of the information, and the product and manufacturing managers that have access to confidential information such as demands and capacities, should present the information in a clear maner in order to avoid the misrepresentation of forecasts.

In recent years, the automotive industry has faced a significant shortage of semiconductors, which are essential for various electronic components used in vehicles. This shortage, primarily driven by increased demand from other industries and disruptions in semiconductor manufacturing, has led to the allocation of available semiconductor supply among automakers. As a result, some manufacturers have prioritized the production of high-demand vehicles or models with higher profit margins, while others have had to reduce production or temporarily halt the production of certain vehicles.

As for the experience with an allocation process for a multinational company, this paper has the purpose the analyze are popping up in the allocation process and how can be avoided to have unexpected devices entering this process.

2. PREVIOUS RESEARCH AND LITERATURE REVIEW

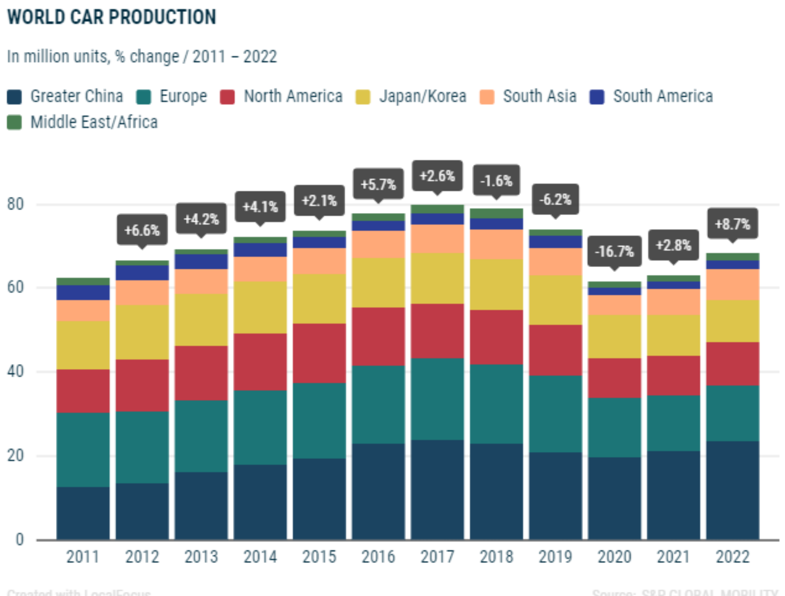
Accordingly, to East and Kaspar in an article for Industrial analytics platform,the actual status of the semiconductor chip crisis was caused by multiple factors in the early 2020s.The variability in the market and the complexity of the production, which was affected by the COVID-19 lockdowns, with the supply chain disruptions lead to an unstable situation at the manufacturing companies.These multi stage production processes, where for som suppliers, where for example for som suppliers the back-end process happens in one location and the front-end process is realised in another one, with extreme labour, are challenging and hard to maintain in challenging situation. The production capacities for the semiconductors are mainly in Taiwan, China and Republic of Korea, Japan, the United States and few in Europe.With the complexity of the process and the few available options for specific tehnologies, the criticality incresed over time, as the demands grew higher, and the production capacity stayed the same.

As visible in below figure, the world car production incresed yearly until 2019, where we have a decrese for two year in a row, this drastical change was based on the COVID-19. As we can see in the graphic, the decreasing trend was for the period when the pandemic was at his hight end. After the lockdowns and the situation was stabilized, as it is visible in the graphic, the production of the cars wordwide started to grow once again, being altmost at the same level, as before the pandemic. And so, only from 2021 to 2022, we are having an increase in car production of 8.7%. An increase which was redirected and transposed in the demands for the semicondutors.

Taking into consideration, the fact that the smartphone industry, had an highly increase over the last years as well, this also increased the demands for microchips, and split the capacity at some of the supplier for producing specific outputs for automotive and non-automotive usage.

Accordigly, to Mallik and Harker (2004), when such situation arise, when the demands keep on growing and where the capacity extension is expensive and time consuming, it is very common to go for an allocation process.

Figure 1 WORLD CAR PRODUCTION, In million units, % change / 2011 – 2022,

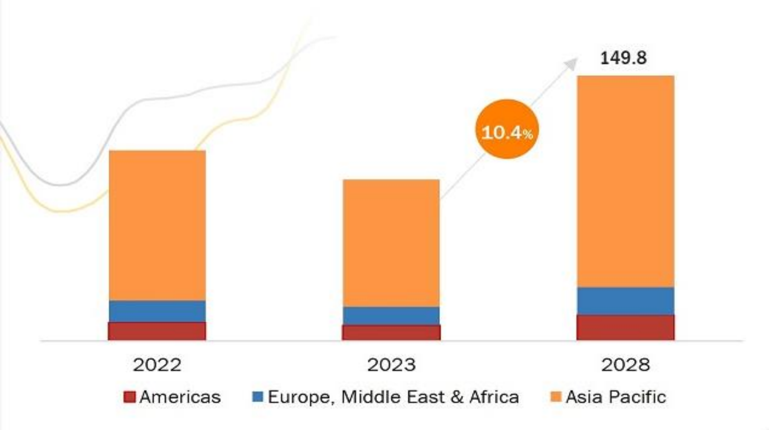


Source: ACEA, 2023

Accordingly, to Mallik and Harker (2004), when such situation arise, when the demands keep on growing and where the capacity extension is expensive and time consuming, it is very common to go for an allocation process.

The semiconductors market it is increasing acording to Markets and Markerts report, the goal to reach for 2028 it is USD 149.8 billion in manufacturing equipement, an increase of 10.4% of the actual status now in 2023, as visible in the Figure 2 below.

Figure 2 Semiconductor manufacturing equipment market, global forecast to 2028



Source: Marketsandmarkets.com (2023)

Even if the forecast it is for improvements, in the actual situation we are still facing challenging situation with the actual supply, which leads to follow several strategic options in order to prevent any types of disruptions in the production processes.

One of the strategic options companies are following as stated by Miller & Graham is to have a more selective view on the suppliers. Today we are having a lot of accesible platforms where we can monitor the score of the suppliers such as, for example, Z2data. For the scoring process are taken into consideration several different criteria such as: lead time, capacity constraints, price, tehnology, alteratives proposed by the same supplier, delivery in time.

As a completion on the above statement, we need to add the perspective from Yu et al. (2008), which stated that manufacturers are now in the search of improving the colaboration with the suppliers, to build up a partnership, in order to improve the performance.We can conclude here, that based on a good selection of the suppliers, we can select the competitives and trusthworty ones, and we can build up stronger partneships with the help of which we can fluidize the supply chain.

Overall, building partnerships with suppliers is about creating a collaborative, mutually beneficial, and resilient supply chain. These partnerships can enhance the competitiveness, reduce risks, and contribute to business's long-term success.

Another constrains that apear here is the bullwhip effect, which apears in the variability of the market, according to Cachon et al. (2007), it is affecting the whole supply plan from retail to manufacturing. This is where the uncerstainty it is build, based on the variability from customers we add variability to the supplier, taking into consideration the longer lead times that we are having today for such types of componets, adding variability only increases the risk of shortages.

In summary, the bullwhip effect can complicate the allocation process by introducing demand variability and uncertainty at different points in the supply chain. To address this challenge, companies often need to implement better communication and collaboration practices, invest in advanced forecasting and demand management tools, and adopt more flexible and responsive allocation strategies to adapt to changing demand patterns. Reducing the bullwhip effect can lead to more efficient and effective allocation of critical components and resources in the supply chain.

3. METHODOLOGY

3.1 Rules for entering in the allocation process.

In industry, the allocation of critical components refers to the process of determining and distributing limited or scarce resources, particularly those components that are essential for the functioning of various industries or sectors. These critical components can include raw materials, parts, or specialized components that are integral to the production or operation of certain products or systems.

The allocation of critical components is typically necessary during times of supply chain disruptions, such as natural disasters, economic crises, or geopolitical events that can impact the availability of key resources. In such situations, industries must

prioritize and allocate these critical components strategically to ensure continued production and minimize disruptions.
For every company the rules for some devices to enter into an allocation process may differ as the time frame for which an allocation should be kept it is defined by every business. Internally, it was defined that the allocation process often involves several key steps:

- Identification of critical components: Industries assess which components are essential for their operations and identify those that are most vulnerable to supply chain disruptions. These components could be sourced from a single supplier, have long lead times, or have limited availability.
- Prioritization: Once critical components are identified, industries establish a priority system based on factors such as the impact on production, customer demand, safety requirements, and contractual obligations. This helps determine which sectors or customers should receive the limited supply of components.
- Allocation strategy: Industries develop an allocation strategy to distribute the available critical components based on the established priorities. This strategy may involve allocating a percentage of the available components to different sectors, customers, or geographic regions.
- Communication and coordination: Effective communication among suppliers, manufacturers, distributors, and customers is crucial during the allocation process. Transparent and timely communication helps manage expectations, address concerns, and ensure a coordinated approach.
- Monitoring and adjustment: The allocation process requires ongoing monitoring of the supply chain and the availability of critical components. Industries must adapt their allocation strategy as conditions change, ensuring the most efficient use of limited resources.

For the company in cause the time horizon which a material it is kept in allocation it is one year, and the so named material enters the allocation when the coverage for it is under 13 weeks. The same methodogy is used for all components that enters the allocation process.

The coverage is given by the actual inventory, actual demands and confirmed delivery plan from the supplier, as calculated by formula (1).

$$Coverage = Actual\ Inventory + Confirmed\ delivery - Demands \quad (1)$$

So as a first rule, a material enters in allocation if the coverage it is lower than 13 weeks. The coverage may go under this green value (over 13 weeks) due do one of the following factors:

- The supplier does not have enough capacity;
- Insuficient orders/not enough capacity reserved at the supplier;
- Quality issues;
- Poor planning and poor mix optimization.

Despite the reason behind entering the allocation, another rule for this company is that the material will not be excluded from this process until the coverage is stable for the entire year. Once in allocation another golden rule it is to postpone or avoid, if possible, the customer impact.

The company the research was made on it is a multinational company, so it has worldwide site where finished goods are produced, in many cases, more than one site use the same raw material, for different project/finished goods and for different customers. As for that the first step is an internal allocation, and a fair distribution between the sites that are using the critical component, and further a distribution on projects and customers at the site level.

2.1.1 Distribution for the critical components

For the analysis we will take 4 components (A,B,C,D) from one of the supplier of semiconductors. These components are used in three sites on a different number of projects/final customers split as per bellow table no. 1.

Table 1 Split per projects

Site/Product	A	B	C	D
Site 1	4P	1P	1P	2P
Site 2	2P	3P	1P	4P
Site 3	1P	1P	1P	1P

Source: author

The P in the table it's noted for project, so based on that we can see that for examplethe raw material, A it's used in 3 diferent sites, in site 1 for 4 diferent projects, in site 2 for 2 different projects and in site 3 for only one particular project. Product B is used in 3 sites, for site A is used for 1 project, for site 2 is used for 3 projects, and for site 3 for 1 project. Product C is used in 3 site, and in each of them is only used for one project. Product D is also used in 3 sites, for site 1 for 2 projects, for site 2 for 4 projects and for site 3 in 1 project. Based on this table we can see, that mostly product A and D had the highest usage globally, both of them being used on 7 different projects. Also, for site 3, we can see that as for now they are only using the products for one projects, leading that this is a site with a low capacity for production, comparing with the other two sites.

The above split per project generates the demands for every site for every component. Based on that and taking into account the actual stock and future deliveries, we can calculate the coverage. In below table, will have a view an the actual situation for each site, for each of the mentioned products. With that we will have a line which will contain the actual stock existing in each site for each component. Another thing included into the view will be the demands per week, pieces needed generated by the production planning, which was also generated by customer orders. Another column in the table, it's stating the weekly deleveries, confirmed and aligned with the supplier for each of the four components. The orders for these devices were placed according to the lead time specifed by the supplier, and the quarterly volumes were splited weekly accordigly to sites demands. Having the current view, with the actual stock, actual demands based on the production planning and the weekly qty delivered per week as per bellow table no 2.

Table 2 Actual view for the components

Site	Product	Current stock	Demands/week (QTY)	Deliveries/week (Qty)
Site 1	A	256,000	76,000	26,000
Site 2	A	93,000	20,000	26,000
Site 3	A	27,000	15,000	26,000
Coverage all sites Product A				
Site 1	B	18,563	15,000	30,000
Site 2	B	88,761	15,000	30,000
Site 3	B	32,700	15,000	30,000
Coverage all sites Product B				
Site 1	C	10,000	5,000	5,000
Site 2	C	8,644	5,000	1,000
Site 3	C	5,469	2,000	4,000
Coverage all sites Product C				
Site 1	D	96,400	21,000	20,000
Site 2	D	154,600	45,000	30,000
Site 3	D	44,000	12,000	20,000
Coverage all sites Product D				

Source: author

Based on all the information above, we will calculate the coverage and will determinate a specific way of allocation. The deliveries are done based on the negotiations made by every site with the specific supplier. The coverage it is determined by the time frame a site can produce finished goods, without internal line downs based on the actual stock, demands and weekly consumption.

The red numbers in the table below, indicates when a certain site will face a challenging situation with one of the raw materials. By challenging situation, it's understatable that the specific site can face internal line downs which is usually followed by stopping the customer production line, if some improvements in the supply plan received by the site are not performed.

Table 3 Coverage for all sites for all products

Site	Product	End week 1	End week 2	End week 3	End week 4	End week 5	End week 6	End week 7	End week 8	End week 9	End week 10	End week 11	End week 12	End week 13
Site 1	A	206,000	156,000	106,000	56,000	6,000	(44,000)	(94,000)	(144,000)	(194,000)	(244,000)	(294,000)	(344,000)	(394,000)
Site 2	A	99,000	105,000	111,000	117,000	123,000	129,000	135,000	141,000	147,000	153,000	159,000	165,000	171,000
Site 3	A	38,000	49,000	60,000	71,000	82,000	93,000	104,000	115,000	126,000	137,000	148,000	159,000	170,000
Coverage all sites Product A		343,000	310,000	277,000	244,000	211,000	178,000	145,000	112,000	79,000	46,000	13,000	(20,000)	(53,000)
Site 1	B	33,563	48,563	63,563	78,563	93,563	108,563	123,563	138,563	153,563	168,563	183,563	198,563	213,563
Site 2	B	103,761	118,761	133,761	148,761	163,761	178,761	193,761	208,761	223,761	238,761	253,761	268,761	283,761
Site 3	B	47,700	62,700	77,700	92,700	107,700	122,700	137,700	152,700	167,700	182,700	197,700	212,700	227,700
Coverage all sites Product B		185,024	230,024	275,024	320,024	365,024	410,024	455,024	500,024	545,024	590,024	635,024	680,024	725,024
Site 1	C	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000	10,000
Site 2	C	4,644	644	(3,356)	(7,356)	(11,356)	(15,356)	(19,356)	(23,356)	(27,356)	(31,356)	(35,356)	(39,356)	(43,356)
Site 3	C	7,469	9,469	11,469	13,469	15,469	17,469	19,469	21,469	23,469	25,469	27,469	29,469	31,469
Coverage all sites Product C		22,113	20,113	18,113	16,113	14,113	12,113	10,113	8,113	6,113	4,113	2,113	113	(1,887)
Site 1	D	95,400	94,400	93,400	92,400	91,400	90,400	89,400	88,400	87,400	86,400	85,400	84,400	83,400
Site 2	D	139,600	124,600	109,600	94,600	79,600	64,600	49,600	34,600	19,600	4,600	(10,400)	(25,400)	(40,400)
Site 3	D	52,000	60,000	68,000	76,000	84,000	92,000	100,000	108,000	116,000	124,000	132,000	140,000	148,000
Coverage all sites Product D		287,000	279,000	271,000	263,000	255,000	247,000	239,000	231,000	223,000	215,000	207,000	199,000	191,000

Source: author

The number presented in table 3, are the remaining quantities available at each site, at the end of each week, taking into consideration the actual stock, substracting the consumption and adding any deliveries recevaible for that week.

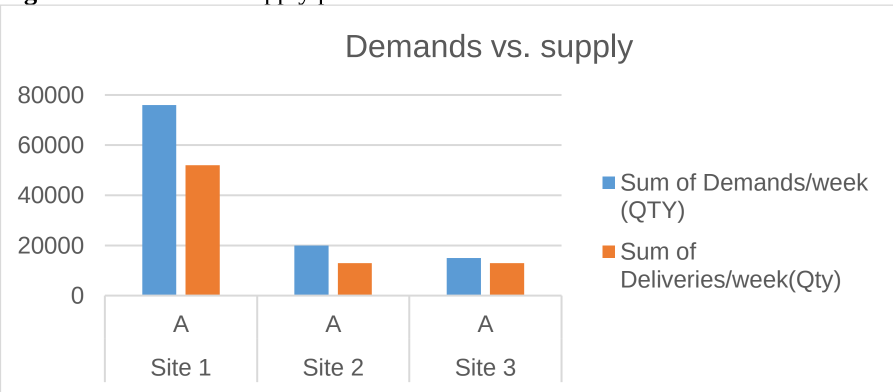
As visible in the table above, table no. 3 for product A, we are having a shortage in site A at the end of week 6, and increasing creating backlog, based on the demands and further deliveries, but for site 2 and 3 the situation it is stable, and overall the shortage should happen at the end of week 12, so following the rules of allocation a further balance should be made between plants. So by aligning with the supplier we will move some of the quantities destinated to site 2&3 to site, to prolong the impact for all the customers. By subtracting volumes from 2&3, we can prolong the impact until week 12 where the whole supply is insufficient to cover the demands, nevertheless we will gain 6 weeks in order to find other solutions to cover the gaps (pull-ins from the supply, search of alternatives, negotiations of capacity swaps).

In the above example we can see that product B started to recover since in allocation and it is building up stock, so if this product shows no criticality until end of year, and the tendency of building up stock remains, this component will be proposed for a swap of capacity with component A, reducing the supply here in order to increase product A supply. The same issues it is visible in product C, where site 2 goes into shortage by the end of week 3, while site 1 stock remains constant and site 3 stock builds up. As shown in the table above with a proper balance we can cover all the plants by moving volumes from supply from one site to another, with the concept of shared stock, and postpone the impact until end of week 13, where we will have a gap of almost 2,000. This week can be saved by a pull-in, but further the same as in product A, we need to find further solutions to improve the situation as we will only go in shortages based on the fact that the supply it is lower than the demands. For product D, as visible in the table, it is only a problem of balance, as the overall supply it is enough to cover all sites.

As visible in table 3. Coverage for all sites for all products, if the planning is poor for a single site, the situation, is, in most cases fixable wth a balancing between sites.But as seen in the cae for the product C, even if the shortages only comes from one site, as the other sites only work with a low level of stock (based on the price of this respective devices/most expensive one), the solution of balancing it is not enogh to cover all the sites. Here is a more challenging situation, were the first focus will be renogociating with the supplier the posibility to received in advance the supply available for the next week. Nevertheless, this is a short term solution which will only postphone the impact. Further will be analyzed the posibility of switching between capacity between components that share the capacity at the supplier, if were we have enough inventory or testing alternatives components.

These four components shows us the most common cases met in an allocation process. As visible in the below graphic, the main topic on why these products entered the allocation process is that the supply is lower than the demands.As we can see in the graphic below, for each site the demands for product A are higher than the deliveries confirmed by the supplier.

Figure 3 Demands vs supply product A



Source: author

It is a common case for the products in allocation that the supply it is not high enough to cover our demands, and the main root cause for this is either capacity issues and constrains at the supplier, or poor planning and negotiation for the volumes required.

In the first case scenario we have no input, when it comes to adding capacity in the production of semiconductors that it is a difficult topic which requires time and financial efforts from the suppliers, and these are topics in which we can not be directly involved in.

Nevertheless, for the second case scenario, where the poor planning and negotiation for the volumes required where mistaken by us, here it is still room for improvement. In below table, was calculated the difference between demands and supply, marked with black are the products were the demands was higher than the supply, and market with red are the products where the supply can cover the demands. As shown in the table bellow some site required the quantities that they needed but some did not.

Table 4 Difference between demands and supply

Site	Product	Demands-Deliveries
Site 1	**A**	**24,000**
Site 2	**A**	**7,000**
Site 3	**A**	**2,000**
Site 1	**B**	**(15,000)**
Site 2	**B**	**(15,000)**
Site 3	**B**	**(15,000)**
Site 1	**C**	**0**
Site 2	**C**	**4,000**
Site 3	**C**	**(2,000)**
Site 1	**D**	**1,000**
Site 2	**D**	**15,000**
Site 3	**D**	**(8,000)**

Source: author

By the difference between demands and supply we can get overall an idea if the planning was poor or some other issues were responsible for the parts to be in allocation. For the numbers marked with red in the above table, means that the supplier overdelivered our actual demands, enough to build us a buffer. We can see that the planning for site 3 was almost enough to cover all the components, with a little gap only for product A, where all the sites did not plan enough volumes in order to sustain their demands. We can also see in the above table, that for product B all the sites have done a proper planning in correlation with their actual demands. This is also visible in table number 3: Coverage for all sites for all products, product B it is the only products that in the overview for 13 weeks builds up stock. For product where all the sites requested less quantities than their actual requirements we can see, that this also affect the overall coverage ending up with a shortage of over 50,000 pieces at the end of the 13 weeks. For product C it is both a combination of poor planning and capacity constraints on the supplier side, which also translates to shortages.

The poor planning comes from uncertainty, from the fluctuations in the supply chain, mainly the side effect of the bullwhip effect, defined in chapter 2.

Taking into consideration the bullwhip effect, we are returning to the first premises that we are in a volatile market, subjected to changes, changes that affect the flow of the production and generates uncertainty. As demand signals become distorted and amplified as they move up the supply chain, suppliers often experience erratic and unpredictable orders. This makes production planning and scheduling difficult, as suppliers have to respond to surges and drops in orders. Taking into account all the information's shared above, the allocation process for products it is a tool used to improve the coverage of all sites using a certain type of raw materials.

3. CONCLUSION

In conclusion, the present paper has shown that the main problematic issue when it comes to why some products enter into allocations it is poor planning followed by the capacity constrains of production at the suppliers.Both situations analyzed, were impacting the manufacturing process, nevertheless in the case presented the poor planning had a bigger impact, and the process of monitoring them under the allocation was more challenging.

It is important to note that the allocation of critical components is typically a temporary measure to address supply chain disruptions. Industries strive to restore normal operations and diversify their supply chains to mitigate future risks, reduce dependence on limited sources, and enhance resilience.

Overall, the allocation of critical components plays a significant role in minimizing the impact of supply chain disruptions on industries, enabling them to continue operations and meet the demand for essential products or services.

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IV. OPTIMIZATION METHODS IN LOGISTICS

ACHIEVING DYNAMIC STABILITY OF SUPPLY CHAINS IN THE WHIRLPOOL CHANGES

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Abstract

Modern supply chains are exposed to a changing competitive environment dominated by health, military, political, economic, and other swirling changes that are almost impossible to control. Business stability in such conditions takes on a completely different meaning. The supply chain's dynamic stability means its participants' ability to quickly and efficiently adapt to turbulent changes. Accordingly, this paper will specifically investigate the impact of inflation and negative market conditions on supply chain operations. This work's main hypothesis is that supply chains can successfully manage overall change by achieving dynamic stability. The results of the research are based on the method of dynamic programming and the method of simulation. The main finding of this paper points to the conclusion that by achieving dynamic stability, supply chains are able to operate successfully even in negative market conjuncture.

Keywords: supply chains, dynamic stability, inflation, market conjuncture

1. INTRODUCTION

A supply chain consists of all parties (manufacturers, suppliers, transporters, warehouses, retailers, and customers) and, within each organization, all the functions involved, directly or indirectly, in fulfilling a customer request (Chopra and Meindl 2010). Supply chains can operate under conditions of static and dynamic stability. Unlike traditional supply chains, which can be said to have operated in static stability conditions, modern supply chains operate in conditions of disturbed stability, extreme dynamism, and almost whirlwind changes. Changed business conditions require traditional supply chains built for relatively stable business conditions to reorganize and achieve dynamic stability as a fundamental prerequisite for achieving their business goals. According to (Abrahamson, 2000), “dynamic stability is a process of continual but relatively small change efforts that involve the reconfiguration of existing practices and business models rather than the creation of new ones.” Supply chain managers have to create a dynamic stable network that is capable to implement big and small changes at the right time and right place. A dynamic supply chain anticipates changes in its global, regional, and national environment, developing full visibility, agility, and resilience.

A research hypothesis is: Supply chains can successfully manage unexpected changes in the business environment by achieving dynamic stability.

This paper aims to address the following research questions:

- How to reduce supply chain disruption?
- How to optimize supply chain in disruption conditions?
- What are the main differences in the operation of an optimized supply chain in conditions of dynamic and static stability?
- How to mitigate the next global supply chain disruption that will come?

The results of the research are based on the method of dynamic programming and the method of simulation. The method of dynamic programming was chosen for the reason that it enables step-by-step cost minimization within the supply chain. However, as the application of the dynamic programming method requires numerous calculations for the purposes of this scientific discussion, a computer model was developed in an MS Excel spreadsheet. The application of simulation based on a computer-supported model will be presented to solve a complex business problem with the aim of achieving dynamic stability of the supply chain in turbulent business conditions.

2. LITERATURE REVIEW

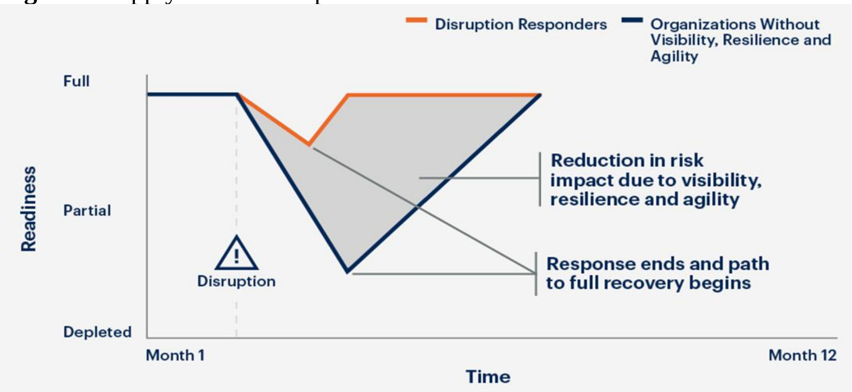
At the beginning of the 21st century, supply chains become one of the most important topics of investigation. Traditional supply chains do business in relatively stable environments, seeking to achieve stability and minimize costs. Future supply chains will need to be much more dynamic—and be able to predict, prepare, and respond to rapidly evolving demand and a continually changing product and channel mix. In short, supply chains will need to achieve agility, visibility and resilience. The capacity to detect and respond promptly to supply chain disruptions while limiting risk implications is referred to as agility. Visibility ensures that the supply chain detects threats early and is aware of the best reaction options so that it can respond appropriately. The ability to withstand, absorb, and recover from supply chain disturbance is referred to as resilience.

In the relatively stable business environment in which traditional supply chains were created and developed, the emphasis was on inventory management and control (Eilon, 1961). Increasing fluctuations in demand will direct researchers to manage production and develop dynamic models for production planning (Bedini & Toni, 1980). These models are based on demand planning, capacity planning, material planning, etc. The end of the 20th and the beginning of the 21st century will mark the end of stability in business, and uncertainty and disruption will begin to play an increasingly important role in supply chain management. Instabilities as well as unreliable suppliers are increasingly becoming the subject of research (Benyoucef, Xie, Tanonkou, 2013). The global financial crisis of 2008 will mark the path into the unknown. Global trade is down by a third in 2009 from 2008 (The Economist, 2009). This is leading active participants in supply chains to refocus on stability and risk management (Pisano-Ferry & Santos, 2009). Accordingly, Kleindorfer and Saad (2009) investigate risks arising from disruptions to normal activities which may arise from natural disasters, from strikes and economic disruptions, and from acts of purposeful agents, including terrorists. Supply chain resilience is one of the main issue in the current supply chain management (Melnyk et al. 2014; Ivanov, 2018).

The COVID-19 crisis will cause previously unimaginable disruptions in supply chains. For example, 94% of the Fortune 1000 companies faced supply chain disruption due to COVID-19 (Fortune, 2020). In supply chain management disruption events and recovery policy start to play a crucial role (de Sousa Jabbour et al., 2020). COVID-19 crises triggered supply chain disruption and caught many companies off guards (https://sloanreview.mit.edu). Shekarian & Parast (2021) identified flexibility and collaboration as the most important strategy to cope with supply chain disruptions. Dynamic stability can enable active participants in the supply chain to obtain, and maintain, stable and lasting competitive advantages (Hu and Fun, 2023).

The war in Ukraine and the associated inflation threaten permanent instability. The war produced disruption in regional supply chains and increased the risks to global growth (Guenette, Kenworthy, Wheeler, 2022). In a whirlwind environment, changes are so frequent and fast that it is almost impossible to keep track of them. Change is the only constant in modern business. Financial, health, military, political, economic, and other whirlwind changes point to the necessity of searching for models that guarantee the establishment of dynamic stability. Aslam, et al. (2022) see the dynamic capabilities of the supply chain as the key factor to raise the level of supply chain competition. Dynamic stability is the main prerequisite for the reduction in risk and quick response to supply chain disruptions (cf. figure 1).

Figure 1 Supply Chain Disruptions



Source: Gartner, 2021.

Based on Figure 1, it is clear that supply chains that are unable to achieve visibility, agility, and resilience, that is, to establish dynamic stability, expose their business to high risk, lose their competitive position, and question their viability on the market. Dynamic stability means a high level of readiness of the supply chain for a quick response to the whirlwind changes in the environment and the path to full recovery. Supply chain managers now have full attention of top management and mandate to redesigning their supply chains. Resilience, agility, and sustainability are key factors in the transition to dynamic stability (Heinrich, at al, 2022).

3. MATHEMATICAL MODEL

The optimization of the supply chain is reduced to the problem of determining the optimal amount of production in time (x_t), with the condition that procurement costs (n_t, t = 1.2, ..., T), production costs (c_t, t = 1.2, . .., T), costs of keeping stocks of finished products (will appear in case production x_t is greater than demand d_t, $F(x_t-d_t)$, t = 1, 2, ..., T), transportation costs (t_t , t = 1, 2, ..., T) and costs of unsatisfied demand (will appear in the event that demand d_t is greater than production x_t, $F_1(d_t-x_t)$, t = 1, 2, ..., T) be minimal.
All constraints relevant to the production process within the supply chain must also be satisfied.

As far as restrictions are concerned, it is assumed that there are restrictions regarding the maximum possible production (Q_t, t = 1, 2, ..., T), minimum and mandatory production (q_t, t = 1, 2, ..., T) in each period.

Accordingly, the following restrictions are set

$$q_t \le x_t \le Q_T \qquad t = 1, 2, ..., T,$$

or

$$x_t \ge q_t \text{ i } x_t \ge Q_t, \; t = 1, 2, ..., T.$$

In each, even the T-period, of the production process within the supply chain, there are two different possibilities for the organization of production, namely:

1) The known demand d_T will be satisfied, and then procurement costs, production costs, storage costs, and transport costs may appear, which should be minimized, which can be represented mathematically in the following way:

$$\min \{F(S - d_t + x_t) + n_T c_T t_T x_T\},$$

with constrains

$$x_T \ge d_T - S,$$
$$q_T \le x_T \le Q_T,$$

where S is the number of products produced in the previous periods and delivered in the T-th period.

2) Known demand does not have to be met, so there will be costs of unfulfilled demand (costs of lost sales), procurement costs, production costs, and transport costs, and this can be represented mathematically as follows:

$\min \{F_1(d_t - S - x_t) + n_T c_T t_T x_T\}$,

with constrains

$x_T \leq d_T - S$,
$q_T \leq x_T \leq Q_T$.

It implies that of these two possibilities, one should choose the one that will give lower total costs of the supply chain, which means that the recursive form $f_T(S)$, which minimizes the total costs in the T-th period, can be written as

$$f_T(S) = \min \begin{Bmatrix} \min\{F(S \ d_t + x_t) + n_T c_T t_T x_T\} \\ x_T \geq d_T - S \\ \min\ \{F_1(d_t \ - S - x_t) + n_T c_T t_T x_T\} \\ x_T \leq d_T - S \end{Bmatrix}$$

with constrains

$q_T \leq x_T \leq Q_T$.

4. DATA AND RESEARCH METHODOLOGY

For the purpose of this scientific debate we present next practical example. Supply chain has recognised in the Middle East market certain demand for the product A. Market price of the product is 23 €. Six-month' demand for the product A are shown table 1.

Table 1 Demand for the product A on the Midlle East market (in 000)

January	February	March	April	May	June
136	92	88	138	116	132

Source: Authors

All the participants of supply chain are aware of all expenses within certain supply chain (table 2).

Table 2 Unit costs per one product A

Unit costs	Jan.	Feb.	March	April	May	June
Procurement	3,5	3,5	3,4	3,4	3,4	3,4
Production	8,2	8,2	8	7,8	7,5	7,5
Inventory	1,5	1,5	1,4	1,3	1,3	1,3
Transport	4	4	3,8	3,8	3,9	4
Lost Sales	1,8	1,8	2,1	1,7	2,3	2,3

Source: Authors

Within an established supply chain there are limitation regarding maximum possible and obligatory monthly production (table 3.):

Table 3 Production limits and obligatory production within certain supply chain (in 000)

	Jan.	Feb.	March	April	May	June
Q_t	140	144	148	152	156	156
q_t	60	56	70	56	60	60

Source: Authors

Further to the information presented, it is necessary to determine optimum quantity of production during next six months (t = 1, 2, 3, 4, 5, 6) in a way that a supply chain gains the largest possible profit, and at the end of the said period has 15 000 product A in stock.

The assumption is that within the first two months, business will be conducted in a stable business environment, that is, in conditions of static stability. In the third month, inflation will appear, which will mark an increase in the prices of all goods and services in the supply chain at a rate of 6%. Inflation is expected to be an additional 6.5% in the fourth month, an additional 4% in the fifth, and only 1.5% in the sixth. The increase in the selling price of the supply chain will occur only in the fourth month, immediately by 10%, in the fifth month by an additional 6%, and in the sixth month by 0.75%. Inflation and the associated increase in sales prices will result in a decrease in demand for the supply chain product by 5% in the fifth month and by an additional 10% in the sixth month compared to the forecasted demand. In such conditions, for speculative reasons, the supply chain decided to increase the stock at the end of the observed period from 15 to 30 thousand products.

The problem posed in this way is solved by dynamic programming methods, i.e. by applying appropriate recursive relations, which help to minimize the costs of the supply chain in stages. However, as the application of the dynamic programming method requires numerous calculations for the purposes of this scientific discussion, a computer model was developed in an MS Excel spreadsheet. The application of simulation based on a computer-supported model will be presented to solve the presented business problem with the aim of achieving the dynamic stability of the supply chain.

5. RESEARCH RESULTS

To create a simulation for the mentioned business problem, the Excel spreadsheet is a very useful tool. A good computer simulation is the cheapest way to test different business actions and identify the most effective decisions. Solving the problem can be approached in two ways: 1) by setting up a general model that corresponds to the conditions of stable business and 2) by setting up a modified model that corresponds to the conditions of unstable business. Due to the limited space in this scientific discussion, we will immediately proceed to set up a modified model that corresponds to the conditions of vortex unstable business (cf. table 4).

Table 4 Model of dynamic optimization of the supply chain in unstable business conditions

	A	B	C	D	E	F	G	H
1	Economic climate					95%	85%	
2	Rate of inflation			1.065	1.125	1.165	1.17	
3	Market price	23	23	23	25.3	26.82	27.02	
4	**Unit costs**	Jan	Feb	March	April	May	June	
5	Procurement	3.5	3.5	3.4	3.4	3.4	3.4	
6	Production	8.2	8.2	8	7.8	7.5	7.5	
7	Inventory	1.5	1.5	1.4	1.3	1.3	1.3	
8	Transport	4	4	3.8	3.8	3.9	4	
9	Lost Sales	1.8	1.8	2.1	1.7	2.3	2.3	
10								
11	Obligatory production	60	56	70	56	60	60	
12	Optimal production	0	0	0	0	0	0	
13	Max production	140	144	148	152	156	156	
14								
15	Initial inventory	15	0	0	0	1	0	
16	Monthly demand	136	92	88	138	110	112	
17	Ending inventory	0	0	0	0	0	0	30
18		0	0	0	0	0	0	
19		0	0	0	0	0	0	
20								
21	Procurement costs							
22	Production costs							
23	Inventory costs							
24	Transport costs							
25	Lost Sales costs							

26	Total monthly costs							
27						TOTAL	PROFI T	

Source: Authors

In the header of the table (A1:G3), the conditions from the business environment that will determine the operation of the supply chain in the next six-month period are first entered, namely: market conditions, inflation, and the movement of market prices. After that, in the address areas B5:G5, B6:G6, B7:G7, B8:G8, and B9:G9, it is necessary to enter the unit costs of procurement, production, inventory, transportation, and lost sales. Then, data on mandatory production is entered in the address area B11:G11. Address area B12:G12 contains decision variables, and address area B13:G13 data on maximum possible production for each period. The initial stocks for the first month are known and given in the address field B15, while the stocks at the end of the month are determined by the formula =B12+B15-B16. The specified formula is copied to the address area B17:G17. Closing stocks at the end of a month represents the beginning stocks of the following month. In the address field B18 there is the formula =IF(B17>0; B17;0), which is copied to the entire address area B18:G18. This formula determines the size of the inventory (if it exists) in order to be able to calculate the associated costs. Likewise, the address field B19 contains the formula =IF(B17<0;-B17;0), in order to calculate the cost of lost sales for each period. That formula is copied into the address area B19:G19.

The address area B21:G25 contains the appropriate formulas to calculate the monthly costs of procurement, production, inventory, transportation, and lost sales, while the address area B26:G26 contains the formulas needed to calculate the total six-month costs of procurement, production, inventory, transportation and lost sales selling. Address area H27 contains the formula =B3*SUM(B16:D16)+E3*E16+F3*F16+G3*G16-H26, which calculates the total profit of the supply chain and at the same time represents the objective function (it needs to be maximized).

After the dynamic optimization model has been formulated in the spreadsheet in the Tools menu, the Solver program is called and data entry is accessed in the Solver Parameters tab.

Set Target Cell: H27
Equal To: Max
By Changing Cells: B12:G12
Subjects to the Constraints:
B12:G12 ≤ B13:G13
B12:G12 ≥ B11:G11
B12:G12 ≥ 0
B12:G12 =integer
G17 = H17

When all parameters have been entered, click on the Solve button of the Solver Parameters form, which activates the Solver program that calculates the value of the decision variables in the address sequence B12:G12. The decision variables that are calculated in the address sequence B12:G12 define the optimal solution. Table 5 shows the optimal solution to the problem using an MS Excel spreadsheet.

Table 5 The optimal solution for supply chain production in unstable business conditions

	A	B	C	D	E	F	G	H
1	Economic climate					95%	85%	
2	Rate of inflation			1,065	1,125	1,17	1,17	
3	Market price	23	23	23	25,3	26,8	27,02	
4	**Unit costs**	Jan	Feb	March	April	May	June	
5	Procurement	3,5	3,5	3,4	3,4	3,4	3,4	
6	Production	8,2	8,2	8	7,8	7,5	7,5	
7	Inventory	1,5	1,5	1,4	1,3	1,3	1,3	
8	Transport	4	4	3,8	3,8	3,9	4	
9	Lost Sales	1,8	1,8	2,1	1,7	2,3	2,3	
10								
11	Obligatory production	60	56	70	56	60	60	
12	Optimal production	121	92	88	138	110	142	691
13	Max production	140	144	148	152	156	156	
14								
15	Initial inventory	15	0	0	0	0	0	
16	Monthly demand	136	92	88	138	110	112	676
17	Ending inventory	0	0	0	0	0	30	30
18		0	0	0	0	0	30	
19		0	0	0	0	0	0	
20								
21	Procurement costs	423,5	322	318,648	527,85	435,71	564,876	**2592,584**
22	Production costs	992,2	754,4	749,76	1210,95	961,125	1246,05	**5914,485**
23	Inventory costs	0	0	0	0	0	45,63	**45,63**
24	Transport costs	484	368	356,136	589,95	499,785	524,16	**2822,031**
25	Lost Sales costs	0	0	0	0	0	0	**0**

26	Total monthly costs	1899,7	1444,4	1424,544	2328,75	1896,62	2380,716	**11374,73**
27						TOTAL	PROFIT	**5.360.793**

Source: Authors

6. DISCUSION

Based on the data from Table 5, it is clear that even in turbulent business conditions, the supply chain can operate successfully and will make a profit in the amount of €5,360,793. It is an optimal solution that is 9.36% better than the empirically least favourable solution obtained when the function is solved by the minimum. The offered solution ensures production with minimal inventory within the supply chain and without the costs of lost sales. Operating a supply chain without the cost of lost sales means that all customer requests will be met on time. The total inventory costs will amount to €45,630, and that's only because the management decided to increase inventory for speculative reasons in order to respond more efficiently to the challenges of inflation. Otherwise, the supply chain would operate without inventory costs. Disruption in the supply chain affects the inventory management. For example, shortages of inventory versus surplus of inventory have different impact on the supply chain (Ozgur, Fedor, Michel, 2021). Shortages of inventory result in the costs of lost sales, dissatisfied customers, and loss of business reputation while the surplus of inventory results in higher costs, wasted resources, and lost profits. Building a more dynamic supply chain through diversifying suppliers and taking steps to identify local (near-shore) alternatives to current suppliers who might pose less risk could be the right solution.

Table 6 gives a comparative view of the operations of the optimized supply chain under conditions of dynamic and static stability.

Table 6 Comparison of operations of the optimized supply chain under conditions of dynamic and static stability

	Dynamic stability	Static stability	+/-	%
Optimal production	691	702	-11	-1,57
Total demand	676	702	-26	-3,70
Procurement costs	2592,584	2408,1	184,484	7,66
Production costs	5914,485	5499,5	414,985	7,55
Inventory costs	45,63	19,5	26,13	134,00
Transport costs	2822,031	2691,2	130,831	4,86
Lost Sales costs	0	0	0	0,00
Total costs	11374,73	10618,3	756,43	7,12
Total revenue	16735,52	16146	589,52	3,65

Profit	5360,793	5527,700	-166,907	-3,02

Source: Authors

Based on the data from Table 6, it is clear that disruptions in the supply chain resulted in 1) a decrease in demand, 2) a decrease in production, 3) an increase in costs in all categories, and 4) a decrease in profit. This finding is similar to the findings of Mishra, Singh. and Subramanian (2021) and Sharma and Kumar (2021) who recognize disruption in supply chains on three different sides; supply side, demand side, and logistical side. Supply chain product demand decreased by 26,000 thousand products while production decreased by 11,000 thousand products. The difference of 15,000 products is intended to increase inventory at the end of the six-month period for speculative reasons. Disruptions in the supply chains changed the inventory policy to combat extreme shocks (Raj et al., 2022). The total costs of the supply chain are higher by €756,430 or by 7.12%, which is the result of the increase in all prices due to inflation. According to the research conducted by The Economist Intelligence Unit (2021) disruptions have incurred substantial financial costs (averaging 6-10% of annual revenues). However, thanks to the timely increase in the selling prices of product A, the supply chain in conditions of dynamic stability achieved higher total revenues by €589,520 or by 3.65%. According to the research conducted by The Economist Intelligence Unit (2021), the disruption of the supply chain caused by COVID-19 hit the revenue between 6% and 20%. Due to the achievement of dynamic stability, the supply chain was able to consolidate and optimize it s operations and operate profitably, even in conditions of whirlwind changes in the environment (inflation, decrease in demand). The profit is only €166,907 or 3.02% less than in the conditions of static stability. One McKinsey study (2020) found that supply chain disruptions cost companies 42 % of one year's profits over the course of a decade. The set model offers numerous "what-if" answers. For example, if the supply chain had failed to raise the price of its product by 10% in the fourth month, the total revenue and total profit of the supply chain would have been lower by more than €860,000.

7. CONCLUSION

Supply chain disruptions are a „new normal in business for all supply chain active participants. Supply chains have to prepare for future "black swan" threats. Supply chain disruption has many negative consequences such as 1) a decrease in demand, 2) a decrease in production, 3) an increase in costs in all categories, and 4) a decrease in profit. To avoid negative consequences of disruptions future supply chains will need to be much more dynamic. The dynamic stability of the supply chain is based on its ability to anticipate, detect, diagnose, and monitor changes and activate appropriate mechanisms with the aim of protecting the supply chain from unwanted disruptions. Dynamic stability is the shield against disruption in the supply chain and the main factor in increasing the performance of all active participants in the supply chain.

In the presented example, despite the unfavourable conditions from the economic environment (high inflation, decrease in demand), thanks to the achievement of dynamic stability, the supply chain achieved a lower profit of only 3.02%, in contrast to the operation of the supply chain in conditions of static stability (unchanged business conditions). This result confirmed the hypothesis that supply chains can successfully manage unexpected changes in the business environment by achieving dynamic stability.

The research has some limitations because the proposed model does not directly include the disruptions in supply chains that produced new Western country policies that promote "friendshoring" of strategic industries. Future research should be directed to building a model that will enable the optimal restructuring of supply chains, shifting production away from geopolitical rivals to friendly powers. The new policy in the first plan put the place where the product is produced rather than profit.

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THE OPTIMIZATION METHODS IN SUPPLY CHAIN MANAGEMENT – A BIBLIOMETRIC ANALYSIS

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Abstract

To find the most relevant articles applying optimization methods in supply chain management, the Web of Science Core Collection database was searched. 465 papers matching the search query were found. After excluding papers that were not articles and articles that were not in English, 359 articles remained, which were further evaluated using the following bibliometric analyses: Co-authorship analysis (Unit of analysis: Authors and Countries), Citation analysis (Unit of analysis: Documents, Sources and Authors), Co-occurrence analysis (Unit of analysis: Authors keywords). The graphical bibliometric overview was created using the Visualization of Similarities - VoSviewer program. The paper contributes to the understanding of the literature in which optimization methods in supply chain management are applied by showing the main articles, authors, journals, countries where the main articles come from, and the keywords used by the authors when writing the researched articles. To find relevant literature, it is possible to extend the search to the Scopus database and apply the above to future searches. It is also possible to perform other bibliometric analyses in future searches.

Keywords: optimization methods, supply chain management, bibliometric analysis

1. INTRODUCTION

In today's world, a growing population, consumption, and competition in the global marketplace are leading to a reduction in natural resources and an increasing strain on the environment. Current resource use practices are therefore unsustainable. Manufacturing companies need to focus not only on cost-efficient and profitable operations but also on environmentally friendly and sustainable production at the same time to increase their competitiveness. New innovative technologies are needed to improve the efficiency of processes and the optimization of global supply chains (GSC) to achieve sustainability in environmental, social and economic terms (Kovacs & Illes, 2019). Optimizing strategic and tactical decisions related to sustainability and resilience are important because they affect supply chain performance over time

(Saffari, 2023). The supply chain is a complex network from supplier to customer that includes people, technologies, activities, information and resources. Its design and management aim to achieve the best global performance under union operating criteria. A typical supply chain consists of different levels, it is composed of the following elements: Suppliers, manufacturing plants, warehouses, distribution centres (DCs), and customers/final markets (Mastrocinque et al., 2013). Integrating the various processes and actors that make up the supply chain (SC) is essential for better coordination (Roldan, 2017). Vertical and horizontal supply chain collaboration is widespread and has been identified as one of the most important issues for improving competitiveness. However, the implementation of supply chain collaboration faces many obstacles, such as the nature, scope and security of information sharing, equality in benefit sharing, joint decision-making, coordination tasks, etc.

Optimizing a supply chain is the optimal choice of resources to fulfil an objective function. Supply chain models based on the realization of a single objective function usually aim at minimizing total cost. However, supply chain modelling usually involves the realization of multiple objective functions. Some examples of objective functions that can be achieved through supply chain modelling are: Minimizing inventory, maximizing service levels, minimizing delivery times, maximizing environmental impact, etc. Sometimes achieving one desired objective function conflicts with achieving another desired objective function. For example, increasing the level of service companies want to provide to your customers usually increases costs. It is necessary to find a solution that satisfies the conflicting objectives. Thus, in optimization problems with multiple objective functions, one cannot speak of an optimal solution, a dominant solution, i.e., there is no solution in which the improvement of one objective function would not lead to a deterioration of at least one of the other objective functions. A solution that satisfies conflicting objectives is a compromise solution and is called a Pareto-optimal solution (Mastrocinque et al., 2013).

The study aimed to find out in which articles optimization models are used in supply chain management and to answer the following research questions:

RQ1: How many articles have been published over the years that match the researched query, and what is the citation rate of the articles? To test RQ1, the data of all articles and the citation report were downloaded from the Web of Science database;

RQ2: What are the most productive countries in terms of the number of published articles from the studied field, and what is the distribution of the countries in terms of the citation of the articles? To test RQ2, Co-authorship analysis (Unit of analysis: Countries) and Citation analysis (Unit of analysis: Countries) were performed;

RQ3: In which journals are the studied articles mainly published? To test RQ3, a Citation analysis (Unit of analysis: Sources) was performed;

RQ4: Who are the main authors in the studied field in terms of number of published articles and citations? To test RQ4, Co-authorship analysis (Unit of analysis: Authors) and Citation analysis (Unit of analysis: Authors) were performed;

RQ5: What are the most cited articles in the research area? To test RQ5, a Citation analysis (Unit of analysis: Documents) was performed;

RQ6: What keywords did the authors use when writing the research articles and how frequently do they occur? To test RQ6, a Co-occurrence analysis (Unit of analysis: Authors keywords) was performed.

The paper consists of five chapters. The introduction is followed by a chapter that gives an overview of previous research and presents some applications of optimization methods in the supply chain. Chapters 3 and 4 refer to the research part of the paper - data description and methodology were performed and the results of the bibliometric analysis were presented. The last chapter contains the main results and conclusions, as well as recommendations for future research.

2. LITERATURE REVIEW – APPLICATION OF OPTIMIZATION METHODS IN SUPPLY CHAIN MANAGEMENT

Azizi et al. (2021) aimed to design a sustainable agile retail chain. They presented a mathematical model with five objectives: (1) "minimise costs," (2) "minimise unsatisfied demand," (3) "maximise the quality of goods supplied by suppliers," (4) "maximise social responsibility or social benefit," and (5) "minimise environmental impact." Since the model contained multiple objectives, multi-objective optimization methods were used. The model was solved using three algorithms (NSGA-II, PESA and SPEA-II) run in MATLAB software. The results showed that the SPEA-II algorithm gave the best results.

A study by Saffari et al. (2023) proposes a model for a resilient, sustainable, and responsive forward/backward logistics network that considers multiple objectives, including cost, social responsibility, CO2 emissions, water consumption, response time, and cooperation risk. Key cost impacts were identified using an experimental design, and operational risk was managed by applying a robust optimization method. Analysis of data from the iron and steel sector demonstrated the value of resilience measures and the further development of metrics for cost, sustainability, and responsiveness.

To improve and maintain corporate competitiveness in a changing market environment and global competition, new supply chain paradigms are emerging. The goal of Kovacs' (2017) article was to optimize the virtual enterprise network formed by the members of the Agile supply chain - production companies, service providers, and customers. In this way, they can react flexibly and quickly to changes in customer requirements. The optimization method, the objective function for which total cost and lead time were used, and the design constraints were elaborated. Software was developed that can be used to optimize networks at both the micro- and macro-regional levels.

To improve production efficiency and capacity utilization in production companies, supply chain production scheduling is essential. The article by Liao & Lin (2019) presents a job store supply chain scheduling optimization method based on particle swarm optimization (PSO). A simulation system to solve production scheduling problems was also developed. The mentioned system is based on an intelligent algorithm and Microsoft SQL Server platform. Problems of nonconvergence in production scheduling can be effectively overcome by PSO and quickly find out how to execute the job schedule optimally.

Kappelman and Sinha (2021) identify a dynamic food supply chain with numerous interconnected phases. The selection of suppliers and the determination of their process parameters must be decided at each step. At the step level, they make the following assumptions: (1) the quality of the goods is stochastic and (2) the quality is at a minimum acceptable level, otherwise they are rejected. They present a comprehensive strategy and use Big Data mining techniques to track how actions affect the quality of the final product and to determine the state transition matrix. In determining the best strategy, preferred suppliers and settings for their process parameters are established. The objective of the proposed strategy is to minimize the amount of product returned and maximize the expected profit of the supply chain.

The problem of blood transhipment and allocation has taken on a new dimension in the context of the COVID-19 outbreak. It involves a two-stage, interregional, multimodal transport system. Zhou et al (2023) present a new multi-criteria model for blood allocation in a two-stage transhipment system. They examine the following criteria: (1) maximizing the quality of transshipped blood, (2) satisfying the demand for blood, and (3) total cost (including the penalty for shortages). They proposed an improved integer-coded hybrid multi-objective whale optimization algorithm (MOWOA) with greedy principles to solve the model, which outperforms single-stage optimization approaches for all objectives.

The automotive industry is one of the most important industries in the world due to its economic importance and technological complexity. Supply chain efficiency can have a major impact on the automotive sector. In order to optimize performance, several objectives are pursued, often in conflict with each other. The trade-off between price and service level is modelled in Masoud & Masons (2016) in a heuristic optimization methodology for a two-stage integrated automotive supply chain. They simultaneously increase the proportion of external parts per customer and minimize the total cost of setup, inventory, and transportation.

To ensure survival and competitiveness due to facing strong competition, increasingly strict regulations on products and environmental regulations, but also lower profit margins, oil refiners are increasingly turning to optimization approaches. The article by Khor & Varvarezo (2017) provides an integrated overview of optimization methods ranging from traditional planning through linear programming to supply chain and outside-the-fence considerations. It also provides a review of the literature addressing the above topic.

3. DATA DESCRIPTION AND METHODOLOGY

Since the purpose was to investigate which papers use optimization methods in supply chain management, a query was entered into the Web of Science Core Collection database search engine: "optimization* method*" and "supply chain*". The search was conducted in July 2023. Based on the keywords entered in the search query, 465 papers were found. Regarding the type of work, 361 articles, 88 proceeding papers, 30 review articles, 18 early access, 8 book chapters, and 1 editorial material were found. Only articles were selected for further analysis - 361 articles. For the next filter, the language in which the article was written was used. Of the 361 articles, 1 article was in German, one was in Spanish, and 359 articles were in English. Only English-language articles remained for further analysis - 359 articles.

In 2020, CoreVian introduced the "Citation Topics" analysis function in Incites, which uses Leiden University's clustering algorithm to identify topics in the direct citation network of SCI and SSCI papers, and constructs a composite topic classification framework system, which can for users to search, identify and analyze topics at three levels: macro, meso and micro. This topic classification system assigns each paper to a single research topic, providing researchers with a stable and reliable way to identify topics (Li, 2021). In Table 1 it is possible to see how many researched papers are available on which topic at the meso level.

Table 1 Classification of articles by Citation Topics Meso

Citation Topics Meso	**Number of articles**	**Citation Topics Meso**	**Number of articles**
Supply Chain & Logistics	251	Herbicides, Pesticides & Ground Poisoning	1
Design & Manufacturing	15	Bioengineering	1
Artificial Intelligence & Machine Learning	9	Food Science & Technology	1
Sustainability Science	7	Security, Encryption & Encoding	1
Management	6	Automation & Control Systems	1
Paper & Wood Materials Science	4	Knowledge Engineering & Representation	1
Security Systems	4	Space Sciences	1
Distributed & Real Time Computing	4	Economic Theory	1
Forestry	3	Climate Change	1
Telecommunications	3	Political Science	1
Power Systems & Electric Vehicles	3	Risk Assessment	1
Transportation	3	Geotechnical Engineering	1
Testing & Maintenance	3	Energy & Fuels	1
Data Structures, Algorithms & Complexity	2	Combustion	1
Safety & Maintenance	2	Friction & Vibration	1
Comvergence & Optimization	2	Mechanics	1
Nursing	1	Thermodynamics	1

Blood Clotting	1	Sensors & Tomography	1
Nanofibers, Scaffolds & Fabrication	1	Functional Analysis	1
Catalysts	1	Articles that do not contain data in the field being analyzed	15

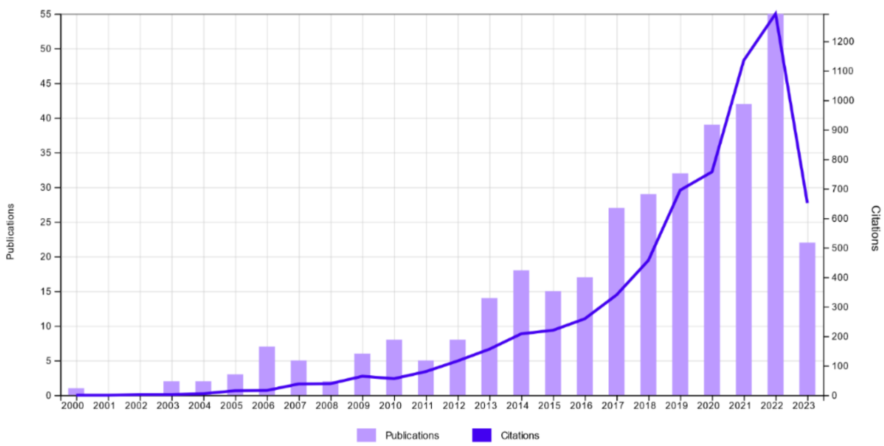
Source: Author, 2023

Table 1 shows that with regard to Citation Topics Meso, as many as 70% of the articles were published in Supply Chain & Logistics.

The search results were stored in RIS and plain text format and contained all essential information such as the title of the paper, authors' names and affiliations, journal, year of publication, abstract, keywords, and references (Fahimnia et al., 2015). The RIS data were imported into Mendeley Reference Manager to facilitate access to all searched papers. Data collected in plain text format were used in VOSviewer for bibliometric analysis (Van Eck & Waltman, 2021).

Figure 1 shows how the number of published articles that are the subject of research and the number of citations of those articles have evolved over the years. It can be seen that the oldest article was published in 2000. It is the paper Auction-theoretical coordination of production planning in the supply chain by Ertogral & Wu. It can also be seen that there is a continuity in the publication of articles from 2000 to 2023. Up to 8 articles were published annually until 2012. From 2013 to 2016, 14 to 18 articles were published annually. After 2017, the number of articles per year increased. The most articles were published in 2022 - 59 articles. By July 2023, 26 articles were published. Figure 1 also shows that the number of citations of articles moves in line with the number of articles published. There were the most citations in 2022 - 1,292 citations. In July 2023, there were 654 citations.

Figure 1 Number of published articles and their citations over the years

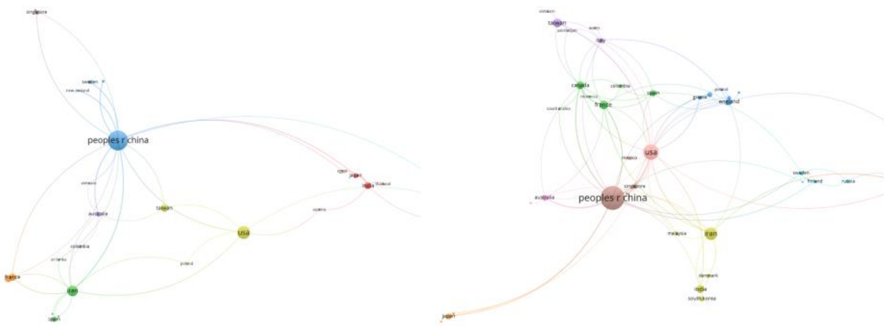


Source: Author, 2023

4. EMPIRICAL RESEARCH AND RESULTS

The articles studied were written by authors from 54 countries. Looking at the size of the circle in Figure 2, it is possible to notice that the order of the most important countries by the number of published articles and citations is the same. In terms of research area, the most significant is the Republic of China, whose author has published 140 articles that have been cited 2,125 times. The United States ranks second (60 articles, 1,616 citations) and Iran ranks third (39 articles, 877 citations). Taiwan ranks fourth by number of articles published but 15th by number of citations. France ranks fifth by number of articles published (19 articles) and fourth by number of citations (431 citations). Canada and India follow by number of articles (17 articles), but also share ninth place by number of citations (289 citations). Germany is in eighth place by the number of articles published (14), but also by the number of citations (312).

Figure 2 The most important countries according to the number of published articles and citations



Source: Author, 2023

The journal Computers and Industrial Engineering (impact factor: 7.180) published the most articles that are the subject of the analysis - 20 articles. In terms of the number of citations of articles published in the mentioned journal (306), the journal ranks 4th. In terms of the International Journal of Production Economics (Impact Factor: 11.251) and the Journal of Cleaner Production (Impact Factor: 11.072) rank second with 12 articles. With 562 citations, the International Journal of Production Economics ranks first by the number of citations, while the Journal of Cleaner Production ranks third with 369 citations. In second place by a number of citations is the journal Computers and Chemical Engineering (Impact Factor: 4.130) with 408 citations. For more journals in terms of number of articles published and number of citations, see Table 2.

Table 2 Journals by number of published articles and citations

Journal	Impact (2022-2023) (Accelerator, 2023)	Articles	Citations
Computers and Industrial Engineering	7.180	20	306
International Journal of Production Economics	11.251	12	562
Journal of Cleaner Production	11.072	12	369
Sustainability	3.889	9	63
Computers and Chemical Engineering	4.130	8	408
Optimization Methods and Software	1.832	8	44
Applied Mathematical Modelling	5.336	7	259
Expert Systems with Applications	8.665	6	151
International Journal of Production Research	9.018	5	199
Journal of Intelligent Manufacturing	7.136	5	136
Mathematical Problems in Engineering	1.430	5	19
Advanced Engineering Informatics	7.862	4	254
Annals of Operations Research	4.820	4	33
Computers and Operations Research	5.159	4	265
European Journal of Operational Research	6.363	4	99
IEEE Access	3.476	4	28
IEEE Transactions on Automation Science and Engineering	6.636	4	58
International Journal of Advanced Manufacturing Technology	3.563	4	55
International Transactions in Operational Research	3.610	4	22
Wireless Communications and Mobile Computing	2.146	4	8

Source: Author, 2023

The most prolific author is Liu, Y., who published 12 articles that are the subject of the analysis. The mentioned author is also on the list of the most cited authors with 164 citations. With 5 published articles, authors Chiu, Yuan-Shyi P. and You, F. are in the next place. Author You, F. is also on the list of most cited authors with 219 citations. Authors who have published 4 or 3 articles that are the subject of the analysis can be seen in Table 3.

Table 3 Authors by number of articles and citations

Authors	Articles	Citations	Authors	Articles	Citations
Liu, Yankui	12	164	He, Junliang	4	309
Chiu, Yuan-Shyi Peter	5	14	Del Ser, Javier	1	260
You, Fengqi	5	219	Diez-Olivan, Alberto	1	260
Chen, Yanju	4	40	Galar, Diego	1	260
Duan, Jianguo	4	30	Sierra, Basilio	1	260
Feng, Cuiying	4	29	Yan, Wei	3	247
He, Junliang	4	309	Ahmadi-Javid, Amir	1	240
Yang, Guoqing	4	54	Seyedi, Pardis	1	240
Zhang, Yingfeng	4	164	Syam, Siddhartha S.	1	240
Brouer, Berit Dangaard	3	62	You, Fengqi	5	219
Chiu, Singa Wang	3	11	Grossmann, Ignacio E.	2	165
Dekker, Rommert	3	80	Liu, Yankui	12	164
Huang, George Q.	3	63	Zhang, Yingfeng	4	164
Huang, Youfang	3	143	Rentizelas, A. A.	1	153
Jolai, Fariborz	3	44	Tatsiopoulos, I. P.	1	153
Karsten, Christian Vad	3	62	Tolis, A.	1	153
Kovacs, Gyorgy	3	13	Huang, Youfang	3	143
Ma, Yanfang	3	22	De Vos, Martijn	1	123
Pardalos, Panos M.	3	15	Epema, Dick	1	123
Pei, Jun	3	15	Esmat, Ayman	1	123
Pisinger, David	3	62	Ghiassi-Farrokhfal, Yashar	1	123

Rezg, Nidhal	3	94	Palensky, Peter	1	123
Turki, Sadok	3	106	Chan, Fts	2	121
Yan, Wei	3	247	Chung, Sh	2	121
Zhong, Ray Y.	3	88	Hahn, G. J.	2	121
			Kuhn, H.	2	121

Source: Author, 2023

In first place by number of citations of published articles is author He, J. with 309 citations for 4 published articles. Authors Diez-Olivan, A., del Ser, J., Galar, D., & Sierra, B. authored the most cited paper in this analysis "Data fusion and machine learning for industrial prognosis: Trends and perspectives towards Industry 4.0", published in the journal Information Fusion (Impact Factor: 17.564). With the mentioned paper, they ranked second among the most cited authors with 260 citations. Author Yan, W. achieved 247 citations for the three articles analysed. Authors Ahmadi-Javid, A., Seyedi, P., & Syam, S.S. authored the second most cited article in this analysis, "A survey of healthcare facility location", published in the journal Computers and Operations Research (Impact Factor: 5.159). This article earned them third place among the most cited authors with 240 citations. Concerning the number of citations (219), the next is author You, F., who is listed as the most prolific author with 5 published articles that are the subject of the analysis. Other most cited articles can be seen in Table 4.

Table 4 The most cited articles

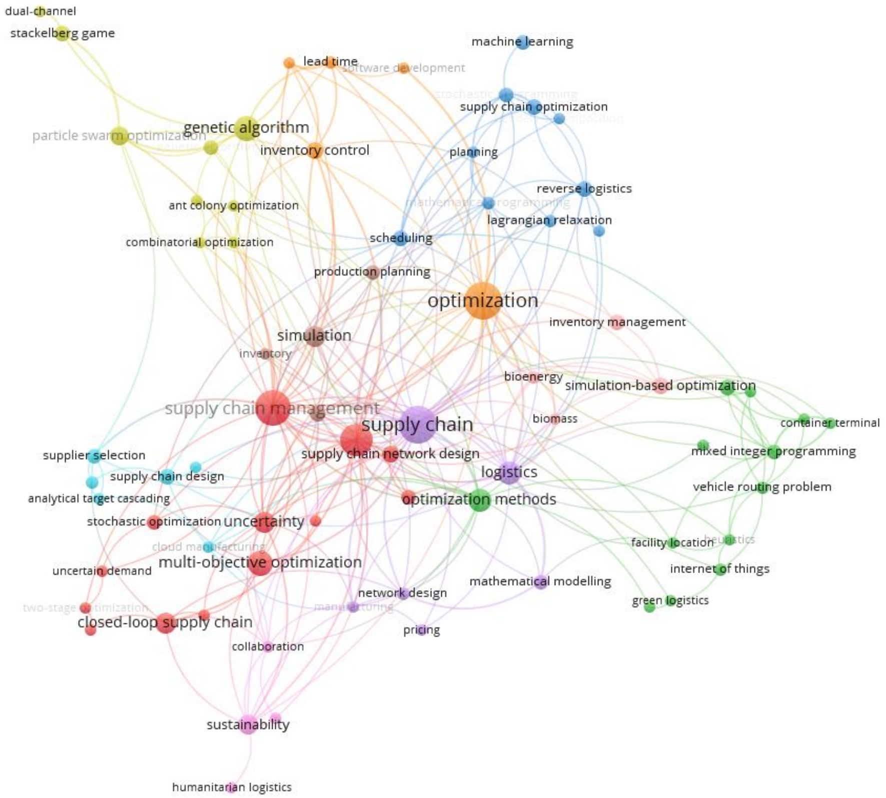
Year	Author	Title	Source	Impact factor	Citations
2019	Diez-Olivan, A., del Ser, J., Galar, D., & Sierra, B.	Data fusion and machine learning for industrial prognosis: Trends and perspectives towards Industry 4.0.	Information Fusion	17.564	260
2017	Ahmadi-Javid, A., Seyedi, P., & Syam, S. S.	A survey of healthcare facility location	Computers and Operations Research	5.159	240
2009	Rentizelas, A. A., Tatsiopoulos, I. P., & Tolis, A.	An optimization model for multi-biomass tri-generation energy supply	Biomass and Bioenergy	5.774	153

2012	Grossmann, I. E.	Advances in mathematical programming models for enterprise-wide optimization	Computers & Chemical Engineering	4.130	139
2021	Esmat, A., de Vos, M., Ghiassi-Farrokhfal, Y., Palensky, P., & Epema, D.	A novel decentralized platform for peer-to-peer energy trading market with blockchain technology	Applied Energy	11.446	123
2015	He, J. L., Huang, Y. F., & Yan, W.	Pharmaceutical Supply Yard crane scheduling in a container terminal for the trade-off between efficiency and energy consumption	Advanced Engineering Informatics	7.862	112
2000	Ertogral, K., & Wu, S. D.	Auction-theoretic coordination of production planning in the supply chain	IISE Transactions	3.425	99
2005	Ding, H. W., Benyoucef, L., & Xie, X. L. (	A simulation optimization methodology for supplier selection problem	International Journal of Computer Integrated Manufacturing	4.420	96
2012	Hahn, G. J., & Kuhn, H.	Coordinating Investment, Production, and Subcontracting	Decision Support Systems	6.969	95

Source: Author, 2023

In creating 359 researched articles, the authors used 1,250 keywords. The most frequently used keyword is "supply chain" with 33 repetitions. Right behind is "optimization," which was used 32 times as a keyword in the researched articles. The keyword "supply chain management" was used just as frequently, with 30 repetitions. In terms of the number of repetitions, the keywords "robust optimization" (24), genetic algorithm and multi-objective optimization (both keywords with 15 repetitions), logistics and optimization methods (with 13 repetitions each) and 10 repetitions for the following keywords: "closed-loop supply chain", "simulation" and "uncertainty". To obtain an optimal keyword network, Figure 3 shows the keywords that occur at least three times.

Figure 3 Keywords with at least three repetitions



Source: Author, 2023

74 keywords met the threshold. The keywords are divided into 10 clusters. Table 5 shows the distribution of keywords by clusters.

Table 5 Classification of keywords into clusters

Cluster	Keywords
Cluster 1 **(red)** 13 items	Closed-loop supply chain, distributionally robust optimization, fuzzy optimization, multi-objective optimization, risk management, robust optimization, stochastic optimization, supply chain management, supply chain network design (scnd), sustainable supply chain management, two-stage optimization, uncertain demand, uncertainty
Cluster 2 **(green)** 13 items	Container terminal, energy consumption, facility location, gis, green logistics, heuristics, hybrid algorithm, internet of things, mixed integer programming, operations research, optimization methods, simulation optimization, vehicle routing problem
Cluster 3 **(blue)** 10 items	Benders decomposition, carbon emissions, lagrangian relaxation, machine learning, mathematical programming, planning, reverse logistics, scheduling, stohastic programming, supply chain optimization
Cluster 4 **(gelb)** **9 items**	Ant colony optimization, combinatorial optimization, differential evolution, dual-channel, genetic algorithm, particle swarm optimization (pso), simulated annealing, stackelberg game
Cluster 5 **(purple) 6 items**	Logistics, manufacturing, mathematical modelling, network design, pricing, supply chain
Cluster 6 **(turquoise) 6 items**	Analytical target cascading, cloud manufacturing, location-allocation, supplier selection, supply chain configuration, supply chain design
Cluster 7 **(orange) – 5 items**	Inventory control, inventory optimization, lead time, optimization, software development
Cluster 8 **(brown) – 4 items**	Inventory, production, production planning, simulation
Cluster 9 **(pink) 4 items**	Collaboration, humanitarian logistics, resilience, sustainability
Cluster 10 **(light brown) 4 items**	Bioenergy, biomass, inventory managment, simulation-based optimization method

Source: Author, 2023

In Figure 3, but also in Table 5, it can be seen that the largest clusters form around the words "supply chain management" and "optimization methods" (both with 13 keywords). The keyword "supply chain management" is in the red cluster (Cluster 1, as indicated in Table 5). It may appear in the researched articles together with some other red-coloured keywords, e.g..: "multi-objective optimization", "supply chain network design (scnd)". Other keywords it may occur with are listed in Table 5. The keyword "optimization methods" is located in the green cluster (Cluster 2, see Table 5). It may occur in researched articles along with some of the other green-coloured keywords, for example: "facility location", "mixed integer programming", "vehicle routing problem". Other keywords it may occur with are also listed in Table 5. above can be done for all other keywords as well.

As can be seen in Figure 3, but also in Table 5, the second keyword of the search query "supply chain" is colored purple. It may appear in several researched articles along with one of the other purple colored keywords, for example: logistics, mathematical modeling. Other keywords it may occur with can be found in Table 5. If it is a purple cluster, you can tell it is Cluster 5.

5. CONCLUSION

To investigate papers that use optimization methods in supply chain management, a review of papers found in the Web of Science Core Collection database was conducted. The search was conducted in July 2023 and resulted in 465 articles. After excluding from the search all papers that were not articles and articles that were not in English, 359 articles remained for further analysis. As for the Citation Topics Meso, 70% of the articles were published in Supply Chain & Logistics. *RQ1*: The oldest published article corresponding to the query under study was published in 2000, and a continuity in article publication has been observed since then. The most articles were published in 2022 - 59 articles. The number of citations of articles moves in line with the number of articles published. There were the most citations in 2022 - 1,292 citations. *RQ2*: The articles that are the subject of the analysis were written by authors from 54 countries. The order of the most important countries is the same according to the number of published works and citations. The most important country is the Republic of China with 140 published articles and 2,125 citations. *RQ3*: The journal Computers and Industrial Engineering (Impact Factor: 7.180) published the most articles subjected to analysis-20 articles. With 562 citations, the International Journal of Production Economics ranks first in terms of number of citations. *RQ4*: The most prolific author is Liu, Y., who published 12 articles that are the subject of analysis. In the first place, in terms of the number of citations of published works, is the author He, J. with 309 citations for 4 published articles. *RQ5*: The most cited article in this analysis, with 260 citations, is Data Fusion and Machine Learning for Industrial Prognosis: Trends and perspectives toward Industry 4.0. published in the journal Information Fusion (Impact Factor: 17.564). *RQ6*: In creating 359 researched articles, the authors used 1,250 keywords. The most frequently used keyword is "supply chain" with 33 repetitions. Right behind is "optimization," which was used 32 times as a keyword in the researched articles. The keyword "supply chain management" was used just as frequently, with 30 repetitions.

In future research, it is possible to conduct further bibliometric analysis: Co-authorship (Unit of analysis: organisations), Citation analysis (Unit of analysis: organisations), Bibliographic coupling (Unit of analysis: Documents, Sources, Authors, Organizations, Countries), Co-citation analysis (Unit of analysis: Cited references, Cited sources and Cited Authors). It is also possible to extend the search to the Scopus database to find relevant literature.

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TRANSPORT NETWORK OPTIMIZATION BASED ON FINDING OPTIMAL AND SUBOPTIMAL SOLUTIONS ON THE EXAMPLE OF THE RIJEKA URBAN AGGLOMERATION

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Abstract

The paper investigates the modeling and optimization of the transport network in finding optimal and suboptimal solutions on the example of the Rijeka Urban Agglomeration with the aim of achieving and improving business results. The urban agglomeration of Rijeka consists of 14 cities and municipalities, which are also called transport hubs, and are connected by routes in the transport network. By modeling and optimizing the transport network of the Urban Agglomeration, Rijeka should provide optimal service to cities, municipalities and their distribution centers in the area of the agglomeration.

The basic criterion for choosing optimal transport routes is the distance between cities (transport nodes). If the distance is the same or similar, dynamic selection can determine multiple transport routes in different periods can be obtained by dynamic selection, so from the point of view of other relevant criteria, one route can be optimal in one period, and another route can be optimal in another period. Based on the exhaustive search algorithm used to solve the traveling salesman problem (TSP), a visual model of the optimization of the transport network of the Urban Agglomeration of Rijeka can be created using the Visual Basic program in the Excel spreadsheet interface.

In the example of optimization of the transport network of the Rijeka Urban Agglomeration, the optimization factors are the minimum length of the transport route, the shortest time at minimum cost, and the maximum utilization of transport capacity. By considering optimal and suboptimal solutions within a given deviation interval, it is possible to break down and analyze the synergy of all relevant factors that determine the best (optimal or suboptimal) solution in different situations in order to achieve the minimum length of the transport. The optimization of the transport network based on finding optimal and suboptimal solutions has significant impact on the efficient and flexible optimization of transport network, which enables the choice between alternative transport routes in different situations. The paper investigates the impact of optimization of the transport network based on the calculation of optimal and suboptimal solutions on business effects in the logistics and transport system.

Key words: transport network optimization, suboptimal solutions, alternative roads, business effects, Rijeka Urban Agglomeration,

1. INTRODUCTION

Due to the large increases in the number of cities in the world, mobility between cities has become difficult because there are many different roads to reach the same city with different travel costs (Ameen, Sleit, & Al-Sharaeh, 2018), where there are several places all directly connected by different long roads, and the passenger wants to make the shortest trip. Some algorithms can be used to guide people using any of the transportation or movement methods (walking, train, car, or bus) to their destination by the shortest route (Zhen & Noon, 1996.).

In this paper, we present the application of the Traveling- Salesman problem (TSP) and an exhaustive search algorithm on the example of the transport network of the Urban agglomeration of Rijeka. The rational use of space and other resources for transport purposes is a very important factor in the planning and design of the transport network of an urban agglomeration (Smojver, Baričević & Schiozzi, 2018). The development of urban agglomeration has led to a large number of potential solutions for the design of a flexible and optimal transport network.

Object modeling and programming in a spreadsheet interface (VBA for Excel) using the exhaustive search algorithm achieves a greater number of optimal alternative routes on the transport network that are examined in the transport network optimization Finding a greater number of optimal and suboptimal transport routes enables the management to achieve greater flexibility and adaptability of the company, as well as faster and easier decision-making. Thus, managers considering various optimal alternative solutions can choose the most useful solution from the point of view of various relevant criteria (Vukmirović, Pupovac, 2013). The Exhaustive Search algorithm used in the modeling of the transport network of the cities and municipalities of Urban agglomeration Rijeka makes it possible to find more optimal and suboptimal solutions, which significantly affects the efficient and flexible optimization and modeling of the transport network, enabling a choice between alternative transport routes in different situations, time and cost savings, better utilization of transport capacity, creating added value and achieving higher profits.

Identifying multiple optimal transportation routes (an optimal solution and suboptimal solutions) allows for greater flexibility in optimizing and modeling the transportation network with the goal of computing several different transportation routes that meet different criteria, such as different transportation needs in different time periods. Among the important decisions related to the optimization of the transport network using the example of the Rijeka agglomeration is the calculation and representation of several alternative transport routes based on suboptimal solutions calculated together with an optimal solution (Vukmirović, Čapko & Babić, 2019a).

Visual and object-oriented methods of modelling and programming and Exhaustive Search Algorithm allows us to solve and visualize the Travelling Salesman Problem, in the way to identify multiple optimal solutions with a clear interpretation of the results not only of the optimal value but also at approximately equal values and their deviations from the optimal value. Given that Urban Agglomeration Rijeka covers 14 cities and municipalities, Exhaustive Search Algorithm is suitable for designing the transport network. In making the program based on the Exhaustive Search Algorithm have been used Visual Basic for Application in Excel spreadsheet interface. The Exhaustive Search Algorithm, with the calculation of the optimal relation, also allows the calculation of suboptimal relations whose values within an acceptable deviation from the optimal value.

In investigating the problem above, the following scientific hypothesis has been proposed: Visual and object-oriented methods of modelling and programming in the spreadsheet interface, on the base of Exhaustive Search Algorithm for solving Traveling Salesman Problem, enable transport network optimization that identify multiple optimal and suboptimal solutions and enable significant influence on the business effects of transport in Rijeka Urban Agglommeration: reduction of transport time and costs, greater safety of transport within the time schedules and better utilization of vehicle capacity.

The paper is divided into seven main chapters:

The **Introduction** is the first chapter and introduces the reader to the research problem of the thesis, the hypothesis and the overall structure of the thesis.

The second chapter entitled **Traveling salesman problem (TSP), Exhaustive Search Algorithm and Object programming in the spreadsheet interface** consists of previous research and presentation of the exhaustive search algorithm in solving TSP in a spreadsheet interface, considering the example of the base of a square pyramid in the calculation and finding a large number of optimal and suboptimal solutions of the transport network, as well as the visualization and transparency of the solutions in the spreadsheet interface.

The third chapter entitled **Urban aglommeration of Rijeka and transportation network** considers the significance of the transport network in connecting the City of Rijeka, the Port of Rijeka and the cities and municipalities of the Urban Agglomeration of Rijeka

In the fourth chapter, titled **Conceptual Model of Transport Network Optimization** on the Example of the Urban Agglomeration of Rijeka, the transport network is divided into two segments from the point of view of identifying repeated transport routes and finding optimal and suboptimal solutions.

The fifth chapter, titled **Exhaustive Search Algorithm Approach to Finding the Suboptimal Solutions of the Transportation Network**, discusses and describes the use and importance of the Exhaustive Search Algorithm, based on object-oriented modeling and programming methods in finding and visualizing optimal and suboptimal solutions for the selected transportation network segment.

In the sixth chapter, titled the **Significance of identifying and finding more optimal and suboptimal solutions of the transport network to the business effects**, there have been analysed and explained influence on the business effects of transport in Rijeka Urban Agglommeration: reduction of transport time and costs, greater safety of transport within the time schedules and better utilization of vehicle capacity.

The last chapter is the **Conclusion**, which includes a summary statement and presents a synthesis of the key points and the main research results.

2. TRAVELING SALESMAN PROBLEM, EXHAUSTIVE SEARCH ALGORITHM AND OBJECT PROGRAMMING IN THE SPREADSHEET INTERFACE

The Travelling Salesman Problem (TSP) is an optimization problem used to find the shortest path to travel through the given number of cities. Travelling salesman problem states that given a number of cities N and the distance between the cities, the traveler has to travel through all the given cities exactly once and return to the same city from where he started and also the length of the path is minimized (Rao, Hegde, 2015).

The Travelling Salesman Problem (TSP) can be formulated as follows: to choose a pathway optimal by the given criterion. In this, optimality criterion is usually the minimal distance between towns or minimal travel expenses. Travelling salesman should visit a certain number of towns and return to the place of departure, so that they visit each town only … The travelling salesman problem can be classified as Symmetric Travelling Salesman Problem (STSP), and Asymmetric Travelling Salesman Problem (ATSP). In STSP the distance between two cities is same in both the directions. In ATSP the distance between two cities is not same in both directions (Rao, Hegde, 2015).

In terms of combinatorial optimization, the Travelling Salesman Problem (TSP) can be formulated in the following way: Given a list of *n* cities C and distance dij from city *i* to city *j*; TSP, is to find the best possible way of visiting all the cities by visiting each city only once finding minimum total travel distance. In analogy to the above definition, the following formulations are valid: 1) Travel distance or distance between cities is symmetric: $d_{ij} = d_{ji}$ (1) or asymmetric d_{ij} # d_{ji} (2); 2) Final list of cities is defined as incoming variable by the formula C = (c_1 … c_n), while distance matrix containing distance between city c_i and city c_j for each pair i,j is defined by $d(c_i,c_j)$; 3) Permutations or in other words all permuted relations that can be achieved for a given number of cities are computed as resulting variables. Permutations p(1), …, p(n) in the list 1, …, n are calculated and compared to give the minimum sum (Abdoun, Abouchabaka, Tajani 2012), (Vukmirović, Pupovac, 2013).

Exhaustive search algorithm, also known as brute force search, is a very general problem-solving technique. This algorithm calculates the length for all possible relations and finds the relation with the smallest length. Also, the number of possible relations is factorial of n number of towns, that is, the number of permutations of n elements. In the Travelling Salesman Problem (TSP), every tour corresponds to a permutation of the cities. In a permutation problem every freasible solution can be specified as a total ordering of an underlying ground set (Fomin, F.V., Kratsch, D., 2010). The Exhaustive Search Algorithm enumerating all possible candidates for the solution (permutations) and checking whether each candidate satisfies the problem's statement. It is considered as approach to apply and is useful for solving small–size instances of a problem.

The majority of existing software solutions allows calculation and insight into one optimal solution. Using visual and object methods in programming and modelling to form an algorithm of detailed search criteria can simulate models with more than one optimal solution for small scale patterns, with clear interpretation of the results, not only those in optimal value, but also those of approximately equal values and their deviation from the optimum. Finding a large number of optimal transport relations allows greater flexibility in making a multiobjecitive selection of optimal transport relation, especially over different periods of time. In this paper, the basic criterion for selection of optimal transport relation is the distance between cities (trade-transport centres). In cases of the same or similar distance, there is a possibility of dynamic selection of multiple transport relations for diff erent periods of time, so, from the perspective of other relevant criteria, there can be one optimal relation for a certain period of time, and another optimal relation for other periods (Vukmirović, Pupavac, 2013).

Object program for the algorithm of Exhaustive search algorithm in the spreadsheet interface explores and fi nds all relations with the minimal value achieved. Also, the program can explore and find relations with values close to optimal (minimal) value with predefined minimal deviation. Crucial factor for structuring a transport network with transportation at minimal cost, maximal profi ts and minimal time is the use of relevant information technologies and computer applications that allow the calculation of the optimal connectivity of nodes (towns) and scheduling of transport relations. Methodological frame of use of Visual Basic as a development tool in the visual modelling of Exhaustive Search Algorithm in VBA for Excel can serve as an incentive in creating new highly sophisticated algorithms, which will enable us to compute optimal and suboptimal solutions of transport network (Vukmirović and Pupavac, 2013), (Vukmirović, Čičin-Šain and Host, 2015).

The transport network model based on a quadratic pyramid is used to prove and analyze the possibilities of achieving a large number of optimal solutions with the same or similar values (Vukmirović, Pupovac, 2013.; Vukmirović, Čičin-Šain, Host, 2015; Vukmirović, Čapko, Babić, 2019a). Table 1 shows the application of the Exhaustive Search algorithm on the example of the base of a square pyramid, using the Visual Basic for Excel program, the spreadsheet interface.

In the address range N1:V9, the distance values between the nodes of the square pyramid are entered. In the address range A1:J20160, all possible solutions for the transport network in the form of a square pyramid, consisting of 9 nodes, were calculated. Since the matrix shown in the address range N1:V9 is symmetric, 20160 possible solutions were calculated, sorted by the value of the transport path from the smallest to the largest value. The smallest value of the transport path represents the optimal solution. The Table 1 shows that 18 optimal solutions were calculated and found, where the value is 41.

Table 1 Exhaustive search algorithm in spreadsheet interface

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1	1	2	5	6	8	9	7	3	4	1	**41**	**0,0%**		1,0	5,0	5,0	3,5	7,0	10,5	11,0	11,0	14,0	**1**	**A**
2	1	2	5	8	6	9	7	3	4	1	**41**	**0,0%**		5,0	1,0	7,0	3,5	5,0	8,0	10,0	7,0	11,0	**2**	**B**
3	1	2	5	8	9	6	7	3	4	1	**41**	**0,0%**		5,0	7,0	1,0	3,5	5,0	8,0	7,0	10,0	11,0	**3**	**C**
4	1	2	8	9	7	6	5	3	4	1	**41**	**0,0%**		3,5	3,5	3,5	1,0	3,5	7,0	8,0	8,0	10,5	**4**	**D**
5	1	2	8	9	6	7	5	3	4	1	**41**	**0,0%**		7,0	5,0	5,0	3,5	1,0	3,5	5,0	5,0	7,0	**5**	**E**
6	1	2	8	6	9	7	5	3	4	1	**41**	**0,0%**		10,5	8,0	8,0	7,0	3,5	1,0	3,5	3,5	3,5	**6**	**F**
7	1	2	8	6	9	7	5	4	3	1	**41**	**0,0%**		11,0	10,0	7,0	8,0	5,0	3,5	1,0	7,0	5,0	**7**	**G**
8	1	2	8	9	6	7	5	4	3	1	**41**	**0,0%**		11,0	7,0	10,0	8,0	5,0	3,5	7,0	1,0	5,0	**8**	**H**
9	1	2	8	9	7	6	5	4	3	1	**41**	**0,0%**		14,0	11,0	11,0	10,5	7,0	3,5	5,0	5,0	1,0	**9**	**I**
10	1	2	4	5	6	8	9	7	3	1	**41**	**0,0%**		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
11	1	2	4	5	8	9	6	7	3	1	**41**	**0,0%**		**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**	**I**		
12	1	2	4	5	8	6	9	7	3	1	**41**	**0,0%**												
13	1	3	7	9	6	8	5	2	4	1	**41**	**0,0%**												
14	1	3	7	6	9	8	5	2	4	1	**41**	**0,0%**												
15	1	3	7	9	8	6	5	2	4	1	**41**	**0,0%**												
16	1	3	5	7	6	9	8	2	4	1	**41**	**0,0%**												
17	1	3	5	7	9	6	8	2	4	1	**41**	**0,0%**												
18	1	3	5	6	7	9	8	2	4	1	**41**	**0,0%**												
19	1	2	8	6	9	7	3	5	4	1	**43**	**4,9%**												
20	1	2	8	9	6	7	3	5	4	1	**43**	**4,9%**												
21	1	2	3	7	6	9	8	5	4	1	**43**	**4,9%**												
22	1	2	3	7	9	6	8	5	4	1	**43**	**4,9%**												
49	1	3	7	6	9	8	2	5	4	1	**43**	**4,9%**												
50	1	3	7	9	6	8	2	5	4	1	**43**	**4,9%**												
51	1	2	5	8	9	7	6	3	4	1	**43,5**	**6,1%**												
52	1	2	5	7	9	8	6	3	4	1	**43,5**	**6,1%**												
20157	1	6	2	7	5	3	8	4	9	1	**81**	**97,6%**												
20158	1	9	4	7	2	5	8	3	6	1	**81**	**97,6%**												
20159	1	9	4	8	3	5	7	2	6	1	**81**	**97,6%**												
20160	1	6	3	8	5	2	7	4	9	1	**81**	**97,6%**												

Source: Authors

In column L, in the address area L1:L20160, deviations from the optimal value are calculated. In the example, a value of 5% of the permissible deviation is defined. The Table 1 shows that 32 suboptimal solutions were calculated within the address area A19:J50, the value of which is within the permissible deviation of 5%.

3. URBAN AGLOMMERATION RIJEKA AND TRANSPORTATION NETWORK

The Development Strategy of the Urban Agglomeration Rijeka is based on strategic and territorial documents of all cities and municipalities of the Urban Agglomeration Rijeka and is linked to all higher order strategic documents (Grad Rijeka, 2017). According to the Guidelines for the Establishment of Urban Areas and the Urban Development Strategy, the City of Rijeka has proposed a change in the scope of the Rijeka agglomeration for the period 2021-2027 and submitted to the

Ministry the final proposal for the scope of the Urban Agglomeration of Rijeka according to which the Rijeka agglomeration would include 14 units of local self-government: The cities of Rijeka, Bakar, Kastav, Kraljevica and Opatija, and the municipalities of Čavle, Jelenje, Klana, Kostrena, Lovran, Matulji, Mošćenička Draga, Omišalj and Viškovo. The proposal also included the approval of the accession of the above-mentioned cities and municipalities to the system of urban agglomeration (Grad Rijeka, 2021).

The relations between the port and the city are thus variable, both spatially and over time, and the idea of the interdependence of port activities and urban phenomena has been re-emerging throughout the history and around the world. By studying the concept of the port-city interface, it is concluded that the relationship between the port and the city, despite the fact that they are separated, becomes increasingly intertwined and complex as new changes affecting both the port and the city are constantly emerging (Jugović, Sirotić, Peronja, 2021).

Within the port and city interface, however, there are specialized business activities that are related to the port, shipping, and the city through various types of transactions (e.g. finance, risk management, consulting, etc.) (Zhao et al., 2017 as cited in Jugović, Sirotić, Peronja, 2021).

The port-city interface can be described as a system, as a concept, or as a system of mechanisms that, together and individually, connect the port and the city.» (Hoyle, 2006). This intermediate zone is a 'threshold' (Crotti, 2000 as cited in Brambilla, Laine, Bocchi, 2015) with variable thickness and configurations that vary depending on a number of factors. The research of this system offers opportunities for setting strategies for urban-port territories and in this context for the development of urban agglomeration.

Global positioning of Rijeka with the development of the Rijeka Traffic Direction as the Strategic Objective 1 directly contributes to the strengthening of Rijeka's competitiveness on a global level, with its port as the greatest comparative advantage. The development of the Port of Rijeka involves a whole range of supporting services with a trend of enhancing the port logistics chains. This implies linking and aligning all entities within the transport sector. The purpose of such linking is to develop the Rijeka Traffic Direction as the unique economic offer on the global market (Strategija razvoja grada Rijeke, 2013.)

Based on the conceptual model of the transport network of the Urban Agglomeration of Rijeka, a flexible and adaptive transport network has been designed, for which it can be assumed that in addition to the optimal solution, there may be several suboptimal solutions. The city of Rijeka is defined as the origin and destination of the flexible transport network (start/end city). By identifying and scientifically based analysis of the problem of more optimal and suboptimal relations, a significant impact on the synergy of the parameters of success and efficiency of the transport network of the Rijeka Urban Agglomeration can be achieved, and thus on a better connection of the Port of Rijeka and the city of Rijeka with the cities and municipalities of the Rijeka Urban Agglomeration.

4. CONCEPTUAL MODEL OF TRANSPORTATION NETWORK OPTIMIZATION ON THE EXAMPLE OF THE URBAN AGGLOMERATION OF RIJEKA

Urban Agglomeration of Rijeka consists of 14 cities and municipalities, which represent 14 transport nodes or junctions in the transport network as explained in Chapter 3. Table 2 shows the distances between the cities and municipalities of the Rijeka agglomeration. Google Maps technology was used as a data source for the distances. Google Maps is a digital mapping platform that offers various services such as satellite imagery, route planning, location solutions, etc. and provides an automatic graphical representation of the selected route on a digital map.

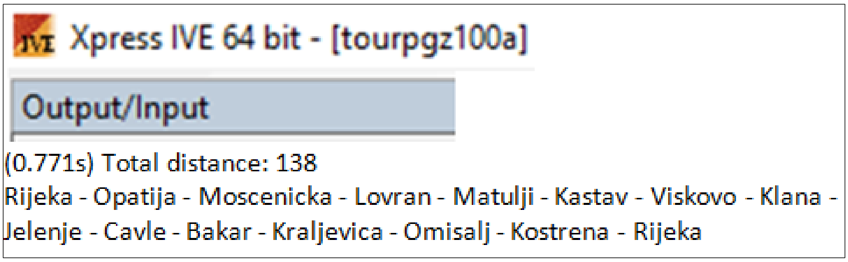
Table 2 Distances between cities and municipalities of Urban Agglomeration of Rijeka

No	City	Abb	Distances													
1	Rijeka	RI	0	22	12	7	14	12	9	11	9	18	27	21	28	15
2	Kraljevica	KR	22	0	8	15	37	33	31	32	17	40	6	49	57	31
3	Bakar	BA	12	8	0	7	27	23	20	22	9	29	13	39	47	15
4	Kostrena	KO	7	15	7	0	22	26	23	24	12	32	20	35	43	18
5	Opatija	OP	14	37	27	22	0	4	12	7	22	20	41	7	14	28
6	Matulji	MA	12	33	23	26	4	0	8	3	19	15	38	10	19	25
7	Viškovo	VI	9	31	20	23	12	8	0	5	16	10	34	19	26	11
8	Kastav	KA	11	32	22	24	7	3	5	0	18	13	36	14	22	14
9	Čavle	ČA	9	17	9	12	22	19	16	18	0	22	22	30	37	6
10	Klana	KL	18	40	29	32	20	15	10	13	22	0	44	29	36	16
11	Omišalj	OM	27	6	13	20	41	38	34	36	22	44	0	47	55	35
12	Lovran	LO	21	49	39	35	7	10	19	14	30	29	47	0	10	43
13	Mošćenička Draga	MO	28	57	47	43	14	19	26	22	37	36	55	10	0	50
14	Jelenje	JE	15	31	15	18	28	25	11	14	6	16	35	43	50	0
			RI	KR	BA	KO	OP	MA	VI	KA	ČA	KL	OM	LO	MO	JE

Source: Authors

The conceptual model of optimization of the transport network of Urban agglommeration Rijeka, was designed in the function of finding suboptimal solutions. **The solution of the transport network was calculated using the programming language for mathematical modeling FICO Xpress – solver for linear and quadratic programming with continuous or integer variables (Figure 1).**

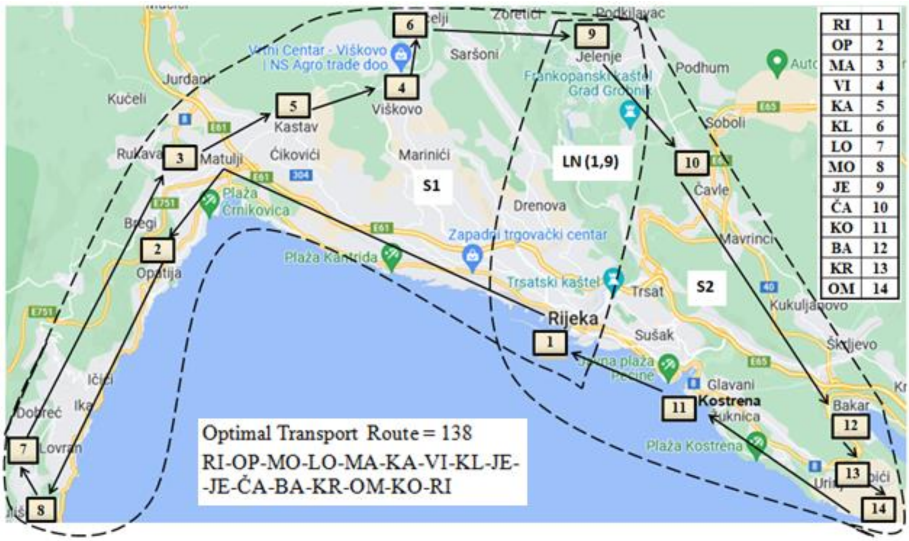
Figure 1 Solution of transport network has been calculated by usage of programming language for mathematical modeling Xpress



Source: Authors

On the Map 1 is a graphical representation of the optimal transport route and the conceptual model of the transport network of the Urban Agglomeration of Rijeka. In the Table 2 in Map 1, the right part shows the names of the cities and the abbreviations of the cities and their numbers, and the lower part shows the value of the optimal solutions and configurations (direction) of the optimal transport route.
In accordance with the calculated optimal solution presented in Map 1, a conceptual model of the transport network of the Rijeka agglomeration was designed in order to find possible optimal and suboptimal solutions. It is considered that in the exhaustive search algorithm used in this work, the maximum number of nodes is 9.

Map 1 Graphical display of the optimal transport route and the conceptual model of the transportation network of Urban agglommeration Rijeka



Source: Authors

The conceptual model of the transport network of is divided into two groups (segments) S1 and S2 from the point of view of finding optimal and suboptimal solutions (Vukmirović, Čapko, Babić, 2019a). The model shows that segment S1 includes nodes (cities and municipalities) from 1 to 9 and segment S2 includes nodes 9 to 14 and node 1. In segments S1 and S2, the possibilities of connecting cities (nodes) via different transport routes were analyzed and optimal and suboptimal solutions were calculated using an exhaustive search algorithm. The example also defines nodes 1 and 9 (cities of Rijeka and Jelenje), which are common to the defined segments of the S1 and S2 transport network. Nodes 1 and 9, marked in Map 1 as LN (1,9), represent in the model the common points and at the same time the end points for the S1 and S2 transport network segments and enable the connection of the transport network segments.

Table 2a shows data of estimated transport times between cities and municipalities (nodes) of the Urban Agglomeration of Rijeka, which were collected in a certain time interval, using the Google Maps tool.

Table 2a Estimated Times between cities and municipalities of Rijeka Urban Agglomeration

No	City	Abb	Estimated Times													
1	Rijeka	RI	1	24	19	16	27	22	21	22	17	31	26	40	52	24
2	Kraljevica	KR	24	1	12	16	34	28	28	30	21	36	13	48	59	28
3	Bakar	BA	19	12	1	13	31	26	26	27	17	33	20	46	58	25
4	Kostrena	KO	16	16	13	1	30	24	24	26	16	32	22	45	57	23
5	Opatija	OP	27	34	31	30	1	9	23	15	25	28	37	19	31	32
6	Matulji	MA	22	28	26	24	9	1	18	9	21	21	33	29	41	28
7	Viškovo	VI	21	28	26	24	23	18	1	12	19	14	31	37	48	20
8	Kastav	KA	22	30	27	26	15	9	12	1	24	15	35	33	46	24
9	Čavle	ČA	17	21	17	16	25	21	19	24	1	26	24	39	51	7
10	Klana	KL	31	36	33	32	28	21	14	15	27	1	39	46	56	28
11	Omišalj	OM	26	13	20	22	37	33	31	35	24	39	1	51	62	30
12	Lovran	LO	40	48	46	45	19	29	37	33	38	46	51	1	16	45
13	Mošćenička	MO	52	59	58	57	31	41	48	46	47	56	62	16	1	54
14	Jelenje	JE	24	28	25	23	32	28	20	24	8	28	30	45	54	1
			RI	KR	BA	KO	OP	MA	VI	KA	ČA	KL	OM	LO	MO	JE

Source: Authors

5. EXHAUSTIVE SEARCH ALGORITHM APPROACH TO FINDING THE OPTIMAL AND SUBOPTIMAL SOLUTIONS OF THE TRANSPORTATION NETWORK

An Exhaustive Search algorithm developed in Visual Basic was used in the optimization of the transport network of Urban Agglomeration of Rijeka. Object-oriented programming in Visual Basic was used to create and visualize the Exhaustive Search Algorithm in order to calculate one or more optimal transport routes. The cities included in the transportation network calculation belong to the S1 and S2 node groups explained in the previous chapter and shown in Map 2. Table 4 and Table 5 contain the results for the given example.

Table 4 shows the optimal solution for the first segment (S1) of the transport network using the exhaustive search algorithm. The results were calculated using the Visual Basic in Excel (VBA for Excel) program created by the authors of this paper. It can be seen from Table 3 that 20160 possible transport routes (relations) were calculated, where the minimum route length is 82 km.

Table 5 shows the optimal solution of the second segment (S2) of the transport network according to the method of exhaustive search using the Visual Basic program in the Excel spreadsheet interface. It can be seen from Table 4 that four optimal transport routes (relations) with a minimum route length of 56 km were calculated (rows 1-4).

The exhaustive search algorithm used in this work resulted in a solution with a maximum of 9 nodes. The Table 5 shows cities and municipalities as nodes representing transport nodes and ordinal numbers of nodes from 1 to 9. Nodes 1 and 9 (cities of Rijeka and Jelenje) are common to both city segments (transport network segments) defined and shown on Map 2, representing the end points of the city segment.

Table 4 Solution of the first segment (S1) of the transport network

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	**Nodes**								**Length**	**Time**	**Distances**							**City**	**No.**
2	1	9	10	14	13	12	11	1	56	85	0	22	12	7	9	27	0	RI	1
3	1	9	10	13	14	12	11	1	56	90	22	0	8	15	17	6	31	KR	13
4	1	9	10	12	13	14	11	1	56	87	12	8	0	7	9	13	15	BA	12
5	1	9	10	12	14	13	11	1	56	89	7	15	7	0	12	20	18	KO	11
6	1	9	10	11	14	13	12	1	64	89	9	17	9	12	0	22	6	ČA	10
7	1	9	10	11	13	14	12	1	64	91	27	6	13	20	22	0	35	OM	14
8	1	9	10	11	12	13	14	1	66	87	0	31	15	18	6	35	0	JE	9
9	1	9	10	11	12	14	13	1	66	93	RI	KR	BA	KO	ČA	OM	JE		
10	1	9	10	13	14	11	12	1	68	95	1	13	12	11	10	14	9		
11	1	9	10	14	13	11	12	1	68	92									
12	1	9	11	13	14	12	10	1	70	106	**OPTIMAL TRANSPORT ROUTE**								**Length**
13	1	9	11	14	13	12	10	1	70	104	1	9	10	14	13	12	11	1	56
14	1	9	11	12	14	13	10	1	70	107	RI	JE	ČA	OM	KR	BA	KO	RI	
15	1	9	11	12	13	14	10	1	70	102		0	+6	+22	+6	+8	+7	+7	=56
16	1	9	10	12	11	14	13	1	70	96									
357	1	14	10	12	11	9	13	1	136	155	**OPTIMAL TRANSPORT ROUTE**								**Time**
358	1	12	11	10	14	9	13	1	141	154	1	9	10	14	13	12	11	1	85
359	1	12	11	10	13	9	14	1	141	153	RI	JE	ČA	OM	KR	BA	KO	RI	
360	1	12	10	11	13	9	14	1	141	152		0	+7	+24	+13	+12	+13	+16	=85
361	1	12	10	11	14	9	13	1	141	156									

Source: Authors

Table 5. Solution of the second segment (S2) of the transport network

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Nodes										Length	Time	Distances									No.	City
2	1	2	8	7	3	5	4	6	9	1	82	166	0	14	12	9	11	18	21	28	0	1	RI
3	1	7	8	2	3	5	4	6	9	1	83	159	14	0	4	12	7	20	7	14	28	2	OP
4	1	8	7	2	3	5	4	6	9	1	83	159	12	4	0	8	3	15	10	18	25	3	MA
5	1	2	7	8	3	5	4	6	9	1	83	166	9	12	8	0	5	10	19	26	11	4	VI
6	1	3	7	8	2	5	4	6	9	1	84	167	11	7	3	5	0	13	14	22	14	5	KA
7	1	2	8	7	3	5	6	4	9	1	85	161	18	20	15	10	13	0	29	36	16	6	KL
8	1	3	2	8	7	5	4	6	9	1	85	165	21	7	10	19	14	29	0	10	43	7	LO
9	1	3	8	7	2	5	4	6	9	1	85	167	28	14	18	26	22	36	10	0	50	8	MO
10	1	2	7	8	3	5	6	4	9	1	86	161	0	28	25	11	14	16	43	50	0	9	JE
11	1	8	7	2	3	5	6	4	9	1	86	160	RI	OP	MA	VI	KA	KL	LO	MO	JE		
12	1	7	8	2	3	5	6	4	9	1	86	160	1	2	3	4	5	6	7	8	9		
13	1	5	2	8	7	3	4	6	9	1	86	173											
14	1	4	5	2	8	7	3	6	9	1	86	173	OPTIMAL TRANSPORT ROUTE										Length
15	1	5	3	7	8	2	4	6	9	1	86	172	1	2	8	7	3	5	4	6	9	1	82
16	1	3	2	7	8	5	4	6	9	1	86	166	RI	OP	MO	LO	MA	KA	VI	KL	JE	RI	
17	1	4	5	3	7	8	2	6	9	1	87	174		14	+14	+10	+10	+3	+5	+10	+16	+0	82
40317	1	3	6	8	9	7	4	2	5	1	205	273											
40318	1	5	7	9	8	6	2	4	3	1	206	279	SUBOPTIMAL TRANSPORT ROUTE										Length
40319	1	3	4	8	9	7	6	2	5	1	206	276	1	7	8	2	3	5	4	6	9	1	83
40320	1	3	4	7	9	8	6	2	5	1	206	275	RI	OP	MA	VI	KA	KL	LO	MO	JE	RI	
40321	1	5	8	9	7	6	2	4	3	1	207	282											

Source: Authors

Table 6 presents the consolidated optimal and suboptimal solutions of the transport network in which segments S1 and S2 of the transport network are connected and that were calculated values of minimum distances (column Length) and estimated transport times (column Time). In the segment Optimal and suboptimal transportation routes, the abbreviations denote the cities and municipalities of the Urban agglomeration of Rijeka, as defined in table 2. The city of Rijeka (RI) is defined and presented as a start/end node.

Table 6 Consolidated solutions of the transport network

No.	Optimal and suboptimal transport routes															Length	Time
1	RI	OP	MO	LO	MA	KA	VI	KL	JE	ČA	BA	KR	OM	KO	RI	138	253
2	RI	OP	MO	LO	MA	KA	VI	KL	JE	ČA	KR	OM	BA	KO	RI	138	256
3	RI	OP	MO	LO	MA	KA	VI	KL	JE	ČA	OM	KR	BA	KO	RI	138	251
4	RI	OP	MO	LO	MA	KA	VI	KL	JE	ČA	BA	OM	KR	KO	RI	138	255
5	RI	LO	MO	OP	MA	KA	VI	KL	JE	ČA	OM	KR	BA	KO	RI	139	244
6	RI	LO	MO	OP	MA	KA	VI	KL	JE	ČA	KR	OM	BA	KO	RI	139	249
7	RI	LO	MO	OP	MA	KA	VI	KL	JE	ČA	BA	KR	OM	KO	RI	139	246
8	RI	LO	MO	OP	MA	KA	VI	KL	JE	ČA	BA	OM	KR	KO	RI	139	248
9	RI	MO	LO	OP	MA	KA	VI	KL	JE	ČA	OM	KR	BA	KO	RI	139	244
10	RI	MO	LO	OP	MA	KA	VI	KL	JE	ČA	KR	OM	BA	KO	RI	139	249
11	RI	MO	LO	OP	MA	KA	VI	KL	JE	ČA	BA	KR	OM	KO	RI	139	246
12	RI	MO	LO	OP	MA	KA	VI	KL	JE	ČA	BA	OM	KR	KO	RI	139	248
13	RI	OP	LO	MO	MA	KA	VI	KL	JE	ČA	OM	KR	BA	KO	RI	139	251
14	RI	OP	LO	MO	MA	KA	VI	KL	JE	ČA	KR	OM	BA	KO	RI	139	256
15	RI	OP	LO	MO	MA	KA	VI	KL	JE	ČA	BA	KR	OM	KO	RI	139	253
16	RI	OP	LO	MO	MA	KA	VI	KL	JE	ČA	BA	OM	KR	KO	RI	139	255
17	RI	MA	LO	MO	OP	KA	VI	KL	JE	ČA	OM	KR	BA	KO	RI	140	252
18	RI	MA	LO	MO	OP	KA	VI	KL	JE	ČA	KR	OM	BA	KO	RI	140	257
19	RI	MA	LO	MO	OP	KA	VI	KL	JE	ČA	BA	KR	OM	KO	RI	140	254
20	RI	MA	LO	MO	OP	KA	VI	KL	JE	ČA	BA	OM	KR	KO	RI	140	256
21	RI	OP	MO	LO	MA	KA	KL	VI	JE	ČA	OM	KR	BA	KO	RI	141	246
22	RI	OP	MO	LO	MA	KA	KL	VI	JE	ČA	KR	OM	BA	KO	RI	141	251
23	RI	OP	MO	LO	MA	KA	KL	VI	JE	ČA	BA	KR	OM	KO	RI	141	248
24	RI	OP	MO	LO	MA	KA	KL	VI	JE	ČA	BA	OM	KR	KO	RI	141	250

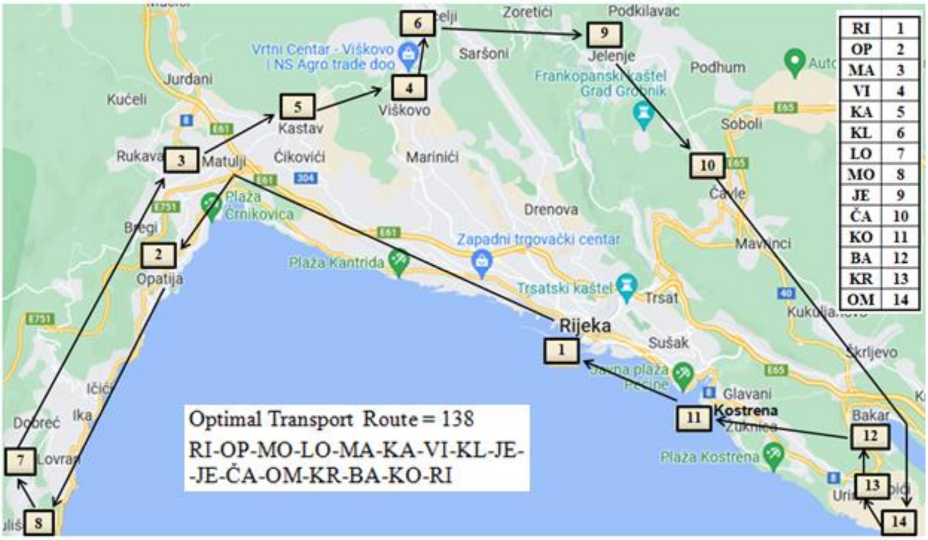
Source: Authors

In Table 6, it can be seen that four optimal relations and twenty suboptimal relations were calculated. In column No. ordinal numbers from 1 to 4 indicate optimal relations, and ordinal numbers from 5 to 24 indicate suboptimal relations. By comparing the optimal solution, which represents the minimum length and configuration of the transport route, calculated by the exhaustive search algorithm in VBA for Excel (Table 4, column No., row 1), with the optimal solution obtained using the mathematical modeling program Xpress (Figure 1), it can be observed that the results match. From the point of view of the minimum distance criterion, 4 optimal solutions were calculated.

From the point of view of the minimum distance criterion, 4 optimal solutions were calculated. Suboptimal solutions were calculated and selected from the viewpoint of minimum distance and minimum transport time criteria. From the point of view of the minimum distance, the deviation values range within 3 km, that is, 2.5% of the deviation interval from the calculated total minimum length of the route. From the point of view of minimum time, the values of suboptimal relations are less than or equal to the time values of optimal relations.

Map 2 shows the optimal solution of the transport network of Urban Agglomeration of Rijeka, which corresponds to the solution calculated in Table 5 and shown in row 1 (No.1). Map 3 shows an example of another optimal solution of the transport network, which corresponds to the solution calculated in Table 5 and shown in line 3 (No.3).

Map 2 Example of another optimal transport route



Source: Authors

Map 3 presents the suboptimal solution of the transport network that corresponds to the solution calculated in Table 5 and shown in line 9 (No. 9).

Map 3 Suboptimal transport route

Source: Authors

Comparing the optimal solutions on Map 2 and the suboptimal solution on Map 3, we can see the change in the order of cities (nodes) in segments S1 and S2 of the transport network of the Rijeka. By considering several optimal and suboptimal solutions within the interval of a given deviation, it is possible to identify and analyze the synergy of all relevant factors that determine the best (optimal) solution or a set of best solutions (optimal and suboptimal solutions). The change can be observed in the route depicted on Map 2, which goes from Rijeka to Opatija, passing over Opatija to Mošćenička Drag and Lovran. On Map 3, it can be seen that the route goes from Rijeka to Mošćenička Draga and Lovran, then to Opatija, and to Matulji. By identifying more optimal and suboptimal routes, it is possible to achieve a significant impact on the synergy of the parameters of transport performance and efficiency from the origin to the destination: minimum travel time, minimum time, minimum cost and maximum utilization of transport capacity.

6. SIGNIFICANCE OF CALCULATING AND FINDING MORE OPTIMAL AND SUBOPTIMAL SOLUTIONS OF THE TRANSPORT NETWORK TO THE BUSINESS EFFECTS

When considering the meaning of suboptimal solutions, it is necessary to distinguish between two problem situations: 1) a situation in which the optimal solution is the most favorable and 2) a situation in which a suboptimal solution can achieve better effects compared to the optimal solution. It should be noted that it is always possible to calculate a suboptimal solution.The Traveling Salesman Problem

(TSP) is a problem which requires an optimal solution, especially if the route is to be used several times. In general, if the solution is to be applied only once, a suboptimal solution will be adequate and a very close to optimal solution may be even more desirable than the optimal solution (Gregory, 1970). Sequential insertion with possible requests for variable quotes to all trucks and to all routes potentially produces suboptimal solutions (Greenwood, 2009).

In Table 6, it can be seen that four optimal relations and twenty suboptimal relations were calculated. In column No. ordinal numbers from 1 to 4 indicate optimal relations, and ordinal numbers from 5 to 24 indicate suboptimal relations. From the point of view of the minimum distance criterion, 4 optimal solutions were calculated. Suboptimal solutions were calculated and selected from the viewpoint of minimum distance and minimum transport time criteria. From the point of view of the minimum distance, the deviation values range within 3 km, that is, 2.5% of the deviation interval from the calculated total minimum length of the route. From the point of view of minimum time, the values of suboptimal relations are less than or equal to the time values of optimal relations.

It can be seen from the Table 6. that the relationships between the calculated distance values and the time values are not proportional. Also, it should be noted that distance values are fixed, and time values are variable, that is, subject to change. This means that in different periods of time significant changes in the duration of transport are possible for transport routes. **In the transportation network model in Table 6, four optimal solutions were calculated from the point of view of minimum distance. Considering the criteria of distance and time, the optimal solution in Table 6 is transportation route No. 1. However, unlike the distance values, which are fixed, the transportation times change, so in a different time period, the minimum time for a different transportation route can be calculated.**

Transport time is an important dimension in the evaluation of transport costs, particularly since logistics concomitantly involves cost and time management. Transport time is an important dimension in evaluating transport costs, particularly since logistics concomitantly involves cost and time management. The major time-related elements are (Rodrigue, 2013):

- **Transport time**. Concerns the real duration of transport, which tends to be easily understood since commonly a proportional function of distance. Geographical constraints such as weather or technical limitations such as operational speed have a direct impact on transport time. Transport time on roads is technically limited to legal speed limits. For maritime and air, the limitation mainly concerns fuel economy and design speed. Although rail can accommodate a variety of speeds, tight schedules impose limited variations in operational speeds.
- **Order time**. Almost all transport requires a form of advance preparation, mainly to secure a capacity, an itinerary and a rate. In some cases, the order time is short and a matter of queuing on a basis, while in other cases orders have to be secured months in advance.
- **Timing**. Involves the usage of a specific departure time, which depending on the mode can have a level of flexibility. While for air and rail travel timing is commonly tight due to ? xed schedules and access to a terminal capacity (such as a gate and a take off time), commuters and trucking have more flexibility. If there

is congestion either at the origin, destination or in between, trucking companies may elect to modify their schedule accordingly (earlier or later delivery).

- **Punctuality**. Represents the ability to keep a specifed schedule, which can be represented as an average deviation from a scheduled arrival time. The longer the distance, the more likely are potential disruptions that may affect schedule integrity. Some movements may have a level of tolerance to disruptions in punctuality while others, such as heading to a business meeting or flows in a just-in-time supply chain, have limited tolerance.
- **Frequency**. The number of departures for a specific time range. The higher the frequency, the better the level of service. However, a high frequency ties up a larger quantity of vehicles. Distance is also a factor for lower frequency since transport demand tends to decline accordingly. Combining long distance travel and high frequency is an expensive undertaking for transport providers as a greater number of vehicles must be assigned to a specific route, as in the case of maritime container shipping.
- **Optimal speed for fuel economy**. According to the United States Department of Energy, fuel economy is the highest at driving between 35 and 60 mph. At higher or lowest speed, the fuel efficiency drops, costing an additional value per litre (Davis, Boundy, 2012), (Ahmad, 2022). That means that in the case of choosing a longer (suboptimal) transport route on which the estimated driving time is shorter, lower or equal fuel consumption is possible compared to a shorter (optimal) transport. By comparing the optimal and suboptimal solution in Table 6, No.2 (optimal) and No.6 (suboptimal), we may see that time for suboptimal solution is 12 minutes shorter than time for optimal solution.

In the example of the transport network optimization of Urban agglomeration Rijeka, the criterion (factor) of optimization is the minimum length of the transport relation. Considering the more optimal solutions within a given deviation interval, it is possible to parse and analyze the synergy of all relevant factors that determine the best (optimal) or set of best solutions (transport cost and time, choosing the alternative route in different cases of traffic jams, punctuality, frequency and possibilities for the greater utilization of transport capacity.

7. CONCLUSION

It was proved the hypothesis that the visual and object-oriented methods of modelling and programming in the spreadsheet interface, on the base of Exhaustive Search Algorithm for solving Traveling Salesman Problem, enable transport network optimization that identify multiple optimal and suboptimal solutions and have significant influence on the business effects of transport in Rijeka Urban Agglommeration: reduction of transport time and costs, greater safety of transport within the time schedules and better utilization of vehicle capacity. Based on the conceptual model of the transport network of the Urban Agglomeration of Rijeka, it is possible to define a transport network segment for which it can be assumed that there can be several solutions of approximately equal value in an optimal solution. Based on the conceptual model, a route redundancy problem can also be defined, which can generate further optimal (minimum) values for the transport route. By identifying and performing a scientifically sound analysis of the problem of multiple optimal and suboptimal routes, a significant impact on the synergy of transportation performance and efficiency parameters from origin to destination can be achieved: minimum distance traveled, shortest time at minimum cost, and maximum utilization of transportation capacity.

The implementation of an Exhaustive Search algorithm in Visual Basic for optimizing the transport network of the Urban Agglomeration of Rijeka has demonstrated its potential to address numerous transportation challenges. By utilizing object-oriented programming and visualization techniques, this algorithm efficiently calculated one or more optimal transport routes within the network. The results obtained from this approach, as presented in Table 4 and Table 5, showcased the effectiveness of the algorithm in finding optimal solutions with minimal route lengths. The exhaustive search algorithm's ability to calculate a vast number of possible transport routes, as evidenced by the 20,160 calculated relations in Table 4, demonstrates its comprehensive exploration of the network.

Additionally, the identification of multiple optimal routes with varying lengths in Table 5 underscores the algorithm's flexibility in accommodating diverse transportation needs.

By utilizing this approach, transportation planners and businesses can benefit from the algorithm's ability to optimize route planning, resulting in more efficient and cost-effective transportation operations. In this research the algorithm's successful implementation, considering up to 9 nodes, indicates its scalability for handling larger transport networks. Overall, the utilization of the Exhaustive Search algorithm in this study has shown promising results in addressing transportation challenges, enhancing route optimization, and positively impacting various aspects businesses and urban development, including possibility for cost reduction, time efficiency, resource utilization, environmental sustainability, improved urban planning, infrastructure investment, economic growth, and enhanced urban livability.

In this paper, research on the optimization of the transportation network is limited to the parameters of distance and time. The objective of the research on the optimization of the transportation network based on the analysis of transportation distance and time was to consider the importance of calculating suboptimal solutions in order to find alternative transportation routes. In future research, the transportation network optimization model can be extended to other optimization parameters such as transportation costs, transportation capacity optimization, and variable transportation conditions.

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A KNOWLEDGE BASE FOR STRATEGIC LOGISTICS PLANNING

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Abstract

In the paper, a knowledge-based engineering approach to strategic logistics planning is presented. Semantic web technologies for managing a knowledge base of business experiences are used. The proposed knowledge base comprises experiences gained by the SCOR model of logistics planning, according to the Deming's observe, plan, do, study, act cycle. By appropriate structuring of the knowledge base, easy access to the stored experiences for on-line analytic processing is enabled. By the proposed approach an expert system for smart logistics management is founded.

Keywords: predictive analytics, applied industrial technology, artificial intelligence, smart business models, big data and sustainability

1. INTRODUCTION

The Supply-chain operations reference (SCOR) model recognizes six major processes — plan, source, make, deliver, return and enable (AIMS, 2021). The planning processes comprises the activities associated with developing action plans for a company's supply chain management and improvement.

Strategic logistics planning is used to define an approach or a number of activities to follow by an organization in order to achieve its purpose and goals. The strategy is used by its management to define action plans that will enable the organization to always make decisions that are in the organization's best interests. Depending on the time frames and management levels they impact, these plans are classified as operational, tactical and strategic.

In this article knowledge-based engineering is introduced to facilitate strategic logistics planning. Overall, different business intelligence based methods may be applied at different levels of strategic logistics planning, depending on the results one strives to achieve – from business analytics to process optimization, cp. (Gumzej & Rakovska, 2020). In addition, to achieve optimal logistics planning, they should also include total quality management (TQM) (Ciampa, 1992) and just-in-time (JIT) principles (Britannica, 2023).

The main objective of this paper is to provide an overview of methods for strategic logistics planning and investigate a solution for smart logistics management based on knowledge-based engineering. The proposed approach is based on the semantic web and online analytical processing (OLAP) technologies. The research outcomes are summarized by an analysis of the proposed approach, utilizing a knowledge base of business experiences to improve logistics and supply chain management.

2. METHODS

From the methodological point of view, strategic logistics planning is used to define an approach or a number of activities to follow by an organization in order to achieve its purpose and goals. This strategy is used by its management to define action plans that will enable the organization to always make decisions that are in the organization's best interests. They are founded on what is commonly known as institutional knowledge. In combination with business analytics on historic and current data, business decisions are formed in order to maintain or improve the organization's market position.

While institutional knowledge can be based on competent individuals, it is sensible to store it in a knowledge base and make it sustainable. With progression of data storage from data-bases to -warehouses and data migration to the cloud, over time, the next logical step is moving the knowledge base as well. By this research a semantic web approach is proposed to manage a knowledge base of business experiences.

2.1 Six Sigma

Manufacturing and business processes have characteristics that can be defined, measured, analysed, improved, and controlled (DMAIC). Continuous efforts to achieve stable and predictable process results by reducing process variation (6-sigma) are of vital importance to business success (Tennant, 2001). 6-sigma ideas have been combined with lean manufacturing to create a methodology named Lean Six Sigma (Wheat et.al., 2003). Lean manufacturing and 6-sigma originate from Japanese business culture and share similar methods and tools to define best practices.

The lean 6-sigma methodology considers lean manufacturing (“just-in-time” production), which addresses process efficiency, and 6-sigma, with its focus on reducing variation and waste, as complementary disciplines that promote business and operational excellence. Achieving sustained quality improvement requires commitment from the entire organization, particularly from top-level management.

6-sigma projects follow two project methodologies, inspired by W. Edwards Deming's Plan-Do-Study-Act (PDCA) cycle (Tague, 2005), each with five phases:

1. DMAIC is used for projects aimed at improving an existing business process
2. DMADV is used for projects aimed at creating new product or process designs

where individual letters of these abbreviations refer to the aforementioned activities, i.e., define (D), measure (M), analyse (A), improve (I) and control (C) or design (D) and verify (V).

New knowledge usually comes from creating new products or process designs by the phases of the DMADV methodology:

1. Define design goals that are consistent with customer demands and the enterprise strategy.
2. Measure and identify characteristics that are Critical to Quality (CTQ), measure product capabilities, production process capacity, and measure risks.
3. Analyse to develop and design alternatives.
4. Design an improved alternative, best suited per analysis in the previous step.
5. Verify the design, set up pilot runs, implement the production process and hand it over to the process owner(s).

Due to its suitability for progression from design to optimisation, the DMADV methodology is also known as Design for Six Sigma (DFSS) (Chowdhury, 2002).

2.2 Business Intelligence

The methods and technologies used in the process of planning and decision making are commonly termed business intelligence (BI). They are used in

- business analytics (BA), comprising data mining, analysis and decision making, as well as
- knowledge based engineering (KBE), used in production, warehousing and transport planning.

Both are addressing, what is commonly known as *institutional knowledge*[3]. Over time different companies have developed various forms of storing and retrieving this knowledge. In their most rigorous form, they have been included in the Advanced Planning Software (APS) tools (Ueda, 2010). However, in strategic logistics planning

[3] Institutional knowledge is knowledge possessed by a company or other organisation and its employees. It includes all of their skills, processes, data, values, expertise and experience gathered through the history of the organisation, but also gain by new employees in the organisation. Sometimes, it is referred to as „institutional memory“.

they are often considered the last resort for implementing the reached strategic decisions on the tactical and operational levels. Hence, another form of knowledge management and sharing is required – one that will enable retrieving experiences, representing company's best practices, as well as learning from own mistakes, easier and more transparent.

2.2.1 Business Analytics

By definition Business Analytics (BA) is a process, based on BI, enabling new insights into the business process and better strategic decision making for the future.

BA is composed of the following steps (Tableau, 2023):

1. Data Aggregation: prior to analysis, data must first be gathered, organized, and filtered, either through volunteered data or transactional records.
2. Data Mining: data mining sorts through large datasets using databases, statistics, and machine learning to identify trends and establish relationships.
3. Association and Sequence Identification: the identification of predictable actions that are performed in parallel with other actions or sequentially.
4. Text Mining: explores and organizes large, unstructured text datasets for the purpose of qualitative and quantitative analysis.
5. Forecasting: analyses historical data from a specific period in order to make informed estimates that are predictive in determining future events or behaviours.
6. Predictive Analytics: predictive business analytics uses a variety of statistical techniques to create predictive models, which extract information from datasets, identify patterns, and provide a predictive score for an array of organizational outcomes.
7. Optimization: once trends have been identified and predictions have been made, businesses can engage simulation techniques to test out best-case scenarios.
8. Data Visualization: provides visual representations such as charts and graphs for easy and quick data analysis.

BA emerged from data mining (DM), being the process of finding anomalies, patterns, and correlations in larger data sets, to predict the results. Based on the same principles it extends its use to analysing processes and predicting their outcomes.

2.2.2 Knowledge-Based Engineering

Knowledge Based Engineering (KBE) is an engineering methodology that integrates engineering knowledge systematically into the design system (Prasad, 2005). In terms of DFSS it can be considered the introduction of continuous improvement principles to enterprise strategic planning, based on quality-related product or process performance indicators, such as SCOR.

KBE comprises a number of intertwined methods, systematically addressing the common knowledge base, to achieve planned results:

- Computer aided project management (PS),
- Computer aided design (CAD), production (CAM) and robotics (CIM),
- Computer simulation modelling and analysis (SMA),
- Computer aided detailed production planning (MPS / MRP).

The combined use of these methods produces results, whose application leads to controlled changes in the enterprise, which are again analysed to determine possible improvements. These findings enrich the common institutional knowledge and should be included in its knowledge base.

Ultimately, BI is meant to facilitate enterprise decision making using BA and KBE methods as tools. They may form decision support systems (DSS) or expert systems (ES) to be used by experts and decision makers. DSS is an interactive system, which assists the decision makers to use the data and models for solving unstructured or partly structured problems. ES is an application program or environment, which effectively supports problem solving in a specialized problem area, requiring expert knowledge and skills. Although both are serving the same purpose, there is a distinctive difference between the two which narrows down their target audience.

The methods presented above all support strategic logistics planning from different perspectives and levels of decision making. In the sequel an expert system is outlined, which may include results from all previously mentioned methods and is based on the principles of KBE. It combines the gained institutional knowledge in ontologies (Hofweber, 2023) and supports Online Analytic Processing (OLAP) (Codd & Salley, 1993) of the stored knowledge.

3. KNOWLEDGE MANAGEMENT SYSTEM

The lifecycle of knowledge- or experience-based engineering (Andersson et.al., 2011) is founded on the iterative use of the Deming's OPDSA (Observe-Plan-Do-Study-Act) cycle:

1. Identify: a non-conformance with the desired state that appears in the manufacturing process due to an ill-defined product or process.
2. Capture: the experience is captured.
3. Analyse: a root cause analysis of the captured experience is made to identify an appropriate remedy strategy and its re-use to prevent recurring anomalies.
4. Store: insights from the analysis are archived; hereby, the experience is stored.
5. Search & Retrieve: the experience is searched for and retrieved.
6. Use: an element of the experience is used.
7. Re-use: concludes this cycle of knowledge management and starts a new one.

The experts involved in the decision-making process access this information through the enterprise Knowledge Management System (KMS). Hence, the KMS represents an expert system for collecting, cataloguing and retrieving experiences stored in the knowledge base. It may store various kinds of information, however, the most important are the experiences themselves, representing key pieces of information for addressing concrete problem situations (Sowa, 2010).

3.1 Knowledge Base

The knowledge base stores experiences as pieces of information, an organization can utilize in the process of KBE to make better informed and quicker planned decisions. With respect to using the principles of the intelligent Web, the proposed form of knowledge organisation is by an ontology. Here, the collected experiences are stored as entities that can be retrieved and combined in various ways. They have properties, characterizing their nature, and relations, outlining their structure and interconnections.

The proposed form to represent the individual experiences as pieces of information is by using SOAP notes. They contain four distinct pieces of information:

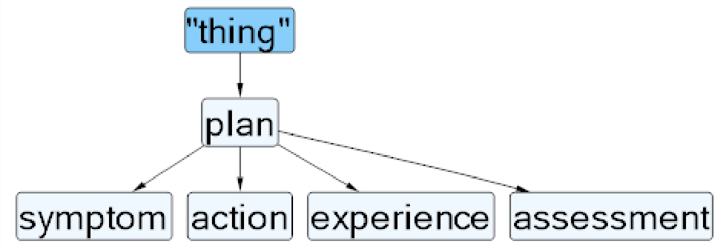
1. Subjective data (S), such as quotes, or paraphrased statements; a few sentences that best capture the most pressing concern.
2. Objective data (O), such as factual, observable values.
3. Assessment (A) of the situation; based on the subjective and objective data, a statement is made about, what they mean; in association with them, here, also planned interventions, goals, and objectives can be included.
4. Plan (P) for interventions.

SOAP notes are the most common type of business experience notes, used here to enable the experts to reason about the problem in an understandable and addressable way. Such notes are commonly used in marketing research, when interviewing clients, to determine customer satisfaction. Hence, they usually lack precision, much needed when making enterprise-level decisions about additions/improvements to the production process. Another kind of business experience notes are DAP notes, which combine the previously mentioned S and O data into D (diagnosis). Such notes are often used in medicine, when treating patients. Diagnosed symptoms are represented by qualitative descriptions and quantitative indicators.

In general, one cannot limit oneself to factual data only. Because of this, concise subjective data also have an important role in the assessment. An assessment comprises the methods used in the analysis of the identified non-conformance with the aspired state. As continuation of the analytic process, plans represent remedy actions that have been identified as beneficial for the improvement of the current state by its assessment.

For simplicity reasons DAP notes have been chosen to represent the enterprise experiences of the proposed KMS. The structure of knowledge in the knowledge base of experiences can thus be presented in the form of an ontology graph, as shown in Figure 1. Here, the planned activities are grouped around experiences formed by analysing the symptoms and assessing the situation to form improvement actions.

Figure 1 KMS ontology



Source: own

3.2 Knowledge Organization

Every piece of experience in the enterprise KMS is catalogued as an entity, having properties and relations to the rest. As mentioned above, every experience has symptoms, an assessment and planed actions. Symptoms are characterised by their descriptions and indicators, listing their specific current as well as target values. Assessments are short descriptions of the methods used in the analysis of the symptoms. Actions are short descriptions of remedy actions taken. Experiences of the same action plan can be grouped to form complex systemic (multi-level) action plans. They are formulated as facts and rules, using Ontorion's controlled natural language (CNL) statements (Kaplanski, et.al., 2015), as presented below.

```
Every experience is something.
Every symptom is-part-of an experience.
Every assessment is-part-of an experience.
Every action is-part-of an experience.

Every symptom that belongs-to an experience has-description nothing-
but (some string value).
Every symptom that belongs-to an experience has-value nothing-but
(some real value).
Every symptom that belongs-to an experience has-target-value
nothing-but (some real value).
Every assessment that belongs-to an experience has-description
nothing-but (some string value).
Every action that belongs-to an experience has-description nothing-
but (some string value).

If X is-part-of Y then X belongs-to Y.
Every-single-thing that is an experience and-or belongs-to something
(that is an experience) is a plan.
```

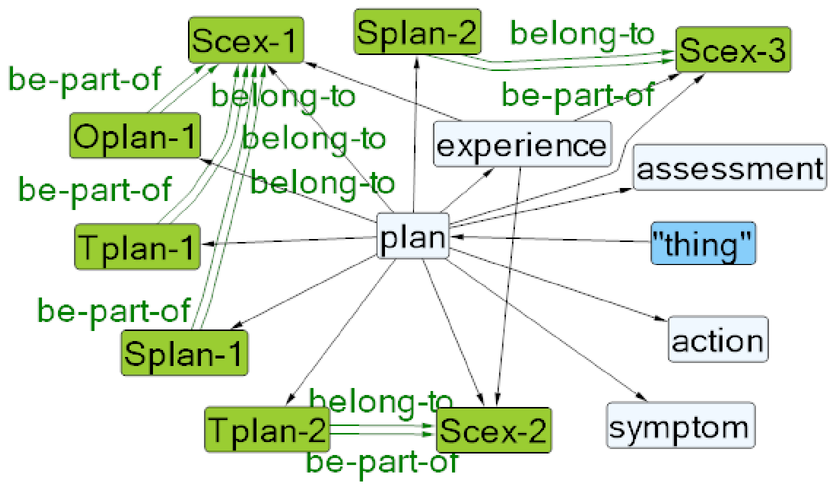
In supply chain management (SCM), experiences may be further characterised by their scope, type and focus. Considering their scope, they may be strategic, tactical or operational. By type, they are classified as network design, strategy formulation and operations planning experiences. Regarding their focus, they may be directed towards capacity planning, performance monitoring or quality assurance. This is expressed by the distinguishing properties of their plans, as outlined below.

```
Every experience has-scope nothing-but (either 'strategic', 'tactical' or 'operational').
Every experience has-type nothing-but (either 'network-design', 'strategy-formulation' or 'operations-planning').
Every experience has-focus nothing-but (either 'capacity-planning', 'performance-monitoring' or 'quality-assurance').
```

3.3 Knowledge Management

SCM experiences (cp. Figure 2) are formed and maintained as entries in the knowledge database. It can be local (intranet), enterprise wide (extranet) or global (cloud repository). Regardless of its location, the access to the knowledge base is by client-server architecture. The host serves the requests of the clients by a semantic web service using RDF, RDFS, OWL, SPARQL, SKOS or SWRL technologies.

Figure 2 SCM Experiences



Source: own

The Fluent Editor ontology management tool can be used by experts to access, maintain and retrieve information from the knowledge base. Besides Cognitum's Fluent Editor, its Ontorion knowledge base server can also be accessed via similar tools, including Stanford's Protege and W3 interfaces. An additional option is to access the knowledge management tools via the Python and R-language plug-ins.

As an example, a simple knowledge base is outlined below. Three experiences with several action plans are listed, each addressing distinct levels of decision making, usage scenarios as well as performance indicators. The first experience (Scex-1) demonstrates the ability to join experiences in a plan to achieve a complex goal, addressing multiple levels of decision making.

```
Scex-1 is an experience.
Scex-2 is an experience.
Scex-3 is an experience.

Oplan-1 is-part-of Scex-1.
Oplan-1 has-scope equal-to 'operational'.
Oplan-1 has-type equal-to 'operations-planning'.
Oplan-1 has-focus equal-to 'capacity-planning'.
Oplan-1 has-symptom that has-description equal-to 'utilization'.
Oplan-1 has-symptom that has-value equal-to 0.89.
Oplan-1 has-symptom that has-target-value lower-or-equal-to 0.5.
Oplan-1 has-assessment that has-value equal-to 'discrete event
simulation'.
Oplan-1 has-action that has-value equal-to 'double capacity'.

Tplan-1 is-part-of Scex-1.
Tplan-1 has-scope equal-to 'tactical'.
Tplan-1 has-type equal-to 'operations-planning'.
Tplan-1 has-focus equal-to 'capacity-planning'.
Tplan-1 has-symptom that has-description equal-to 'cycle-stock'.
Tplan-1 has-symptom that has-value equal-to 260.
Tplan-1 has-symptom that has-target-value lower-or-equal-to 200.
Tplan-1 has-assessment that has-value equal-to 'just-in-time
production'.
Tplan-1 has-action that has-value equal-to 'improve operations
reliability'.

Splan-1 is-part-of Scex-1.
Splan-1 has-scope equal-to 'strategic'.
Splan-1 has-type equal-to 'strategy-formulation'.
Splan-1 has-focus equal-to 'performance-monitoring'.
Splan-1 has-symptom that has-description equal-to 'out-of-stock'.
Splan-1 has-symptom that has-value equal-to 5.
Splan-1 has-symptom that has-target-value equal-to 0.
Splan-1 has-assessment that has-value equal-to 'lean production'.
Splan-1 has-action that has-value equal-to 'plan safety stock'.

Tplan-2 is-part-of Scex-2.
Tplan-2 has-scope equal-to 'tactical'.
Tplan-2 has-type equal-to 'network-design'.
Tplan-2 has-focus equal-to 'performance-monitoring'.
Tplan-2 has-symptom that has-description equal-to 'bottleneck'.
Tplan-2 has-symptom that has-value equal-to 3.
```

```
Tplan-2 has-symptom that has-target-value equal-to 0.
Tplan-2 has-assessment that has-value equal-to 'systems dynamics'.
Tplan-2 has-action that has-value equal-to 'balance flows'.

Splan-2 is-part-of Scex-3.
Splan-2 has-scope equal-to 'strategic'.
Splan-2 has-type equal-to 'strategy-formulation'.
Splan-2 has-focus equal-to 'quality-assurance'.
Splan-2 has-symptom that has-description equal-to 'quality-of-service'.
Splan-2 has-symptom that has-value equal-to 0.4.
Splan-2 has-symptom that has-target-value greater-or-equal-to 0.9.
Splan-2 has-assessment that has-value equal-to 'agent based simulation'.
Splan-2 has-action that has-value equal-to 'quality-of-service monitoring'.
```

As outlined in the example each experience in itself is a member of a distinct plan. It is further characterized by its scope, type and focus providing for classification of knowledge. In terms of its content, it comprises the essential DAP components mentioned above, i.e., symptoms (by description, value and target value), assessment (by the description of the methods used to address the symptoms) and action (by the proposed action plan). Depending on the complexity of knowledge, of course the descriptions may be more elaborate, including links to appropriate documentation. Nevertheless, it is important for them to be concise to enable automated decision making (e.g., by artificial intelligence methods).

4. KNOWLEDGE RETRIEVAL

There are various ways to retrieve knowledge from the knowledge base. The simplest is to use the associated knowledge management tools (e.g., Protege, Fluent Editor, etc.) with its knowledge aggregation, classification and representation tools. However, this may prove unpractical to end users, usually being non-experts. ASP tools may use the mentioned programming/statistical language API interfaces provided, by issuing appropriate queries to render the desired results. Below are some SPARQL examples to demonstrate the use of the knowledge base.

To narrow down the search results by scope, one may issue the following query:

```
select * {?x :hasScope "tactical"}
```

lists Tplan1 and Tplan2, since they are both tactical experiences.

To narrow down the search results by application area or focus, one may issue the following query:

```
select * {?x :hasFocus "capacity-planning"}
```

lists Tplan1 and Oplan1, since they both focus on capacity planning, although they have distinct scopes.

To list all experiences which belong to a certain plan, one may issue the following query:

```
select * {?x :isPartOf :Scex1}
```

lists Oplan1, Tplan1 and Splan1, since they belong to the same planned activities group of Scex1.

Of course, one may combine the queries to pinpoint specific experiences. An example of such a combined query is given below:

```
select * {
    ?x :hasType "strategy-formulation".
    ?x :hasFocus "performance-monitoring".
}
```

By the above statement experience Splan1 is rendered, representing the experience with appropriate type *and* focus.

By this mechanism also new experiences may be added to the knowledge base. Once its structure is complete, the aggregation of knowledge is possible by direct input or by results of search queries producing new experiences.

The mentioned knowledge management tools provide interfaces to analytical software packages, like the R-Studio, and programming languages, like the R-language or Python. This extends the application space to the entire range of contemporary OLAP and semantic Web applications.

5. ANALYSIS

The proposed solution has all the properties of an expert system for strategic logistics planning. It contains:

- a knowledge base of improvement solutions to various logistics problems,
- a reasoner to manage this institutional knowledge,
- various tools to access this knowledge and to perform analytic processing and decision making.

The knowledge base is composed of facts and rules, based on the DAP principle. This allows for targeted representation of experiences forming the knowledge base. The experiences are structured according to the SCOR reference model in terms of their management level, scope, type and focus.

The associated knowledge base management tool allows for immediate exploitation of the stored knowledge by managing the structure of knowledge and reasoning based on its key terms. Different types and levels of access to the knowledge base – direct, API and APS – provide for various kinds of reasoning.

The knowledge base is typically stored in a cloud and may be accessed via the Fuseki intelligent Web server (Apache, 2023) directly or via the mentioned interfaces. The various access options enable its private, corporate and even public use. By this, the knowledge base may outgrow the company and even sustain its life in other forms in case its ownership changes or even, if a company seizes to exist and only its brand with its corporate know-how remains.

6. DISCUSSION

Considering the reasons for introducing knowledge bases in the first place, i.e., to store institutional knowledge in a transparent and persistent way, one may claim that ontologies are up to the task. They provide a somewhat less rigorous representation of the knowledge, whilst on the other hand, they provide for their consistent and transparent storage as well as diverse applications.

The simple example presented in the article merely indicates their use and provides a proof-of-concept solution, however a real knowledge base like this may be much more elaborate and complex. For instance, it may provide links to past projects documentation on improvement solutions and similar solutions from corporate partners. Nevertheless, it is a good example to show how a next-generation knowledge base may look like. With its CNL notation it somehow reduces the complexity of ontological knowledge representation and makes it human readable without losing the benefits of the rigorous form of predicate logic behind it.

From the management's perspective, the knowledge base may provide appropriate insights into the prospected solutions for concrete problems, enabling them to reason on their impact, feasibility and cost. Mostly, they represent the management's primary concern. According to the knowledge base organisation, the solutions asked may apply to different levels of decision making and execution environments.

From the expert’s perspective the knowledge base provides them with a catalogue of previous experiences for root cause analysis and fine-tuning in case they would need to be applied again in adjusted form. The mentioned documentation from previous projects provides them with the ability to foster targeted improvement solutions faster and more accurately. In its essence the knowledge base reduces the need to investigate everything from scratch. As such, it may well serve as an expert system to provide for strategic logistics planning and decision making.

7. CONCLUSION

In this article the different forms of knowledge representation and management have been discussed with focus on the Deming's improvement cycle in strategic logistics planning.

In the proposed approach smart logistics management (Gumzej, 2021) is supported by semantic Web and online analytical processing (OLAP) technologies. They form a knowledge management system (KMS) based on a logistics knowledge base of experiences, expressed in controlled natural language (CNL). The underlying experiences address the different levels of supply chain management decisions – from strategic, over tactical to operational. They are also structured in way which distinguishes the main supply chain management concerns.

By the proposed approach, logistics knowledge-based engineering (KBE) can be conducted, based on an appropriately structured logistics knowledge base of supply chain improvement experiences.

In future research, a more elaborate example of a knowledge base of supply chain management experiences shall be constructed to provide a first reference point of supply chain management knowledge to practitioners, researchers and students. The main limitations of this research are the use of free and open-source software and the limited knowledge base available.

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V. SUPPLY CHAIN SOLUTIONS IMPLEMENTATION

THE IMPLEMENTATION OF THE PARK AND RIDE LOGISTICS TECHNOLOGY TO IMPROVE THE QUALITY OF PASSENGER TRANSPORT IN THE TATRA REGION IN SLOVAKIA

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Abstract

There are currently a large number of traffic and parking systems to solve the complex traffic situation in city centers that mitigate the negative effects of traffic on the cities and on the lives of its residents. Many solutions of these problems associated with parking are already used in Western European countries. A tool for improving the traffic situation in the region is greater use of public passenger transport, especially rail transport. A motivational system for improving the use of public passenger transport is also a number of modern progressive logistics technologies, especially the "Park & Ride" system. This system combines the advantages of individual car traffic with public transport, priority ecological rail transport, which has the effect of improving the position of rail transport in society. The aim of the contribution is to propose their construction in the Tatra region, which is attractive tourist region in Slovakia, based on the analysis of the "Park & Ride" parking system. It mainly concerns the railway stations Štrba, Svit, Poprad – Tatry, Kežmarok with the most efficient use of the space around these railway stations. The mentioned proposal also contains a technical and economic evaluation.

Keywords: Individual car traffic; Park and Ride system; Public; Tatra region

1. INTRODUCTION

Railway transport, which has existed on the territory of the Slovak Republic for more than 170 years, which is considered as a key transport system, is currently being replaced by road transport, especially individual car transport, in the leading places in the transport system of the country. With the development of the degree of automobilization, there are also problems associated with the solution of static and dynamic traffic in cities, which are not adapted to such a high number of cars. To solve the complex traffic situation in city centers, a number of traffic and parking systems are currently proposed to mitigate the negative impact on traffic in the city and on the lives of its residents (Vidriková, 2010). Many of the solutions to the problems associated with parking are already used in the western part of Europe in countries such as Germany, Italy, Austria, the Netherlands, Sweden and many others. Nowadays good transport chain management does not mean social engineering or central planning but is based on market principles of guiding transport demand by offering more reliable, faster, better and, if possible, cheaper systems (Abramović et al., 2021). Today when a great emphasis is put on the quality and high level of provided services the application of optimization methods in logistic processes is a necessity (Pečený et al., 2019) (Lukašík et al., 2021).

The main goal of the paper is to present the concept of the Park & Ride system. The basic research question is based on the creation of a methodological procedure of the Park & Ride system and the subsequent possibility of practical application. Subsequently, the mentioned system is practically applied to High Tatras region. The network of "Park & Ride" parking lots is also an incentive system for improving the use of public passenger transport, which combines the advantages of individual car transport with public transport, especially ecological rail transport, which results in improving the position of rail transport in society. The Tatra region and the High Tatras region is the most famous tourist area in Slovakia. A tool for improving the traffic situation in the region is greater use of public transport, especially rail transport. Therefore, it is necessary to solve the mentioned issue in this region much more effectively. A suitable solution will be to propose and implement "Park & Ride" logistics technology.

There are lots of interesting and useful publications which deal with the topic of modern logistics principles and technologies, as well as the issue of Park and Ride system. A contribution (Ying and Xiang, 2009) focusing on the influence factors and the demand willingness to investigate choice behavior of Park and Ride, use disaggregated model to analyze the influence factors' importance of Park and Ride, bring forward that the main factors influence Park and Ride choice behavior are passive factors such as road traffic congestion, lack of parking space, etc. Another publication (Huang et al., 2021) deals with the park-and-ride-sharing (P&RS) which is proposed to manage morning peak hour congestion in a monocentric linear city, where there is a multilane highway with a single bottleneck connecting the residential area and the central business district. The study (Yaliniz, 2016) park and ride system as well as the other applicable scenarios have been evaluated with Analytical Hierarchy Process (AHP) method with practical application in Turkish city of Eskisehir. Other important publications on the mentioned topic (Kumar and Khani, 2021); (Wiradinata, 2019); (Shen et al., 2017); (Liang et al., 2021) contain several interesting progressive scientific outputs. However, there are several unexplored and unresolved professional and scientific topics within the mentioned issue. A brief methodological procedure for solving the issue of the Park and Ride system, including a specific practical application, is the subject of the mentioned contribution.

2. RAILWAY STATIONS AS „PARK & RIDE“ SYSTEM

Tourist centers, city centers and other busy places in cities are congested, have a shortage of parking spaces and are also burdened with high parking fees determined by their parking policies. The construction of temporary parking lots will contribute to the relief of road traffic. International visitors, as well as domestic residents, commuting to work can reach the railway station by car, where they board a train to another city and use local public transport there. The rush hour will thus be divided between several places and the negative effects of traffic on the city, which include traffic jams and polluted air, will be eliminated. With an appropriate number and distribution of passenger rail and public transport connections, people will be able to get to work much faster, without being delayed in queues.

2.1 Legislation regulating parking

The proposal and construction of parking spaces is subject to standards and laws. The proposal and construction of parking areas is limited by the area available for short-term or long-term parking. The basis for building parking lots is to create as many parking spaces as possible, so the proposed parking spaces are made as narrow as possible to accommodate as many as possible. Laws and strategic plans determine the conditions for building parking lots. Standard STN 73 60 56 determines the minimum dimensions and other conditions for creating parking spaces. Designing and building a network of "Park & Ride" parking lots is subject to many legislative regulations valid within the Slovak Republic:

- Strategic plan for the development of the Slovak transport infrastructure for the years 2021 - 2028,
- Operational program Integrated infrastructure for the years 2021 - 2028,
- Design of static transport in accordance with STN 73 6110,
- Act no. 135/1961 Coll. on Land Communications (Road Act), as amended,
- Act no. 725/2004 on the conditions for the operation of vehicles in traffic on land roads and on the amendment of certain laws,
- Act no. 8/2009 Coll. on road traffic and on amendments to certain laws,
- Act no. 144/2010 Coll., amending Act no. 8/2009 Coll. on road traffic and on amendments to certain laws, as amended, and on amendments to certain laws,
- Act no. 56/2012 Coll. on road transport, as amended,
- Act no. 168/1996 of 17 May 1996 on road transport,
- Decree of the Ministry of Health of the Slovak Republic no. 549/2007 Coll., which establishes details on the permissible values of noise, infrasound and vibrations

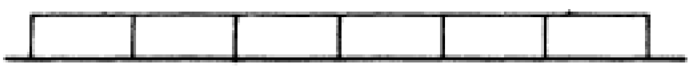
and on the requirements for the objectification of noise, infrasound and vibrations in the environment, as amended by later amendments and regulations,

- Decree no. 311/1996 of October 17, 1996, implementing the Road Transport Act,
- Decree 130/2010 of March 23, 2010, amending Decree 9/2009 on traffic signs,
- Decree no. 35/1984 Coll., which implements the Act on Land Communications (Road Act),
- Decree no. 578/2006 Coll., which establishes details of some provisions of Act no. 725/2004 Coll. on the conditions for the operation of vehicles in traffic on land roads and on the amendment of certain laws as amended.

2.2 Types of parking lots and parking areas

Parking lots and parking areas are divided into several types, which include parking lanes, parking strips and separate parking areas. The transverse slope of parking and parking areas cannot exceed 5% and the longitudinal slope should not exceed 3%. In the case of parking lanes, the longitudinal slope must not exceed 6%. **Type A**: parking lanes along roads, where vehicles park parallel to the roads are shown in Figure 1. (STN 73 6056, 1987)

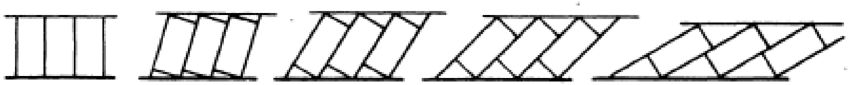
Figure 1 Schematic representation of parking lanes



Source: (STN 73 6056, 1987)

Type B: parking strips along roads where parking is directed perpendicularly or diagonally to the roads are shown in Figure 2 (STN 73 6056, 1987).

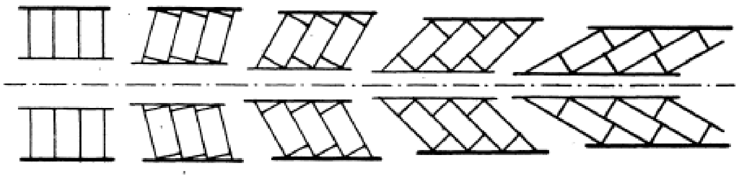
Figure 2 Schematic representation of parking strips



Source: (STN 73 6056, 1987)

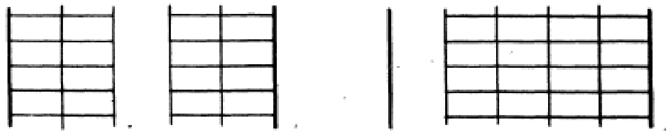
Type C: separate parking areas where parking is controlled according to internal parking roads, mostly perpendicular or diagonal to them in one row or in several rows in a row are shown in figures 3 and 4 (STN 73 6056, 1987).

Figure 3 Schematic representation of sloping parking areas



Source: (STN 73 6056, 1987)

Figure 4 Schematic representation of perpendicular parking areas



Source: (STN 73 6056, 1987)

2.3 Technical requirements - location

Parking areas may not be designed on local roads of classes A1, A2, B2 (high-speed roads with a traffic function). On local roads of class B2 (collector with traffic-service function) only in justified cases, where the territorial conditions and the intensity of traffic allow it. The following may not be placed on other roads:
• observation fields of intersections,
• intersections of local roads along the entire length of the parking lanes,
• spaces designated for public transport stops and other bus transport,
• viewing areas of railway crossings,
• at pedestrian crossings,
• at the points of entry and exit from purpose-built roads and private lands (STN 73 6056, 1987).

3. PROPOSAL FOR “PARK& RIDE” SYSTEM CREATION

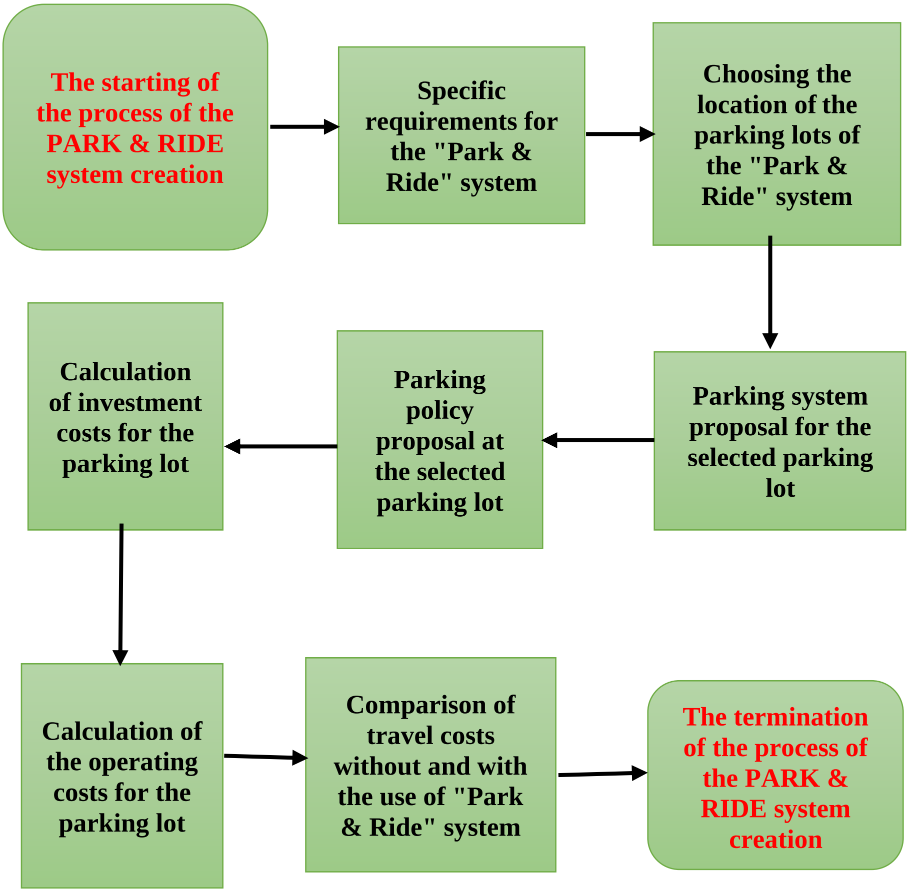
The most famous parking system “Park & Ride” combines transport, telecommunication, and information technologies. It is based on the connection of individual car traffic outside the city and on the outskirts of cities and public urban transport to city centers. For this parking system, it is necessary to have sufficient capacity and attractive parking lots for the passenger, where public transport stops, bus and railway stations must be located in close proximity. By building temporary parking lots with the “Park & Ride” system, the traffic situation in the transport system of a city, village or region can be improved. With the growing number of residents living outside the city, the extent of individual car traffic also increases, which makes this form of transport inefficient, lengthy and unreliable. Parking lots and the “Park & Ride” system is a solution to this problem, where public transport is connected with individual car traffic. Among the advantages of the “Park & Ride” system is the price of parking in a temporary parking lot, which is many times lower than the price of parking in city centers, or the price of parking in popular tourist spots. By using "Park & Ride" system, passengers save time that they would have spent driving and can use it for other activities. Thanks to parking near public transport stops, the costs of operating personal motor vehicles are also reduced, for example savings on maintenance, fuel and parking fees (Fabianova et al., 2020); (Stopka et al., 2019).

Based on the stated facts, it is necessary to solve the mentioned problem systematically and conceptually. Therefore, it is necessary to propose a certain methodical procedure of "Park& Ride" system creation that can be applied universally. The mentioned procedure contains several steps. Since it contains several elements of heuristics, it can be considered a heuristic procedure. The following scientific methods are used to propose the particular steps of this procedure:

- synthesis method – this method, based on experience or logic, proceeds from the simplest principles to more complex ones by merging and connecting individual parts into a whole. In the case of proposals and outputs of this paper, it is a combination of partial steps of the methodological process;
- mind mapping method – this method is developed method of the brainstorming method, through which the logic of the researched problem, context and priorities are developed;
- the heuristic method – the method offers and discovers new ways of solving problems and inventing certain new contexts; it is a scientific activity based on a "discovery" procedure, which usually starts with a general proposal or some rough estimate, which is gradually refined; this method represents an intersection between empirical and exact methods (Dorda, 2020).

On the basis of the mentioned methods, it is possible to propose specific steps of the established procedure. The comprehensive heuristic procedure including all steps is shown in figure 5.

Figure 5 Methodical procedure for solving the problem of the PARK & RIDE system



Source: authors' own processing

The individual proposed steps are most effectively explained on a concrete example. Therefore, the explanation of the individual steps immediately includes a practical application of the raised issue in the context of the "Park & Ride" system introduction in the Tatra region. We focused in detail on the parking lot near the Poprad – Tatry railway station. The description of the particular steps is expressed in subsections 2.1 to 2.7.

3.1. Specific requirements for the "Park & Ride" system

The requirements placed on the proposal and construction of parking lots are necessary to ensure the improvement of the quality of the traffic situation in the region. The "Park & Ride" system in the Tatra region solves the problem of static traffic in the towns of Svit, Poprad, Kežmarok and the village of Štrba, as well as problems with traffic in the High Tatras. To create and implement "Park & Ride" system in the Tatra region, the following requirements must be met (Šebest, 2018):

- the number of parking spaces depending on the frequency of passengers in a given node,
- proximity to a railway or bus station,
- public transport stop in close proximity,
- fixed parking area, connection to roads,
- installation of appropriate traffic signs and marking of parking spaces according to standard STN 73 6056,
- marking of parking conditions to prevent abuse of parking spaces,
- installation of information panels on parking prices, as well as public transport and passenger train timetables,
- low price of parking, which will be more advantageous than parking in city centers or in the High Tatras,
- operational security of parking lots.

3.2. Choosing the location of the parking lots of the "Park & Ride" system

Parking lots and parking areas in the Tatra region are most advantageously located in the areas around railway stations, which represent the transport hubs of the region with a high passenger frequency on weekdays, consisting of workers commuting to work, as well as with a high passenger frequency during weekend days, consisting mainly of visiting tourists High Tatras. The most mined nodes in the region include:

- Štrba railway station: express station, which is the starting station for the cogwheel railway (the fastest and
  cheapest way to the High Tatras by public transport),
- Svit railway station: a station where only passenger trains stop, located in the Tatra region center, in proximity
  to an important enterprise for the region,
- Poprad – Tatry railway station: a railway station of international importance, where trains of all categories stop,
  it is the starting point for the Tatra Electric Railways, as well as for the regional line heading to Stará Ľubovňa,
  also known as the gateway to the High Tatras,
- Kežmarok railway station: a city with importance for the region, the proximity of the railway station to the city.

At each of these railway stations, it is advantageous to place temporary parking lots, i.e. a total of four. The proposal for the location of parking lots in the region is shown in Figure 6.

Figure 6 Proposal for the location of parking lots

Source: processed by the authors based on www.google.maps.sk

"Park & Ride" system location in Poprad – Tatry railway station

The temporary parking lot of the "Park & Ride" system at the Poprad – Tatry railway station is advantageous to place next to the railway station, opposite the bus station and the Hotel Europa. One part of the parking lot will be along Jiří Wolker Street, continuing towards the Poprad – Tatry station track. Currently, vehicles are parked on this area, but the parking area and parking spaces are not marked.

By building a new temporary parking lot, 20 parking spaces will be created on the area along Jiří Wolker Street on a parking lane that is separated from the road and is elevated, and the parking method will be longitudinal to the road. An additional 30 parking spaces will be created on the area located from this longitudinal parking lot towards the railway track. Parking will be arranged perpendicular to the track and perpendicular to the approach road in two rows. One row along the track at a sufficient distance from the cross section and the other row facing Jiří Wolker Street. In total, 50 parking spaces for the "Park & Ride" system will be created in this space. The access road will be one-lane and one-way, only passenger motor vehicles will park here, so according to STN 73 6056, its width of 2.50 meters will be sufficient. The dimensions of these parking spaces are in accordance with STN 73 6056. Based on the terms of Decree 532/2002 Coll. 5% of the built-up parking spaces will be designated for persons with reduced mobility. The proposal of the parking lot at Poprad – Tatry railway station is shown in Figure 7 (Maslaric et al., 2012).

Figure 7 Proposal for the location of the parking lot at Poprad – Tatry railway

Source: authors´ own processing based on www.google.maps.sk

The detailed characteristics of the parking lot at the Poprad – Tatry railway station are expressed in table 1.

Table 1 Characteristics of the detention parking lot near Poprad – Tatry railway station

Site name	Poprad – Tatry railway station
Local part	Poprad – city center
The width of the parking space	2.30 m
The length of the parking space	5.30 m
Number of longitudinal parking spaces	20
The number of perpendicular parking spaces	30
Total number of parking spaces	50
Width of driveway	2.50 m
Bus stop availability	50 m
Availability of rail transport	45 m

Source: prepared by the authors based on his own analysis

In addition to this parking area, there is also one modern parking lot at the Poprad – Tatry railway station, where 89 passenger motor vehicles can be parked. This parking lot is part of the pre-station area and is located in front of the Slovak Post office. However, this parking lot is owned by the city of Poprad. Parking and the parking price list are governed by the price and parking policy of the city of Poprad. The area is included in the urban parking zone 2, where the hourly parking fee is €0.40/1 hour and the operating hours of the parking lot during the working week are limited from 8:00 a. m. to 4:00 p. m. On the weekend and all holidays, the parking lot is opened and parking is free. This parking area can also be used free of charge at the peak of the rush of passengers, which is on weekends and holidays. During the working week, the proposed parking lot of the "Park & Ride" system will also be sufficient for parking vehicles (Šebest, 2018).

3.3 Parking system proposal for the parking lot at Poprad – Tatry railway station

It is possible to build one "Park & Ride" parking lot near the Poprad – Tatry railway station. With this parking lot, it will not be necessary to remove any greenery, it will only be sufficient to modify and reinforce the existing parking area, which is currently not paved. It is necessary to mark the horizontal traffic markings to determine the space for parking vehicles, mark the entrance and exit lanes for vehicles and complete the necessary vertical traffic markings. In terms of space, it is possible to use only one parking barrier for the entrance from the bus station on Jiří Wolker Street and the second parking barrier for the exit near the railway station building on the same street. In the parking lot, one-way traffic will be determined by traffic signs. The parking barriers will be equipped with a screen designed to display the necessary information for parkers and it will also be possible to use it to display advertisements. The proposed barrier is approximated in Figure 8.

Figure 8 Single-arm parking barrier for vehicle entry

Source: www.1pohony.cz

Two camera systems can be used in this parking lot. The first camera system will be a recognition one, located at the entrance parking barrier, which will record the registration number of the parked vehicle and store it in the database of the parking system, and the second camera system will be located on the lighting poles and will be surveillance, which will supervise the safety of the parking lot, the safety vehicles and for the safety of passengers or pedestrians on the adjacent sidewalk around the parking lot. Due to the greater distance from the station, two automatic parking ticket offices will be located at the "Park & Ride" Poprad – Tatry parking lot. One will be located at the exit near the railway station building, and the other will be located next to the construction materials building in the extended parking area near the station tracks. The parking system will be based on the use of ChipCoin parking tokens, when the entry ticket will be issued when the vehicle enters the parking area through the entrance parking barrier, and the exit ticket will be issued when paying at the automatic parking cash register. The parking ticket office will accept cash or credit card payments. It will also be equipped with a reader of QR codes on travel tickets. After reading the QR code of a valid ticket, it will issue a free exit token to leave the parking lot. The proposed automatic parking ticket with a QR code reader is shown in Figure 9 (Šebest, 2018).

Figure 9 Automatic parking ticket office for P+R Poprad – Tatry

Source: www.trnava-live.sk

In addition to parking barriers and automatic parking cash registers, it is advisable to supplement this parking lot with information boards in the number of two pieces. We propose to place one at the intersection of Alžbeta and Hviezdoslav streets, and the other at the intersection of Jiří Wolker and Railway streets. The proposed information boards will display the total number of parking spaces and the number of free parking spaces. Information boards will be placed together with the parking sign “Park & Ride”.

3.4 Parking policy proposal at “Park & Ride” parking lots

A correctly chosen parking policy of P+R parking lots will help to use temporary parking lots at railway stations, to solve static traffic in cities, to solve overcrowded city centers or centers in the High Tatras, to motivate commuters to use public transport. Nowadays the biggest problem is not the high price of public transport tickets, but the absence of parking rules, as people can park their cars anywhere, where it complicates traffic and where there is a possibility of damage to them. Parking policy is an effective tool to increase the use of public transport, to increase the attractiveness of rail transport as well as to reduce travel costs. We therefore propose free parking for passengers using rail transport at the proposed “Park & Ride” car parks. Free parking will also be available for everyone for the first hour after entering the parking lot, which will be intended for people waiting for their loved ones from the trains, or who drove them to the trains. The “Kiss & Ride” system will be applied. Other parkers who will not use the services of passenger rail transport will be charged for parking. There is proposed a parking price for these people based on an analysis of parking prices in this region. The parking price list and free parking conditions are shown in table 2 (Šebest, 2018).

Table 2 Price list for parking at "Park & Ride" parking lots

Parking, using rail transport, equipped with a valid travel ticket	Free
Parking up to 1 hour ("Kiss & Ride")	Free
Railway employees	Free
Parking without using rail transport (1 hour)	0.20€
Parking without using rail transport (1 day)	2.00€

Source: authors´ own processing

3.5 Calculation of investment costs for the parking lot at Poprad – Tatry railway station

One variant of building a "Park & Ride" parking lot is proposed near the Poprad-Tatry railway station and the costs of its construction are expressed in the following tables 3, 4 and 5.

Table 3 Construction costs for the Poprad - Tatry parking lot

Description of activity	Measure unit	Quantity	Unit price (€)	Total price (€)
Earthworks				
Removal of bushes and trees	m^2	0	1.21	**0**
Excavation work (up to 0.5 m)	m^3	192.5	8.21	**1,580.43**
Pipe lining	m^3	0.5	10.84	**5.42**
Aggregate for the bed	t	5.2	19.23	**100.00**
Adjustment of the plan	m^2	385	0.2	**77.00**
Subsoil compaction	m^2	385	0.26	**100.10**
Horizontal structures				
Bed of pipes, drains, small objects	m^3	0.5	40.27	**20.14**
Communications				
Foundation, underfill, compaction	m^2	385	2.66	**1,024.10**
Asphalt cover (4-5 cm)	m^2	385	12	**4,620.00**
Installation of a drainage channel	m	70	13,83	**968.10**
Drainage channel	m	70	87	**6,090.00**
Pipeline				
Pipeline assembly	m	11	0,98	**10.78**

Sewer pipe	pcs	1	7	**7.00**
Connection of the trap with the drainage of the parking lot	pcs	1	35	**35.00**
Other constructions and works				
Fitting the curb into the bed	m	88	5.02	**441.76**
Flower bed border (100x5x20 cm)	pcs	88	3.5	**308.00**
Bed under the curb	m^3	4.23	95.63	**404.51**
A fee for depositing soil at a landfill	t	68	20	**1,360.00**
Rental of temporary fencing	m	130	9	**1,170.00**

Description of activity	**Measure unit**	**Quantity**	**Unit price (€)**	**Total price (€)**
Installation and assembly of vertical traffic signs	pcs	6	18.95	**113.70**
Traffic signs	pcs	6	55.9	**335.40**
Horizontal traffic marking	m	160	2.51	**401.60**
Price for construction works without VAT				**19,173.03**
VAT			20%	**3,834.61**
Total price for construction works with 20% VAT				**23,007.64**

Source: prepared by the authors based on www.scheidt-bachmann.sk, 2023

Table 4 Costs of the parking system in Poprad – Tatry parking lot

Device description	**Measure unit**	**Quantity**	**Total price (€)**
Control computer	pcs	1	**4,304.00**
Entry terminal	pcs	1	**4,691,00**
Departure terminal	pcs	1	**4,425.00**
Automatic barrier	pcs	2	**3,094,00**
Automatic cash register	pcs	2	**24,496.00**
Intercom server	pcs	1	**301.00**
Other devices	pcs	1	**2,081.0**
Installation of the parking system		1	**5,339.00**
Price for the parking system without VAT			**48 731,00**
VAT		20%	**9,746.00**
Total price for the parking system with 20% VAT			**58,478.00**

Source: prepared by the authors based on www.scheidt-bachmann.sk, 2023

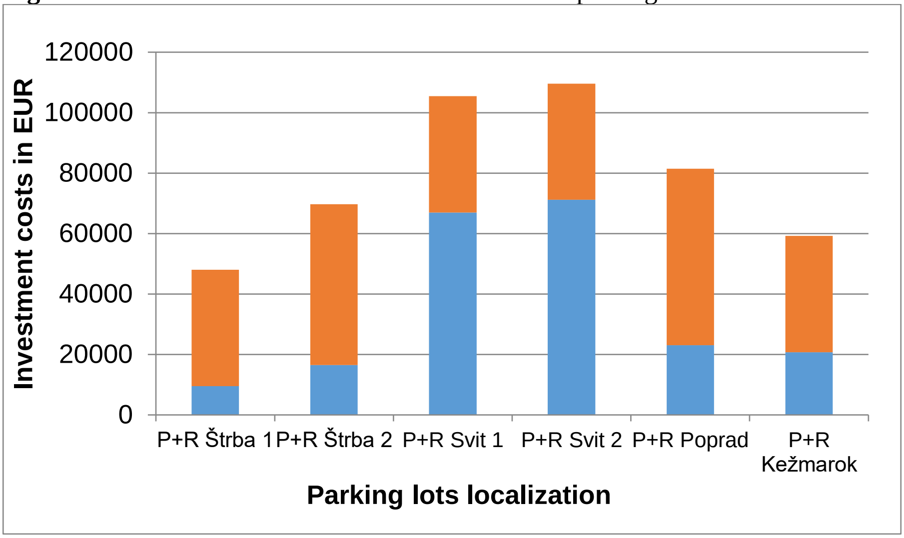
Table 5 Total investment costs for Poprad – Tatry parking lot

Description	Price (€)
Total price for the realization of the parking lot without VAT	**67,904.03**
VAT 20%	**13,580.61**
The total price for implementation including 20% VAT	**81,485.64**

Source: authors' own processing

Comparison of investment costs (construction costs and costs of parking facilities) for individual "Park & Ride" parking lots at the Štrba, Svit, Poprad – Tatry and Kežmarok railway stations are shown in Figure 10. Parking facility costs are highlighted in orange and construction costs are highlighted in blue.

Figure 10 Investment costs for individual variants of parking



Source: authors´ own processing

3.6 Calculation of the operating costs for the parking lot at Poprad – Tatry railway station

Operating costs include all costs associated with electricity consumption, summer and winter maintenance of the parking lot, snow and ice removal, cleaning of the parking area. Other significant costs are the costs of maintenance and possible repair of damaged parts as well as the costs of remuneration for inspection and operational maintenance workers. For the evaluation of operating costs for the purpose of the contribution, the offer prices of the service company Vetron s.r.o. are used and are expressed in table 6. These operating costs apply to all designed parking areas, as they are almost the same in size and technical equipment (Šebest, 2018).

Table 6 Annual operating costs for the parking lot

Description of activity	**Total price with VAT (€)**
Annual regular maintenance and inspection	**1,056**
Professional examination and inspection of parking systems	**624**
Surcharge for an hour of work of technicians outside working hours	**24**
Annual operating costs	**1,200**
Total annual costs of operating the parking lot	**2,880 €**

Source: prepared by the author based on www.scheidt-bachmann.sk, 2023

3.7 Comparison of travel costs without and with the use of "Park & Ride" system

Among the important factors for the decision to use public passenger transport and the "Park & Ride" parking system is certainly the saving of travel costs. For the parking incentive system, the costs associated with traveling must be lower than traveling the entire journey by car. The following tables (7 - 9) show the costs of traveling the entire route by car and the costs of traveling the entire route by a combination of individual and public passenger transport. For the purposes of this thesis, a Kia Cee'd passenger car and selected transport route within the Tatra region are used as a model example. The passenger car will be occupied by one person (Šebest, 2018).

Table 7 Travel costs for a car trip

Passenger car	**Consumption liter/100 km**	**Fuel price (€)**	**Distance (km)**	**Fuel consumed (l)**	**Total journey costs (€)**
Štrba - Kežmarok					
Kia Cee´d	7.1	1.34	35	2.49	3.34
Štrba – Štrbské Pleso					
Kia Cee´d	7.1	1.34	10.5	0.86	1.13
Štrba – Poprad - Tatry					
Kia Cee´d	7.1	1.34	20.1	1.43	1.92
Poprad – Tatry – Štrbské Pleso					
Kia Cee´d	7.1	1.34	28	2	2.68
Kežmarok – Štrbské Pleso					
Kia Cee´d	7.1	1.34	42.2	3	4.02

Source: authors' own processing

Table 8 Travel costs for a trip by public transport

Train	Distance (km)	Fare price (€)	Parking price (€)	Total costs (€)
Štrba - Kežmarok				
601/8309	33	1.90	0	1.90
Štrba – Štrbské Pleso				
8002	5	1.00	0	1.00
Štrba – Poprad - Tatry				
3451	19	1.02	0	1.02
Poprad – Tatry – Štrbské Pleso				
8102	29	2.00	0	2.00
Kežmarok – Štrbské Pleso				
8302/8106	43	1.82	0	2.86

Source: authors' own processing

Table 9 Comparison of travel costs

Transport route	The train journey costs (€)	The trip car costs (€)	The difference/savings (€)
Štrba - Kežmarok	1.90	3.34	1.44
Štrba – Š. Pleso	1.00	1.13	0.13
Štrba – Poprad-Tatry	1.02	1.92	0.90
Poprad-Tatry – Š. Pleso	2.00	2.68	0.68
Kežmarok – Š. Pleso	2.86	4.02	1.16

Source: authors' own processing

From the previous analysis of travel costs, it follows that the use of the "Park & Ride" car park system and public transport combined with individual personal transport on these selected transport route leads to significant cost savings on each trip made.

4. CONCLUSIONS

Based on the analysis of the current state of the traffic situation in the Tatra and the High Tatras region, it is possible to conclude that the problem with increasing the share of individual car traffic is significant and causes considerable problems with the organization of transport. The problem of a high proportion of passenger cars in the centers also causes time, social, economic, but especially ecological damage. To eliminate these negative impacts and reduce problems, it is necessary to look for modern, progressive and effective solutions for static and dynamic traffic in the cities.

Analyses of the current situation show that the biggest problems are the insufficient number of parking spaces and their unsatisfactory condition.

Several alternatives are being prepared to solve these problems. The most suitable way to solve traffic problems in the centers and in important traffic hubs is the implementation and subsequent use of the "Park & Ride" system at the railway stations in Štrba, Svit, Poprad - Tatry and Kežmarok, which are important for this region. The "Park & Ride" system, i.e. park and go by public transport, contains several measures and motivation for drivers and passengers and thus solves an inappropriate traffic situation.

This contribution proposes the most suitable locations for the location of a network of these parking lots near four important railway stations, in order to facilitate the connection of public passenger transport and individual passenger transport and to make railway transport the supporting transport system of the region, thus reducing the load on road communications, which should positive economic, social and ecological effects. For the efficiency and functionality of this system, it is necessary to connect with dense and high-quality urban public transport. Basic scientific claim is proposal of the generally applicable methodological procedure, which contains individual steps for solving the raised issue in the first part of the proposals. The mentioned scientific questions from the introduction of the paper regarding the creation of a methodological procedure and subsequently its practical application were answered and thus the goal of the paper was fulfilled and achieved. Specifically, detailed practical outputs of the mentioned system were developed for the parking lot at the Poprad - Tatry railway station. Suggestions for further research will consist of more detailed analyzes and the development of other specific logistics technologies that could be used as an alternative to individual motoring. The limitation of this research may consist in the problematic linking of these systems to the current state of passenger transport, current transport infrastructure, as well as its financial demands.

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ANALYSIS OF SMART MOBILITY SOLUTIONS IN SELECTED URBAN CENTERS IN POLAND

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Abstract

With the dynamic expansion of urban areas, the effective development of cities is becoming a priority both for technologically advanced countries and for countries that are not among the world leaders. Sustainable and modern in terms of infrastructure and management, ecological urban centers are seen as key foundations of the future. It should be noted that traditional transport systems may become insufficient in the near future, given the growing demand for mobility. Smart urban mobility solutions are aimed at implementing the assumptions of sustainable transport, intelligent traffic management systems, minimizing traffic jams and travel time, and optimal use of transport infrastructure. Polish cities are also starting to take part in the process of transforming urban mobility towards intelligent solutions. This article will present the results of analyzes of smart urban mobility solutions in selected Polish cities participating in the Intelligent Cities Challenge initiative, these are: Poznań and Gdańsk (ICC, 2023). The aim of the article was to analyze smart urban mobility solutions in selected Polish cities (Poznań and Gdańsk). The research methods used were desk research and focus expert interview. Analysis of the level of development of smart urban mobility (at the national level) showed that Poznań ranks higher than Gdańsk in the categories of electric transport, bicycle transport, facilities for electromobility and clean air. Moreover, based on the expert research conducted, it can be indicated that both cities are characterized by similar development factors (e.g., focus on introducing new technologies) as well as development threats (e.g. residents' fears of changing the scope of transport solutions used, such as giving up private transport). Based on the analyzes performed, it can be indicated that both Poznań and Gdańsk are taking active steps to develop solutions related to intelligent mobility, although there are some differences in transport infrastructure and achievements in individual areas. Both urban centers show potential for further

development in the field of urban mobility, which may bring benefits for both residents and the natural environment.

Keywords: smart urban mobility, urban mobility, mobility innovation, smart city, urban mobility solutions, smart mobility solutions

1. INTRODUCTION

In the modern world, the role of cities as the main centers of life, concentrating an increasing part of society, is growing dynamically. It is estimated that the urban population in the world is 3.5 billion and is systematically increasing. According to the United Nations forecast, approximately 60% of the world's population will live in cities in 2030 (BI, 2023). Technological development, combined with a significant increase in the world's population, brings very dynamic changes in the way societies function. The main place of interaction of these two basic factors are rapidly changing cities and their character (Ryba, 2007; Gądecki, 2013).

It should be noted, however, that cities evolve and adapt to the changing needs of their inhabitants, which is why they have often begun to become centers of innovation supporting the development of countries (Florida, 2023). Demographic growth and dynamic urbanization, reinforced by globalization processes and unprecedented flows of population, capital and information, cause cities to face unprecedented challenges, requiring new operational concepts, technologies, technical solutions and development strategies (Neirotti et. al., 2014). Currently, significant socio-economic and technological changes are taking place, in which cities play a key role. That is why the concept of the so-called smart cities (Ryba, 2007). Intelligent solutions implemented in cities can use their advanced infrastructure to support transport operation and management (Stawasz et al., 2012; Pichlak, 2018).

It can be argued that smart urban mobility plays a key role in urban centers by providing efficient, sustainable and connected transport solutions. It uses advanced technologies (e.g., Internet of Things IoT, artificial intelligence AI, analysis of large data sets) to improve the way people move and the flow of goods (through intelligent road traffic management, optimization of routes and schedules and adaptation of transport services to needs in real time, intelligent traffic lights, parking management systems, smart bus stops or mobile applications integrating various means of transport). On this basis, it can be indicated that developing intelligent urban mobility is important from the point of view of the efficiency of urban centers and improving the quality of life of their inhabitants.

The aim of the article was to analyze smart urban mobility solutions in selected Polish cities participating in the Intelligent Cities Challenge initiative (these are: Gdańsk and Poznań).

The study consists of several parts: introduction, analysis of the literature on the subject (in relation to the location of smart urban mobility in the broader concept of smart city, as well as the scope of the concept of smart urban mobility), materials and methods, results, discussion and conclusive remarks.

2. SMART MOBILITY CONCEPT – LITERATURE REVIEW

Modern urbanized urban areas constantly strive to ensure coherence between social, economic and environmental phenomena. Continuous improvement of processes and increasing mobility through the sharing economy are priority issues in the era of rapidly developing urbanization. Cities of the future must adapt to changing environmental conditions in order to quickly respond to: climate change, population size, ongoing globalization of the economy and demography, technology development, geopolitical threats and changes, urban mobility, population aging, conflicts and social inequality (Caragliu, 2016 ; Czupich et al., 2016; Makieła et. al., 2022).

City authorities, in order to take care of urbanized urban areas and their users, are increasingly implementing the smart city concept, which is now becoming a strategic plan of many agglomerations both in Poland, Europe and around the world (Bachanek, 2019).

According to the definition of the Massachusetts Institute of Technology, a smart city is: intelligence contained in the combination of increasingly effective digital telecommunications networks communication (compared to nerves), ubiquitous, continuous intelligence processes (compared to brains), sensors and receptors (compared to sense organs), and software (compared to knowledge and cognitive competences) (Mitchell, 2007).

In turn, Mohanty et. al. (2016) considers a smart city to be: a place where traditional networks and services are more flexible, efficient and sustainable. They are based on the use of information, digital and telecommunications technologies to improve the functioning of cities and for the benefit of residents. Therefore, smart cities are greener, safer, faster and friendlier. It is assumed that a smart city is one that is characterized by (Giffinger et. al., 2007; Manville et. al., 2014):

- a smart economy, i.e. a highly efficient and technologically advanced economy thanks to the use of ICT technology;
- smart transport networks, i.e. integrated transport and logistics systems using mainly clean energy;
- sustainable use of resources (smart environment); i.e. striving for economical management of natural resources;
- high-quality social capital (smart people), the creation of which is possible in conditions of social diversity, tolerance, creativity and commitment;
- high quality of life (smart living), which means safe and healthy living in a city with a rich cultural and residential offer, providing wide access to ICT infrastructure enabling the creation of lifestyle, behavior and consumption;
- smart public management, i.e. one in which social participation in decision-making, including strategic decisions, transparency of operations, quality and availability of public services play an important role.

A smart city is a creative, sustainable city in which the quality of life improves, the environment becomes friendlier, and the prospects for economic development are stronger (Lee et al., 2014). Its distinguishing feature is "intelligence", which can be understood as the sum of various improvements regarding the functioning of urban infrastructure and city resources, as well as public services related to the sphere of mobility (Gontar et al., 2013; Angelidou, 2014; Jong et. al., 2015; Trinidade et. al., 2017).

It is in this field that intelligent mobility becomes an important area of research and an important research gap that is worth filling. Improving the functioning of the broadly understood sphere of logistics in the city is one of the city's development priorities. Since its inception, the concept of intelligent mobility has been used in transport networks, both in the area of urban planning and transport planning due to innovation (Łabędzki, 2022). At the same time, it is one of the main factors of the attractiveness of cities and determines the level and quality of life of residents (Bielińska-Dusza et. al., 2021).

It should be noted that there are many definitions of the concept of smart mobility. This is because this idea is evolving. Gabrys (2014) indicates that intelligent mobility is an approach that helps reduce the emission of toxic exhaust gases emitted into the atmosphere by vehicles, encouraging residents to use environmentally friendly means of transport. In turn, Allam and Newman (2018) point out that smart mobility is not only about integrating technology into urban infrastructure, but also calling on citizens to use the urban environment in an intelligent and rational way and derive benefits from it. Giffinger (2020) defines smart mobility as the use of creativity or advanced technologies to manage transport and communication (including digital). The indicators are: transport efficiency, the use of sustainable solutions, the use of public transport, local and global transport availability and technological infrastructure, e.g. access to smart city cards.

Smart mobility aims to improve mobility while reducing the impact of transport on the environment and society, as well as managing traffic congestion, reducing independent travel, encouraging people to change modes of transport, reducing the length of trips and increasing the efficiency of the transport system (Papa & Lauwers 2015).

Benevolo et al. (2016) define the following fundamental goals relating to the implementation of smart mobility assumptions: reducing transport costs, reducing air pollution, reducing the nuisance of emitted noise, reducing traffic congestion, increasing safety and shortening the time of movement of goods and movement of people .

To achieve maximum effects when introducing individual elements of smart mobility, a balanced approach is necessary, combining innovative technologies and the needs of city residents. Smart mobility should integrate technologies, systems, infrastructure and capabilities where innovation is a means, not just an end. Intelligent mobility systems include public transport systems as well as individual mobility systems, including ridesharing, bicycle sharing, car sharing and on-demand ride services (Boichuk, 2020).

In individual urban centers, there can be significant differences and levels of advancement in the implementation of solutions or technologies related to intelligent mobility. Differences occur both at the global level, but also at the national and regional level.

The following points will present the methodological assumptions of the authors' own research, and then the research results relating to the comparison of the activities of municipal authorities of selected Polish cities (Poznań and Gdańsk) in the development of the idea of smart mobility.

3. MATERIALS AND METHODS

The main aim of the study was to analyze smart mobility solutions in selected Polish cities: Gdańsk and Poznań. The identified urban centers were selected for the study based on their participation in the Intelligent Cities Challenge (ICC) initiative. This is a project supported by the European Commission, the aim of which is ecological and digital transformation in accordance with the assumptions of the Local Green Deals (for local economies - e.g. within the city). ICC is intended to support the use of innovative technologies while improving economic competitiveness, strengthening civil society and improving the lives of residents. Mobility is one of the dimensions of the indicated transformation (ICC 2023).

The following specific objectives were formulated:

- P1: Determining the level of smart mobility of selected Polish cities.
- P2: Determining the development factors of smart mobility in selected Polish cities.
- P3: Identification of challenges in the field of smart mobility of selected Polish cities.

The main research problem is the question: what smart mobility solutions operate in selected Polish cities: Poznań and Gdańsk?

The main research problem was decomposed into the following detailed questions:

- RQ1: What is the level of smart mobility in selected Polish cities?
- RQ2: What are the development factors of smart mobility in selected Polish cities?
- RQ3: What are the challenges in the development of smart mobility in selected Polish cities?

The study was carried out in three stages (preparation, implementation, results analysis). In each of these phases, specific tools, techniques and research methods were used.

3.1 Preparation phase

At this stage of the research, the desk research method was used, which involves the analysis of records of available data sources, including in particular their compilation, mutual verification and processing. Such an analysis constitutes the basis for developing conclusions about the examined problem (Bednarowska, 2015).

It was used to select smart mobility indicators and related data. Due to the availability of data and the possibility of their comparison, the following groups of measures were selected:

- public roads with hard surface [km];
- bicycle paths per 100 km2 of total area;
- bus lines [km];
- tram lines [km];
- trolleybus lines [km];
- buses [pcs.];
- trams [pcs.];
- trolleybuses [pcs.];
- passenger transport per year [million people];
- based on the report on the Ranking of Electromobile Cities (Piznal et. al., 2021), aspects relating to electric transport, bicycle transport, facilities for electromobility, public transport and clean air.

3.2 Realization phase

The research method in this step was a focus expert interview, which is a special type of methodological research because it draws on the knowledge and creativity of people who are experts in a given field. It involves obtaining data by asking questions based on a specially prepared questionnaire - obtaining answers by the interviewer from respondents selected on the basis of appropriately selected research samples (Magruk, 2005). It is assumed that respondents with extensive professional achievements and professional knowledge on a given topic can present interesting analytical proposals. Thanks to professional knowledge and "imagination rooted in reality", they can also create valuable (realistic) forecasts of the development of the situation in a given fragment of economic and social reality (Churchill, 2002).

The authors' own research was conducted between August and September 2023. The technique of purposeful selection of experts was used. The selection criteria for the study were significant practical experience in the implementation and functioning of intelligent mobility technology solutions. A total of 40 experts participated in the study (two groups of 20 people from each of the analyzed cities).

The interview questionnaire consisted of two parts:

- specifications (defining the profile of experts);
- core containing development factors and threats to smart mobility in selected cities based on the STEEP analysis, containing sociological, technological, economic, ecological (environmental) and political factors, selected on the basis of the modified research approach of Kachniewska (2020) referring to medium-sized cities in Poland.

3.3 Developing research results phase

The development of research results was based on the use of elements of descriptive statistics, such as the arithmetic mean and median (Ręklewski, 2020). This concerned both the analysis of smart mobility indicators and the results of the expert interview.

The analysis of the research results is presented in the next section.

4. RESULTS

Two selected urban centers in Poland - Poznań and Gdańsk - will be subject to comparative analysis in relation to smart mobility solutions. When characterizing these cities, it can be indicated that Poznań is located in the western part of the country - in the Greater Poland Voivodeship, on the Warta River. The area of Poznań is 261.9 km2. The number of inhabitants in 2022 was 541,316 people. Gdańsk, in turn, is a port city on the Polish Baltic coast - in the Pomeranian Voivodeship, located at the mouth of the Motława River and the Vistula River on the Bay of Gdańsk. The area is 265.9 km2. In 2022, the number of inhabitants was 486,345 people. Therefore, we can point to a comparable area and number of inhabitants, which is important from the point of view of selecting these centers for research. Additionally, both cities participate in the Intelligent Cities Challenge, which shows that they intend to develop and implement solutions, technologies and concepts regarding smart city solutions, including in relation to broadly understood mobility.

Considering the elements of the transport network, the length of public roads in Poznań (31.23 thousand km) is much longer than in Gdańsk (12.23 thousand km). Moreover, both bus and tram lines are longer in Poznań. The existing fleet of buses and trams is also larger in Poznań. Public transport in Poznań carried 11.59% more passengers. Only in the case of saturation with bicycle paths, a better result was obtained in Gdańsk - table 1.

Table 1 Selected parameters of the transport network of Poznań and Gdańsk in 2021

Element oceny lub wskaźnik	Poznań	Gdańsk
Public roads with a hard surface	31230,7	15233,6
Bicycle paths per 100 km2 of total area	7,84	8,5
Bus lines in km	6237,5	3248
Tram lines in km	207,5	156
Trolleybus lines in km	-	211
Buses in pcs.	988	719
Trams in pcs.	228	141
Trolleybuses in pcs.	-	108
Passenger transport in public transport per year in millions	213	207

Source: own work based on (USG, 2021; USP, 2021)

The analysis of the level of development (at the national level) of smart urban mobility in the surveyed cities will be based on the Ranking of electromobile cities developed by Polityka Insigh (Piznal et. al., 2021). The list was prepared on the basis of numerical data regarding various types of quantifiable aspects of local government activities in the 50 largest Polish cities with county rights in terms of population, compiled in a total of 27 indicators, in five categories: electric transport, bicycle transport, facilities for electromobility, public transport and clean air (Piznal et. al., 2021). It should be noted that the city of Poznań achieved a higher position than Gdańsk in four of the five indicated categories: in the field of electric transport, bicycle transport, facilities for electromobility and clean air. However, in terms of public transport, both cities were ranked in the same place - table 2.

Table 2 The level of smart urban mobility in Poznań and Gdańsk in relation to the largest cities in Poland

Group of indicators	**Poznań**	**Gdańsk**
Electric transport: 1. City hall car fleet 2. Electric public transport 3. New registrations of electric cars 4. Electric vehicle charging stations 5. Analysis of the benefits of using zero-emission vehicles	5	9
Bicycle transport: 1. Number of city bikes 2. Number of city bike stations 3. Length of bicycle paths 4. Expansion of the bicycle path network 5. Electric scooters	5	26
Facilities for electromobility: 1. Planned expenditure on transport and communications 2. Index of changes in transport and communications expenditure 3. Electromobility development strategy 4. Charging station location plan 5. Support for commercial charging stations	1	4
Public transport: 1. Length of bus lanes 2. Operation of public transport vehicles 3. Change in the number of vehicle kilometers traveled 4. Expenditures on public transport 5. Type of fuel in buses 6. Tram and bicycle infrastructure	7	7
Clean Air:	2	12

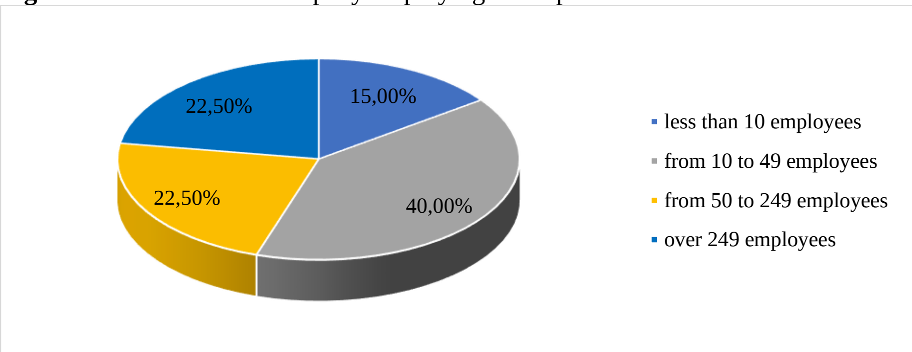
Group of indicators	**Poznań**	**Gdańsk**
1. Street green areas 2. The amount of funding for the replacement of furnaces 3. Subsidies for heating replacement 4. Clean air campaigns 5. Co-financing for renewable energy 6. Number of smog alerts		

Source: own work based on (Piznal et. al., 2021)

The next analyzed aspects will refer to development factors and threats in the development of intelligent mobility in Poznań and Gdańsk. The results were developed based on focus group interviews with experts.

A total of 40 deliberate selected experts took part in the study. The largest percentage of experts (40%) were employed in small organizations (employing from 10 to 49 employees). Then experts employed in large enterprises (employing at least 249 people), as well as in medium-sized enterprises (employing from 50 to 249 employees) - both 22.5%. The remaining 15% were experts employed in micro-enterprises (employing up to 10 employees) – figure 1.

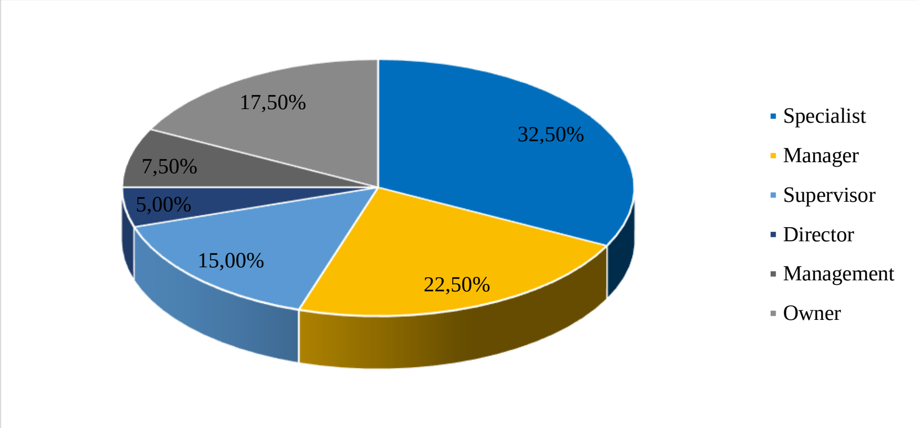
Figure 1 The size of the company employing the expert



Source: own work

The largest percentage of experts (32.50%) were employed as specialists, 22.50 as managers, 17.50% as owners, 15% as supervisors, 7.50% as management and 5% as directors (figure 2).

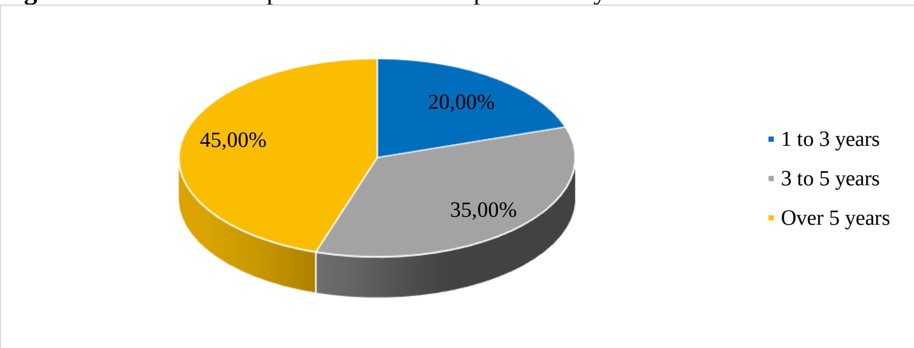
Figure 2 Expert workplace



Source: own work

Referring to the professional experience of experts in the current position, the largest part of experts (45%) were employed for over 5 years, 35% for 3 to 5 years, and 20% for 1 to 3 years (figure 3).

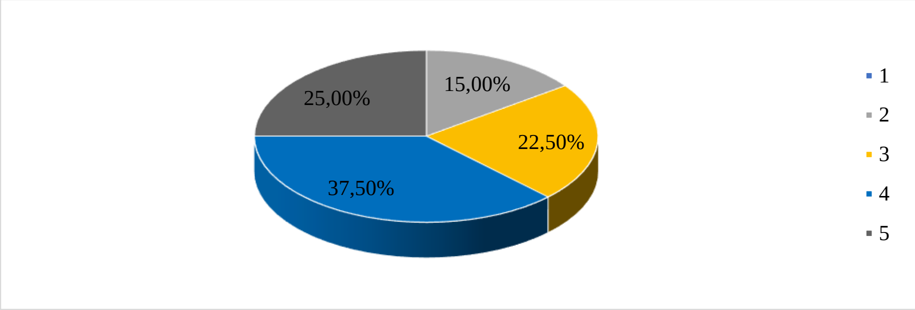
Figure 3 Professional experience in the last position in years



Source: own work

Experts also assessed their own knowledge and experience on a scale of 1 to 5 (where 1 means a low level of knowledge and experience, and 5 a high level of both knowledge and experience). Most largest part of experts (37.50%) made a self-assessment at level 4, 25% at level 5, 22.50% at level 3, and the remaining 15% at level 2. There was no answer regarding the level 1 assessment. The average grade was 3.73 and the median was 4 (figure 4).

Figure 4 Self-assessment of expert knowledge and experience



Source: own work

With regard to the development factors of intelligent mobility, experts indicated the role of individual factors both from the proposed list and based on their own indications. Scales from 1 to 5 were adopted, where 1 meant the factor was of little importance and 5 was very important (no answer meant no importance). For each of the factors (sorted into categories: sociological, technological, economic, ecological and political), the arithmetic mean and median were calculated for both cities.

In the sociological sphere, both places receive similar assessments of individual factors. In both cities, improving safety and quality of life as well as improving mobility solutions received the highest scores. Also in the technology category, Poznań and Gdańsk also received similar ratings. The highest rated development factors were new technologies and the development of ICT. In turn, factors in the ecological sphere received similar ratings. Both towns should focus on reducing the number of vehicles, lower energy consumption and reducing water and air pollution. In Gdańsk, the factor of reducing energy consumption is also important. Moreover, similar assessments were obtained also with regard to economic factors. In both cities, the development of small and medium-sized high-technology enterprises and the reduction of costs related to pollution disposal are important. In the last group - political factors, similar assessments were also obtained. Important development factors include motivating increased financing for technology development and developing a coherent strategy for the development of intelligent mobility (table 3).

Table 3 Assessment of development factors of intelligent mobility in Poznań and Gdańsk

Factors	Poznań		Gdańsk	
	Average	Median	Average	Median
Sociological				
improving mobility solutions	4,21	4	4,23	4
improving safety and quality of life	4,28	5	4,45	5
social interest in solutions known from larger or more developed urban centers	3,83	4	4,03	4
lifestyle	3,68	4	3,84	4

Factors	Poznań		Gdańsk	
	Average	**Median**	**Average**	**Median**
education level and health awareness	3,60	4	3,71	4
demographic trends	3,28	3	3,42	4
promoting a healthy lifestyle	3,68	4	3,87	4
promoting an ecological lifestyle	4,05	4	4,10	4
Technological				
new technologies	4,45	5	4,48	5
ICT development	4,20	4	4,29	4
market niche related to "green technologies"	3,68	4	3,97	4
patents, inventions and intellectual property protection	3,40	3,5	3,65	4
level of digital competences in society	3,48	4	3,74	4
growing acceptance and interest in modern solutions in the field of city bike and scooter systems	3,68	4	3,97	4
growing acceptance and interest in car sharing systems	3,70	4	3,97	4
implementation of multimodal integration systems for passenger traffic and goods transport	3,88	4	4,10	4
renewable energy technologies	3,80	4	3,84	4
Ecological (environmental)				
reducing the number of vehicles	3,88	4	3,94	4
lower energy consumption	4,13	5	4,50	5
reducing water and air pollution	4,15	4	4,45	5
technologies that do not use or process harmful substances (e.g. synthetic fuels)	4,08	4	4,26	4
implementation of the circular economy concept	4,05	4	4,19	4
Economical				
development of (small and medium-sized) high-technology enterprises	3,68	4	3,68	4
reduction of costs related to waste disposal	3,90	4	4,00	4
reducing traffic intensity	3,88	4	3,97	4
reducing the shortage of parking spaces	3,75	4	3,77	4
reducing the number of accidents and the costs of treating the injured	3,78	4	3,90	4

Factors	Poznań		Gdańsk	
	Average	Median	Average	Median
availability of funds for the development of environmentally friendly technologies	3,80	4	4,03	4
growing rate of implementation and commercialization of innovative technologies	3,53	4	3,71	4
market size	2,95	3	2,97	3
increasing the reuse rate of resources and raw materials	3,75	4	3,87	4
Political				
increasing financing for technology development	4,28	4	4,26	4
developing a coherent strategy for the development of intelligent mobility (indicating priority directions of development) and European guidelines	3,63	4	3,68	4
national scientific and research base	3,55	3	3,65	4

Source: own work

With regard to the threats to the development of intelligent mobility, experts indicated the role of individual factors both from the proposed list and based on their own recommendations. Scales from 1 to 5 were adopted, where 1 meant the factor was of little importance and 5 was very important (no answer meant no importance). For each of the factors (sorted into categories: sociological, technological, economic, ecological and political), the arithmetic mean and median were calculated for both cities.

Regarding development threats of a sociological nature, individual factors received similar ratings in both cities. The residents' fears about changing the scope of transport solutions used, such as giving up private transport, were rated the highest. Poznań has a slightly higher result in the absence of qualified staff, which may suggest a greater challenge related to acquiring specialists to work on the development of smart mobility. In the technological sphere, factors also received similar ratings, especially in terms of high technology competition in the international market and the low technical base of technical universities. In the case of the group of ecological factors, the potential increase in environmental risk and increase in energy consumption related to new needs was rated highly in both cities. In Gdańsk, the generation of harmful waste during the operation of devices was also highly rated. In turn, in the case of economic factors, in both cities the costs of changes in the city's architecture, the costs of new communication solutions and the costs of developing the city bike system were highly rated. In the last, political sphere, both cities received similar ratings in the case of difficulties in financing research in the field of smart mobility and the lack of units supporting scientists in obtaining/financing patents (table 4).

Table 4 Assessment of development threats of intelligent mobility in Poznań and Gdańsk

Factors	**Poznań**		**Gdańsk**	
	Average	**Median**	**Average**	**Median**
Sociological				
fear of changing the scope of transport solutions used (resignation from private transport)	3,65	4	3,77	4
lack of qualified staff (programmers, architects, planners)	3,58	3,5	3,45	3
lack of social trust in modern transport solutions	3,43	3	3,55	3
Technological				
competition of high technologies on the international market (pressure on the costs of the solutions used, low profitability and low scalability of solutions and applications offered by local entrepreneurs)	3,75	4	3,84	4
low technical base/condition of technical universities	3,56	4	3,68	4
lack of readiness to implement "green technologies"	3,45	3,5	3,39	3
Ecological (environmental)				
potentially increasing environmental risk by introducing an unknown solution	3,83	4	3,90	4
increase in energy consumption related to new needs	3,85	4	3,94	4
generation of harmful waste during operation of devices (e.g. electric vehicles)	4,30	5	4,45	5
Economical				
costs of changes in the city's architecture	4,05	4	4,16	4
costs of new communication solutions, new investments, purchase of new vehicles	4,10	4	4,19	4
costs of developing the city bike system	3,20	3,5	3,26	4
cost of experts (smart mobility issues) and programmers	3,65	4	3,77	4

Factors	Poznań		Gdańsk	
	Average	Median	Average	Median
low rate of implementation and commercialization of innovative technologies	3,28	3	3,32	3
Political				
difficulties in financing research in the field of smart mobility	4,07	4	4,29	4
lack of incentives to launch large-scale commercial enterprises, "know-how" contribution	3,33	3	3,45	3
lack of units supporting scientists in obtaining/financing patents	3,45	3	3,58	4
lack of legal regulations allowing for quick implementation of the technology	3,50	4	3,52	4

Source: own work

6. DISCUSSION

It should be noted that both cities - Poznań and Gdańsk take actions and initiatives that are aimed at the development of smart mobility, and there are analyzes in this area in the literature on the subject.

As pointed out by Czupich et al. (2016), the development factors for the implementation of smart mobility in Poland include the creation of transfer hubs, reconstruction of the communication framework, introduction of intelligent street traffic control, and increased interest in sustainable development; reducing energy consumption and CO2 emissions; organizing urban transport more effectively. However, the barriers mentioned by the authors include: a difficult financial situation caused mainly by investment activity in cities in recent years, and the term of office of the authorities, which may negatively affect the continuation of the strategy chosen by the predecessors.

Sikora-Fernandez (2019), in turn, points to slightly different threats to the implementation of the smart city concept (including aspects of smart mobility). This concerns a specific division of decision-making in the selection, location and financing of urban investments. While urban matters are mainly decided by the cities themselves (local level), the decision on spending EU funds is made by marshal offices (regional level). Moreover, investment decisions that are key for the needs of the entire country (e.g. main power lines, transport lines, related to public safety), even if they concern individual urban areas, are undertaken at the central level, and their location often depends on the voting power and importance of the parliamentarian representing a given region. In addition, cities implement selected initiatives selectively, to the extent that overlaps with the smart city concept (especially in areas such as energy, intelligent transport system, e.g. -administration), however, these are investments involving the so-called single shots, not integrated projects covering the entire city.

Ratti and Townsend (2011) point to innovative technologies that enable fast, unlimited data transfer, availability of databases, creation of effective and easily programmable infrastructure and an expanded network of sensors and controllers as the development factor of smart mobility. The main opportunity in this approach is to improve the quality of services provided to city users and to save money, time and energy from the point of view of the city's operation.

On the other hand, it can be pointed out that there is a need for cooperation between many stakeholders and entities within the city's activities in the context of the effective implementation of smart urban mobility. As Kauf (2016) points out, such intelligent technologies as e.g. intelligent traffic control, modular containers, to improve utilization of vehicle capacity, and alternative means of transport. This helps to reduce the load on the road infrastructure, thus improving the quality of the environment and life in the city. The main trend in sustainable city logistics is cooperation between suppliers, customers and the public administration. Implementation of intelligent logistics requires developing of new business models, enabling to generate benefits not only for the city, but also its operating entities.

7. CONCLUSION

The article discusses the issue of smart mobility, which is a key element of the future of urban transport and is a response to the challenges related to city development and mobility.

The cities of Poznań and Gdańsk were selected for a comparative analysis of smart mobility solutions. Although these centers differ geographically, they have a similar population and urban area, which makes them suitable centers for research on smart city solutions. In addition, both cities actively participate in the Intelligent Cities Challenge, clearly indicating their commitment to developing and implementing innovative mobility technologies and solutions.

In the context of transport infrastructure, Poznań is distinguished by a much greater length of public roads and a more extensive public transport network, including both buses and trams. Also having a larger fleet of public transport vehicles. Poznań transports more passengers in public transport. Gdańsk achieved better results only in terms of bicycle infrastructure.

The analysis of the level of development of smart urban mobility (at the national level), based on the Ranking of Electromobile Cities, showed that Poznań ranks higher than Gdańsk in four of the five analyzed categories: electric transport, bicycle transport, facilities for electromobility and clean air. In terms of public transport, both cities are at the same level.

Based on the expert research conducted, it can be indicated that both cities are characterized by similar development factors. In both urban centers, in the context of the development of smart mobility, there should be a focus on introducing new technologies, promoting an ecological and healthy lifestyle and developing sustainable mobility infrastructure. In turn, with regard to threats, similarities were found in both towns, such as residents' concerns about changes in the scope of transport solutions used, such as giving up private transport, costs of changes in the city's architecture, or costs of new communication solutions.

To sum up, the comparative analysis indicates that Poznań and Gdańsk are taking active steps towards the development of smart mobility solutions, although they differ slightly in terms of transport infrastructure and achievements in individual categories. Both cities have the potential for further development in the field of urban mobility, which could bring benefits to both residents and the natural environment.

The limitations of the study are related to its qualitative nature - carried out based on focused group interviews. Further detailed analyzes relating to aspects of sustainable transport, greening of transport, and assessment of changes over time should be based on quantitative research. Moreover, as part of future research, residents should be involved in the assessment of smart mobility changes and, preferably, such research should be carried out on a representative sample.

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WOOD BIOMASS IN SUPPLY CHAIN – EVIDENCE FROM THE FGI STUDIES

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Abstract

Wood is a versatile raw material that can be used in many different ways – from paper and packaging to construction. In addition, wood products can be reused and recycled when their original use becomes obsolete. An important renewable resource is wood biomass, which is mostly derived from forest residues, wood processing residues or construction and municipal waste. These materials can be processed and reused, providing a more environmentally friendly alternative. Although recovery rates are relatively low, environmental awareness is increasing. Companies are investing in optimising technological and logistical processes, while at the same time reducing their environmental impact. These efforts can reduce a company's costs and also reduce environmental waste.

The aim of this paper is to characterise residual wood biomass, its forms, sources and uses, and to identify reverse supply chain and their main challenges.

For the needs of the paper, research was conducted using Focus Group Interviews (FGIs). We carried out three direct structured group interviews using questionnaires with managers from companies dealing with residual wood biomass.

Keywords: biomass, wood, residual wood, reverse supply chain, focus group interview

1. INTRODUCTION

Wood is a universal and renewable resource. It comes from trees that can be grown and replaced by new cuttings. It is known for its strength and durability. Properly processed and maintained, wood can last for many years, making it not only environmentally valuable but also economically viable (Moncada et al. 2016).

Wood has a wide range of applications. It can be used to make furniture, building structures, flooring, doors, windows, paper, packaging and many other products. Its versatility makes it an indispensable raw material in many areas of life (Srinivas & Pandey, 2017; Falk, 2019).

It is a renewable resource, so it can be used without running out of natural resources. However, this does not mean that it is not worth seeking its reuse. Its wise use can contribute to sustainability and environmental goals. Particularly relevant here is residual wood biomass (Nunes et al., 2023).

One of the most important reused wood resources is biomass, which is mostly derived from forest residues, wood processing residues or construction and municipal waste. The biomass materials can be processed and reused, providing an environmentally friendly solution (Daian & Ozarska, 2019; Kawa, 2023).

All waste wood can be recycled therefore the same tree can be used in many different ways (Wang et al., 2016). For example, if one makes a beam out of a tree that's being replaced over time, you can get it back and turn it into wooden cutlery, which, when it's recycled back, can be used later as a base for conifers or gardening tools. However, recovery rates for wood biomass are still relatively low, indicating that there is room for improvement. Nevertheless, there is a growing recognition of the importance of environmental sustainability.

Wood biomass is derived from the organic material found in wood, including trees, branches, bark, sawdust, wood chips, etc. It comes from a variety of sources, including forest residues, wood processing by-products and construction and demolition waste. It offers a solution to the disposal of wood waste, such as forest residues and wood processing. Instead of allowing these materials to decompose or contribute to landfill waste, they can be used as a valuable resource for energy production. It is a renewable energy resource that can be used for a variety of purposes, including the production of heat and electricity (Evans et al., 2010). It is valued as a sustainable alternative to fossil fuels because of its ability to reduce greenhouse gas emissions and promote environmentally friendly use of natural resources (Ciesielczuk, 2016).

Residual wood biomass, like wood and wood-related products, is subject to numerous technological and logistical processes (Rentizelas et al., 2009). We are dealing with a supply chain that is referred to as a reverse supply chain because of the reverse direction of the residual biomass flow (Prahinski & Kocabasoglu, 2006). There are many challenges associated with this, as biomass requires special storage and transport conditions (Burnard et al. 2015; Allen et al. 1998; Tatsiopoulos & Tolis 2003). It is of relatively low value, so processes need to be well planned and efficiently executed.

To date, the reverse supply chain of residual wood biomass is little recognised, particularly on the empirical side. There are many theoretical works and with mathematical models. Practical knowledge is therefore lacking. In particular, there is a lack of answers to the questions:

- For what purpose is residual biomass used (other than for energy purposes)?
- How is the reverse supply chain of residual wood biomass understood?

- What are the key processes and actors in the reverse supply chain of residual wood biomass?
- What are the problems and opportunities in the reverse supply chain of residual wood biomass?

The primary objective of this paper is to provide an in-depth characterization of residual wood biomass, encompassing its various forms, origins, utilization, and the exploration of challenges within the reverse supply chain associated with it.

To fulfil the objectives of this study, we employed focus group interviews as our research approach. We conducted three separate groups interviews, employing a research scenario, with managers representing companies engaged in the management of residual wood biomass.

2. EMPIRICAL RESEARCH PROCESS

In this article we present the results, which are part of a multi-stage research procedure. In the initial stage of the study, we relied on a literature review. Here, we present the results of a group interview. This stage was qualitative in nature and served as a tool for exploring the research area.

Participants for the study were selected in a purposive way. A prerequisite for taking part in the interview was experience of the wood industry, particularly biomass. Persons working in companies: related to the wood industry, sawmills or involved in handling and recycling were selected. Care was therefore taken to ensure representation of the various actors in the wood industry supply chain. Entities that can be described as typical were selected for the research sample. An attempt was made to differentiate the group in terms of gender, age and positions held. Taking into account the recommendations for the number of participants in a focus group interview (Rabiee, 2004; Krueger & Casey, 2000), the sample size was set at 6 people (additionally, 1 person was always a reserve in case of the absence of another person from the planned group). The structure of the sample in terms of gender, age, position and company focus is shown in Table 1.

Table 1 Characteristics of the study sample

No.	Position	Subject of activity	Age	Gender
Date of interview: 05.07.2022				
1	Manager	Manufacture of scantlings, angle beams, slats, quarter rounds	42	F
2	Assistant manager at a sawmill	Sawmill	36	M
3	Specialist technologist	Sawmill	n.a.	M
4	Junior manager	Sawmill	n.a.	M
5	Senior contractor contact person	Wood processing plant	46	F

No.	Position	Subject of activity	Age	Gender
Date of interview: 05.07.2022				
6	Owner	Production of wooden structures and timber houses	n.a.	M
Date of interview: 06.07.2022				
1	Assistant manager	Structural timber production	n.a.	F
2	Quality control of finished goods	Garden architecture and pellet production	n.a.	F
3	Logistics specialist	Sawmill	32	F
4	Production line assistant manager	Sawmill	46	M
5	Assistant sawmill manager	Sawmill	34	M
6	Manager	Production of wooden structures, elements and houses	41	M
Date of interview: 07.07.2022				
1	Assistant manager for logistics and transport	Production of wooden packaging	26	F
2	Assistant Sawmill Manager	Sawmill	25	M
3	Assistant sawmill manager	Sawmill	26	M
4	Customer service advisor	Production of chairs and frames	25	F
5	n.a.	Processing and production of pellets	35	M
6	Assistant manager	Sawmill	n.a.	M

Source: own studies

A total of three FGIs were scheduled. They were originally planned to take place in different cities, but due to the holiday season and the prevalence of conducting surveys remotely during the pandemic (Willemsen, 2022), interviews were organised on different dates (4,5 and 6 June 2022) with different respondents in an online version. Online FGIs have many advantages, e.g. no need to travel to the interview site, which increases elasticity and reduces travel costs, no need to rent a room and no need for recording equipment. The disadvantages, however, are less interaction between survey participants and fewer opportunities to observe responses.

Interviews were organised by an independent research agency that specialises in carrying out a variety of both qualitative and quantitative research on behalf of companies and academic institutions. They were conducted by a professional moderator.

The research took place on the basis of the research scenario, which was prepared by the research team and submitted to the research agency. The scenario was developed on the basis of literature studies and the experience of the researchers.

The interview took the form of a discussion in which the moderator gave tasks and posed questions according to a set scenario and the participants expressed their opinions on the topics that were covered (Dilshad & Latif, 2013). If there were doubts in the group about the content of the questions, the moderator helped to clarify the context or clarify concepts by giving examples.

The moderator was given the following guidelines before the study began:

- encourage respondents to be active by stressing the importance of the results of this study, their relevance in the context of ongoing research. If the discussion slows down or drifts into other topics, the moderator stimulates the group by asking additional questions and seeing if participants have anything to add that is worth including.
- encourage respondents to express their feelings and opinions – especially if they are evasive (e.g., claiming ignorance or theorising)
- ensure that all respondents have an opportunity to express themselves, and stress that each opinion is important,
- reassure them that the researchers are interested in hearing different voices and exploring different views – especially if confrontational interactions arise between respondents.

The process of the interviews was documented by means of audio and video recording. The participants' statements were then transcribed on the basis of the recordings. The first analysis of these transcripts made it possible to conclude that the study managed to avoid unfavourable phenomena such as spontaneous conversations between participants (both on topics related and unrelated to the topic of the study), overactivity or complete inactivity of some participants (Olejnik et al., 2022).

The interview consisted of three main parts: an introduction (including participants presenting themselves), a main part (containing tasks and questions – as shown in Table 2), and a conclusion (summarising and thanking participants for participating in the discussion).

At the beginning of each interview, the moderator presented the name of the research project, its purpose and for which institution the study is being conducted and by whom it is funded. She then informed the research participants that they were participating in a focus group interview. She also presented the main principles of this type of research and encouraged participants to express their opinions. She informed the participants about the recording of the study and assured them that the study is confidential. The empirical material collected will be subjected to qualitative analysis excluding the possibility of identifying respondents. The meeting was scheduled to last up to 120 minutes.

The moderator then asked the respondents to briefly introduce themselves, in particular to give their first names, which were needed for their efficient identification during the survey. Once this procedure was completed, the moderator moved on to the first stage of the survey.

The main part of the study was composed using 16 tasks. Some of these tasks were performed individually to encourage each participant's active participation. At the same time, other tasks were carried out by the whole group of participants in order to achieve synergy. All questions were open-ended, giving participants the freedom to express their opinions. In cases where the answers were insufficient from the point of view of the research being conducted, the moderator provided additional clarifications and questions to elicit more detailed information.

The tasks in the core part of the study were divided into 2 groups: sources and uses of residual wood biomass and reverse supply chain.

Before the moderator asked the first question, she did a warm-up exercise. She asked the respondents to write on their own sheets the associations connected with the keyword "residual biomass" and "residual wood biomass".

The first group of tasks (tasks 5-8) covered "”forms and sources of residual wood biomass”, “use of residual biomass”, and “use of residual wood biomass”. The second group (tasks 9-16) dealt with supply chain, in particular associations with the keyword "reverse supply chain" and the identification of processes, actors, problems and opportunities related to it.

Table 2 Focus group interview scenario

No.	Task	Content of the task presented to respondents	Task type
1.	Associations with the keyword “residual biomass”	Moderator says the words "residual biomass" and asks the respondents to write on their own sheets the associations connected with this keyword.	Individual task
2.	Associations with the keyword “residual biomass”	Moderator asks: • Can the answers be grouped in some way? • Why did you group the associations in such a way? • According to what criteria?	Group task
3.	Associations with the keyword "residual wood biomass"	Moderator says the words "residual wood biomass" and asks the respondents to write on their own sheets the associations connected with this word.	Individual task
4.	Associations with the keyword "residual wood biomass"	Moderator asks: • Can they be grouped in any way? • Why did you group the associations this way? • According to what criteria?	Group task
5.	Forms and sources of residual wood biomass	Moderator asks to write on their own sheets what "forms and sources of residual wood biomass" respondents know.	Individual task
6.	Use of residual biomass	Moderator asks respondents to write on their own sheets what residual biomass are used for (in general, regardless of the source).	Individual task

No.	Task	Content of the task presented to respondents	Task type
7.	Use of residual wood biomass	Moderator asks respondents to think about how and what residual wood biomass are used for.	Individual task
8.	Use of residual wood biomass	Moderator asks respondents if the uses of woody biomass can be categorized. Moderator asks respondents if industries, products, technologies, etc. can be assigned to these uses of woody biomass residues.	Group task
9.	Associations with the keyword “reverse supply chain”	Moderator says the words "Reverse Supply Chain" and asks the respondents to write on their own sheets the associations connected with this word. Why these associations?	Individual task
10.	Associations with the keyword “reverse supply chain”	Moderator asks: • Can they be grouped in some way? • Why did you group these associations in such a way? • According to which criteria?	Group task
11.	Reverse supply chain processes	Moderator asks respondents to consider what reverse supply chain processes are and to write on their own sheets their associations.	Individual task
12.	Reverse supply chain processes	Moderator asks the respondents to identify the most important and the most difficult processes. Moderator asks respondents to indicate the criterion for selecting the most relevant and most difficult processes.	Group task
13.	Actors in the reverse supply chain of residual wood biomass	Moderator asks the respondents to give actors in the reverse supply chain of residual wood biomass.	Individual task
14.	Actors in the reverse supply chain of residual wood biomass	Moderator asks the respondents to indicate the criterion for grouping the entities.	Group task
15.	Problems and opportunities in the reverse supply chain of residual wood biomass	Moderator asks respondents to write on the sheets what problems/challenges and opportunities/possibilities are related to residual wood biomass	Individual task

No.	Task	Content of the task presented to respondents	Task type
16.	Problems and opportunities in the reverse supply chain of residual wood biomass	The moderator encourages the respondents to rank the identified problems and opportunities according to their importance/significance.	Group task

Source: own studies

The audio-visual recordings made during the study were the basis for creating the transcription. The process of creating the transcription started with the person responsible for recording the interview, who prepared a first version of it. The transcription was then reviewed by the moderator to verify its accuracy. Appropriate corrections were made where necessary. After these corrections, the transcriptions were handed over to the research team.

The transcriptions were analysed using an inductive approach, following a commonly used method in qualitative research (Thomas, 2003). The analysis process involved reading the transcriptions multiple times and partial coding, which involved assigning short words or phrases to describe specific features of the utterances. After careful analysis of the transcriptions, a set of codes was established based on the content of the utterances and the features found in the literature. The codes were grouped according to different categories, such as the sources of wood biomass and the types of actors in the reverse supply chain identified in the participants' statements.

3. RESULTS

As mentioned, the moderator did a warm-up at the beginning, asking respondents to make associations with the terms “residual biomass” and “residual wood biomass” respectively. Respondents gave a lot of keywords associated with these terms. These were spontaneous responses, so they were often linked to other categories. Associations were often connected to experience and place of work. Below are a few sample statements:

“In my case, it is mainly sawdust, woodchips, such waste materials. Then there's bark, conifer needles and sometimes roots from cuttings. In addition, demolition wood also comes to us, used pallets or contaminated waste. Grass can also be a biomass material, but that's not exactly in my line of work”.

“The 'bio' itself indicates that it is something that should be organic and decompose on its own in nature”.

“If we have to prepare boards to size, there is waste left over that is irregularly shaped. In addition to this, shredded wood, sawdust, offcuts that remain after wood processing”.

"I would add leftover food, as one collects, anything that can ferment. Semi-finished products from animals, from vegetables, from fruit, anything that even causes fermentation and causes gases, creating".

"My associations with this term are: shavings, bark, leaves, straw, low-quality cereals, oilseed cake, animal excrement, municipal waste".

"Briquettes, sawdust, shavings, chips, worked pieces, larger pieces, such remnants which were not suitable for production, beams or similar things, frames from dismantling of windows for example".

The moderator then asked for the responses to be grouped together. This task resulted in the categories shown in Table 3.

In this task, respondents gave a lot of associations related to wood, which they were asked about in the next question. In order to avoid repetition of wood-related answers, only those associations related to „residual wood biomass" are shown in Table 4.

Table 3 Categories and examples of residual biomass

Categories	**Energy**	**Waste**	**Agriculture**	**Food**
Examples	- renewable energy - heat sources - biofuel - biogas production - biodegradation - biology - fermentation and gas formation	- recycling - municipal waste - industrial waste - post-production residues - scrap material	- low-quality cereals - manure - straw - animal excrement - hay - grass - agricultural waste - pomace from oilseed crops	- products from vegetables, fruits - food scraps - potato peelings

Source: own studies

Table 4 Categories and examples of residual wood biomass

Categories	**Wood**	**Reuse**	**Demolition wood**	**Others**
Examples	- sawdust - shavings - bark - woodchips - pieces of wood after processing	- energy source - disposal - recycling - briquette - pellet	- used pallets - doors - old rafters - furniture - windows frames - railroad sleepers	- cellulose - paper - resin - lignin - mulch

	- wood chunks - branches of trees - needles - roots - litter waste - offcuts - shredded wood - leaves - branches - shrubs - brushwood		- old roof trusses - floors - demolition wood	

Source: own studies

The next task was to provide grouping criteria. Respondents grouped biomass according to the following categories:

- by origin: animal and vegetable,
- due to waste: dry and wet,
- due to use: industry and agriculture.

For woody biomass, respondents grouped it according to the following categories:

- in terms of calorific value,
- in terms of moisture content of components,
- in terms of conversion to energy,
- in terms of reuse in another form – recycling,
- in terms of processing – form, solid, gas, liquid,
- due to the purpose – returns to the environment e.g., bark and new products are created,
- due to form-permanent, e.g., OSB (oriented strand board) and non-permanent e.g., energy from combustion.

In the next task, respondents were asked by the moderator to identify "forms and sources of residual wood biomass". In this case, the respondents mostly gave quite similar associations as in the previous tasks. In the case of forms of woody biomass, however, this can be summarised as follows:

- shavings,
- woodchips,
- sawdust,
- shavings,
- branches,
- boughs,
- brushwood,
- needles,

- leaves,
- roots/root systems,
- cellulose,
- tree trunks,
- bark.

Moreover, respondents identified the following sources of woody biomass residues:

- tree cutting: forests, orchards,
- sawmills,
- farms – tree pruning, e.g., during reforestation program,
- secondary market: furniture factories, municipal plants (bulky waste), city cleaning plants, pallet processing, demolition of wooden buildings, doors, windows, floors, railroad sleepers.

The last task in this group concerned the purpose of biomass residues. Respondents most often mentioned energy production as the purpose of biomass residues. The following are examples of statements: "Production of fuels for firing in cookers, such as pellets", "Biomass for energy production, as biocarbon for example, bio-oil".

Examples of using biomass to produce building products and paper were often given: "All kinds of boards, some kind of particle board, fibre board, composite boards, decking boards, OSB, in the form of some kind of underlay or soffits".

Other examples include: "For animal husbandry, i.e. those mulches or production of litter for cats, dogs, rabbits, etc."; "Various kinds of bedding, underlay just for flowers, if someone has rabbits or guinea pigs"; “There are more and more attempts to use cheaper resin glue production. I think in Germany they are making T-shirts out of plastic parts and there are also attempts to use textile parts out of wood".

There was also an interesting theme related to the use of waste biomass in art: "As decorative wood and for the renovation of buildings", "using wood as an art form"; "Certainly folk artists make some artwork out of roots," he said. "From such a bigger root you can make a table or some kind of chair, armchair, whatever".

Another area is cosmetics and herbalism: "For example, an oak bark-scented soap". "Pharmacies that specialise more in herbal medicine or something like that, that's where you can often buy just oak bark for infusions too";

Respondents' statements can be organised into the following categories:

- energy production – pellets, biocarbon, bio-oil;
- recycling – production of osb, pallets, particleboard, fiberboard, composite boards, decking;
- pharmaceutical industry – oak bark for infusions, birch bark for soaks;
- chemical industry – industrial alcohols (ethanol), varnishes, impregnants, resin adhesive production;
- construction – wooden nails, carpenter's pegs, for insulating buildings (processed products similar to styrofoam);
- pulp industry – paper;
- food industry – smoking chips, for smoking various meats, ice cream sticks, toothpicks, trays, cups, cutlery, bowls.
- agriculture – for fertilizer, compost, animal bedding;

- horticulture – bark, mulch, garden chips dyed in various colors for gardens;
- landscaping – roots, sculptures, lamp fragments;
- zoology – bedding for hamsters, rabbits, guinea pigs, for terrariums;
- floristry – flower bases, flower compositions;
- tourism – for marking trails;
- automotive industry – dashboards in cars;
- clothing industry – clothes and shoes from wood residues.

As before in this task, respondents gave a lot of associations related to wood, which they were asked about in the next task. For this reason, statements from the next task will be omitted.

In the second group of tasks, the respondents were asked by the moderator to indicate associations with the keyword “reverse supply chain”. Most respondents do not deal with logistics on a daily basis, so it is interesting to see how the respondents understood the term reverse supply chain. Intuitively, the respondents understand the term quite well: “In our case it looks like this: there is an order, a salesman is responsible for it, then there is a customer like a wholesaler, then some manufacturer who receives the products and produces a product, for example, a piece of furniture, and then the customer should get it. At this stage, there may be some quality problem, resulting, for example, from the fact that we produced a bad quality board. Then the product comes back to us – such a reversal occurs - and we have to think about whether to dispose of it or recycle it and make the right product again”.

Some respondents pointed to the changing role of the actor in the supply chain: “This is the change from seller to buyer”. „Selling in a direction other than what is established”; “As a customer, I buy wood which I then process into furniture. A by-product of this processing is, for example, offcuts and chips. I can collect this residue and sell it, for example, to a wood supplier, who can then turn the chips into pellets for heating”.

Other respondents pointed to a change in process: “Re-using something that has already been used once, to go back to the first process”; “For example a furniture company sells chips to another company that produces particle board, and each of these companies produces something from wood and processes it.”; “For example, a customer who orders something may in the meantime be a supplier to that person from whom he ordered it. He or she has some waste or unnecessary stuff that he or she can pass it back to that supplier to use for his or her needs”; “This can be called recycling of wood material, returning these wood chips to be milled again and again to create wood panels, or just turning some waste that will not be suitable for further restoration, and turning this into fuel material”.

In the next task, respondents were required to identify reverse supply chain processes. The moderator asked the respondents to identify the most important processes and to indicate the criterion for selecting those processes.

In all three interviews, respondents cited different processes. In order to make their presentation more readable, they were divided into the following processes that take place in the reverse supply chain.

Selecting and sorting

"There must be a specific selection of this biomass and then this can go to a specific recipient. This selection of what kind of waste it is and the appropriate grouping and distribution to the right recipients."

"With us, it's sorting and seasoning so that this biomass material doesn't decompose, so that it doesn't become soggy. Then it's resale."

"If we have shavings and sawdust left over, we have to make a selection as soon as possible, because this is material that is subject to decay and cannot always lie for a long time."

"If the wood comes to us at the sawmill, it should not have any additional elements, such as nails. Sometimes there is contamination, so each log simply passes through a metal detector so as not to damage the process line."

Storage

"We have to have a receiver for it who will come and collect it more quickly, because sometimes it's more profitable to burn it than to send it on, because it can't lie in the damp, you need a proper warehouse for it".

"The storage time is also important, so that these products, these wastes are simply stored as short as possible, so that they reach the place of collection as soon as possible".

"You have to have the right conditions for storage so that this waste doesn't lose its quality".

"It can't be stored for too long, so that some processes don't start that will destroy the waste".

"Such a place must meet certain conditions. Certainly, it should be a dry and airy place."

"It is also very important to ventilate the biomass residue, and for ventilating you need a place, but this must be provided, it can't be that we dump it somewhere and it just lies there."

Quality control

Another process mentioned by respondents is quality control: "Longer stored any wood, wood waste, is of lower quality. They begin to spoil, rot, mold, fungi appear. The freshest waste is the best. There is an important quality control, we try to keep up to date".

Transport

"We have to have proper transport, that is, with a tarpaulin for the chips, it can't catch moisture, also we look for transport with a truck with a tarpaulin".

"We have to have special containers to transport or store it, and if we have some tree trimmings left, some branches there, then we need a truck that has some kind of shredder for those branches, so we can store it in a warehouse".

"Transportation plays the most expensive role. We have to think about whether it is profitable to transport it somewhere, whether it is profitable for us to burn it at our place or to dry this wood".

Costs are also highlighted by other respondents: “You have to look for contractors simply as close as possible (...) because then we save on transportation costs”.

"The dimensions of the waste are important, because with some, the transport and logistics costs can exceed that saving on reusing the waste".

"So that it is close, because then we save on transport costs. Then we also reduce the risk of the goods getting mouldy before we get them to the recipient".

Disposal

“If the product is not suitable for sawdust, or is rotten, it is burned.’

“Everything is collected, especially since for the winter, you can always reheat the hall”.

In the next task, respondents were asked to answer the question which actors are involved in the reverse supply chain of woody biomass residues.

Respondents identified types of actors according to their role in the reverse supply chain:

- commodity producer/sawmills,
- recycling/ecological/eco companies,
- transport and logistics companies,
- municipal waste collection companies – furniture,
- urban land reclamation companies,
- distributors of finished wood biomass products.

Respondents also listed the types of companies by industry:

- furniture industry,
- chemical industry,
- paper industry,
- construction industry,
- horticultural companies,
- agriculture.

The further task was to identify problems or challenges in the reverse supply chain for woody biomass residues. Among the most frequently mentioned problems were those related to increasing costs – both of raw materials, energy and labour: “A lot of processes are based on electricity, machines, balers, crushers, shellers, it's all on electricity, today practically nothing is produced by hand anymore on a larger scale. Many companies may struggle to make their operations profitable”; "The problem is the rising costs of transporting and supplying the material in question”; "The challenge is proper logistics to reduce transport and storage costs, optimise stock management, minimise excess waste and optimise fuel consumption during transport"; "The human factor has still been an issue for some time. There are no people to work with, particularly in the male construction type industry"; „The biggest challenge is probably to ensure that the chain is uninterrupted, from the cutting of the tree, by all recipients. So that the wood doesn't lie around and spoil. Here, so that these stages between one recipient and another are very short”; "Environmental protection can also be a challenge. It is known that they are tightening a lot of standards all the time regarding emissions of various gases. Technological processes, such as composting, must not have a negative impact on the environment".

Opinions of respondents can be identified as the following problems and challenges:

- processing – high electricity costs, all machines run on electricity which contributes to low profitability;
- maintenance of timber stocks in Poland;
- economic instability – price increases, inflation;
- purchase of new equipment – issue of investment in plant and equipment.
- environmental protection – tightening of environmental standards;
- taxes and law – problems related to taxes, social security;
- lack of human resources – lack of people to work in sawmills on machinery;
- access to timber, blockades, high tariffs, inability to import timber from Ukraine, Belarus and Russia;
- limits on felling;
- storage – expensive and risky due to possible loss of wood properties.

Respondents in the same task were also asked to identify opportunities and possibilities related to residual wood biomass. They found it difficult in the context of the current economic and social situation. However, they pointed to several issues: „As an energy source, biomass will increase its market share. Given the energy crisis we're having now, limited access to coal, limited access to gas, it seems to me that this is just the way to go in terms of an energy source"; "The chances are, looking at what the European Union is doing in terms of ecology, that maybe the residual wood biomass industry will get more attention and maybe there will be subsidies to make it work more efficiently, just as farmers have, etc."; "Emphasis on making people aware of the fact that wood is better for us than many other things, i.e. plastic, coal, gas, and can be used in an easier way, in a more environmentally friendly way"; „Perhaps one day we will be able to make clothing from this woody biomass, why not, eco clothing".

Grouping the contributions, the following opportunities related to residual wood biomass can be identified:

- increasing the share of energy production,
- the possibility to process wood more than once,
- green products – educating the public that wood products are green,
- strengthening of environmental policy by the EU and creating new opportunities for products made from wood biomass,
- new markets after the end of the war – after the end of the war in Ukraine, an opportunity could be new markets, the reconstruction of Ukraine.

4. CONCLUSIONS

Our research has shown that the concept of waste biomass is very broad and can be looked at in different ways. One that has a very high potential is residual wood biomass. The paper characterises residual wood biomass, its forms, sources and uses, and identification of reverse supply chain processes and the main challenges associated with it.

In this paper, the results presented are an integral part of a multi-stage research process. Focus group interviews were used as part of the research conducted. As the qualitative research was the first stage of the study, hence the interview was treated as a tool for exploring the research field. The findings from the discussion will help us to formulate hypotheses that will be further verified in the second stage of the research, using a quantitative approach. Moreover, these findings played an important role in the development of the research tool, the interview questionnaire.

We are aware of the limitations of research using the FGI method. Firstly, the group of participants in a group interview is not representative of the general population, which limits the possibility of general conclusions. Secondly, the results of an FGI have a subjective character, as it depends on the perception of the participants. Thirdly, respondents may express their opinions while being influenced by the opinions of others, which may not reflect their true beliefs.

Despite these limitations, FGIs are a research method that is used to discover new phenomena, but also to explore opinions on known issues. In addition, their results are used, as mentioned, to prepare studies using the quantitative method.

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TENDERING OF RAIL TRANSPORT SERVICES IN SLOVAKIA

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Abstract

The population's rising standard of living also leads to a rise in passenger demands for the quality of transport and the provision of additional services in railway transport. This factor also caused the arrival of private rail carriers on the EU rail network, including Slovakia, which opened the rail passenger transport market to competition. In line with the intentions of the EU's common transport policy to create a fair competitive environment and open the railway sector to competition, processes aimed at improving the quality of transport services and streamlining the use of public funds necessary for their operation have been ongoing in Slovakia for several years. The research is focused on the process of public procurement of transport services. On the ground of describing the principles, experiences, and mistakes in organising public tenders in railway passenger transport, the methodology of the public tender process is proposed. That is applied to a case study on the railway line Bratislava – Banská Bystrica – Košice, while Slovakia has had several public competitions. A limitation of this research is the fact that only one public tender was successfully evaluated. The issue of the allocation of transport services in the public interest needs to be solved from the point of view of compliance with EU legislation as well as ensuring this service, so that the technological efficiency of the processes for the operator that will implement these services is also ensured.

Key words: public tenders, public service contracts, rail passenger transport, public competition

1. INTRODUCTION

Public transport services have a crucial role in passenger transport in the European Union, both from a political and an economic aspect. Many passenger transport services in the EU are currently provided within the context of public service contracts, which in many cases represent substantial revenue for railway undertakings. Public transport is an important social policy tool for public authorities (Johnson & Nash, 2012). The liberalisation process of the market for rail services has not yet been fully completed in all Member States. Liberalisation has contributed to fair competition and led to a customer-oriented approach and more efficient acquisition activities for railway undertakings. Transport services began to be provided based on market demand and requirements. Better and more affordable rail transport services have become more competitive with other transport modes. The liberalisation process needs to be further expanded and suitable conditions for the provision of quality rail transport services need to be prepared (Gutiérrez-Hita & Ruiz-Rua, 2019).

The European Union considers the liberalisation of the rail transport services market as the main solution to support economic competition, which can contribute to the development of rail transport and the higher utilisation of its capacity possibilities. Economic, ecological, and social aspects of rail transport are part of sustainable development (Solina & Abramović, 2022). The advantage of the liberalisation of the railway services market is the existence of economic competition based on basic market principles. The arrival of new railway enterprises can be identified as innovation, investment, an increase in service quality, increase in technological and organisational modernisation and, on the other hand, it allows the customer to choose from more than one provider of transport services, thus stimulating the relationship between quality and price (Broman & Eliasson, 2019).

Some transport services, often associated with specific infrastructure, are operated mainly for their historical interest or tourist value. As the purpose of these operations is clearly different from the provision of public passenger transport, they do not have to follow the rules and procedures applicable to public service requirements. Long-term contracts can lead to market foreclosure for longer than necessary, reducing the benefits of competitive pressure. To minimise distortions of competition, while protecting the quality of services, public service contracts should be of limited duration. In keeping with the principle of subsidiarity, competent authorities are free to establish social and qualitative criteria that will maintain and raise quality standards for public service obligations. This pertains, for instance, to minimum working conditions, passenger rights, the needs of people with reduced mobility, environmental protection, the security of passengers and employees, as well as collective agreement obligations and other rules and agreements concerning workplaces and social protection at the place where the service is provided. To ensure transparent and comparable conditions of competition between operators, the risk of social dumping should be avoided.

The issue of assigning services in the public interest needs to be addressed not only about compliance with EU legislation, but especially about their very nature. One of the obstacles to the implementation of public tenders is the non-existent uniform legislative basis for the course and functioning of public tenders in railway passenger transport and the current non-existence of a uniform methodology for the allocation of services in railway passenger transport based on public tenders.

The paper deals with the process of announcing and organizing public tenders in railway passenger transport in the Slovak Republic. Based on the analysis of the issue, a methodology was created for organizing public tenders under the conditions of the Slovak Republic, which is divided into individual stages of the public tender. Each of these phases forms a significant part of the entire public tender. Based on the proposed methodology, a case study of the announcement of a public tender for a specific railway line is developed, which is an example of how public tenders in railway transport should be organized under the conditions of the Slovak Republic. The case study shows that the correct setting of competence and evaluation criteria in public tenders, based on a non-discriminatory approach, are important steps.

2. EXPERIENCE WITH ORGANIZING PUBLIC TENDERS IN RAILWAY PASSENGER TRANSPORT

The allocation of services in the public interest is regulated mainly through regulations and directives. The basic legislation governing the allocation of services in the public interest is Regulation (EC) No 1370/2007 of the European Parliament and the Council on public passenger transport services by rail and by road, and Regulation (EU) 2016/2338 of the European Parliament and of the Council amending Regulation (EC) No 1370/2007 concerning the opening of the market for domestic passenger transport services by rail (European Commission, 2007; European Union, 2016). Within each state, the allocation of transport performance in the public interest in railway passenger transport is also regulated according to national legislation. In Slovakia, this national legislation is Act 343/2015 on public procurement and others (Slovak Republic, 2015).

The analysis of the organisation of railway passenger transport on the liberalised market describes Abramović, et al. (2018). Nash, et al. (2019) in their research solve the experience of Europe's three most liberalised railways - Sweden, Germany, and Britain - in opening-up rail passenger services to competition by means of competitive tendering and seeks to draw lessons for countries that are just starting the process, such as France. Litră & Burlacu (2014), in their research paper, propose to analyse the management of the public service contract through the current regulations in the field and to correlate trends in the railway industry with the specific situation. They conducted a series of comparative analyses and SWOT analyses considering the context of the Romanian railway industry. The issue of the effective conclusion of public service contracts in rail passenger transport has been analysed by Dementiev (2018). Hensher & Stanley (2008), Alexandersson, et al. (2008) and others conducted research of the same type. Further case studies and analyses of the liberalization of the railway market in individual countries, such as Sweden or Norway, have been carried out. They include, for instance, Nilsson & Jonsson (2011), Odolinski & Smith (2016), and Alexandersson, et al. (2020). Competition in the railway passenger market in the Czech Republic was analysed by Tomeš, et al. (2014), Fitzová, et al., (2021) and liberalisation Czech rail market and capacity allocation were described in their research by Nachtigall, et al. (2020). Position of railway passenger transport companies in the current liberalised transport market solved Záhumenská, et al., (2018). Stojić, et al., (2018) propose a novel model for determining public service compensation in integrated public transport systems. Lakatos & Mándoki (2020) performed a sustainability analysis of competition in public transport systems in Hungary and Finland. Criteria for the quality of services of public interest organised by train operators proposed in their research Humić & Abramović (2019). Competitive tendering versus performance-based negotiation in Swiss public transport describe Filippini, et al. (2015). Brenck & Peter (2007) describes their experience with competitive tendering in Germany. Open access competition in long-distance passenger rail services in Poland solved Król (2017). In the Slovak Republic, the research about public tenders and liberalisation railway market conducted Gašparík, et al. (2017) and Bulková, et al. (2023) describes technological aspects of public tenders in Slovakia. The research of Mašek, et al. (2015) deals with the operation of regional passenger transport in Slovakia, liberalization and competition in railway transport, principles of the contract on transport services in the public interest, and the current state of regional passenger transport on the regional railway line Bratislava – Dunajská Streda – Komárno. Experience from the Bratislava – Košice railway line solved Kvizda & Solnička (2019). Dolinayová, et al. (2021) solved their research competition on the domestic rail passenger transport market under public service obligation in some selected European countries and Slovakia.

In 2009, the Ministry of Transport (hereinafter referred to as the Ministry) of the Slovak Republic announced a public tender for a carrier on the regional line Bratislava – Komárno. In the end, the Ministry assigned operation on this line to the private carrier Regiojet (in short, RJ) in 2011 directly (Kvizda & Solnička, 2019). The carrier concluded the contract until the end of 2020. Therefore, the Ministry announced a public tender for this line in 2019 (Slovak Republic, 2019a). This private carrier Regiojet has been operating on the Prague – Žilina line since 2011, and in 2014 extended this line to Košice in an open access regime. At the beginning of 2014, another Czech private carrier, Leo Express, entered on the line Prague – Košice. Both carriers have maintained their position on this segment until today on a commercial basis under the "open access" regime, i.e., without any financial support from the state. The next tendered line by the Ministry was Bratislava – Banská Bystrica in November 2015. The result was the non-awarding of the contract to any tenderer. The tender was cancelled due to changes in the common EU legislation and due to insufficiently defined rules for a uniform travel document recognised between carriers (problem of tariff integration). Table 1 shows a chronological overview of the allocation of transport performance in railway passenger transport in the Slovak Republic.

Table 1 Opening of the public transport services market in Slovakia

Year	Market event	Railway Line
till 2003	The state carrier Železničná spoločnosť Slovensko (ZSSK) monopoly	Whole Slovak railway network
2009	Announcement of the 1st public tender on the regional line in Slovakia	Bratislava–Dunajská Streda–Komárno
2011	Public tender completed, direct allocation to RegioJet carrier	
	Regiojet starts IC trains (open access)	Prague–Žilina
2012	ZSSK starts IC trains (open access)	Bratislava–Žilina–Košice
2014	Regiojet has extended the IC train line	Prague–Žilina–Košice
	Leo Express starts IC trains (open access)	Prague–Žilina–Košice
2015	Announcement of the 1st public tender on long-distance railway line (cancelled)	Bratislava–Banská Bystrica
2016	ZSSK cancels IC trains (January)	Bratislava–Žilina–Košice
	ZSSK re-introduces IC trains (December)	
2017	Regiojet cancels IC trains (January)	Bratislava–Žilina–Košice
2018	Public tender on the regional line (cancelled)	Žilina–Rajec
	Public tender on the regional line	Košice- Moldava nad Bodvou
	Public tender on the regional line (cancelled)	Bratislava–Dunajská Streda–Komárno
2019	Plan of tender announcement on the regional line	Košice–Moldava nad Bodvou (not published yet)
2020	Repeated public tender on the regional railway line (cancelled)	Žilina–Rajec
	Repeated public tender on the regional railway line	Bratislava – Dunajská Streda – Komárno (successful)

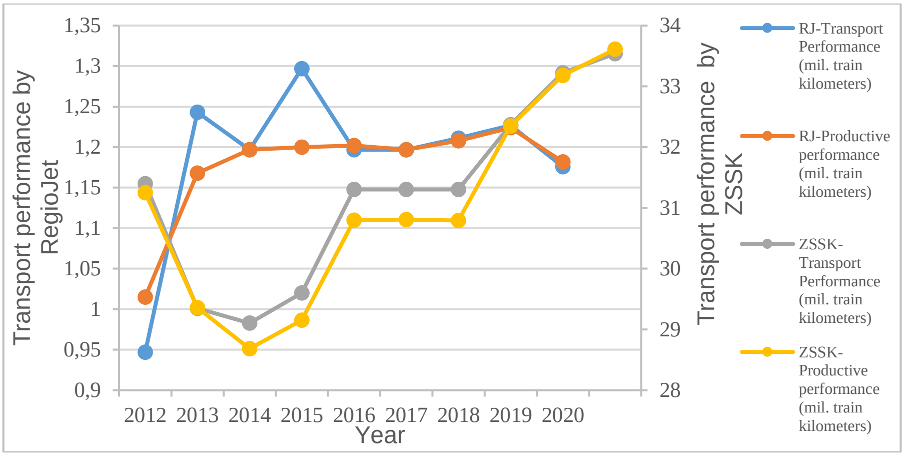
Source: (authors, according to data of Ministry of Transport of the Slovak Republic)

Currently, there are two regional lines in the phase of the liberalisation process in Slovakia: Žilina – Rajec and Košice – Moldava nad Bodvou. The public tender for the carrier on the Žilina – Rajec line was announced twice (Slovak Republic, 2019b). Due to non-fulfilment of the conditions, even the state ZSSK did not win the competition, and therefore, in 2020 the Ministry announced the second public tender for this line (Slovak Republic, 2020). Three carriers have confirmed their participation in the public tender: ZSSK, LeoExpress, and Arriva. In the line Košice – Moldava nad Bodvou, the public tender began to be prepared in 2018. (Slovak Republic, 2018).

Several public tenders for selected regional railway lines and one long-distance railway line have already been announced in Slovakia. All of them ended in failure until the moment in August 2022, when the ministry announced the result of the first successful public tender for the operation of the Bratislava - Dunajská Streda - Komárno line. Thus, after many years of unsuccessfully announcing public tenders, the Ministry has reached the point where the method of setting the conditions of public tenders and their evaluation has a successful basis. All public tenders announced so far have been unsuccessful, due to insufficiently defined conditions and poorly set tender criteria. This made the given railway lines unattractive for carriers. All other lines were assigned by direct assignment to the selected carrier.

Performances in railway passenger transport are currently ordered by the Ministry based on one Contract on transport services in the public interest for the period 2021–2030, which is amended annually by an addendum containing the ordered transport performance for a specific year. The required volume of transport performance intended for long-distance and regional rail passenger transport is always differentiated in the partial contract. Figure 1 shows an overview of ordered transport performance, i.e., the development of productive transport performance.

Figure 1 Overview of the ordered and realized transport performance of the operators ZSSK and RJ on the ŽSR network



Source: authors, according to Contracts of transport services and its additions

In the figure 1 is shown the carrier ZSSK (green curve) and for the carrier RegioJet (blue curve) within the scope of public transport services. Also, this figure shows the development of productive transport performance. This means that these are transport operations carried out on the ŽSR network by the carrier ZSSK (purple curve) and the carrier RegioJet (red curve).

3. RESULTS

Based on the analyses in the framework of tendering in railway passenger transport, we created the methodology of public tender process in railway passenger transport. This methodology can be applied when organising a public tender in the EU member state, while it is important to pay attention to the national legislation of the relevant state, which very often differs from the national legislation of other European Union states. The methodology of the public tender process in railway passenger transport is shown in Figure 2.

As the entity responsible for the preparation of the tender, its announcement and the selection of the winning carrier, we propose the national Ministry of Transport or other responsible transport authorities, e.g. national or coordinating public passenger transport body. This entity will be the contracting authority for the provision of public service in rail passenger transport with its main tasks:

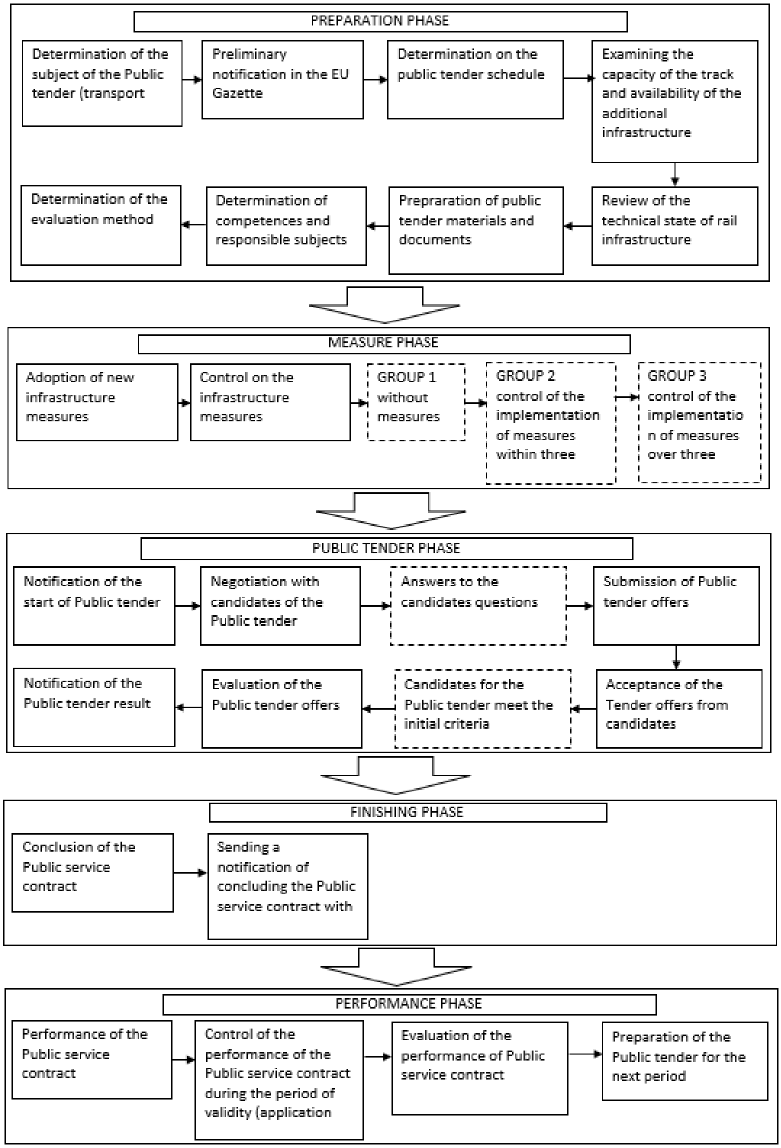
- definition of long-distance lines,

- defining performance and quality requirements for individual items of the public tender, scope of transport in train-kilometers, requirements for quality and equipment of railway rolling stock, etc.
- verification of track capacity, availability of additional and ancillary infrastructure services in cooperation with the infrastructure manager
- creation of a draft train schedule for the period of validity of the public service contract,
- determination of the terms and conditions of the tender to be met by the winning operator,
- on the basis of the established timetable and in cooperation with the infrastructure manager, identify the necessary infrastructure measures to ensure compliance with the required timetable,
- publication of a preliminary notice, preparation of tender documents and determination of evaluation criteria and their weight,
- receiving and evaluating requests to participate,
- evaluation of bids and selection of the most advantageous bid according to the set criteria,
- concluding a contract for the provision of services in the public interest with the selected tenderer and evaluation of its performance.

Adequate preparation is required before launching a call for tenders. The relevant lines will be divided into three groups depending on the need to implement infrastructure measures (Group 1-3).

Based on this methodology, a case study of the announcement of a public tender for the allocation of services in the public interest in railway passenger transport in the Slovak Republic has been prepared. This case study is applied precisely to the conditions established by this methodology and the relevant legislation of the state where the public tender is announced. The case study shows the optimization of the setting of the conditions and criteria of the public tender for the solved railway line.

Figure 2 Methodology of the public tender process in railway passenger transport – public tender phases



Source: authors

4. CASE STUDY OF A PUBLIC TENDER ANNOUNCEMENT IN THE SLOVAK RAILWAYS CONDITIONS

To illustrate the method of announcing a public tender in the Slovak Republic, a case study of the announcement of a public tender in the Slovak Republic is proposed on the exemplary example of the representation of the ministry as the customer for the selected line of long-distance railway passenger transport.

For this study, we chose the long-distance line Bratislava – Zvolen – Banská Bystrica/Košice, divided into Bratislava – Banská Bystrica as the main line and Zvolen – Košice as a secondary line. The subject of the contract is to ensure safe, efficient, and high-quality transport services for the traveling passengers between cities on the line Bratislava – Levice – Zvolen – Banská Bystrica and then Zvolen – Fiľakovo – Košice by long-distance trains through the carrier. A contract on transport services in the public interest will be concluded with the successful applicant in accordance with the provisions of § 21 of Act no. 514/2009 Coll. about transport on railways (SR, 2009). Technical and qualitative conditions will be set for the carrier to ensure transport performance. The expected start and duration of the contract or the period of execution is from 1.1.2031 for a duration of 120 months (from the beginning of the validity of the Contract, that means the validity of the new train traffic diagram - usually December, in this case December 2030).

The place of execution of the contract is the line Bratislava – Zvolen – Banská Bystrica and Zvolen – Košice. This line is divided into the main line (Bratislava – Banská Bystrica) and a minor line (Zvolen – Košice) within the evaluation. There are no regional lines associated with this line, this means that the tender is only for the long-distance main line with the associated branch line.

For such a competition, the duration from the first step to the start of operation of the line is 48 months. The case study proposes the start of line operation in train traffic diagram 2031/32 from December 2031.

The next step is the publication of the Preliminary Notice on the announcement of the public tender in the EU Gazette on 1/1/2029. The preliminary notice contains only basic information regarding the announcement of the given public tender, such as the identification data and contact points of the ordering party, the subject of the contract and its brief description, areas, which are the subject of the Contract, the expected start and duration of the Contract or the period of execution and information on subcontracts. The preliminary notice does not define the legal, economic, financial, and technical information, the conditions regarding the contract or the conditions of participation. Furthermore, this announcement does not define the range of train kilometres, the criteria for evaluating bids, the conditions for obtaining tender documents and supplementary documents, the deadline for submitting bids or requests to participate, the language in which bids or requests for participation can be submitted, the minimum period during which bids are bidders bound, conditions for opening bids and others.

The customer's requirements are listed in the tender documents of the public tender. The tender documents contain all the necessary information about the public tender, identification data of the customer, definitions of terms that define the subject of the contract, time and place of performance of the contract, requirements for proof of qualification (ability), business and payment conditions, requirements for the method of processing the price of performance, evaluation method of tenders together with the defined evaluation criteria and their weights and subsequently also the method of evaluation of tenders. The tender documents also contain the binding nature of the customer's requirements, the possibility of inspecting the place of fulfilment, explanations of the tender documents, possible changes or additions to the tender documents, the deadline and place for submitting bids and information on opening envelopes with tender offers. It also defines the submission deadline, the form and amount of the bank guarantee, information in the event of a change in the qualifications of a participant in a public tender, conditions and requirements for the processing and submission of an offer and other conditions, rights, and obligations of the contracting parties.

When preparing tender documents, the relevant employees of the public tender contracting authority are obliged to find out whether the capacity of the railway infrastructure is sufficient and whether ancillary and supplementary services are available. A draft of the perspective train traffic diagram will also be published here on the public tender line for the period of validity of the Agreement. Subsequently, it will be determined whether the current state of the railway infrastructure meets the set requirements or whether measures need to be taken in the field of infrastructure to ensure the implementation of the required scope of train traffic diagram. The last point in the preparation of the tender documents is the determination of tender evaluation criteria, which will also be published in the Notice of the start of the public tender, as well as the determination of the deadline for submitting the application for participation and tender offers. As part of the preparatory phase, the timetable for the public tender will also be determined. After the finalization of the tender documents, the stage of the public tender process is reached, which begins now of publication of the Notice of the start of the public tender.

As part of the announcement of the public tender and the determination of the conditions and requirements of this tender, it is necessary to define the required operational, technical and economic parameters for the Bratislava – Zvolen – Košice long-distance line. Table 2 shows an overview of the required parameters for the relevant main and secondary long-distance lines.

Table 2 An overview of the parameters required by the customer for the long-distance line Bratislava – Zvolen/Banská Bystrica – Košice

Line		Line length (kilometres)	Number of trains in even / odd direction (train per day)	Transport performance per day (train kilometres per day)	Transport performance per year (train kilometres per year)	Charge per train kilometre (€)
Main line	Bratislava — Banská Bystrica	230.00	10 / 10	4,600	1,679,000	7
Connecting line	Zvolen — Košice	233.00	9 / 9	4,194	1,530,810	7
Total				8,794	3,209,810	

Line		Minimum number of seats on the train (seats)	Transport performance (seats kilometres per day)	Transport performance (seats kilometres per year)	Amount for daily transport performance (€)	Amount for annual transport performance (€)
Main line	Bratislava — Banská Bystrica	286.00	1,315,600	480,194,000	32,200	11,753,000
Connecting line	Zvolen — Košice	286.00	1,199,484	437,811,660	29,358	10,715,670
Total			2,515,084	918,005,660	61,558	22,468,670

Source: authors

According to the definition of the order from the aspect of operational technology, the order body requests the composition of the train with the inclusion of a 1st class waggon, 2nd class waggons, a waggon for transporting wheelchair users, and a children's section. The capacity of the set is determined as the total number of seats in the train to a minimum value of 286 seats, while the condition of the evaluation is that 14.69% of the seats are seats in the 1st class, 69.93% of the seats are seats in the 2nd class, 14.69% of the places are places in children's sections, and 0.7% of the places are places for wheelchair users. Furthermore, the client established a timetable, which shows that on the main lines Bratislava – Zvolen and Zvolen – Banská Bystrica there will be 10 pairs of trains in the category Express train (Ex), and on the secondary line Zvolen – Košice there will be 9 pairs of trains in the category Express train (Ex).

Table 3 An overview of the commercial parameters required by the order body for the long-distance line Bratislava – Zvolen – Košice

Line		Line length (kilometres)	Minimum number of seats on the train (seats)	Number of seats in 1st class	Number of seats in 2nd class	Number of wheelchair spaces	Number of seats in children's sections
Main line	Bratislava — Banská Bystrica	230.00	286	42 (14.69%)	200 (69.93%)	2 (0.7%)	42 (14.69%)
Connecting line	Zvolen — Košice	233.00	286	42 (14.69%)	200 (69.93%)	2 (0.7%)	42 (14.69%)

Source: authors

The order body sets the annual traffic performance on the main line at 1,679,000 train kilometres and on the secondary line at 1,530,720 train kilometres. The total annual traffic performance within the entire line is 2,955,810 train kilometres. The estimated unit price per train kilometre is 7 euros. The total amount for the annual transport performance within the entire long-distance line is 22,468,670 €. Table 3 shows the required numbers of seats in a train set and the relative numbers of seats within 1st class, 2nd class, wheelchair seats, and seats in children's sections.

At the same time, the order body sets the percentage values of the relative number of seats in the train, which are necessary for the evaluation of tenders. It is important to state that the ordering party, within the framework of determining all parameters for the competitive line, only specifies the minimum values of the given parameters, which must be met by the participant in the public tender. Failure to meet these minimum required parameters will result in the applicant's exclusion from the competition.

Table 4 Determination of evaluation quality criteria and their weights within the case study

Criterion		Weight
K1	Price of seats kilometres on the main railway line	30.0 %
K2	Price of seats kilometres on connecting railway lines	30.0 %
K3	Price of seats kilometres of alternative bus transport	2.0%
K4	Number of seats in 1st class on the main railway line	3.0 %
K5	Number of seats in 2nd class on the main railway line	1.5 %
K6	The possibility of reserving seats on the main railway line	1.0 %
K7	Wheelchair space on the main railway line	3.0 %
K8	The children's section on the main railway line	2.5 %
K9	Direct wagons on connections from the main line to the connecting line (minimum 50% of the connections of the main line without a transfer)	5.0 %
K10	Free Wi-Fi connection on the main railway line	1.0 %
K11	Possibility of refreshments on the main railway line	2.0 %
K12	Number of seats in 1st class on connecting railway lines	3.0 %
K13	Number of seats in 2nd class on connecting railway lines	1.5 %
K14	The possibility of reserving seats on connecting railway lines	1.0 %
K15	Wheelchair space on the connecting railway lines	3.0 %
K16	The children's section on the connecting railway line	2.5 %
K17	Direct wagons on connections from the secondary line to the main line (minimum 50% of the connections of the secondary line without transfer)	5.0 %
K18	Free Wi-Fi connection on the connecting railway line	1.0 %
K19	Possibility of refreshments on the connecting railway line	2.0 %

Source: authors

The determination of evaluation criteria and the allocation of weights to individual criteria are carried out by the order body. As part of the evaluation of the competitive offers of the participants in the public tender, the ordering party established optional evaluation criteria, the fulfilment of which will favour the offer submitted by this applicant. In this competition, the bonus is for the electric traction (an electric locomotive or electric unit). Furthermore, the order body could favour the use of sleeper or couchette carriages in the train composition within the framework of night connections. The order body also set other bonus quality criteria, such as an entertainment portal on board and the possibility of bicycle transportation.

In the tender documents, it is stipulated that the criterion for the evaluation of offers is the economic advantage of the offer, depending on the established evaluation criteria. The scoring method on a scale of 0–100 points can be used to evaluate the tenders. Table 4 shows the proposed criteria and the weights assigned to them.

Each tender is awarded a point value that reflects the success of the tender within the relevant evaluation criterion. For a numerically expressive evaluation criterion for which the most advantageous tender has the lowest criterion value, the evaluated tender receives a point value, which is a multiple of 100, and the ratio of the value of the most advantageous tender to the evaluated tender. The score will be calculated according to the formula:

$$number\ of\ criteria\ points = \frac{offer\ with\ the\ lowest\ value}{evaluated\ offer} \times 100\ (points) \qquad (1)$$

For a numerically expressive evaluation criterion, for which the most advantageous tender has the highest criterion value, the evaluated tender receives a point value, which is created by a multiple of 100 and the ratio of the value of the evaluated tender to the most advantageous tender. The score will be calculated according to the formula:

$$number\ of\ criteria\ points = \frac{evaluated\ offer}{offer\ with\ the\ highest\ value} \times 100\ (points) \qquad (2)$$

The score calculated in this manner is determined or rounded to the specified number of decimal places. For each criterion, the candidate is awarded several points, which are calculated as the product of the weight of the criterion and the points awarded. The final number of points for a given candidate is calculated as the sum of the points obtained for each criterion and is rounded to the appropriate number of decimal places. When the tender with the highest value is equal to zero, the above formula is not used, and the evaluated tender receives zero points.

4. DISCUSSION

The basis for the correct setting of the transport service offer, or, respectively, the definition of the subject of each public tender (railway passenger transport lines), is knowledge of the transport requirements of passengers. When defining them, it is possible to start from the analyses of transport flows or the potential of passengers carried out so far, or from the results of more extensive research into the behaviour of passengers. In addition to possible research, the proposed methodology also places demand on the operational and technical issues of securing transport processes. For the assumption of growth in the number of passengers, it is necessary to offer a more attractive timetable, ensuring punctual transport and a higher travel speed with a shorter travel time compared to other modes of transport.

A very important moment in planning a public tender for transport performance is the correct choice of lines that will be included in the tender package. The question is whether it is appropriate to mix long-distance and regional transport. According to experience, it is advisable to design the haulage package according to the traction and attraction circle so that it is possible to plan the perfect circulations and turns of vehicles and to achieve savings from the scale and uniformity of the vehicle fleet and technological advances in the service of track sections.

Based on this, the timetable for the tendered line section Bratislava – Banská Bystrica – Košice as part of the case study was created. Trains in this timetable run in the section Bratislava – Banská Bystrica and Zvolen – Plešivec – Košice and back.

Bratislava – Šurany – Zvolen

km	Train		Ex		Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
	From station												
0	**Bratislava hl. st.**		**0 04**		**4 04**	**6 04**	**8 04**	**10 04**	**12 04**	**14 04**	**16 04**	**18 04**	**20 04**
4	Bratislava Vinohrady		**0 10**		**4 10**	**6 10**	**8 10**	**10 10**	**12 10**	**14 10**	**16 10**	**18 10**	**20 10**
49	Galanta		**0 38**		**4 38**	**6 38**	**8 38**	**10 38**	**12 38**	**14 38**	**16 38**	**18 38**	**20 38**
60	Šaľa		**0 47**		**4 47**	**6 47**	**8 47**	**10 47**	**12 47**	**14 47**	**16 47**	**18 47**	**20 47**
89	Šurany		**1 09**		**5 09**	**7 09**	**9 09**	**11 09**	**13 09**	**15 09**	**17 09**	**19 09**	**21 09**
104	Podhájska		**1 23**		**5 23**	**7 23**	**9 23**	**11 23**	**13 23**	**15 23**	**17 23**	**19 23**	**21 23**
132	Levice		**1 48**		**5 48**	**7 48**	**9 48**	**11 48**	**13 48**	**15 48**	**17 48**	**19 48**	**21 48**
144	Kozárovce		**1 59**		**5 59**	**7 59**	**9 59**	**11 59**	**13 59**	**15 59**	**17 59**	**19 59**	**21 59**
159	Nová Baňa		**2 14**		**6 14**	**8 14**	**10 14**	**12 14**	**14 14**	**16 14**	**18 14**	**20 14**	**22 14**
170	Žarnovica		**2 25**		**6 25**	**8 25**	**10 25**	**12 25**	**14 25**	**16 25**	**18 25**	**20 25**	**22 25**
187	Žiar na Hronom		**2 38**		**6 38**	**8 38**	**10 38**	**12 38**	**14 38**	**16 38**	**18 38**	**20 38**	**22 38**
209	**Zvolen os. st.**		**2 56**		**6 56**	**8 56**	**10 56**	**12 56**	**14 56**	**16 56**	**18 56**	**20 56**	**22 56**
	To station		Optionally Zvolen os.st./Banská Bystrica/ Košice		Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice	Optionally Zvolen os.st./Banská Bystrica/ Košice

Zvolen – Banská Bystrica

km	Train	Ex		Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
	From station	Optionally Zvolen os.st./ Bratislava hl.st./ Košice		Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice	Optionally Zvolen os.st./ Bratislava hl.st./ Košice
0	**Zvolen os.st.**	**3 02**		**7 02**	**9 02**	**11 02**	**13 02**	**15 02**	**17 02**	**19 02**	**21 02**	**23 02**
1	Zvolen mesto	**3 06**		**7 06**	**9 06**	**11 06**	**13 06**	**15 06**	**17 06**	**19 06**	**21 06**	**23 06**
6	Sliač kúpele	**3 11**		**7 11**	**9 11**	**11 11**	**13 11**	**15 11**	**17 11**	**19 11**	**21 11**	**23 11**
20	Banská Bystrica mesto	**3 23**		**7 23**	**9 23**	**11 23**	**13 23**	**15 23**	**17 23**	**19 23**	**21 23**	**23 23**
21	**Banská Bystrica**	**3 26**		**7 26**	**9 26**	**11 26**	**13 26**	**15 26**	**17 26**	**19 26**	**21 26**	**23 26**
	To station											

Zvolen - Plešivec - Košice

km	Train		Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
	From station		Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionally Zvolen os.st./ Bratislava hl.st. / Banska Bystrica
0	**Zvolen os.st.**		**3 11**	**5 11**	**7 11**	**9 11**	**11 11**	**13 11**	**15 11**	**17 11**	**19 11**
23	Detva		**3 29**	**5 29**	**7 29**	**9 29**	**11 29**	**13 29**	**15 29**	**17 29**	**19 29**
26	Kriváň		**3 33**	**5 33**	**7 33**	**9 33**	**11 33**	**13 33**	**15 33**	**17 33**	**19 33**
54	Lučenec		**3 58**	**5 58**	**7 58**	**9 58**	**11 58**	**13 58**	**15 58**	**17 58**	**19 58**
69	Fiľakovo		**4 12**	**6 12**	**8 12**	**10 12**	**12 12**	**14 12**	**16 12**	**18 12**	**20 12**
69	Jesenské		**4 39**	**6 39**	**8 39**	**10 39**	**12 39**	**14 39**	**16 39**	**18 39**	**20 39**
114	Čiž kúpele		**4 52**	**6 52**	**8 52**	**10 52**	**12 52**	**14 52**	**16 52**	**18 52**	**20 52**
133	Tornaľa		**5 08**	**7 08**	**9 08**	**11 08**	**13 08**	**15 08**	**17 08**	**19 08**	**21 08**
149	Plešivec		**5 23**	**7 23**	**9 23**	**11 23**	**13 23**	**15 23**	**17 23**	**19 23**	**21 23**
162	Rožňava		**5 37**	**7 37**	**9 37**	**11 37**	**13 37**	**15 37**	**17 37**	**19 37**	**21 37**
202	Moldava nad Bodvou		**6 10**	**8 10**	**10 10**	**12 10**	**14 10**	**16 10**	**18 10**	**20 10**	**22 10**
233	**Košice**		**6 35**	**8 35**	**10 35**	**12 35**	**14 35**	**16 35**	**18 35**	**20 35**	**22 35**
	To station										

Banská Bystrica – Zvolen

km	Train		Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex	Ex
	From station											
0	**Banská Bystrica**		**2 32**	**4 32**	**6 32**	**8 32**	**10 32**	**12 32**	**14 32**	**16 32**	**18 32**	**20 32**
1	Banská Bystrica mesto		**2 35**	**4 35**	**6 35**	**8 35**	**10 35**	**12 35**	**14 35**	**16 35**	**18 35**	**20 35**
15	Sliač kúpele		**2 46**	**4 46**	**6 46**	**8 46**	**10 46**	**12 46**	**14 46**	**16 46**	**18 46**	**20 46**
20	Zvolen mesto		**2 52**	**4 52**	**6 52**	**8 52**	**10 52**	**12 52**	**14 52**	**16 52**	**18 52**	**20 52**
21	**Zvolen os.st.**		**2 55**	**4 55**	**6 55**	**8 55**	**10 55**	**12 55**	**14 55**	**16 55**	**18 55**	**20 55**

	To station		Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice	Optionall y Bratislava hl.st./ Zvolen os.st./ Košice

Zvolen – Šurany – Bratislava

km	Train		**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**
	From station		Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice	Optionall y Zvolen os.st./Ban ská Bystrica/ Košice
0	**Zvolen os.st.**		**3 00**	**5 00**	**7**	**9 00**	**11 00**	**13 00**	**15 00**	**17 00**	**19 00**	**21 00**
4	Žiar na Hronom		**3 18**	**5 18**	**7 18**	**9 18**	**11 18**	**13 18**	**15 18**	**17 18**	**19 18**	**21 18**
49	Žarnovica		**3 31**	**5 31**	**7 31**	**9 31**	**11 31**	**13 31**	**15 31**	**17 31**	**19 31**	**21 31**
60	Nová Baňa		**3 42**	**5 42**	**7 42**	**9 42**	**11 42**	**13 42**	**15 42**	**17 42**	**18 42**	**21 42**
89	Kozárovce		**4 00**	**6 00**	**8 00**	**10 00**	**12 00**	**14 00**	**16 00**	**18 00**	**20 00**	**22 00**
104	Levice		**4 12**	**6 12**	**8 12**	**10 12**	**12 12**	**14 12**	**16 12**	**18 12**	**20 12**	**22 12**
132	Podhájska		**4 36**	**6 36**	**8 36**	**10 36**	**12 36**	**14 36**	**16 36**	**18 36**	**20 36**	**22 36**
144	Šurany		**4 51**	**6 51**	**8 51**	**10 51**	**12 51**	**14 51**	**16 51**	**18 51**	**20 51**	**22 51**
159	Šaľa		**5 14**	**7 14**	**9 14**	**11 14**	**13 14**	**15 14**	**17 14**	**19 14**	**21 14**	**23 14**
170	Galanta		**5 25**	**7 25**	**9 25**	**11 25**	**13 25**	**15 25**	**17 25**	**19 25**	**21 25**	**23 25**
187	Bratislava Vinohrady		**5 52**	**7 52**	**9 52**	**11 52**	**13 52**	**15 52**	**17 52**	**19 52**	**21 52**	**23 52**
209	**Bratislava**		**5 58**	**7 58**	**9 58**	**11 58**	**13 58**	**15 58**	**17 58**	**19 58**	**21 58**	**23 58**
	To station											

Košice – Plešivec – Zvolen

km	Train		**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**	**Ex**		**Ex**
	From station											
0	**Košice**		**3 21**	**5 21**	**7 21**	**9 21**	**11 21**	**13 21**	**15 21**	**17 21**		**23 21**
31	Moldava nad Bodvou		**3 46**	**5 46**	**7 46**	**9 46**	**11 46**	**13 46**	**15 46**	**17 46**		**23 46**
71	Rožňava		**4 18**	**6 18**	**8 18**	**10 18**	**12 18**	**14 18**	**16 18**	**18 18**		**0 18**
84	Plešivec		**4 32**	**6 32**	**8 32**	**10 32**	**12 32**	**14 32**	**16 32**	**18 32**		**0 32**
100	Tornaľa		**4 46**	**6 46**	**8 46**	**10 46**	**12 46**	**14 46**	**16 46**	**18 46**		**0 46**
119	Čiž kúpele		**5 02**	**7 02**	**9 02**	**11 02**	**13 02**	**15 02**	**17 02**	**19 02**		**1 02**
135	Jesenské		**5 17**	**7 17**	**9 17**	**11 17**	**13 17**	**15 17**	**17 17**	**19 17**		**1 17**
164	Fiľakovo		**5 44**	**7 44**	**9 44**	**11 44**	**13 44**	**15 44**	**17 44**	**19 44**		**1 44**
179	Lučenec		**5 59**	**7 59**	**9 59**	**11 59**	**13 59**	**15 59**	**17 59**	**19 59**		**1 59**
207	Kriváň		**6 24**	**8 24**	**10 24**	**12 24**	**14 24**	**16 24**	**18 24**	**20 24**		**2 24**
210	Detva		**6 28**	**8 28**	**10 28**	**12 28**	**14 28**	**16 28**	**18 28**	**20 28**		**2 28**
233	**Zvolen os.st.**		**6 46**	**8 46**	**10 46**	**12 46**	**14 46**	**16 46**	**18 46**	**20 46**		**2 46**
	To station		Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica	Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica		Optionall y Zvolen os.st./ Bratislava hl.st. / Banska Bystrica

Source: authors

There is also a need to plan an infrastructure measurement of construction and reconstruction on the railway lines, which will ultimately contribute to increasing the line capacity to fulfil the planned timetable. Such measures can include, for example, increasing the number of traffic tracks in railway stations, extending their useful length, adjusting the slope and direction of the tracks, increasing speed, building crossing points, double-tracking, or electrifying railway lines.

From an operational aspect, it is also possible to encounter certain risks. This may be due to the risk of low passenger numbers in rail passenger transport due to the current state of the infrastructure and its lower ability to compete with the more flexible individual car transport; carriers' lack of interest in participating in public tenders and their unsatisfactory fleet of railway vehicles; and the risk of financing public passenger transport.

As part of further scientific and research activities, the area of economic focus could be examined in more detail, or economic factors related to the solved issue. It may refer to the area of payment for ordered transport services, or fees for a railway transport route. An important moment of the competition for transport performance in long-distance railway transport is the very subject of the competition, the operational nature of the line, the set timetable, the timing of the connections, the possibility to plan efficient turns of sets and their operational maintenance. For this reason, the setting of the line or set of lines that are the subject of the competition is an important moment from the operational point of view of their technology and conditions for planning efficient traffic, which creates a direct impact on the results of the economic efficiency of operating the line. Another important moment is the provision of a sufficient period to the selected applicant in the supply phase before the start of line operation. For the future direction of research in the area of the addressed issue, it would be appropriate to focus on a more detailed division of competences in the event of the emergence of possible risks within the framework of the implementation of services in the public interest in railway passenger transport, such as tariff risk, capacity risk with a focus on railway vehicles, which carriers must bear and also unpredictable circumstances.

5. CONCLUSION

A public tender is a method of selecting a carrier, which aims to reduce the amount of necessary financial resources due to competitive pressure. The funds are spent on the operation of transport services and at the same time it is about increasing the quality of transport services and their efficiency. This can make rail transport more attractive for as many passengers as possible. Compared to a public tender, direct award is the traditional way of concluding contracts for transport services in the public interest, as for many years the Ministry concluded contracts with the state carrier ZSSK.

Several public tenders have already been announced in Slovakia for selected regional railway lines and one long-distance railway line. All of them ended with an unsuccessful result until the moment when in August 2022 the Ministry announced the result of the first successful public tender for the operation of the line Bratislava – Dunajská Streda – Komárno. Thus, after many years of unsuccessfully announcing public tenders, the Ministry has reached the point where the method of setting the conditions of public tenders and their evaluation has a successful basis.

The case study can serve as an example of the announcement of public tenders in EU conditions. The correct setting of the complete methodology of public tenders for the allocation of services in the public interest in long-distance railway passenger transport can significantly reduce the identified risks in the field of economy. The issue of public tenders for the allocation of performance in rail transport needs to be resolved in view of the possible operational or economic benefits of conducting public tenders and at the same time in view of the common European legislation that every member of the European Union must comply with. However, for the needs of ensuring efficient transport on the entire railway network, it is necessary to develop a methodology for awarding services in long-distance and regional transport through a public tender. It is necessary to assess whether public tenders will be held separately for regional transport or whether performance in regional transport will be associated with long-distance rail passenger transport as part of the introduction of integrated transport systems.

The public tender is relatively rigid and formalized in its process, but there is an easily applicable and controllable principle of transparency and non-discrimination. It is characterized by precisely defined conditions and deadlines, which are decided exclusively by the Department of Transport. These conditions are immutable, so it is important that they are set well. On the contrary, it may happen that the competition does not generate any winner, because no applicant will be able to fulfil the conditions. Based on the fourth railway package, from 2024 every carrier should be able to operate railway passenger transport services through a public tender. If the department of transport is interested in public tenders being as effective as a direct award, it is important that it prepares such tender documents that many carriers will be able to fulfil.

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VI. DIGITALIZATION IN LOGISTICS

LOGISTICS SYSTEMS DIGITALISATION AND SOFTWARE QUALITY: WHY IT'S IMPORTANT AND HOW IT'S RELATED TO ISO/IEC 25010

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Abstract

Software quality is critical in supply chains, ensuring that software products meet user expectations and deliver value by digitalising their business. Organisations rely on established standards and frameworks to achieve and assess software quality effectively. The ISO/IEC 25000 family of standards, also known as the SQuaRE (Software Quality Requirements and Evaluation) series, provides a comprehensive and internationally recognised set of guidelines for software quality management. The ISO/IEC 25000 series consists of standards and technical reports covering various aspects of software quality characteristics, including quality models, evaluation processes, and measurement methods. ISO/IEC 25010 serves as the core standard in the series, defining a comprehensive quality model and a set of quality characteristics. Quality characteristics encompass functionality, reliability, usability, efficiency, maintainability, and portability. By following these characteristics, organisations can evaluate, measure, and improve the quality of software products. It also provides a systematic approach enabling organisations to set quality requirements, define evaluation criteria, and select appropriate evaluation techniques. These standards promote consistency and comparability in software quality evaluation, facilitating effective communication among stakeholders, improve decision-making processes, enable effective risk management, enhance customer satisfaction, and promote continuous improvement. By aligning with these standards, supply chain organisations can achieve greater transparency, reliability, and interoperability in their digitalised business processes. This paper explores the significance of software quality and its relationship to the ISO/IEC 25010 standard in a supply chain, a complex logistics system consisting of logistics processes and facilities that transform raw materials into finished products, which are later distributed to end consumers. This paper delves into the details of the ISO/IEC 25010, which provides key guidelines for ensuring software quality. Practical examples of standards usage will be presented by

Software Quality Measurement (SQM) model and evaluation of vehicle telematics to better understand how standards can enhance the quality of technological solutions.

Keywords: supply chain, logistics processes, digitalisation, software, software quality

1. INTRODUCTION

Understanding "quality" is subjective since different definitions of quality are appropriate for different people, areas of study or work, and circumstances. If we search for the word in dictionaries, many different meanings will arise, such as: "how good or bad something is" (Cambridge Dictionary, 2023); "a degree of excellence" (Merriam-Webster dictionary, 2023); an essential or distinctive characteristic, property, or attribute (Dictionary.com, 2023); and "performance upon expectations" or even "fit for functions " (TQP, 2020).

When speaking of quality in companies, the word can be used to describe different things, like quality of work, production, service, product, software, people, process, system, management, and many others. Regarding the latest, the ISO organisation presents quality management principles (QMPs) in ISO 9000 standards. The principles are meant to be a foundation that guides organisations to better performance (ISO, 2015). Their importance varies from company to company and can be used as needed. The quality management principles are Customer focus, Leadership, Engagement of people, Process approach, Improvement, Evidence-based decision-making, and Relationship management (Nahil, 2020).

The digitalisation of supply chains is essential since the utilisation of digital supply chains provides insights for enhanced efficiency to assist and create an increased economy (Menon & Shah, 2019). Supply chain technologies validate the performance of companies with better plans, designs, and management of the flow of goods, products and services (Nasir et al., 2017). The digitalisation of logistics and supply chains represents an essential tool for resilience (Gupta et al., 2022), where it plays a pivotal role in enabling sustainable and environmentally friendly supply chains (Chauhan et al., 2023). Based on digitalisation capabilities for supply chains, companies can harness ICT resources to transition their physical operations into digital domains, seamlessly integrating them to optimise resource efficiency and foster productivity enhancements. This comprehensive approach encompasses physical and digital activities, facilitating reduced resource consumption, heightened network visibility, and real-time feedback mechanisms. Additionally, it covers a variety of specialised tools for tailored production and cooperative relationships with suppliers throughout all network stages. (Queiroz et al., 2019)

Thus, software quality plays a pivotal role in determining the success of any project. Inadequately constructed code can give rise to a litany of problems, including bugs, system crashes, security vulnerabilities, software malfunctions, and performance bottlenecks, all of which can lead to considerable challenges in the future. Moreover, suboptimal software quality can precipitate elevated expenses, extended development timelines, and an escalated likelihood of project failure.

(Quality Gurus, 2021) This is where software quality standards and frameworks come into play. Standards and frameworks encompass a compendium of best practices, guidelines, and principles, all geared towards guaranteeing the dependability, usability, maintainability, and security of software products and processes. Adherence to these standards and frameworks becomes imperative, facilitating the delivery of top-tier software that aligns with the expectations and demands of the company, stakeholders, customers and end-users. (Software Project Management, n.d.)

In contemporary supply chain management, information and communication technologies (ICT) are pivotal (Buxmann et al., 2004), where software can immensely improve operations performance. Enhanced coordination is frequently achieved by implementing a unified software platform capable of aggregating, processing, and transmitting information from diverse ICT systems spanning the supply chain. A diverse offer of supply chain management software (SCMS) is available through software packages that offer a spectrum of services encompassing material requirements planning (MRP), warehouse management system (WMS), enterprise resource planning (ERP), and workforce management (WfMs) solutions. The scope of these services extends from facilitating operations related to logistics, inventory management, planning, forecasting, sales, cash flow, and acquisition, among others. (Haulder et al., 2019) Software solutions also enable shipment monitoring at every stage of the supply chain journey (Mohsen, 2023) and data-driven decision-making (Di Vaio & Varriale, 2020). Supply chain management methods are made feasible through ERP software, which monitors and records business processes, providing various departments with productivity insights about each transaction conducted within the company (Aroba & Prinavin, 2023). Thus, software quality plays a critical role in supply chains, ensuring that software products meet user expectations (Kitchenham & Pfleeger, 1996) and deliver value by digitalising their business (Krasner, 2021).

This paper explores the significance of software quality and its relationship to the ISO/IEC 25010 standard in a supply chain, a complex logistics system consisting of logistics processes and facilities that transform raw materials into finished products, which are later distributed to end consumers.

2. FRAMEWORKS FOR SOFTWARE QUALITY

Software quality is essential for the success of any software project. Developers can deliver valuable, dependable software products that meet user expectations and business requirements. Software quality is measured by (ISO, 2011):

1. **Testing**: helps identify defects and ensures the software functions as expected (unit testing, integration testing, and user acceptance testing).
2. **Code Reviews**: helps to identify code issues and improve overall code quality.
3. **User Feedback**: allows developers to address pain points and make necessary improvements.
4. **Quality Metrics**: help track and measure software quality over time (defect density, response time, uptime).

These measures ensure ongoing improvement and maintain high software quality standards and can bring us the following (ISO, 2011):

1. **Customer Satisfaction**: high-quality software leads to satisfied customers, positive reviews, and increased user retention.
2. **Cost-Effectiveness**: fixing defects early in the development process is less expensive than addressing them later or after deployment.
3. **Reputation and Trust**: high-quality software builds trust among users and establishes a good reputation for the organisation.
4. **Competitive Advantage**: quality software differentiates a company's products from competitors and attracts more users.
5. **Reduced Risks**: quality software is less prone to crashes, security breaches, and data loss, reducing risks to the organisation and its users.

However, several software industry frameworks and methodologies are used to ensure and improve software quality. These frameworks provide guidelines and best practices for managing software quality throughout the development and maintenance processes. Here are some prominent frameworks and standards for software quality management:

1. **ISO/IEC 25000 (SQuaRE - Software Product Quality Requirements and Evaluation)**: a comprehensive standard defining a series of international software product quality evaluation standards. It includes models and metrics to assess various aspects of software quality (functionality, reliability, usability, efficiency, maintainability, and portability).
2. **ISO/IEC 9126 (replaced by ISO 25010)**: defined software quality characteristics and sub-characteristics, providing a structured approach for evaluating software quality attributes.
3. **ISO/IEC 25010 (System and Software Quality Models): the successor to ISO/IEC 9126 defines the quality model, a set of quality characteristics and sub-characteristics to assess software quality.**
4. **ISO 9000 series:** family of standards focuses on quality management systems and provides general guidelines for quality management systems. **While not exclusively for software, ISO 9001:2015** sets the requirements for a quality management system that an organisation can use to enhance customer satisfaction and consistently provide products and services that meet regulatory requirements. It also **includes specific requirements for quality management that can be applied to software development.**
5. **Capability Maturity Model Integration (CMMI)**: is a process improvement framework that helps organisations optimise their processes and improve software development quality. It provides a set of best practices for developing, maintaining, and acquiring products and services.
6. **Six Sigma**: is a data-driven methodology aimed at improving the quality of process outputs by identifying and removing the causes of defects and minimising variability in business and manufacturing processes.
7. **Agile Development**: agile methodologies, such as Scrum and Kanban, prioritise delivering working software in short iterations. Frequent feedback, collaboration, and continuous improvement are integral to Agile approaches, ensuring that software meets user needs effectively.

8. **Test-Driven Development (TDD)**: is a software development approach where developers write automated tests before writing the actual code. It helps ensure that the software meets requirements and that tests cover any changes to the code.
9. **Behaviour-Driven Development (BDD)**: is an extension of TDD that focuses on collaboration between developers, testers, and business stakeholders to define and verify the behaviour of the software in natural language.
10. **Continuous Integration and Continuous Delivery (CI/CD)**: automate integrating code changes, running tests, and delivering software to production. This ensures frequent feedback, early detection of defects, and faster delivery of high-quality software.
11. **Risk-Based Testing**: prioritizes testing efforts based on identified risks to the software, ensuring that critical areas are thoroughly tested, and any potential issues are addressed early.
12. **Open Web Application Security Project** (OWASP): provides a list of the most critical security risks of web applications. Developers can use this list to focus on securing their software against common vulnerabilities.
13. **IEEE 730 Standard**: defines software quality assurance processes, including planning, implementation, and evaluation.
14. **IEEE 829**: outlines the software test documentation format, helping maintain consistent and comprehensive testing practices.
15. **Information Technology Infrastructure Library (ITIL)**: is a set of best practices for IT service management that includes practices related to software quality management within the broader context of IT service delivery.
16. **Project Management Body of Knowledge (PMBOK)**: includes guidelines for project management, which indirectly influences software quality management by addressing project planning, risk management, and quality assurance processes.
17. **ASTM E2500**: focuses on risk-based and science-based verification and validation of software, providing guidelines for software development and testing.

When selecting a framework or standard for software quality management, organisations should consider their specific needs, the complexity of their projects, industry requirements, and the maturity of their development processes. Integration of multiple frameworks might be necessary to cover different aspects of software quality and align with organisational goals and industry standards.

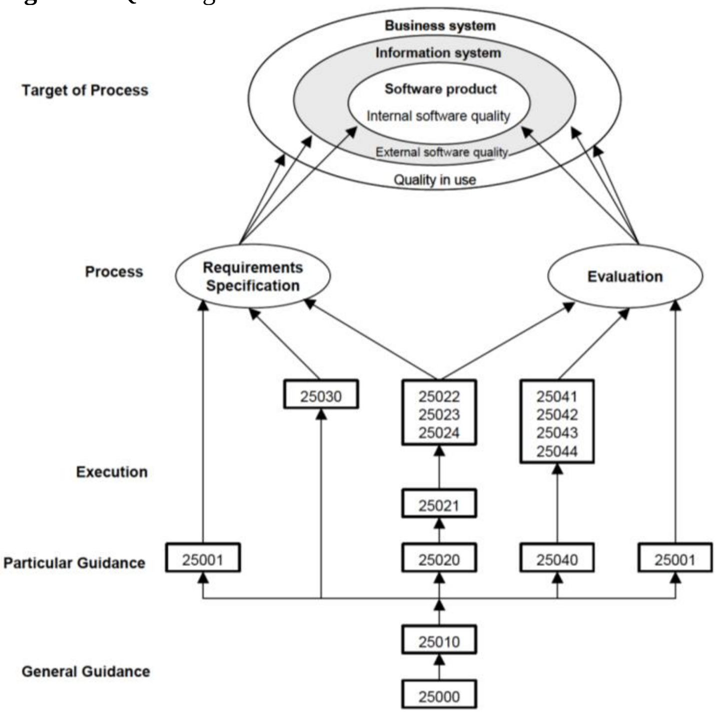
ISO standards are internationally agreed upon by experts and provide a common set of guidelines and best practices that are recognised and accepted globally. They are the distilled wisdom of people with expertise in their subject matter who know the needs of the organisations they represent. This helps ensure consistency and uniformity in various industries and sectors across different countries. In the remaining part of this paper, we will describe the ISO/IEC 25000 family of standards that provide a comprehensive and internationally recognised set of guidelines for software quality management. (ISO, 2014)

3. ISO/IEC 25000 AND 25010

ISO/IEC 25000, also known as Software Product Quality Requirements and Evaluation (SQuaRE), is an international standard that provides a comprehensive framework for evaluating and managing software product quality. SQuaRE was developed by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) to address the need for a structured and consistent approach to software quality assessment to help organisations understand, define, and evaluate the quality of their software products, as well as make informed decisions about improvements and optimisations (ISO, 2011).

This standard comprises a collection of documents that establish quality models, delineate quality attributes, and outline quality requirements for software products. These models and attributes serve as valuable tools for evaluating and gauging various facets of software quality. They find utility among software development organizations, clients, and other concerned parties for the purposes of evaluating, communicating, and enhancing the quality of software products. By adhering to the guidelines and principles set forth in this standard, organizations can elevate the overall quality of their software products, ultimately resulting in heightened customer satisfaction and successful software deployments. The foundational reference model of SQuaRE can be found in Figure 1.

Figure 1 SQuaRE general reference model



Source: ISO (2014)

ISO/IEC 25010 provides a detailed quality model with specific quality characteristics and sub-characteristics for evaluating software product quality. SO/IEC 25000 and ISO/IEC 25010 are related standards but serve different purposes within the broader SQuaRE series. (ISO, 2011) The key differences between ISO/IEC 25000 and ISO/IEC 25010 are presented in Table 1.

Table 1 Key differences between ISO/IEC 25000 and ISO/IEC 25010

	ISO/IEC 25000	**ISO/IEC 25010**
Scope and Purpose	- the overarching standard in the SQuaRE series; - provides a framework for software product quality requirements and evaluation; - defines the general concepts, terms, and principles related to software quality management; - introduces the quality models and metrics used to assess software quality and guides users to other specific standards in the series, including ISO/IEC 25010.	- a specific standard within the SQuaRE series that defines a comprehensive quality model; - outlines the quality characteristics and sub-characteristics that can be used to evaluate and measure software product quality; - dives deeper into the various dimensions of software quality, providing specific criteria for assessing software products.
Content	- an informative standard that introduces the software product quality framework, the overall structure of quality characteristics and sub-characteristics; - it acts as a guiding document for understanding software quality evaluation in the context of the SQuaRE series.	- a normative standard containing specific requirements and is intended to be used directly for software quality evaluation; - defines the eight primary quality characteristics and their sub-characteristics (accuracy, compliance, efficiency).
Usage	- primarily used to provide an overview of software quality management and direct users to other relevant standards in the SQuaRE series; - sets the context and terminology for the quality models and metrics for software quality assessment.	- used directly for evaluating software product quality; - serves as a reference for practitioners who want to assess and measure the quality attributes of a software product; - guides the selection of relevant quality characteristics and sub-characteristics to be evaluated based on the specific needs and goals of the evaluation.

Source: ISO (2011); ISO (2014)

In summary, ISO/IEC 25000 is an informative standard that introduces broader concepts and structures for software quality evaluation. At the same time, ISO/IEC 25010 is a normative standard that explicitly defines the quality model and criteria for assessing software product quality.

3.1. ISO/IEC 25010 System and software quality models

ISO/IEC 25010 Systems and Software Quality Models consists of (ISO, 2011):

1. **Quality Model:** covers eight main quality characteristics, where each represents a critical aspect of software quality:
   - Functional Suitability: the extent to which software provides the necessary functions to meet specified needs;
   - Performance Efficiency: the software's ability to perform well concerning resource usage, response time, and throughput.
   - Compatibility: the software's capability to operate with other systems, software, or hardware components.
   - Usability: the ease of software use and the user experience.
   - Reliability: the software's ability to maintain its level of performance under specific conditions for a given period.
   - Security: the software's ability to protect data and functionalities from unauthorised access and harm.
   - Maintainability: the effort required to make modifications, correct defects, or adapt the software to changes.
   - Portability: the ease with which the software can be transferred from one environment to another.
2. **Sub-characteristics:** each quality characteristic is broken down into specific sub-characteristics, making it easier to assess and focus on specific areas of quality evaluation.
3. **Quality Requirements:** includes a set of quality requirements that can specify the desired level of each quality characteristic and sub-characteristic for a particular software product.
4. **Quality in Use:** emphasizes the importance of evaluating how end-users perceive the software quality during actual usage.

Table 2 represents quality characteristics and their subcharachetiristics.

Table 2 ISO/IEC 25010 set of quality characteristics with their subcharacteristics

(Sub)Characteristics			
Functional suitability		**Reliability**	
	- Functional completeness; - Functional correctness; - Functional appropriateness.		- Maturity; - Availability; - Fault tolerance; - Recovery.
Performance efficiency		**Security**	
	- Time behaviour; - Resource utilization; - Capacity.		- Confidentiality; - Integrity; - Non-repudiation; - Accountability; - Authenticity.
Compatibility		**Maintainability**	
	- Co-existence; - Interoperability.		- Modularity; - Reusability; - Analysability; - Modifiability; - Testability.
Usability		**Portability**	
	- Appropriateness recognizability; - Learnability; - Operability; - User error protection; - User interface aesthetics; - Accessibility.		- Adaptability; - Installability; - Replaceability.

Source: ISO (2011)

3.2. Software Quality measurement model (SQM)

A concise explanation of how software quality is measured and quantified by can be provided by (ISO, 2011):

1. **Quality Properties**: These are aspects or attributes of software that determine its overall quality. Examples include performance, reliability, and security.
2. **Measurement Method**: This is a systematic set of steps used to assess and quantify these quality properties. It's like a structured process for evaluating specific aspects of the software.
3. **Quality Measure Element**: This is the result obtained when a measurement method is applied. It represents a specific quantified value related to a quality property.

4. **Measurement Functions**: These are algorithms or formulas used to combine multiple quality measure elements. They help in aggregating or summarizing the individual measurements into a single value.
5. **Software Quality Measure**: This is the outcome of applying a measurement function. It represents a comprehensive measurement of a particular quality characteristic or subcharacteristic of the software.

Table 3 represents Quality in use characteristics and subcharacteristics.

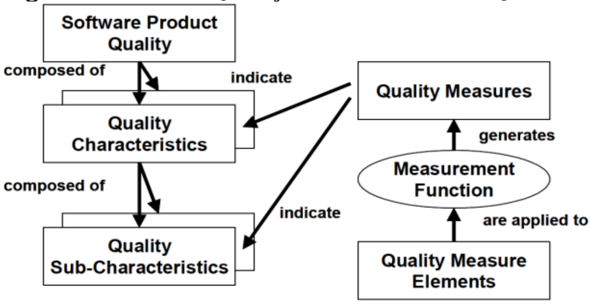
Table 3 Quality in use

Effectiveness	
Efficiency	
Satisfaction	
	- Usefulness; - Trust; - Pleasure; - Comfort.
Freedom from risk	
	- Economic risk mitigation; - Health ans safety risk mitigation; - Envirnmental rist mitigation.
Context coverage	
	- Context completeness; - Flexibility.

Source: ISO (2011)

In essence, this process allows to express the quality of software in a quantifiable manner by breaking it down into measurable components and then aggregating those measurements using appropriate algorithms. This approach provides a structured way to assess and improve the quality of software products. (ISO, 2011) Figure 2 represents Software Quality Measurement (SQM) in SQuaRE.

Figure 2 Software Quality Measurement in SQuaRE



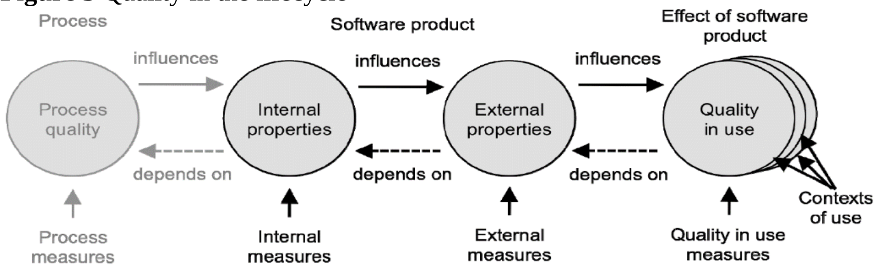
Source: ISO (2014)

User requirements for quality encompass the criteria for system performance in specific usage scenarios (ISO, 2011), as illustrated in Figure 1. These identified requirements serve as valuable inputs when defining both external and internal quality metrics using software product quality characteristics and subcharacteristics.

3.2.1. Approaches to quality

The quality of a software product can be assessed through various approaches. This evaluation can involve measuring internal characteristics, which usually consist of static measurements of intermediate development stages. Another evaluation measure external attributes by evaluating the behaviour of the code during execution. Another approach is to assess quality in use, which involves evaluating the product's performance in real or simulated usage scenarios. See Figure 1 and Figure 3.

Figure 3 Quality in the lifecycle



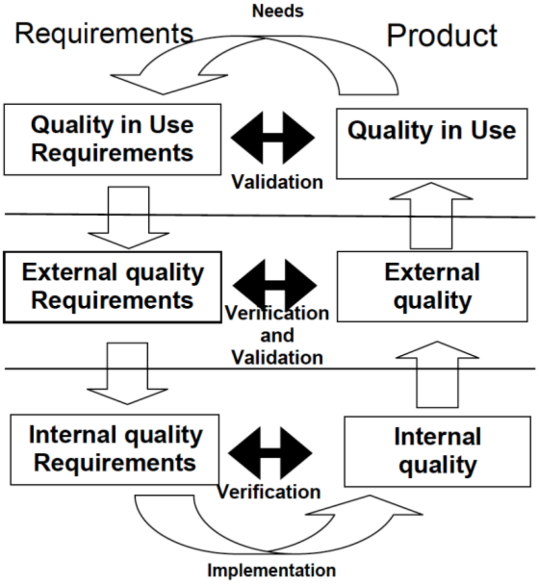
Source: ISO (2014)

3.2.2. Quality life cycle model

The quality life cycle model, as depicted in Figure 4, focuses on ensuring software quality in three key phases of the software product's life cycle (ISO, 2011):

1. During the product under **development phase**, internal measures are used to assess software quality.
2. In the **product testing phase**, external measures are employed to evaluate software quality.
3. In the **product in use phase**, the focus shifts to quality in use assessments.

Figure 4 Quality in the lifecycle



Source: ISO (2014)

Quality in use requirements define the expected quality levels from the user's perspective. These requirements are derived from the needs of various stakeholders, including users, software developers, system integrators, acquirers, or owners. Quality in use requirements serve as the benchmark for user validation of the software product. These requirements for quality in use characteristics should be clearly documented in the quality requirements specification, outlining the criteria for quality measurements used during product evaluation. (ISO, 2011)

Requirements for **external measures of computer system quality** establish the expected quality levels as observed from an external perspective. These requirements encompass criteria derived from stakeholder quality demands, which may include quality-in-use requirements. External software quality requirements serve as the focal point for the technical verification and validation of the software product. To ensure clarity and precision, requirements for external quality measures should be quantitatively defined in the quality requirements specification, outlining the criteria for external assessments used during product evaluation. (ISO, 2011)

Requirements for i**nternal software quality measures** define the desired level of quality from an internal perspective of the product. These requirements encompass criteria derived from external quality requirements. Internal software quality requirements play a crucial role in specifying the characteristics of intermediate software products, such as specifications and source code. They may also extend to non-executable software products like documentation and manuals. These internal software quality requirements can serve as targets for verification at different stages of development. Furthermore, they are valuable in shaping development strategies and establishing criteria for evaluation and verification throughout the development process. (ISO, 2011)

4. EXAMPLES OF USE

4.1. Software Quality measurement model (SQM)

Imagine you are a software quality assurance engineer working for a company that develops web applications. Your team has recently developed a new web application, and you want to ensure that it meets the required quality standards before it is released to the public. You use ISO/IEC 25010 to evaluate the web application's quality to achieve this.

Step 1: Identify Quality Characteristics: the first step is to identify the relevant quality characteristics for the web application. Based on ISO/IEC 25010, you select the following characteristics as most important for your evaluation:

1. **Functionality**: to assess whether the application meets the functional requirements and provides the necessary features.
2. **Usability**: to evaluate how easy and efficient the application is for its intended users.
3. **Performance Efficiency**: to measure the application's responsiveness, resource usage, and throughput.
4. **Security**: to assess the level of protection against unauthorised access, data breaches, and other security threats.

Step 2: Identify Subcharacteristics: for each of the selected characteristics, you identify the relevant subcharacteristics to dive deeper into the evaluation process. For example:

1. **Usability**:
   - **Learnability**: how easy it is for new users to understand and navigate the application.
   - **Operability**: how easy it is for users to operate and control the application.
   - **User Error Protection**: how well the application prevents and handles user errors.
2. **Performance Efficiency**:
   - **Time Behavior:** how fast the application responds to user actions.
   - **Resource Utilization:** How efficiently the application uses system resources like memory and CPU.

Step 3: Define Evaluation Criteria: for each subcharacteristic, you define specific evaluation criteria. For instance:

1. **Usability – Learnability: evaluation criteria**: the application should have clear and concise onboarding instructions, intuitive navigation, and interactive tutorials to help new users get started easily.
2. **Performance Efficiency - Time Behavior: evaluation criteria**: the application should load its main page within 2 seconds for a standard internet connection.

Step 4: Evaluation Process: you evaluate by using various methods such as user testing, performance testing, security testing, and expert reviews. Each evaluation method corresponds to the relevant quality characteristic or subcharacteristic.

Step 5: Analyze Results and Improve: once the evaluation is complete, you analyse the results to identify areas of improvement. For example, if the application's loading time is slower than expected, you may work on optimising its performance. If security vulnerabilities are identified, you will take appropriate measures to address them.

4.2 Evaluating vehicle telematics (includes tachograph data) m-application

In this scenario, let us consider a case where you are a software quality assurance analyst working for vehicle telematics for an easy and efficient fleet management telematics, including tachograph data that develops mobile applications drivers. Your company has recently developed a new fleet m-telematics app designed to help drivers and their companies track their daily activities, monitor their drive metrics, and provide personalised driver recommendations. To ensure the app meets the highest quality standards, use ISO/IEC 25010 for evaluation.

Step 1: Identify Quality Characteristics: Based on the nature of the m-telematics application and its intended use, you identify the following quality characteristics to evaluate:

1. **Functionality**: to assess whether the app includes all the necessary features for tracking physical activity, recording health metrics, and offering personalised health insights.
2. **Reliability**: to measure the app's ability to perform consistently and reliably under various conditions, ensuring it accurately tracks and stores user data.
3. **Usability**: evaluate the application is user-friendly, considering the target audience, which might include individuals of different age groups and technical expertise.
4. **Privacy and Security**: assess the level of protection for sensitive health data and ensure compliance with privacy regulations.

Step 2: Identify Subcharacteristics: for each quality characteristic, you identify the relevant subcharacteristics that are critical for the evaluation:

1. **Functionality**:
   - <u>Completeness</u>: how well the app covers all the necessary functions, such as step tracking, heart rate monitoring, sleep analysis, etc.
2. **Reliability:**
   - <u>Availability</u>**:** the app should be accessible and functional whenever users need it.
   - <u>Data Integrity</u>**:** ensuring the user's health data is accurately recorded and stored without any loss or corruption.
3. **Usability:**
   - <u>Accessibility</u>**:** the app should be usable by individuals with disabilities or special needs.

- User Interface (UI) Design**:** the app should have an intuitive and visually appealing UI.

4. **Privacy and Security:**
   - Confidentiality**:** ensuring that user health data is kept private and only accessible by authorised personnel.
   - Data Encryption**:** the app should use encryption techniques to protect data during transmission and storage.

Step 3: Define Evaluation Criteria: for each subcharacteristic, you define specific evaluation criteria. For example:

1. **Usability - Accessibility: Evaluation Criteria**: the app should adhere to accessibility guidelines, allowing users with visual impairments to use assistive technologies like screen readers.
1. **Privacy and Security - Data Encryption: Evaluation Criteria**: all health data transmitted between the app and the server should be encrypted using SSL/TLS protocols.

Step 4: Evaluation Process: evaluate by combining various methods, including functional testing, usability testing with representative users, security assessments, and reliability testing. Each evaluation method aligns with the relevant quality characteristic or subcharacteristic.

Step 5: Analyze Results and Improve: after the evaluation, you analyse the results to identify areas that require improvement. For instance, if the app's UI is not intuitive for certain users during usability testing, you might redesign some elements to enhance the user experience. If any security vulnerabilities are found, they are promptly addressed to safeguard user data.

5. CONCLUSION

The software quality has revealed its far-reaching implications, from customer satisfaction and cost-effectiveness to reputation building and risk reduction. Utilizing software quality standards and frameworks is imperative in delivering high-quality software products aligned with the expectations of various stakeholders. Moreover, within the dynamic supply chain management landscape, software solutions are indispensable for achieving enhanced coordination, monitoring, and data-driven decision-making. ISO standards are critically important in supply chains and logistics due to their capacity to establish a universal framework of quality, safety, and efficiency criteria. Organisations turn to ISO standards because they provide a structured and internationally recognised basis for evaluating and benchmarking processes, products, and services, ultimately enhancing interoperability, reducing operational risks, and ensuring compliance with regulatory requirements. In the context of supply chains and logistics, adherence to ISO standards fosters consistent and reliable practices, bolsters organisational credibility, facilitates global trade, and contributes to optimising resource utilisation, leading to heightened competitiveness and improved overall performance.

This paper described the vital relationship between software quality, logistics, and ISO/IEC 25000 standards. We emphasised the critical role of software quality in modern supply chains, particularly in facilitating the seamless digitalisation of logistics through ICT. The ISO/IEC 25010 standard, part of the SQuaRE series, defines a comprehensive quality model that serves as a basis for evaluating the quality of software products. This model is organised into two main categories: system and software product quality. Each category has several quality characteristics and subcharacteristics contributing to the overall quality assessment. It has been introduced as a robust framework for comprehensively assessing and managing software quality, covering essential characteristics such as functionality, reliability, usability, efficiency, maintainability, and portability.

Looking ahead, it becomes evident that the collaboration between software quality and logistics systems will continue to evolve and deepen. The application of ISO/IEC 25010 standard in supply chains will likely become more pervasive, fostering greater transparency, reliability, and interoperability. The integration of emerging technologies, such as artificial intelligence, blockchain and digital twins (Kajba et al., 2023), may further enhance the digitalisation of logistics, necessitating even more robust software quality practices. In today’s ever-evolving world, organisations prioritising software quality and embracing ISO/IEC 25000 standards are poised to thrive, offering enhanced efficiency and value to their customers and stakeholders in the complex world of supply chain management.

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THE IMPACT OF BLOCKCHAIN IN CONSUMER MARKETING AMONG VARIOUS INDUSTRIES

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Abstract

A significant trend in the business-to-consumer trade has been the rise of cutting-edge e-commerce platforms supporting mobile devices. The advent of e-commerce ushered in a period of profound change in the value-generating process, which ushered in brand-new organizational structures for many businesses. This study investigates the key factors influencing the adoption and integration of blockchain technology across different industries. Through a comprehensive literature review, the study highlights the various applications of blockchain technology in different sectors, such as finance, supply chain, energy, and marketing. A survey was conducted to gather data on companies' current use of blockchain, plans, perceived benefits, and challenges faced during implementation. The 150 answers were stripped of stop words, punctuation, and adverbs in order to conduct the text mining study. The findings suggest that factors such as awareness, strategic approach, collaboration, addressing barriers to adoption, and careful evaluation of blockchain solutions play critical roles in successful blockchain adoption. Based on these findings, the study offers several recommendations for companies to integrate blockchain technology into their operations effectively. Furthermore, the study identifies limitations and proposes future research directions to enhance our understanding of blockchain adoption across various industries.

Keywords: Blockchain, Consumer marketing, Blockchain adoption across various industries

1. INTRODUCTION

Several studies in different sectors have demonstrated the value of blockchain technology, creating substantial hype along the way. There are numerous potential applications for blockchain in the finance, healthcare, real estate, and supply chain management industries. Therefore, marketing is not one of them (Ali et al., 2014). Blockchain's foundational characteristics of transparency, immutability, and security make it apt for industries like finance, healthcare, real estate, and supply chain, where data integrity and traceability are paramount. In contrast, marketing predominantly thrives on creativity, audience engagement, and content, aspects not inherently addressed by blockchain's core functionalities. Hence, blockchain influences marketing, especially in areas like ad verification, but it is not a primary application platform for the broader marketing industry. The 2008 global financial crisis destroyed people's faith in the established banking system. At this time, the first decentralized electronic currency, Bitcoin, entered circulation, demonstrating the practical application of cryptographic methods to processing monetary transactions (Peres et al., 2022). Hash functions, consensus methods, asymmetric encryption, and time stamping play a role in Bitcoin's underlying cryptographic systems. Because each transaction is recorded in its chronological block, the public ledger on a blockchain cannot be altered after creation (Sihi, 2020).

The advent of the internet was a watershed moment in the movement toward decentralization, ushering in revolutionary shifts in how businesses provide their goods and services to customers. When providing services and solutions for contemporary business, these digital intermediates have mostly supplanted their more archaic predecessors (Rejeb et al., 2020). Today's e-commerce intermediates provide various services, such as trust facilitation, online search tools, communication, information brokering, and advertising. Facebook, Instagram, and Twitter, among others, provide more channels for businesses to interact with their target audiences. It seems as though digital intermediaries are successful at bringing a company's marketing message to its intended customers (Antoniadis et al., 2019). When used in the marketing industry, blockchain technology has the potential to streamline the marketing process by eliminating redundant steps (Harvey et al., 2018). Incentives for customers in the form of loyalty programs are another way businesses may increase their chances of forging a lasting connection with their target audience. Meanwhile, blockchain-based decentralization may provide a fresh approach to fostering productive partnerships with end users (Gleim & Stevens, 2021).

One of the main reasons for the paucity of studies in this area is the absence of real-world applications of blockchain technology in the marketing business. Customers need a reliable means of communication to learn about the company's offerings and developments in the company's goods and services. However, with so many scandals and fraudulent operations, the value of an internet company is called into doubt (Rahman, 2021). Sponsored internet searches have been integral to many search engines' revenue strategies, yet click fraud has become a severe problem for the industry. The rise in the prevalence of click fraud may be directly attributed to the rise of automated digital marketing and the improvement of targeting approaches. It is a deliberate effort to affect a competitor's marketing expenditures by one company or individual (Antoniadis et al., 2020). The capacity to combat click fraud highlights the importance of blockchain technology in marketing. The seriousness of click fraud highlights how it poses a significant risk to digital advertising. By 2022, it may add $44 billion to marketing budgets worldwide. By creating a secure online marketing environment for businesses and consumers alike, blockchain may help mitigate the dangers of click fraud. The goal of a marketing system built on the blockchain would be to have all parties involved work together transparently and honestly in their respective responsibilities (Chang et al., 2020). One use case for blockchain technology in combating click fraud would be eliminating informational gaps. The combined operations would enhance control and oversight by thoroughly examining publishers' reliability, historical information, and credentials (Madhani, 2022b).

Chain is a marketing blockchain platform that uses smart contracts to prevent and detect click fraud. To stop PPC companies from profiting from bot traffic and clicks, the AdChain protocol uses blockchain immutability. Blockchain technology provides a decentralized solution to counteract the influence of digital intermediaries in a company's advertising and strategic planning (Tan & Salo, 2021). However, it is worth noting that consumer trust in brands has been declining at unprecedented rates. Understanding that consumers' trust in a company's marketing is proportionate to the strength of its technical foundation is crucial for crafting an effective blockchain-based marketing strategy. Blockchain technology may bolster confidence in digital advertising by giving businesses and customers a secure, open place to work together (Madhani, 2022a). Because of the trust protocol that supports blockchain, consumers can rest assured that brand and marketing experts will act honestly. This is the technology's most eye-catching feature (Garg et al., 2022). Any reputable blockchain marketing firm wants to make its processes as clear and understandable as possible for its customers, primarily when they must provide sensitive information. In addition, blockchain can protect original producers' intellectual property (IP) rights by combating malicious marketing for counterfeit items. End-to-end product traceability, enhanced visibility, and capacity to verify compliance responsibilities may contribute to more openness in a company's operations (Mukherjee et al., 2021).

While numerous studies have explored blockchain technology's applications and potential benefits in various fields, such as marketing, human resources, and supply chain management, there seems to be a gap in the literature regarding the role of blockchain technology in different industries. Prior studies have primarily focused on the implications of blockchain technology on specific aspects of marketing and consumer behaviour (Stallone et al., 2021; Rejeb et al., 2020; Ertemel, 2018; Jain et al., 2021; Boukis, 2020), with only a few studies examining its applications in niche areas such as the chemical industry (Sikorski et al., 2017) or the electricity market (Cheng et al., 2017; Diestelmeier, 2019; Xue et al., 2017). However, there needs to be a more comprehensive understanding of how blockchain technology can be applied across various industries to improve business processes, streamline supply chains, enhance customer relationships, and provide new opportunities for growth and innovation. The problem, therefore, lies in the limited scope of the existing literature, which still needs to adequately investigate the role of blockchain technology in different industries and its potential to revolutionize various aspects of their operations. Finally, the study develops the research objectives:

1. To provide the existing literature on the applications of blockchain technology in various industries, emphasizing its implications for marketing, supply chain management, and consumer marketing.
2. To identify the key factors that influence the adoption and integration of blockchain technology across different industries and the challenges and barriers that may hinder its successful implementation.
3. To examine blockchain technology's potential benefits and drawbacks for businesses in different industries, including the impact on operational efficiency, transparency, security, and overall competitiveness.

2. LITERATURE REVIEW

2.1 Use Of Block-Chain Technology In Market

There are many computers connected to the block-chain, so the block-chain may be viewed as a distributed ledger. Block-chain technology is used to record and verify transactions for most cryptocurrencies (Du et al., 2019). The use of blockchain technology has garnered significant attention across various industries due to its decentralized, transparent, and secure nature. This literature review aims to provide an overview of the applications and implications of blockchain technology in different industries. In marketing, blockchain technology has been explored for its potential to revolutionize how companies interact with their customers and manage their brands (Stallone et al., 2021; Rejeb et al., 2020; Ertemel, 2018; Jain et al., 2021; Boukis, 2020). For instance, Boukis (2020) suggests that blockchain can enable more transparent and secure data sharing between companies and customers, thus fostering stronger brand-consumer relationships. Rejeb et al. (2020) also identified six research areas where blockchain could benefit marketing, including customer data management, loyalty programs, and supply chain traceability.

In the supply chain and logistics sector, blockchain has been proposed to enhance transparency, security, and efficiency (Coita et al., 2019). Blockchain can provide real-time information sharing between various supply chain stakeholders, helping reduce inefficiencies, minimize fraud, and improve overall performance. For instance, Cheng et al. (2017) explored the application of blockchain technology in distributed electricity markets, highlighting the potential for more efficient energy trading and improved grid management. Blockchain technology has also been investigated for its applications in the financial sector, with various studies examining the adoption of cryptocurrencies and decentralized financial systems (Albayati et al., 2020). These studies indicate that blockchain can enable more secure and efficient financial transactions, offering benefits such as reduced transaction fees, faster processing times, and enhanced security against fraud.

In the energy sector, blockchain has been proposed to manage decentralized energy resources and enable peer-to-peer electricity trading (Diestelmeier, 2019; Xue et al., 2017). Diestelmeier (2019) suggests that blockchain can shift the role of electricity consumers by empowering them to participate in the energy market actively. Xue et al. (2017) demonstrate the feasibility of using blockchain for electricity trading in electricity microgrids. Furthermore, blockchain has been examined in niche industries such as the chemical industry, where Sikorski et al. (2017) proposed its use for machine-to-machine electricity markets, enabling more efficient energy trading between various chemical processes.

2.2 Blockchain Technologies in Retailing, Manufacturing And Supplying Businesses

Since blockchain combines smart contracts, distributed ledgers, and cryptocurrencies, it can solve the distributed trust problem. Fintech was the first industry to adopt blockchain. Still, recent attempts have seen the technology deployed in other sectors, most notably the pharmaceutical industry, where the G-coin blockchain is used to add confidence and value to the pharmaceutical supply chain (Tseng et al., 2018). Blockchain, the technology at the centre of Bitcoin and similar cryptocurrencies that serves as a verifiable record of transactions, is not limited to the financial sector and warrants additional study. In order to keep up with the demands of the IIoT, retailers, manufacturers, and suppliers must all re-engineer their trust links to improve efficiency and the shopping experience for customers. Fuzzy decision-making inside a blockchain platform was offered as a methodology for merging product design and supply chain to handle tactical choices effectively. Research and development are necessary before blockchain can be a reliable choice in Internet advertising. Furthermore, DEPLEST was implemented within a blockchain-based architecture, thereby solving the privacy problem with superior performance compared to standard approaches of proof of work (PoW) and proof of stake (PoS). Artificial intelligence (AI) research indicates that smart contracts in Industry 4.0 must be modernized to meet the security and privacy problems identified (S. Gupta et al., 2020). The introduction of reputation management systems has revolutionized the relationship of trust between businesses and consumers (Tseng et al., 2018).

Liu et al. (2019) emphasized the importance of managing one's reputation by soliciting and responding to customer input in an anonymous reputation system to instil trustworthiness and openness. The system is built on blockchain technology, and Parity Ethereum has developed a proof-of-concept prototype. The use of blockchain technology was also investigated for the food sector to streamline supply chain traceability and empower consumers to make educated purchasing decisions with little effort (Liu et al., 2019). Understanding the potential applications of blockchain in healthcare was provided by Dimitrov (2019) to facilitate the management of large databases and the provision of simple, accurate data processing at a rapid rate, all of which are necessary for the efficient interaction between healthcare service providers and patients. The results of these investigations in various fields are summarized. This demonstrates how studies across industries have identified blockchain's imminent prominence (Dimitrov, 2019).

2.3 Black-Chain Technology and Consumers Marketing

Blockchain technology would drastically alter how consumers engage with brands online if blockchain technology were used in marketing. Blockchain is beneficial because it incorporates several different technologies and, most importantly, maintains a decentralized record of all transactions that have taken place inside the blockchain network. While blockchain technology has many potential economic applications, its primary goal is verifying assets (Pattanayak, 2009). In such a circumstance, being acquainted with how blockchain is now influencing marketing and how it will continue to do so in the future would be beneficial. This piece provides a high-level overview of how blockchain technology may affect the promotional efforts of a business or brand. Communication and information technologies have been essential in the recent revolution of online business marketing (Ismagilova et al., 2019). When initially implemented, the blockchain provided Bitcoin with decentralized ledger transactions. However, blockchain's popularity has grown in the financial technology sector in recent years due to its central role in the industry (Grewal et al., 2018).

Payment systems, which need a technically robust, secure, and efficient transaction infrastructure, have been the primary application area for blockchain in the financial technology sector. To ensure confidential transactions, digital currencies like Bitcoin employ encryption methods, cryptography, and separate sets of keys. Because of this, people are more likely to put their faith in decentralized protocols instead of the more conventional client-server model. Blockchain technology helps build more reliable and transparent consumer marketing strategies. It ensures higher data security, privacy, and control, which are crucial for digital consumers. By recording transactions on a decentralized and immutable ledger, blockchain technology provides an unmatched level of transparency, thereby reducing fraud and increasing consumer trust (Ertemel, 2018).

In order to create value, blockchain has been implemented in a wide variety of industries, including finance and the Internet. Nonetheless, there needs to be more work to uncover the extensive use of blockchain in marketing, with most research focusing on its application in operations, supply chain management, and the retail market. A dearth of writings explores blockchain's function and potential uses in advertising (Risius & Spohrer, 2017). To the best of the researchers' knowledge, more literature specifically examining blockchain's position in marketing is needed. The team searched the Scopus database but found several publications mentioning blockchain or marketing. Because there needs to be more written on blockchain marketing, the researchers felt compelled to fill that void. As such, the current study addressed the knowledge gap and discovered the important literature for future researchers in the burgeoning field of blockchain in marketing, which has a strong place on the research agenda. As such, the current study seeks to bring attention to the integration of blockchain technology and marketing and make a substantial contribution to the literature to aid future researchers by highlighting Future study directions and questions that the published literature will determine. The framework questions introduce a comprehensive literature review that identifies key findings and research gaps, describes the research methodology in detail, identifies future research agendas by bibliometric, network, and discussion analyses, and concludes with a conclusion (Reshmi, 2021).

2.4 Key Factors That Influence the Adoption and Integration of Blockchain Technology Across Different Industries

2.4.1 Transparency, Security and Trust

One of the primary factors driving the adoption of blockchain technology is its ability to enhance transparency, security, and trust (Ertemel, 2018; Jain et al., 2021; Boukis, 2020). Blockchain's decentralized and immutable nature allows for secure data sharing and tracking, making it attractive for supply chain management and marketing (Coita et al., 2019; Rejeb et al., 2020). For example, Boukis (2020) emphasizes the potential of blockchain to foster stronger brand-consumer relationships through transparent and secure data sharing.

2.4.2 Improve Efficacy and Reduce Costs

Another factor influencing the adoption of blockchain technology is its potential to improve efficiency and reduce costs (Lindman et al., 2017; Diestelmeier, 2019). For instance, in the energy sector, Diestelmeier (2019) suggests blockchain can empower consumers to actively participate in the energy market, leading to more efficient energy management. Similarly, in the financial sector, Albayati et al. (2020) highlight the benefits of blockchain technology in terms of reduced transaction fees and faster processing times.

2.4.3 Ability to enable novel business models

Moreover, the growing interest in blockchain technology is partly driven by its ability to enable novel business models and applications, such as decentralized finance and peer-to-peer energy trading (Xue et al., 2017; Marthews & Tucker, 2023). These innovative use cases present opportunities for industries to explore new revenue streams and business models, further encouraging the adoption of blockchain technology.

2.5 Challenges and Limitations of Blockchain in Consumer Marketing

Despite the numerous advantages of blockchain technology, some challenges hinder its widespread adoption. One of the primary concerns is the need for standardized regulations and legal frameworks governing the use of blockchain technology (Lindman et al., 2017; Harvey et al., 2018). Clear regulations create uncertainty for businesses and may discourage them from adopting blockchain technology. Another challenge is blockchain technology's energy consumption and environmental impact, particularly for proof-of-work-based systems like Bitcoin (Sikorski et al., 2017). This concern has led to increased interest in alternative consensus mechanisms, such as proof-of-stake, that are more energy-efficient. Lastly, scalability and interoperability issues pose significant challenges to the widespread adoption of blockchain technology (Lindman et al., 2017). Ensuring that blockchain networks can handle a large volume of transactions and integrate seamlessly with existing systems remains crucial for further research and development. Challenges and limitations persist despite the growing interest in blockchain technology across various industries. These include the lack of standardized regulations, concerns regarding energy consumption, and the need for further technological advancements to ensure scalability and interoperability (Lindman et al., 2017; Marthews & Tucker, 2023).

3. RESEARCH METHODOLOGY

3.1 Research Method

The study used a quantitative research design by following a random sampling approach. First, the study did a systematic literature review and then administered a survey questionnaire among the respondents of variable industries. The objectives of the literature review are to provide the existing literature on the applications of blockchain technology in various industries, emphasizing its implications for marketing, supply chain management, and consumer marketing:

1. To identify the key factors that influence the adoption and integration of blockchain technology across different industries and the challenges and barriers that may hinder its successful implementation.
2. To examine blockchain technology's potential benefits and drawbacks for businesses in different industries, including the impact on operational efficiency, transparency, security, and overall competitiveness.

In quantitative research, a simple random sample is used to collect information from employees who work in marketing firms and agencies in order to comprehend the motivating factors regarding the impact of blockchain in consumer marketing among various industries.

3.1.1 Systematic literature review

This systematic literature review aimed to aggregate, evaluate, and synthesize the vast body of knowledge regarding the applications and challenges of integrating blockchain technology across various industries. The rationale behind this methodology was to maintain a structured, replicable, and transparent approach, ensuring the collection of relevant and comprehensive information.

3.1.2 Data Extraction and Research Strategy

The approach incorporated a multi-stage strategy, ensuring a comprehensive extraction process. We initiated with identifying research questions, then selected databases, determined the search terms, and subsequently executed the search. After locating the articles, we assessed them for relevance and quality then extracted and synthesized data from the qualifying articles.

3.1.3 Database Selection and Search Strategy

A thorough search was executed across prominent databases, including Google Scholar, PubMed, IEEE Xplore, Scopus, and Web of Science. These databases were chosen based on their comprehensive coverage of multidisciplinary scholarly literature, ensuring the inclusion of a broad spectrum of perspectives and findings related to blockchain technology. The search strategy used primary and secondary keywords. Primary keywords such as "blockchain," "adoption," and "integration" were paired with secondary keywords like "industry application," "barriers," "benefits," and "challenges." Boolean operators (AND, OR) refined the search, targeting articles that explicitly discussed the integration and challenges of blockchain across various sectors.

3.1.4 Inclusion Criteria

Articles were included if they:

- Were published in English, ensuring a uniform understanding and evaluation of content.
- Directly addressed blockchain technology's application, challenges, or advantages across industries.
- The findings were published in the last decade, ensuring the relevance and applicability in the current technological landscape.
- Presented original research, reviews, case studies, or theoretical discussions pertinent to the research questions.

3.1.5 Exclusion Criteria

Articles were systematically excluded if they:

- Were not accessible in full text, limiting the depth of analysis.
- Veered off the central focus of the research, diluting the relevance.
- Were replicated across the chosen databases, or were derivative works of previously included articles?

3.2 Data Collection Procedure and Data Analysis

First the study targeted the published records on the impact of blockchain in consumer marketing. For this purpose, the study found 249 records on the basis of title of the study. After removing the irrelevant records, the study used 38 records for systemtic literature review.

In quantitative phase, this study gathered data from the various social media platforms, online forums, and email invitations which is utilized by a population of employees in marketing firms and agencies. The employee's interaction data, which includes approval voting, views, and information sharing, enhance the credibility of the association between the questions and their corresponding answers. The participants of this study include 150 employees (both male and female) from various marketing firms and agencies.

The data analysis for this study was carried out using SPSS (Statistical Package for the Social Sciences) software, which was utilized to compute descriptive statistics. Mean, often known as the average, is a measure of central tendency, which provides a summary statistic representing the typical data point in the sample. This was computed by summing up all the individual responses and dividing by the total number of responses. Standard deviation, on the other hand, is a measure of variability or dispersion in the data. It represents how much the responses deviate from the mean. A lower standard deviation signifies that the responses were close to the mean, indicating a consensus among the respondents. On the contrary, a high standard deviation implies a wider range of opinions or experiences among the participants.

4. RESULTS

4.1 Means And Standard Deviations

The findings from this study highlight the growing interest and investment in blockchain technology across various industries in consumer marketing. Analyzing the mean scores and standard deviation ns of the 20 items provides insights into the current state of blockchain adoption and the anticipated benefits and challenges associated with this technology. Table 2 shows that the majority of respondents (Mean = 4.33, Std. deviation = 0.85) indicate that they are either using or intending to use blockchain technology in their organizations, signifying a strong inclination towards the adoption of this technology. Respondents reported a relatively high degree of blockchain usage within their companies (Mean = 4.37, Std. deviation = 0.76), reflecting the growing integration of blockchain into various aspects of their businesses.

A significant number of organizations have formed specialized teams to support blockchain initiatives (Mean = 4.46, Std. deviation = 0.66), demonstrating a proactive approach to the implementation and management of blockchain projects. Most respondents have planned or allocated budgets for blockchain initiatives, with varied funding sources and budgets (Mean scores between 4.32 and 4.44), indicating organizations' financial commitment towards blockchain technology. Respondents anticipate substantial advantages for their businesses or sectors from utilizing blockchain technology (Mean = 4.41, Std. deviation = 0.68), highlighting the potential benefits and value-add this technology can bring to various industries. Most respondents believe that blockchain technology will significantly disrupt their market or sector (Mean = 4.45, Std. deviation = 0.65), implying that organizations recognize the transformative potential of blockchain technology. Industries are involved in creative blockchain projects, with diverse leaders managing these initiatives (Mean scores around 4.54). This suggests that organizations are actively exploring and experimenting with innovative blockchain use cases and applications.

Respondents identified sectors and areas where they anticipate blockchain technology to have the most significant influence (Mean scores between 4.38 and 4.41), emphasizing the widespread applicability of this technology across industries. Participants believe that specific blockchain applications have a higher likelihood of success (Mean = 4.37, Std. deviation = 0.66), reflecting the need for organizations to carefully select and prioritize the most promising use cases for implementation. In addition, respondents acknowledge barriers to blockchain adoption that their firms face (Mean = 4.34, Std. deviation = 0.73), suggesting that organizations must address and overcome these challenges to harness the potential of blockchain technology fully. Most respondents either use solutions from for-profit vendors or employ open-source blockchain technology. Many are willing to hire outside consulting firms specializing in public blockchain (Mean scores around 4.55 and 4.60). This indicates that organizations are exploring different avenues to access the expertise and resources needed to implement blockchain projects. Respondents consider creating industry standards and procedures essential in enabling blockchain platforms, applications, and for-sale goods (Mean = 4.46, Std. deviation = 0.61), highlighting the need for regulatory clarity and standardization to foster blockchain adoption. Furthermore, participants are generally optimistic about blockchain technology, believing its advantages will live up to the hype (Mean scores between 4.48 and 4.50). This sentiment indicates a strong conviction in the potential of blockchain technology to transform various industries. Finally, some businesses offer products, services, or licenses for using blockchain technology and applications (Mean = 4.26, Std. deviation = 0.72), suggesting a growing market for blockchain-related products and services.

Table 1. Means and standard deviations

No.	**Item**	**Mean**	**Std. deviation**
1	Do you now use or intend to use blockchain technology in your organization?	4.33	0.85
2	How much blockchain technology is currently being used by your company?	4.37	0.76
3	Has your company formed a special team to aid with a blockchain initiative?	4.46	0.66
4	When do you anticipate creating a budget for your company's blockchain initiatives?	4.40	0.72
5	What is/will be the source of funding for the blockchain efforts currently underway or planned by your company?	4.32	0.77
6	What is/will be the Block chain budget?	4.44	0.70
7	What particular advantages for your business or sector do you anticipate to get from utilizing block chains?	4.41	0.68
8	Do you believe that the use of block chain technology will significantly disrupt the market or sector that your business or organisation serves?	4.45	0.65
9	What block chain project is the most creative one in your organisation? Which particular task does this project focus on? Please give a brief description of this project.	4.54	3.17
10	Who is leading or will lead your company's block chain initiative(s)?	4.54	0.68

11	Why did you choose the team you mentioned to manage your Block chain project?	4.38	0.69
12	What sectors and areas do you anticipate block chain technology having the biggest influence in?	4.41	0.63
13	What block chain applications do you think have the most chance of success?	4.37	0.66
14	What barriers to block chain adoption do you think your firm faces the most?	4.34	0.73
15	Do you now use a solution from a for-profit vendor of block chain solutions, or does your company employ open-source Block chain technology?	4.55	2.59
16	Will your company hire outside consulting firms that specialize in public block chain?	4.60	0.72
17	How significant do you see the creation of industry standards and procedures to be in enabling Block chain platforms, applications, and for-sale goods?	4.46	0.61
18	Do you have any more opinions about block chain, either generally or in relation to the projects your company is working on?	4.48	0.61
19	Do you believe that Block chain's advantages will ultimately live up to the hype?	4.50	0.60
20	Does your business offer products, services, or licence for using Block chain technology and applications?	4.26	0.72

Source: Autor

The findings indicate a strong interest in and commitment to blockchain technology across various industries, with organizations actively investing in and exploring its potential applications. The anticipated benefits of blockchain technology, such as increased efficiency, transparency, and security, drive its adoption and integration into diverse sectors. Respondents recognize the disruptive potential of this technology, which is expected to bring significant changes to traditional business models and practices. However, the findings highlight organisations' challenges and barriers to adopting blockchain technology. These include the need for industry standards and regulatory clarity, the selection of appropriate use cases, and access to the necessary expertise and resources. To overcome these challenges, organizations should collaborate with industry partners, regulatory bodies, and technology providers to establish best practices and guidelines for implementing and managing blockchain projects.

Furthermore, businesses should prioritize the development of internal capabilities and explore partnerships with external blockchain experts to ensure the successful execution of blockchain initiatives. The growing market for blockchain-related products and services also presents opportunities for organizations to leverage and offer innovative solutions that cater to the evolving needs of their customers and stakeholders. Overall, the findings from this study underscore the significant potential of blockchain technology to reshape various industries, with organizations increasingly embracing its adoption and integration. As the technology matures and evolves, businesses must stay ahead of the curve by actively exploring and experimenting with innovative blockchain applications and use cases. By addressing the challenges and barriers to adoption, organizations can harness the transformative power of blockchain technology to create value and drive competitive advantage in the rapidly changing business landscape.

5. DISCUSSION

5.1 Block-Chain Security

Block-chain related technology replaces traditional marketing into digital marketing. In today's digital age, preventing data manipulation is a major concern. For large data sets to gain user trust and loyalty, privacy and security measures that it is necessary to implement artificial intelligence, data privacy, privacy-preserving contracts, and smart contracts. According to recent research conducted in the retail business, block chain-based reputation systems provide more anonymity than conventional systems (Taylor et al., 2020). Several studies have been conducted to investigate the vulnerabilities in data safety caused by ransomware assaults Reshmi (2021). By providing a safe, secure platform, block chain is helping businesses face these difficulties front on. Increased safety is achieved when blockchain technology is combined with AI. This connection between blockchain and privacy and security is vital and should be investigated (Reshmi, 2021).

The study delves into the widespread applicability of blockchain technology across various industries, including its profound implications for marketing, supply chain management, and consumer marketing. The results show a marked inclination of organizations towards blockchain adoption, with mean scores predominantly above 4.0, indicating active usage or intent to utilize this technology. Key factors propelling its adoption include anticipated benefits such as improved efficiency, transparency, and security. However, organizations need help in implementing blockchain, with industry standards, regulatory clarity, and appropriate use-case selection standing out as significant barriers. Despite these challenges, the majority of respondents believe in blockchain's transformative potential, emphasizing its capability to revamp traditional business models, enhance operational efficiency, and bolster overall competitiveness in various industries. The optimism surrounding blockchain's promises suggests that its perceived advantages might well live up to the industry's expectations.

5.2 Fostering Disintermediation

Disintermediation is now possible thanks to the development of the Internet, which has also fundamentally altered how businesses market their goods and services. Traditional trading mechanisms have been replaced by new technologies, which have also decreased the need for traditional middlemen and brought up new kinds of electronic intermediaries. New online middlemen have also emerged as a result of the Internet, offering a wider variety of goods and services. Businesses show a strong reliance and dependency on middlemen to understand the needs and wishes of their potential clients (Rejeb et al., 2020). Conversely, businesses strive to catch the attention of customers, but frequently rely on communication channels supported by numerous information intermediaries since they offer a plethora of data on the demand for goods and services (Stallone et al., 2021).

The findings of this study reveal a growing interest and intention among organizations to adopt and integrate blockchain technology. This increasing interest is fueled by the recognition of blockchain's potential benefits, such as improved efficiency, transparency, and security, which can lead to a competitive edge in various industries. The results demonstrate that organizations are becoming more proactive in their approach to blockchain, with the formation of specialized teams and dedicated budgets for blockchain initiatives. While the results indicate a positive outlook for blockchain adoption, they also emphasize the challenges organizations must overcome to realize its potential fully. These challenges include the development of industry standards, regulatory frameworks and identifying suitable use cases. Organizations should collaborate with stakeholders from different industries, regulators, and technology providers to address these challenges. This approach can help establish best practices and guidelines for successfully implementing blockchain projects.

Additionally, organizations should focus on building internal capabilities to manage blockchain projects effectively. This can be achieved by investing in employee training and development and collaborating with external experts and consultants. By doing so, businesses can ensure they are well-equipped to leverage the benefits of blockchain technology. Finally, the study highlights the growing momentum behind blockchain adoption across various industries, driven by the technology's potential to offer significant advantages. Organizations need to address the challenges and barriers to adoption by focusing on collaboration, capacity building, and the development of best practices. By overcoming these obstacles, businesses can successfully leverage the transformative power of blockchain technology to gain a competitive advantage and drive innovation in their respective industries.

6. CONCLUSION

The primary objective of the current study was to determine to analyze the employees' behaviors towards adopting blockchain technology in consumer marketing, are more pertinent when discussing blockchain based and its significance for marketing. The ongoing need to gather and analyze data, create and negotiate contracts, and uphold agreements in order to manage and sustain connections demonstrates how well blockchain technology may be applied to address issues with collaboration and trust in distribution chain networks (Treiblmaier, 2021). The ability of a company to differentiate itself from rivals and obtain a competitive advantage will, in turn, be influenced by the combination of communication channels between the marketing manager and the consumer. Our results can therefore draw the conclusion that putting block chain into practise would surely lead to greater performance and better financial outcomes in the marketing sector (Treiblmaier, 2021). Block chain technology will soon be the standard because of its ability to improve efficiency, minimize costs, mitigate risks, and, most significantly, increase confidence in transactions. The current investigation is driveby by a curiosity about blockchain's potential marketing applications. The authors claim that this study is the first to examine blockchain technology in combination with marketing (Treiblmaier, 2021). The goal was to gain a better understanding of blockchain and marketing by conducting this study. Make the findings to employees in organizations that use blockchain technology in consumer marketing. An inquisitive interest in potential blockchain applications in the marketing realm drives the present investigation. As suggested by Treiblmaier (2021), this study is a pioneer in examining the conjunction of blockchain technology with marketing. The study findings are relevant to employees using blockchain technology in consumer marketing. The analysis provided more profound insights into the intersection of blockchain and marketing. The study identified key areas within blockchain in marketing research with the most significant impact. For professionals in the marketing sector using blockchain, these areas might be focal points for future strategies or improvements in their current practices. Through this study, employees utilizing blockchain in consumer marketing now have a comprehensive understanding of the academic landscape, which aid them in staying abreast of crucial developments, understanding prevailing trends, and formulating effective strategies in their field.

6.1 Recommendations

Based on the findings of this study, several recommendations can be made to facilitate the adoption and integration of blockchain technology across different industries: Industries should invest in raising awareness about the benefits and potential applications of blockchain technology. This can be achieved through training programs, workshops, and collaborations with industry experts, helping employees and decision-makers better understand the technology and its potential impact. In addition, companies should develop a clear strategy for blockchain adoption that aligns with their overall business objectives. This should involve identifying the most suitable use cases, setting realistic goals, and establishing a dedicated team to manage and oversee blockchain initiatives.

Furthermore, blockchain technology can benefit from collaborative efforts among industry players, including competitors. Organizations should be open to forming strategic partnerships and joining industry consortiums to collectively develop standards and best practices, share knowledge, and drive innovation. In addition, companies need to proactively identify and address the barriers that hinder blockchain adoption, such as regulatory uncertainty, technological complexity, and security concerns. This may involve engaging with regulators, investing in research and development, and adopting robust security measures. Finally, industries should carefully assess the various blockchain solutions available in the market, considering scalability, security, and interoperability factors. They should also be open to exploring proprietary and open-source solutions to find the best fit for their specific needs and objectives.

6.2 Limitations

The present study has several limitations that should be acknowledged. First, the sample size may need to be sufficiently large to generalize the findings across different industries and regions. A more extensive and diverse sample would provide a more comprehensive understanding of blockchain adoption across various sectors and geographical locations. Second, the study relies on self-reported data, which might be subject to social desirability bias or inaccuracies in respondents' recollections. The study used only a descriptive analysis which is a limitation of the present study. Future study can use regression analysis to check the effects even hire some demographic variables as control variables. Future studies could use objective measures, such as actual blockchain adoption rates and budget allocations, to validate and supplement the self-reported data. Third, the study's cross-sectional design does not allow for an assessment of causal relationships or changes in blockchain adoption over time. Longitudinal research could provide valuable insights into the evolving dynamics of blockchain adoption and the factors that influence it. Lastly, the study does not explore the challenges and barriers different industries face in adopting blockchain technology. Future research could delve deeper into each industry's unique characteristics to identify the specific factors that influence blockchain adoption and integration, providing a more nuanced understanding of the technology's potential impact.

6.3 Future directions

This study's future directions can focus on several key aspects to further enhance our understanding of blockchain technology adoption and integration across different industries.

1. Expanding the sample size and diversity: Future research could employ larger and more diverse samples that cover a broader range of industries and geographical locations. This would enable researchers to investigate how blockchain technology adoption varies across contexts and better generalize the findings.
2. Longitudinal research: To capture the evolving dynamics of blockchain adoption, future studies could adopt a longitudinal approach, following companies over time to assess changes in their blockchain initiatives, budgets,

and perceived benefits or challenges. This would provide a richer understanding of the factors influencing blockchain adoption and its impact on various industries.

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THE ROLE OF IOT DATA AGGREGATORS FOR OPTIMISING OBJECT TRACKING AND KPI MONITORING

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Abstract

The Internet of Things (IoT) is an innovative technology that has completely transformed how different devices communicate. This includes sensors, actuators, GPS trackers, and other intelligent equipment. Among its many applications, one of the most important is its role in object tracking and monitoring Key Performance indicators (KPI). These functions are particularly crucial for logistics, manufacturing, agriculture, and retail industries.

The main objective of this paper is to explore the significance of IoT data aggregators in optimising these business processes. IoT data aggregators have a vital role to play as they gather, process, and analyse data from multiple IoT devices. This comprehensive approach allows a thorough understanding of the monitored objects and their performance. Moreover, the paper investigates how software designed for data aggregation can enhance the accuracy and efficiency of object tracking. This improvement facilitates real-time tracking of objects indoors and outdoors, analysis of past movements and events, and even predictive maintenance.

Additionally, the paper examines how data aggregators contribute to improved KPI monitoring by providing real-time performance metrics. These metrics enable proactive decision-making and enhance operational efficiency. However, addressing some technical challenges associated with object monitoring and data aggregation is essential, such as interoperability and vendor-free technology.

Keywords: IoT data aggregators, object tracking, Key Performance Indicator, KPI monitoring, operational efficiency

1. INTRODUCTION

In today's academic realm, it becomes apparent that further investigation is necessary to delve into the significance of IoT data aggregators in optimising object tracking and Key Performance Indicator (KPI) monitoring processes. While existing studies explore the utilisation of IoT technology for these intentions, they overlook the pivotal role data aggregators play in collecting, processing, and analysing the vast amount of data generated by IoT devices (mainly sensors and actuators). The current research primarily centres around IoT devices and implementing data analytics techniques for object tracking. However, limited attention has been given to the importance of data aggregators in effectively managing data flow between IoT devices and analytics systems.

This paper seeks to explore the implications of using software designed specifically for data aggregation to strengthen the accuracy and effectiveness of object tracking. This advancement aims to provide the information required for business analytics and reporting. The data analysed can provide insights that can shape strategic business decisions. The field of the article is Information Technology and Economics, explicitly focusing on the Internet of Things (IoT) and Data Analytics.

The field and topic of this work are important because IoT and Data Analytics, along with the ever-present Artificial Intelligence, are key drivers of today's digital transformation. These areas are necessary for all economic industries.

Furthermore, IoT devices generate considerable data that can be analysed in real-time. That is particularly important in healthcare, manufacturing and logistics industries, where real-time data can save lives, prevent downtime and optimise supply chains. When the field of data analytics (Data Analytics) is added to this, which enables the prediction of future trends and behaviour, it allows a much simpler transition from a reactive practice to a proactive one. By analysing previous data and using different prediction algorithms (predictive algorithms), it is possible to change the way of doing business and making decisions significantly. Suppose we add the ability to monitor the company's performance by defining and tracking KPIs. In that case, it is possible to additionally automate routine tasks and have information about business processes practically instantly. There are infinite examples, and this paper focuses on a sample from the logistics field, i.e., the analysis of vehicle driving quality, which is impossible using classic GPS devices.

In conclusion, IoT industry monitoring, data analytics and the ability to monitor economic indicators are essential and crucial for the growth and sustainability of companies and economies in the 21st century. Digital transformation is currently based on technical platforms that are not mature and sufficiently interoperable. Not to mention that the challenges of ensuring data security in the IoT world are a broad and exciting topic of their own.

The research gap in this article is the technical challenges associated with object monitoring and data aggregation in the context of IoT. By reviewing the current literature, we can conclude that some of the main concerns and research gaps nowadays regarding this topic are the following:

- What scalable solutions can be developed to handle the increasing volume of data generated by IoT devices?
- What strategies can be developed to enable real-time analysis of the massive data generated by IoT devices?

- How can interoperability among IoT devices and platforms be improved to facilitate seamless data integration and analysis?
- How can businesses overcome the challenge of vendor lock-in in IoT solutions?
- What methods can be employed to improve the quality of data IoT devices collect?
- How can the security and privacy concerns associated with IoT be effectively addressed to prevent data breaches and privacy violations?

To sum up, the main question can be asked: which technology platforms for data aggregation will integrate all the necessary functionalities required for further digital transformation?

This paper provides an overview of more recent research on the mentioned topic and a sample from the field of outdoor object tracking.

2. METHODS

The primary objective of this paper is to showcase how a data aggregator can be utilised as a foundation for business reporting and monitoring organisational goals using key performance indicators (KPIs). Due to the paper's length, we will not delve into the method of making business decisions based on analysed and presented data, as it should be self-evident. Instead, we will explain the data collection, aggregation, and analysis process.

Firstly, we explored the advances in indoor and outdoor object tracking technologies, as well as provide a review of the most important literature in the field.

We used state-of-the-art GPS/Glonass/Galileo 4G tracker devices and 3-axis accelerometers in eight vehicles to achieve this purpose. These vehicles were tracked via satellite (GNSS) for a one-week duration. The collected data, amounting to approximately 25 Mb, was extensively analysed. This analysis led to the creation a highly analytical report for the management. To ensure the accuracy of the data, we utilised the new generation devices, with Wialon services (Gurtam) serving as the analysis tool. The core concept of this paper centres around demonstrating the potential of consolidating various types of data into a unified source, commonly referred to as "data aggregators". This accumulation of data allows for simplified representation and facilitates efficient analysis.

Furthermore, we mention the possibility of conducting further data analysis using artificial intelligence systems and Neural Language Processing. It offers the potential for gaining additional information if a need arises and better insight into what is of great value for making decisions. It also leads to a better understanding of business data and a better definition of Key Performance Indicators.

3. RESULTS

3.1 Literature Review

Numerous research papers discuss various aspects of GPS outdoor and indoor positioning and tracking, as well as technological aspects of data aggregation and its impact on business processes. Also, numerous papers discuss their usability in real-world scenarios. Some essential papers and their references are mentioned in this chapter, and some papers are in the following chapters of the research results.

Bakhru 2005 explores different outdoor and indoor tracking techniques, including GPS modifications for indoor applications and additional sensors like IMU and MEMS. Hutabarat (2016) combines RFID and GPS for human tracking in both indoor and outdoor areas, achieving high accuracy. Gerdisen (2014) focuses on GPS-based human tracking in closed areas, developing an Android application with an error estimation of around 4 meters, which is more than expected. These papers provide insights into using GPS for outdoor tracking, including vehicle and human tracking, and highlight the potential of combining GPS with other technologies for improved accuracy and coverage.

Numerous papers collectively provide insights into IoT data aggregators. Uddin (2017) proposes a dynamic clustering and data-gathering scheme for IoT in agriculture, utilising an Unmanned Aerial Vehicle (UAV) to assist ground IoT devices in forming clusters and establishing a reliable communication backbone. Saleem (2020) highlights the importance of data analytics in IoT applications, emphasising its role in extracting meaningful insights for intelligent decision-making and performance optimisation. Arora (2017) presents a multi-representation-based data processing architecture for IoT applications, storing data in multiple representations to cater to diverse application demands and enabling real-time analytics. Farrell (2022) in their work introduces the IoT2SD framework, which incorporates an Intrusion Detection System (IDS) to structure unstructured IoT MQTT message data for data analytics purposes. This paper also covers the importance of data security in the IoT world. In addition to others, these papers discuss various approaches and frameworks for aggregating and processing IoT data. They highlight the benefits of efficient data analytics and the potential applications in different domains and industries.

When we seek to provide insights into key performance indicators for the Internet of Things (IoT), there are numerous papers in this domain as well. Malier (2016) emphasises the importance of digital technologies, such as FD-SOI, in enabling IoT devices to combine edge computing capabilities with RF or sensor functionalities. Lai-wu (2011) discusses key technologies based on RFID for achieving intellectual identification, location tracking, and management in IoT applications. Babu (2017) focuses on the performance analysis of data protocols in the network tier of IoT, reviewing protocols like MQTT, MQTT-SN, AMQP, CoAP, XMPP, and DDS and comparing them based on metrics such as network packet loss rate, message size, bandwidth consumption, and latency. Also, numerous papers point out how to prepare IoT-based Big Data for analysis (Kumar et al., 2022). In summary, these papers collectively highlight the significance of digital technologies, RFID-based technologies, and data protocols in ensuring the efficient performance of IoT systems with a straightforward key point in mind - how to create a solid standpoint to measure their performance.

3.2 Current Advances in Object Tracking Technologies

In today's increasingly connected world, the ability to track objects has become a crucial aspect of our daily lives. Whether monitoring the movement of goods in a warehouse or keeping track of personal belongings, indoor and outdoor tracking systems have revolutionised how businesses manage and locate objects. This report explores the nuances of indoor and outdoor tracking, shedding light on the various technologies and methods involved. Vital factors contributing to the successful and confident tracking of objects are understanding the differences between indoor and outdoor environments, harnessing the power of GPS and geostationary satellite systems, leveraging Bluetooth, UWB and IoT technologies, and utilising data aggregators. By delving into the intricacies of these factors, we can gain a comprehensive understanding of the advancements in object tracking and their implications for various industries.

3.2.1 Advances in Outdoor Object Positioning

Global Navigation Satellite System (GNSS) is the central outdoor object positioning and tracking technology. The system is formed from geostationary satellites and required receivers. Most new satellite monitoring devices (GNSS trackers) can simultaneously use more than one geostationary system. This allows location interpolation, leading to slightly more accurate results than relying only on one system. Geopositioning accuracy can vary between 2 to 10 meters, even in such cases. This variation is dependent on the location and various additional factors. Real-time Kinematic Positioning (RTK) corrections have shown the potential to achieve accuracy within a few centimetres (Kumar et al., 2021). However, that technology does not apply to devices in motion, and it is limited to stationary devices used for position collection (such as GMSS devices used for this research).

The issue of precise positioning is widely recognised and extensively discussed in a series of research articles. Numerous problems that are associated with geopositioning are primarily problems of a physical and technical nature. These problems encompass satellite and receiver clock errors, multipath errors, ionospheric delay, tropospheric delay, and GPS ephemeris errors (Kumar et al., 2021). Research on the possible use of a GPS receiver as an acceleration sensor has been conducted by, for example, Sokolova, Borio, Forssell, & Lachapelle (2010). The results seem to confirm that the mathematical model for that is satisfactory.

When it comes to outdoor tracking, the challenges become more complex due to factors such as (1) varying lighting conditions, (2) occlusions, and (3) unpredictable object motion. To overcome that, researchers have explored technologies such as Inertial Measurement Units (IMUs) and sensor fusion techniques. GPS and other satellite GNSS systems provide accurate location information by utilising signals from satellites, but its accuracy can be compromised in urban environments with tall buildings and signal obstructions. IMUs, on the other hand, use sensors such as accelerometers and gyroscopes to measure the object's motion and orientation. Combining data from multiple sensors using sensor fusion techniques can improve the accuracy and robustness of outdoor tracking systems (Huang et al., 2010).

Information regarding the acceleration of the monitored object cannot be solely derived from the current position data, as stated before. To attain this information, GPS tracker devices need accelerometers, which measure the G-forces acting upon the object along the X, Y, and Z axes. Incorporating a triaxial acceleration sensor and gyroscope enables the creation of comprehensive reports on eco-driving in automobiles or trucks. That includes not just the velocity attained from the satellite system but also measurements of the driver's level of aggression in acceleration, braking, and changing direction throughout the journey. A detailed analysis of a particular driver's behaviour becomes achievable by considering the anticipated G-forces for a typical passenger vehicle (which surpasses those observed in trucks or buses). This methodology significantly decreases fuel consumption and minimises the wear and tear on various vehicle components such as tires, suspensions, etc. The primary aim of all these efforts revolves around optimising fleet management costs. The application of IMU technology is viable in almost every aspect of object monitoring, irrespective of whether the object is indoors or outdoors.

If the precise location is not required for outdoor tracking, the unit does not need a GPS module at all. It can acquire its approximate position based on LBS data (Location-Based Services, Cell-ID) and information on what GSM repeater unit is currently connected. LBS location can be informative when there is no GNSS signal, devices must operate in low battery mode, or when the tracked object is inside a building where a GPS signal cannot pass through. LBS position is more accurate in the urban and more populated areas because there are more GSM repeaters. However, it can still show a false distance of about a few hundred meters and even ten kilometres in unpopulated areas (Samama, 2019).

Contrary to the widely held belief that GNSS technology has already peaked, it is undeniably constantly advancing and undergoing remarkable enhancements. According to Rizos (2005), significant improvements are anticipated from various perspectives soon from the (1) communication point of view, (2) instrumentation and techniques, (3) hardware and (4) software point of view. Those enhancements will additionally advance current technology for outdoor tracking.

3.2.2 Advances in Indoor Object Positioning

The precise tracking of an object's location within enclosed spaces such as buildings, underground parking lots, and airports is not feasible with GNSS technology. Multiple reasons exist for this limitation, including a significant decrease in signal quality and quantity from geostationary satellites within enclosed spaces. Additionally, various materials obstruct or reflect microwave signals, negatively impacting accuracy. Interferences also occur within the 1100 to 1600 MHz radiation spectrum, the range most GNSS receivers operate.

The GNSS positioning system offers a notable advantage because users do not need to invest in supplementary equipment installed locally. The sole requirement is possessing a GNSS receiver (tracker device). However, when it comes to indoor object positioning, aside from deploying a transmitter on the targeted object, one must also establish an infrastructure that facilitates tracking within enclosed spaces. That entails incurring extra costs and maintaining equipment such as WiFi hotspots, RFID antenna systems, BLE or UWB receivers, etc.

As a result of these factors, the indoor positioning system (IPS) relies on distinct technological aspects compared to GNSS. Primarily used for business purposes, IPS is widely adopted for navigation in commercial, military, and civilian domains. Retail is one field where IPS finds applications, allowing tracking customers within a store and enhancing understanding of their behaviour. Leveraging data on customer movement can lead to improved product placement, optimised store layouts, and personalised marketing messages. IPS facilitates tracking medical equipment and patients within a hospital setting. That helps enhance efficiency in areas like transportation and medication distribution. IPS can be utilised in an industrial environment for inventory management, monitoring resource mobility, and optimising manufacturing processes. It also contributes to reducing losses and enhancing worker safety while facilitating the implementation of the e-kanban, a digital version of the traditional kanban system used in lean manufacturing.

Wireless Bluetooth Low Energy (BLE) is an emerging IPS technology and the Ultra Wideband (UWB) technology. The precision and reliability of UWB technology have contributed to its increasing popularity, and it is expected to revolutionise indoor object positioning and tracking, offering precise positioning accuracy within about ten centimetres (Samama, 2019). That makes it ideal for indoor object-tracking applications that require meter-level accuracy, such as asset tracking, inventory management, and indoor navigation systems.

An essential factor to be considered pertains to the utilisation of data aggregators, which allow for the merging and processing of outdoor and indoor object-tracking data into a comprehensive and valuable source of information by incorporating location data with supplementary particulars like object specifications, accountable individuals, expiration dates, acceptable impact forces during handling, permissible temperature ranges, and other related data, a remarkably versatile system can be devised (Wang et al., 2022). This system not only tracks the locations of objects but also facilitates the efficient management of business operations.

3.3 The Usage of IOT Data Aggregators

The task of collecting, organising, and analysing data received from various IoT devices, sensors and actuators is managed by IoT data aggregators. These platforms or systems play a central role in this process. The devices that fall within the realm of IoT range from intelligent appliances and wearable devices to industrial machinery and environmental sensors. The capacity of IoT data aggregators lies in their ability to acquire data from diverse devices, regardless of their type or manufacturer, and consolidate it into a centralised location. This consolidation simplifies the management and analysis of the data. Aggregators can gather information from multiple sources, integrate it, and provide a unified perspective of the gathered intelligence.

Apart from consolidating data, these platforms often provide data cleansing, normalisation, and enrichment tools similar to ETL (Extract, Transform and Load) tools in Business Intelligence applications. These tools ensure the data's accuracy, consistency, and usability for analysis purposes. Many applications can "clean" the data and transform it into a format suitable for analysis (Lindel, 2020). Furthermore, IoT data aggregators may also offer storage capabilities for organisations to accumulate vast amounts of IoT data for future utilisation.

According to a study by Trappey et al. (2017), IoT data aggregators enable the integration of diverse data from various sources, including sensors, actuators, and smart devices. This integration occurs in a unified and standardised format, simplifying extracting meaningful insights and deriving effective intelligence (Trappey et al., 2017). By collecting and organising data from a variety of IoT devices, aggregators enhance the visibility and accessibility of data, thereby enabling more efficient data analysis. IoT data aggregators often incorporate advanced analytic techniques like machine learning and artificial intelligence to identify patterns, trends, and anomalies within the collected data. That enables real-time decision-making and predictive analytics. This capability proves particularly valuable in domains that rely heavily on timely and accurate data analysis. Therefore, IoT data aggregators serve as critical components within the IoT ecosystem, facilitating the extraction of insights from the massive volumes of data generated by interconnected devices.

It is worth noting that specific academic works even acknowledge that data aggregators can exist in hardware units, such as routers, access points, gateway devices, various stationary devices and even drones (Sharma et al., 2022). Notably, drones possess the unique ability to surveil inaccessible or hazardous locales, enabling them to gather information from sensors incapable of transmitting data across substantial distances due to their inherent technological limitations (e.g., WiFi, Bluetooth, RFID, and the like).

For an IoT network to be considered robust, it needs to possess the capability of handling malfunctions without compromising its connectivity. Reliable networks are necessary because they establish a dependable foundation for inter-device communication. IoT systems' nodes, or vertices (Dagdeviren et al., 2022), are typically interconnected through wireless channels and engage in message exchange. Consequently, when relay nodes encounter failures, data transmission between nodes can be disrupted, resulting in the inefficient utilisation of various resources. Thus, the underlying communication infrastructure of a reliable IoT network should be equipped with the ability to withstand failures and ensure the connectivity of active nodes.

There is a multitude of challenges that must be taken into account when we are speaking of network communication among IoT devices. One particular issue that stands out prominently is the need for interoperability among diverse devices. This limitation is often acknowledged as a crucial obstacle that needs to be addressed to establish a network that is both seamless and free from vendor restrictions (Rathanasalam et al., 2020), as well as a need for communication protocols in connecting devices and applications. These protocols enable smooth data exchange, establish device address schemes, and determine packet routing strategies (Mahbub, 2022). They also include functions like sequence control and flow control for optimal communication. Within the IoT realm, unidirectional and bidirectional communication among various devices must be logged in the database of a data aggregator. That enables the consolidation of all the data in one central location, thereby facilitating the preparation of reports using business intelligence analytical tools.

Since the data arrives in real-time to the aggregator, tracking Key Performance Indicators (KPIs) even daily is possible. KPIs can be identified and established at different levels, including daily benchmarks, and are commonly utilised to monitor and evaluate the accomplishments of organisational goals or projects. They can be established long-term to assess overall performance and track daily or weekly outcomes and progress at shorter-term levels. With enough computing power, stored data, and a good selection of long-term, middle term and short-term KPIs, we expect management to have a pretty good view of how business processes are conducted in almost real-time.

3.4 Exploring the Potential of Data Aggregators in Outdoor Object Positioning and Driving Quality Analysis

For this paper, we will analyse the data on outdoor object positioning. The situation with indoor object positioning of objects is similar, with certain limitations. Indoor tracking analysis, which relies on data from accelerometers (before mentioned IMUs), can provide valuable information about how goods are manipulated inside the warehouse. That data can be of high value if the business entity deals with sensitive goods. Likewise, additional information (besides g-forces) is obtainable from other types of sensors such as temperature and humidity sensors (if it is a heat and moisture-sensitive goods such as food), magnetic and PIR sensors, identification beacon sensors and the like.

For this paper, data from GNSS satellite tracking of eight vehicles equipped with Teltonika 4G FMC230 GPS/Glonass/Galileo devices will be analysed for outdoor object tracking. These devices are provided with additional 3-axis accelerometers that transmit location and acceleration data in real-time. The accuracy of location is achieved through simultaneous interpolation of 10-19 satellites. All the data is then aggregated in the Fleet Management System (FMS) Wialon, developed by Gurtam. Based on predefined rules, the system determines the driving quality for each vehicle individually. The resulting report assigns a driving quality score on a scale of 1-10, where a higher grade indicates driving that adheres more closely to safety regulations, speed limits, and G-force related to acceleration, braking, and turning. Violations related to speeding are penalised based on the specific road limits applicable to the vehicle's route. For each car, expected g-force values are defined, and penalties for exceeding the expected ranges are also established based on the vehicle type.

Acceleration calculations involve several data points, including:

- the unit's location,
- initial and final speed values,
- travel time between two points,
- the unit's movement direction, and

- particular parameters received from the device (G-forces).

Table 1 presents the chosen tangible values used to calculate and report the quality of driver behaviour.

Table 1 Acceleration values for driving quality assessment

Name	Criterion	Min. value	Max. value	Penalty
Acceleration: extreme	Acceleration	0.4g		2000
Acceleration: medium	Acceleration	0.31g	0.4g	1000
Brake: extreme	Braking	0.35g		2000
Brake: medium	Braking	0.31g	0.35g	1000
Harsh driving	Reckless driving	0.3g		300
Speeding: extreme	Speeding	41 km/h		5000
Speeding: medium	Speeding	21 km/h	21 km/h	2000
Speeding: mild	Speeding	10 km/h	21 km/h	100
Turn: extreme	Turn	0.4g		1000
Turn: medium	Turn	0.31g	0.4g	500

Source: own research

This table shows the criteria and acceleration values used to assess driving quality. The criteria include acceleration, braking, reckless driving, speeding, and turning. Each measure has a range of values representing thresholds for specific driving behaviours. Penalties are assigned based on behaviour severity, with higher penalties for extreme behaviours. For example, extreme acceleration (>0.4g) and extreme braking (>0.35g) receive a penalty of 2000. Medium acceleration and braking (0.31g-0.4g for acceleration, 0.31g-0.35g for braking) receive a penalty of 1000.

Reckless driving (acceleration >0.3g) receives a penalty of 300. Speeding is categorised as extreme, medium, and mild. Extreme speeding (>41 km/h) receives the highest penalty of 5000, while medium speeding (21 km/h) and mild speeding (10 km/h-21 km/h) receive penalties of 2000 and 100, respectively. Extreme and medium turning behaviours are also penalised. Extreme turning (acceleration >0.4g) receives a penalty of 1000. Medium turning (0.31g-0.4g) gets a penalty of 500.

In summary, this table provides an overview of how driving behaviours are assessed and penalised based on severity and impact on driving quality. The aim is to discourage dangerous driving and promote safe and responsible behaviour.

Analysis was executed using data gathered from one week-long drive, thereby revealing a comprehensive ranking of the driving quality of the eight vehicles mentioned above. Through an examination of this data, valuable insights regarding the driving quality of these individual vehicles are revealed, thereby facilitating well-informed business decisions concerning vehicle servicing requirements, as well as the potential for supplementary driver incentives for those who attain higher ranks or, conversely, measures to driver penalty if it is necessary. By correlating this ranking with the fuel consumption (assuming that all vehicles are exact type, model, and engine power), one can present valuable information regarding the potential for minimising overall business expenses for each vehicle. This report cannot be attained solely through GNSS tracker data but can be critical to business owners.

The results of the analysis and the final report are presented in Figure 1.

Figure 1 Driving quality assessment report

Unit	Rank	Penalty	Violations	Duration	Mileage, km	Trips
(693 IJ)	8.3	31	12	05:24:38	403.8	6
SAMIR (960 IF)	6.2	97	59	15:39:15	1249.9	14
DAVOR (165 IF)	5.4	140	100	13:52:23	1133.3	10
TOMO (470 HM)	4.9	172	109	16:55:50	1321.7	12
VRABEC (114 IH)	3.6	335	93	15:08:04	1204.0	12
PAVO (119 II)	3.5	356	97	14:01:39	999.6	14
KOVA (508 IK)	3.0	458	113	15:22:51	1376.6	13
SAMIR (420 HR)	2.9	496	258	18:04:08	1317.6	9

Source: own research

The analysis findings concerning driver behaviour and driving quality are presented clearly, utilising a table for easy comprehension. Each GNSS device and its corresponding g-sensors transmitted an average of 7,000 to 9,000 telemetry messages to the system. A total data accumulation of approximately 2 megabytes occurred, with approximately 1.3 megabytes transmitted and 0.7 megabytes received. These values indicate that nearly 35% of the data traffic is communication overhead, encompassing TCP/IP handshaking and maintaining an open TCP/IP connection. Considering the information above, it becomes evident that this reporting process has significant challenges from the CPU processing power necessary to handle this volume of data and the mentioned calculations.

4. THE IMPACT OF DATA ANALYSIS ON KEY PERFORMANCE INDICATORS

In today's digital age, data has become the lifeblood of organisations, fuelling growth and driving strategic decision-making. With the exponential growth of data, Big Data has emerged, revolutionising how businesses operate, compete and measure their KPIs. Integrating Big Data with Key Performance Indicators (KPIs) has opened up new avenues for organisations to measure and enhance their success. KPIs are not a new concept to companies (Parmenter, 20015), and they "represent a set of measures focusing on those aspects of organisational performance that are the most critical for the current and future success of the organisation". By examining the integration of accounting and economic indicators and the analysis of IoT data as a foundation for

KPIs, leveraging Big Data can facilitate informed decision-making and drive key performance measurements in various industries.

In 1992, Kaplan and Norton introduced the concept of balancing performance indicators and developed the Balanced Scorecard methodology, which translates business objectives into indicators across different dimensions. This has led to various operational approaches (Franceschini et al., 2019):

- the Balanced Scorecard method;
- the Critical Few method;
- the Performance Dashboards, and
- the EFQM (European Foundation for Quality Management) model,

Within data analytics, those models can easily be presented with a graphic user interface that shows the up-to-the-minute state of KPIs.

Big Data has emerged as a crucial tool for measuring and evaluating success in various domains since it refers to the vast amount of information generated from multiple sources. Such sources are web, emails and digital communications, social media, sensory data, and transaction records, and they provide opportunities for organisations to gain insights and make data-driven decisions. According to Wagner-Pacifici, Mohr, and Breiger (2015), Big Data analytics enables the identification and analysis of KPIs that can help assess an organisation's success. By harnessing large datasets, organisations can identify patterns, trends, and correlations that were previously unattainable with traditional data analysis methods. These KPIs can range from customer satisfaction metrics to financial performance indicators, depending on the organisation's specific objectives.

Furthermore, Big Data analytics can also facilitate predictive modelling and forecasting, allowing organisations to anticipate future trends and make proactive decisions. Associated KPIs have inevitably become indispensable tools for measuring and evaluating success, providing organisations with valuable insights and opportunities for improvement (Wagner-Pacific et al. 2015).

As Mikalef, Krogstie, Pappas, and Pavlou (2020) also highlighted, Big Data analytics enables organisations to identify key performance indicators (KPIs) crucial for measuring their success. Organisations can identify patterns and correlations by analysing large volumes of data to help them define meaningful KPIs. Furthermore, Big Data analytics allows organisations to monitor and track these KPIs in real-time, providing timely insights and the ability to make data-driven decisions. This ability to leverage Big Data for KPI measurement, as stated by authors, has been shown to impact organisational performance positively and can lead to increased competitiveness and profitability.

According to a study by Gandomi and Haider (2015), Big Data analytics allows companies to identify key performance indicators (KPIs) crucial in evaluating their success. By "harnessing the power of big data", businesses can measure sales, customer satisfaction, and operational efficiency metrics to assess their performance and make data-driven decisions. The study emphasises that big data analytics provides organisations with real-time and accurate information, enabling them to monitor their KPIs effectively and make timely adjustments to their strategies. Therefore, big data plays a pivotal role in helping businesses identify and evaluate key performance indicators, leading to improved decision-making processes and overall success in today's data-driven world.

As Wagner-Pacifici, Mohr, and Breiger (2015) also pointed out, big data provides organisations with much information that can be used to gain insight into the company's operations and to make the so-called informed decisions. With the proliferation of digital technologies and the Internet, vast amounts of data are generated and collected daily. As the researchers conclude (Lindell, 2015), with the emergence of digital technologies and the Internet, large data sets have become vital in measuring KPIs and enabling data-based decision-making and business optimisation. The analysis of Big Data is significantly impacted by Neural Language Processing (NLP), which can also be used in this scenario. There are several ways in which NLP can enhance the analysis of extensive datasets (Sharma et al., 2022).

In the previous text, sources are presented that point to a long-known fact: for business analysis, it is necessary to have good data sources and reliable metrics and methodologies by which these data are analysed and presented. This paper presents an example of data analysis within the logistic process of vehicle monitoring and the combination of indoor and outdoor object positioning. The possibilities arising from data aggregation (merging) led to introducing a concept known as Intelligent Logistics System Based on IoT (Wang et al., 2022).

5. DISCUSSION AND FUTURE CONSIDERATIONS

This paper aims to help understand the vital role played by IoT data aggregators in transforming business processes, particularly in sectors where an object positioning system (indoor and outdoor) is a must, like logistics and manufacturing, retail and even agriculture. The findings indicate that these data aggregators play a significant role in enhancing the possibility of object tracking by collecting, processing, and analysing data from IoT devices. That enables real-time tracking and more than just analysis of past movements. Furthermore, it demonstrated that the contribution of data aggregators extends to improving KPI monitoring by providing real-time performance metrics. That facilitates proactive decision-making, operational efficiency and predictive maintenance.

There are numerous possible implementations in practice. Some specifics would be energy management (this can lead to significant cost savings and a reduced environmental impact), Agriculture (increased crop yields and reduced costs), Environmental Monitoring (improved environmental conservation efforts) and so on.

Despite the numerous benefits, it is crucial to address technical challenges associated with data aggregation, such as interoperability and vendor-free technology. Integrating Big Data with Key Performance Indicators (KPIs) significantly impacts how organisations measure their success. The abundance of information from diverse sources empowers organisations to gain valuable insights and make informed decisions based on data. By leveraging Big Data analytics, organisations can uncover previously undiscovered patterns, trends, and correlations, facilitating the identification and analysis of KPIs. These indicators encompass a wide range of metrics, covering aspects from customer satisfaction to financial performance, providing organisations with a comprehensive understanding of their business.

Big Data analytics enables predictive modelling and forecasting. That analytics empower organisations to anticipate future trends and make proactive decisions.

Despite the numerous benefits offered by IoT data aggregators, several technical challenges need to be addressed, including data security and privacy, interoperability and cost-effectiveness. Future research should focus on solutions that fully enable the potential of IoT data aggregators as database storage for future analysis while considering the associated challenges. That may be done with numerous systems like Apache Pulsar, NATs, RabbitMQ, Apache Flink, Samza, Redis Streams, Apache NiFi, Flume and, for example, RocketMQ. Many of these systems/platforms integrate required data aggregation possibilities, but more research should focus on standardising needed functions. One of the open questions is whether open-source distributed data streaming platforms like Apache Kafka can provide all the required functions. It is designed for high-throughput, fault-tolerant, and scalable data streaming, allowing large volumes of data to be processed and aggregated in real-time. Also, it can collect, store, and process data from various sources, making it suitable for use as a data aggregator in big data and real-time analytics applications.

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METHODS AND TECHNIQUES TO INVOLVE FREIGHT ACTORS IN THE R&D PROCESS TOWARDS DIGITALISED INTERMODAL COOPERATION

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Abstract

Providing efficient, resilient, and sustainable freight networks requires active participation of freight actors in the transition process towards synchro-modal, multi-level distribution, and zero-carbon emission transportation systems. The vision of the Physical Internet (PI) describes the future of logistics like the operation of the internet today, where flow occurs physically based on network resources, neglecting any pre-defined routes or nodes. Active collaboration of freight actors in such an environment is inevitable to be able to manage transport and distribution activities by a governing body. To be competitive in a PI-based logistics market, freight actors need to modify their behavior. They should change the current approach of competing for customers or exclusive partnerships and focus on "operational excellence". In our paper, we are presenting the main drivers of such a transition towards the PI. We aim to analyze and synthesize the results of some selected scientific and R&D activities related to the evolution of freight systems towards the PI. We apply the TRIZ methodology (Theory of Inventive Problem Solving) and explore the connections between the STRIA and ALICE Roadmaps. Although information technologies are present in the form of digital twins, artificial intelligence, and many other forms, trust in the technology and in the PI as an ultimate ideal solution has not been built up yet. There is a fear and a lack of willingness by actors to share their data voluntarily in the freight data communities. Based on the experience of various R&D projects, analysts concluded that proper organizational and governmental factors of freight data communities are essential for survival. Understanding the nature of these common pool resource (CPR)

management systems and identifying the factors needed to overcome the freight actor point of view is crucial. Proper freight systems can be planned by forming possible strategies for the inevitable transition.

Keywords: Physical Internet (PI), freight actor involvement, Common Pool Resources (CPR)

1. INTRODUCTION

Freight actors are facing multiple challenges in our modern economies: while the demand for transporting goods is constantly growing, they need to evolve according to -often contradicting- efficiency, resiliency, and sustainability requirements. The European freight sector, as it operates today, over-consumes most of the scarcely available critical resources, namely space (lack of capacity related to the transportation network), assets (logistics infrastructure), time (delays and congestions), workforce (lack of sufficient talented employees) and energy (mainly fossil fuels).

A significant part of the challenges can be attributed to the high share of road transport. As it is in the nature of the sector, there are specific spatial distributions identified in the use of space, time, and logistics infrastructure -as resources- in the first mile (ports and logistics hubs) and last-mile delivery activities (urban environments). The bottleneck embodied by the port infrastructure makes it more and more difficult to ensure the fast and smooth movement of goods. Urban freight is also extremely limited by the available space (for loading-unloading and storage) and transport network resources. Just as the bottleneck embodied by the port infrastructure makes it increasingly difficult to ensure the fast and uninterrupted movement of goods, urban freight is also often extremely limited by the available space (for loading-unloading, warehousing, and storage) and the lack of parallel traffic lanes. In both cases, the contradiction tenses up between the fast movement of goods and the fast movement of transport vehicles: the fast movement of individual shipments requires a large fleet of road transport vehicles (along with properly trained and motivated drivers), but only a limited space and time window is available for loading and transporting the freight. Resolving the contradiction is only possible if, for the sake of sustainability, the developments are not only aimed at the expansion of the fleet or the built infrastructure but also at the efficient utilization of the available resources (Szander *et al.*, 2023).

In order to make efficient use of time as a key resource there is a central question regarding intermediate transshipment actions. Based on the TRIZ methodology (Theory of Inventive Problem Solving) (Gadd, 2011), we can identify C1 and C2 contradictions:

- C1) On the one hand, the condition for the rapid movement of goods is the elimination of idle times, in this case, intermediate loading and storage steps, as they represent a waste of time and associated costs from this aspect. (These factors led to the implementation of door-to-door services solely with trucks and delivery vans on the road, which we intend to moderate or decrease).

- C2) On the other hand, for road transport vehicles to move quickly and thus increase transport performance, we should also consider the driving time limitations (9-11/24h). From this aspect, intermediate cross-docking actions are required to provide a continuous flow of freight.

Solving the contradiction – emphasizing that the ultimate goal is the smooth movement of freight– it is necessary to provide services at some stations or logistics hubs of the distribution network with short loading and storage times, cross-docking solutions, and the transfer of properly organized goods with high vehicle capacity utilization.

The Physical Internet (PI) concept proposes pooling resources and assets in open, connected, and shared networks. The existing idle capacity of assets in all modes of transport and storage could be better utilized in supply chains, and flows could be managed more broadly using and combining transport modes and other logistics assets smartly. Open and interconnected logistics services and networks will maximize capacity utilization, meeting current and future demands. Value creation through efficiency should be used to speed up the transition to greener and cleaner assets instead of price reductions and margin erosion resulting from current assets (Ballot *et al.*, 2020). The development of information technology (IoT Internet of Things, 5G, AI Artificial Intelligence, Digital Twin) and many other innovative concepts and solutions bring these plans closer to reality, but there are obstacles arising simultaneously.

The main reasons why clients do not want to use environmentally friendly and high-capacity rail and waterway transport can be identified as (1) transshipment slows down the speed of the flow of goods and there is a fear that damages can occur in the meantime, (2) the consolidation of smaller shipments is difficult, processes become more complex or vulnerable, and (3) incentives and regulations are still not favoring these solutions on the level of attractiveness clients willing to count with. While rail and inland waterway solutions cannot provide door-to-door (or even near-to-door) services, they can contribute (while still not competing) with road transport in the efficient, resilient, and sustainable freight process by maintaining scheduled, high-capacity link along the supply chain (Qasseer *et al.*, 2023).

To achieve the ambitious goals of the PI, there is a requirement for sufficient freight infrastructure and often other specialized resources. At the same time, Europe is lagging in railway and inland waterway freight infrastructure developments (hubs and inland ports equipped with logistics infrastructure assets, loading bays, and warehouses) (Stopka *et al.*, 2023). Intermodal cooperation is held back by the lack of suitable vehicles. Fleet renewal in rail and waterway transport is far behind that of road vehicles. In addition to technical developments, building trust and willingness among logistics companies is key to putting their needs and resources into properly governed freight data communities (Rodriguez, 2023; Szander *et al*., 2023; Boldizsár *et al*., 2022). The operation of these freight data communities is not limited to enterprises but necessarily consists of B2A (Business to Authority) and B2I (Business to Integrator) communication layers on a certain level. Regarding the shared data, it must be ensured that partners with the appropriate access level can only see them to the extent determined by the participants agreeing to share the data, respecting the integrity of business-sensitive information. The best way to ensure stakeholders (authorities, hauliers and freight enterprises, manufacturers, distributors, and service providers) accept the virtual environment, collaborate, and respect the rules of operation is if they are deeply involved in forming such freight data communities.

In our study, we explore the features and possibilities of this transition. We present what techniques, technological, and organizational solutions can help the creation of the Physical Internet (PI), and we pay special attention to the operation of transport data communities as common pool resource (CPR) systems.

2. ROADMAPS TOWARDS EFFICIENT, RESILIENT, AND SUSTAINABLE LOGISTICS SYSTEMS

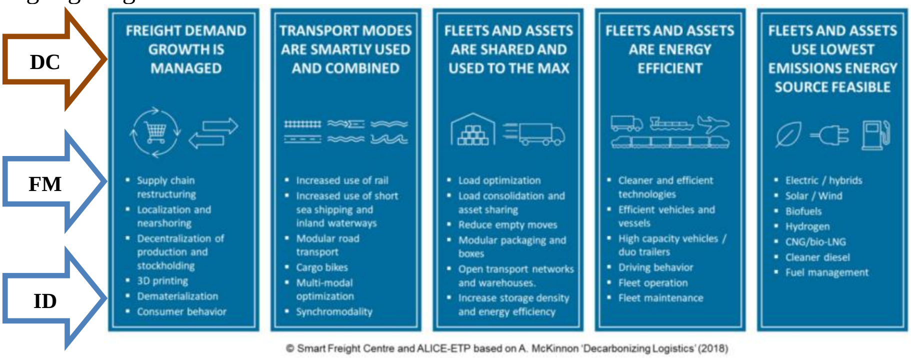
Digitalized intermodal (or synchro-modal) cooperation aims to optimize the efficiency, reliability, and effectiveness of transporting goods across different modes while minimizing delays, costs, and operational complexities and keeping sustainability goals in mind. The critical importance of collaboration has been recognized since the early days of supply chain risk management. By collaborating, companies can gain awareness of potential upstream and downstream risks, try collectively to minimize these risks, and coordinate contingency planning to improve the supply chain's resilience. According to the literature, the success of such a collaboration depends on five things: trust, a willingness to share data, coordinated planning, recognition of mutual interdependence, and a fair distribution of the resulting benefits (McKinnon, 2018).

There are many new, innovative, and green technical solutions available in transportation. However, there is a consensus amongst experts that replacing fossil fuels with electricity or hydrogen will not be sufficient to transform the freight sector to fit all the requirements of the climate goals.

In May 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the ‘Europe on the Move’ package, which highlights main transport R&I areas and priorities for clean, connected, and competitive mobility (Gkoumas *et al.*, 2021). Seven STRIA Roadmaps have been developed covering various thematic areas, namely: Connected and automated transport (CAT); Transport electrification (ELT); Vehicle design and manufacturing (VDM); Low-emission alternative energy for transport (ALT); Network and traffic management systems (NTM); Smart mobility and services (SMO); and Transport infrastructure (INF).

While the STRIA Roadmaps focus mainly on the innovation of different transportation-related technologies, the ALICE Roadmaps (Alliance for Logistics Innovation through Collaboration in Europe) project pathways towards the Physical Internet (PI) (see Figure 1).

Figure 1 A slightly extended representation of the ALICE PI Roadmap Pillars, highlighting the 3 intervention fields.



Source: Modified version of (McKinnon, 2021)

We concluded that all the efforts to intervene in the five highlighted fields can be expressed as the development of freight data communities (DC: data community), innovative (synchro-modal) management of collaborative fleets (FM: Fleet management), and the renewal of transport and logistics infrastructure (ID Infrastructure development).

The SENSE project developed a Physical Internet roadmap to explain the development of the PI over the next twenty years around five areas of development, including:

1) From Logistics Nodes to PI Nodes, focusing on automation, standardization, and digitalization of physical processes.
2) From Logistics Networks to Physical Internet Networks, in which all processes and services are managed as seamless, flexible, and resilient.
3) Developing the System of Logistics Networks towards the Physical Internet, providing individual logistics networks that are interconnected.
4) Access and Adoption, including different steps and the mind shift required to adopt Physical Internet concepts.
5) Governance (GOV).

There are different approaches to defining Physical Internet (PI) governance:

- BU-GOV is a bottom-up (BU) approach where Logistics Nodes, Networks, and Systems of Logistics Networks develop their governance mechanisms, growing and progressing organically. Companies and consortia develop network governance, creating convergence as the models advance. This could lead to islands or subsets of Physical Internet with their standards and protocols.
- TD-GOV is a top-down (TD) approach where there might be two options:
    - TD-GOV-P Public lead. A central body plans and organizes the Physical Internet under the supervision of governments that consider transport and logistics as a universal and public service/

infrastructure, even if companies provide services in a fully regulated framework. This approach would require strong public-sector action at the European/ global level, supported by massive investments, to enforce standards and ensure that market competition rules are not infringed.

- TD-GOV-I Industry lead. Big corporations integrate and/or build strong logistics network capabilities that afterward open to other stakeholders as a service. These digital logistics platforms can deliver services to all types of companies and users up to end consumers making and organizing use of their network and partners' resources and capabilities.

Good governance ensures cooperative management of the Physical Internet by associated partners, openness for all types of organizations, defined service levels and quality standards, transparent management in routing cargo through the network, and common agreed rules in fair allocation of costs, risks, and responsibilities among the involved providers. Evolution from the current ad-hoc trustee-based models is expected, leading to a replicable set of rules and tools addressing all aspects of asset sharing, from mutual liability to gains redistribution (SENSE, 2020).

3. RESULTS AND RECOMMENDATIONS FROM STUDIES OF COMMON POOL RESOURCE MANAGEMENT

According to the extended research activities on the field of social dilemmas, the issue freight actors should deal with can be identified as a multiple-factor common pool resource problem. CPRs are most importantly time or service speed, coupled with space availability and logistics asset utilization as common pool resources in our case.

The canonical representation of collective action problems shows the structure of an n-person prisoner’s dilemma game. Many times –but not always– social science expert groups observed that rational agents were not likely to cooperate in certain settings, even when such cooperation would be to their mutual benefit. The zero-contribution thesis underpins the presumption in policy textbooks (and many contemporary public policies) that individuals cannot overcome collective action problems and must have externally enforced rules to achieve their long-term self-interest. However, the zero-contribution thesis contradicts observations of everyday life. Extensive fieldwork has established that individuals from all walks of life and all parts of the world voluntarily organize themselves to gain trade benefits, provide mutual protection against risk, and create and enforce rules that protect natural resources. Successful self-organized resource regimes can initially draw upon locally evolved norms of reciprocity and trustworthiness and the likely presence of local leaders in most community settings (Ostrom, 2000).

Public sector agencies and industry associations have attempted to sponsor and support the facilitation of horizontal logistics collaboration projects over the past 20 years. However, the literature has yet to reveal that these efforts have largely failed. The worst-case scenario is when outside parties impose rules but achieve only weak control and enforcement. With strong outside control and enforcement, cooperation is enforced without needing internal norms to develop. In a scenario lacking rules or monitoring, norms can evolve to support cooperation. However, in a middle-ground state, a mild level of outside control discourages the formation of social norms while also making it possible for some participants to deceive and defect with a relatively low risk of consequences (Sternberg et al., 2022).

Shipper HLCs fails because shippers are not convinced of the benefits; sponsors and facilitators choose unsuitable shippers (such as shippers that do not have resources to pool); shippers lack self-determination; sponsors choose unsuitable facilitators (who are unable to facilitate pooling as intended); goals conflict; and projects lack control mechanisms. Sometimes, moral hazards are associated (Sternberg et al., 2022).

In order to be able to form sustainable freight communities towards the PI it is worth implementing the results of previous analogue field studies. Resource regimes that have flourished over multiple generations tend to be characterized by the following design principles (Ostrom, 2000):

1) Clear boundary rules enable participants to know who is in and out of a defined set of relationships and, thus, with whom to cooperate.
2) The local rules-in-use restrict the amount, timing, and technology of harvesting the resource, allocate benefits proportional to required inputs, and are crafted to consider local conditions. If some users get all the benefits and pay a few of the costs, others become unwilling to follow rules over time.
3) Individuals affected by a resource regime can participate in making and modifying their rules.
4) Most long-surviving resource regimes select their monitors, who are accountable to the users or users themselves, and who monitor resource conditions and user behavior.
5) Long-life surviving resource regimes use graduated sanctions that depend on the seriousness and context of the offense.
6) Access to rapid, low-cost local arenas is needed for open collaboration to resolve conflict among users or between users and officials by devising simple, local mechanisms to get conflicts aired immediately and resolutions that are generally known in the community, the number of conflicts that reduce trust can be reduced.
7) The capability of local users to develop an ever-more effective regime over time is affected by whether they have minimal recognition of the right to organize by a national or local government. Unanimity as a decision rule for changing rules imposes high transaction costs and prevents a group from searching for better-matched rules at relatively lower costs. Users frequently devise their own rules without creating formal governmental

jurisdictions. As long as external governmental officials give at least minimal recognition of the legitimacy of such rules, the community members may be able to enforce the rules. However, if external governmental officials presume that only they can make authoritative rules, then it is difficult for local users to sustain a self-organized regime.

8) When common pool resources are somewhat larger, governance activities organized in multiple nested enterprise layers are inevitable. Consequently, among long-enduring self-governed regimes, smaller-scale organizations tend to be nested in ever-larger organizations.

4. KEY FACTORS IN INVOLVING FREIGHT ACTORS IN DIGITALISED INTERMODAL COOPERATION

The initiation of forming freight data communities -by exploiting the synergies between supply chain actors and transport operators- will ultimately increase the currently low transport capacity utilization; thus -if not the speed of individual goods- the speed of all goods will significantly increase. The necessity of the transition -like the processes of global economic transformation or the challenges of climate change- has not yet necessarily exceeded the stimulus threshold of all actors in the supply chain. However, it is precisely the untenable situation of the critical actors that forces it (both long-distance road transport and urban goods transport system case) (Szander et al., 2023).

Beyond that, the broad involvement of small and large companies in the collaboration along logistics nodes and networks is essential to achieve common goals, as well as individual efficiency and profit. (To express that in addition to the competition of the actors, their cooperative attitude is also needed -supporting each other to achieve the individual goals- the majority of the authors use the word “coopetition”. In the CPR situations we examined related to PI, “collapetition” is much more recommended since collaboration means joint action to achieve common goals).

Based on previous research in social sciences, we can conclude that governance activities need to be organized in multiple layers of nested enterprises for the success of the PI systems. In order to ensure the success of the governance model, it is worthwhile to address the freight companies in the early stages of development and, in cooperation with them, create the interfaces along which the complex management task can be implemented.

To define the possible layers of collaboration, there is a need to widen the approach of current bottom-up and top-down governance formulation scenarios (formed based on which actor has the power to initiate and exercise influence) and place more emphasis on the nature of the collaborative supply chains related to the contradictions described in the context of CPRs.

A few of the possible partnership layers of freight actors in PI systems are based on:

- the time-sensitivity of the supply chain they are interacting with or the product families they are transporting (BU-GOV-TS where TS is time-sensitivity)
- the frequency of shipments or warehousing activities, with consideration of seasonality issues (BU-GOV-FQ where FQ is the frequency of shipments)
- the specialty of loading-unloading and storage tasks (considering unit sizes, SKU-s, and level of automation) (BU-GOV-LS where LS is loading-unloading and storage)
- the info-communication, material handling, green and other technologies, and innovative solutions they prefer (BU-GOV-TY where TY is technology)
- the spatial distribution of their tasks (complementary, auxiliary, extender) (BU-GOV-SP where SP is spatial distribution)
- the local environment, they have certain –special- tacit knowledge to operate (BU-GOV-LO where LO is locality)
- the utilization of human resources and workforce (BU-GOV-HR where HR is Human resources)
- and many other factors only the actors themselves can explore.

The quadruple helix model (recommended by ALICE, 2020) seems to be feasible for such collaborations, as it invites companies (supply chain partners, manufacturers, producers, distributors, freight, and logistics companies), governmental actors (national and local authorities, official coordinators) research and development bodies (academic research and education) and the civil society.

Certainly, there is a need to strengthen the knowledge transfer related to PI and its governance models between attendees in the frame of webinars, online collaboration platforms, social media communities, pilot projects, personal meetings (conferences, workshops, exhibitions, site visits, and observations) and many other forms of dissemination activities. There is a need for further research on the socio-economic aspects of PI developments in surveys, benchmarks, and network research.

Personal issues and relations are highly important to develop PI tools with user-centric design, real-world relevance, smooth implementation, and long-term sustainability. Shipper HLCs -having shippers pool resources and bundle flows- are typically formed spontaneously through personal relationships between the shippers rather than as an effort orchestrated from the outside (McKinnon, 2018). Effective engagement of freight actors throughout the R&D process fosters a sense of ownership, ensures that their needs are met, and increases the likelihood of successfully adopting the developed digital solutions. Combining a mix of these strategies allows for a well-rounded approach to gathering insights and involving stakeholders in creating solutions that truly address their challenges.

5. CONCLUSION

The transition towards an efficient, resilient, and sustainable freight and logistics system (PI) requires a new approach for all stakeholders, the authorities, state and local government actors, the partners who use the service, and the service providers. The most important element of this is the strengthening of awareness in the choice of the supply chain strategy, in the design and operation of a system that integrates sustainable and resilient multi-stage distribution and environmentally friendly, alternative drive vehicles, as well as in the management and governance of shared information, as common pool resources.

The active contribution of PI partners in broad and voluntary information sharing is an essential part of these systems to operate and survive. Most of all, partners involved must understand and accept that the previously (in the present or past) critical success factor, the exclusive management of the flow of goods and information between the sender and the recipient, has been replaced by the operational excellence (service excellence) factor between distribution stations and steps in the PI systems.

Managing common pool resources in PI systems is challenging due to the opportunistic behavior of individuals and the prerequisite of maintaining visibility and transparency. While existing research in PI focuses mainly on mathematical or simulation models of potential gains rather than on implementing the promising complex PI system, some models and solutions exist in socio-economics studies to solve the contradictions.

There is a need to extend the research of freight data communities with a broad analysis of success stories considering the proposed approaches of this paper (TRIZ methodology, Roadmap analysis, CPR Research, etc.). Future research is also needed to explore the organizational factors influencing the adaptation of the physical internet and propose policy frameworks for encouraging data sharing among freight actors.

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ABSTRACTS

TRAFFIC FORECASTING FOR DYNAMIC ROUTE SCHEDULING

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Abstract

The distribution of goods in cities is one of the main sources of energy consumption and air pollution. Most routing solutions are designed to address common transportation problems but not to supply a specific group of food items. The supply of fresh food places new demands on e-grocery solutions. The specificity of the supply of fresh food is based on the fact that the products are delivered in small quantities to several delivery points. However, this is contrary to the principles of sustainability. An analysis of the scientific literature has revealed that more research is needed into food quality assessment and route planning taking into consideration sustainability and resilience aspects. The aim of this is to develop a dynamic route planning methodology for sustainable delivery of fresh food. The development of the methodology is based on dynamic route planning methods. This presentation focuses on traffic forecasting aspect of the recommended approach. The analysis tested various deep learning techniques to estimate traffic flow patterns in Vilnius. The analysis compared multiple features, missing value analysis and time horizon accuracy.

Keywords: Traffic Forecasting; Dynamic Route Scheduling; Sustainability; Fresh Food Delivery; Deep Learning