

LOGISTICS 4.0 IN WAREHOUSING – CURRENT STATE AND TRENDS

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Abstract

The aim of the article is to analyse the state of advancement of the Logistics 4.0 concept from the perspective of science and practice – evaluation of the current situation and the main trends for its development in warehousing. In the theoretical part, a systematic review of the literature was carried out – the subject of the bibliographic analysis were scientific articles indexed in the Scopus and Web of Science databases. The aim of the theoretical part is to identify key topics, people, research centres, countries, fields of science and journals – important for the development of Logistics 4.0. In the practical part the characteristics of the PROMAG case study – a fully autonomous and automatic AutoMAG Mover storage system – are presented, illustrating the main area of global interest within the framework of warehouse intralogistics 4.0. The aim of the practical part is to show the advancement of the Logistics 4.0 application in warehouses.

Logistics 4.0 is most often located in the following fields: Engineering and Computer Science. This shows that Logistics 4.0 deals very much with modern technical and technological issues. Evidently there is a strong trend towards autonomous and automatic functioning of facilities in the storage area. Within Logistics 4.0 two distinct trends of interest can be distinguished: processual and technical – technological.

The analysis of the state of knowledge in the field of Logistics 4.0 is based on articles from two scientific databases – Scopus and Web of Science. The key area of interest in intralogistics 4.0 is illustrated by one selected example. In the future, the author plans to expand and deepen the analysis of articles dedicated to Logistics 4.0 (new sources) and carry out surveys on Logistics 4.0 among Polish intralogistics companies. The digitization of warehouse intralogistics 4.0 implies the need to change the roles and tasks of people operating in this area. It creates both threats and opportunities for employers and employees.

Keywords: Logistics 4.0, Industry 4.0, systematic literature review, Scopus, Web of Science, warehousing, storage systems, autonomy, automatization, case study

1. INTRODUCTION

In the era of the 4th industrial revolution, against the backdrop of broadly understood digitalization, the transformation of business logic is taking place. Its visible manifestation in the organization of processes is the increase of their autonomy through the wide application of automation. A typical element for Industry 4.0 and Logistics 4.0 is putting modern informatics and information technologies into practice. Contemporary warehouse intralogistics 4.0 is based primarily on artificial intelligence and technological equipment. The functioning of Industry 4.0 is not possible without complementary existence next to Logistics 4.0. An intelligent factory indisputably needs an intelligent warehouse.

The Industry 4.0 stream, whose beginnings go back to 2011, has for several years been the area in which strictly logistic issues are also discussed – Industry 4.0 inclusive of Logistics 4.0. Since 2015, however, we have been able to observe progressive autonomy of Logistics 4.0 – its formal release as a separate thematic stream. The subject of interest of this article is generally Logistics 4.0, in particular warehouse intralogistics 4.0, at the intersection of science (articles from Scopus and Web of Science databases) and practice (case study – the AutoMAG Mover warehousing system by the PROMAG company). As of now, Scopus and Web of Science databases do not contain many publications on this subject – hence the list of references in this article is so short. Logistics 4.0, however, is an evolving topic and apart from Scopus and Web of Science databases, much more about this subject is being published in other sources (e.g. Google Scholar).

The research problem of the article focuses on assessing the advancement of Logistics 4.0 in the warehouse logistics system. The aim of the article is to analyse the state of advancement of the Logistics 4.0 concept from the perspective of science and practice – evaluation of the current situation and the main trends for its development in warehousing. The aim of the theoretical part is to identify key topics, people, research centres, countries, fields of science and journals – important for the development of Logistics 4.0. The aim of the practical part is to show the advancement of the Logistics 4.0 application in warehouses. In the article, the author performed the theoretical meta analysis of the Logistics 4.0 concept (Scopus and Web of Science databases) and presented a practical solution in this area from the Polish market (case study).

The paper is organized as follows: section 1 – introduction (research problem, goals – general, theoretical, practical), section 2 – state of Logistics 4.0 in scientific literature (Scopus and Web of Science databases); section 3 – subject of research (PROMAG S.A. company); section 4 – case study (autonomous automatic warehouse AutoMAG Mover system); section 5 – general conclusion (summary).

2. STATE OF LOGISTICS 4.0 IN SCIENTIFIC LITERATURE

2.1. Logistics 4.0 in the Scopus Database

Based on the search criterion “logistics 4.0” as of 1.12.2018, only 20 potential articles were identified in the Scopus database that have this term in their title, abstract or keywords. Further analysis of 19 articles was conducted (one article was excluded – accidental hit, an article from before the establishment of the term Logistics 4.0).

The distribution of the number of articles about Logistics 4.0 is as follows: 2015 – 1, 2016 – 3, 2017 – 3, 2018 – 9, 2019 – 3. The most cited authors are: Polak-Sopinska A., Wisniewski Z., Wrobel-Lachowska M. – 4 articles each. The most important research centres where the concept of Logistics 4.0 is discussed are: Lodz University of Technology (4 affiliations) and Otto von Guericke University of Magdeburg (2 affiliations). From the national perspective, Logistics 4.0 first of all is discussed in: Poland (6 articles) and Germany (5 articles). Logistics 4.0 is most often located in the following fields: Engineering (12 articles), Computer Science (10 articles), Social Sciences (6 articles), Business Management and Accounting (4 articles), Mathematics (4 articles). Publications about Logistics 4.0 mostly take the form of conference papers (10 articles) or articles (7 articles). They are usually placed in journals (7 articles), as book series (7 articles) and conference proceedings (5 articles). The most important titles in the Logistics 4.0 topic are: *Advances in Intelligent Systems and Computing* (5 articles), *Journal of Applied Engineering Science* (2 articles) and *Proceedings, GOL’2018: International Conference On Logistics Operations Management* (2 articles). Apart from two articles in German, English is the dominant language of publications.

The identified 19 articles cover a broad spectrum of topics related to Logistics 4.0., e.g. they take up the issues of: education and theory of information (a large collection of articles), as well as transport, maintenance, ergonomics (single publications). From the perspective of the subject of this article, publications devoted to the general assumptions of Logistics 4.0 (6 articles) comprise:

1. The framework of Logistics 4.0 Maturity Model (Oleśków-Szłapka & Stachowiak, 2019),
2. Industry 4.0, Logistics 4.0 and materials – Chances and solutions (Glistau & Machado, 2018),
3. Costs of transaction in Logistics 4.0 and influence of innovation networks (Loureiro et al., 2018),
4. Logistics 4.0 and emerging sustainable business models (Strandhagen et al., 2017),
5. Industry 4.0 implications in logistics: an overview (Barreto et al., 2017),
6. Logistics 4.0: The vision of the Internet of Autonomous Things (Hompel & Kerner, 2015).

Oleśków-Szłapka and Stachowiak present the framework of Logistics 4.0 Maturity Model, developed to provide companies with an opportunity to assess the current status with respect to Logistics 4.0 and develop a road map for the improvement process (Oleśków-Szłapka & Stachowiak, 2019). Glistau and Machado – 1 citation – present the overview of important solutions in Industry 4.0 and Logistics 4.0 as two of the most important trends in production and logistics (Glistau &

Machado, 2018). Loureiro, Simões and Cartaxo focus on the reduction of transaction costs through Logistics 4.0 in information systems (Loureiro et al., 2018). Strandhagen, Vallandingham, Fragapane, Strandhagen, Stangeland and Sharma – 3 citations – present current trends in the drive towards Logistics 4.0 as an element of Industry 4.0 (Strandhagen et al., 2017). Barreto, Amaral and Pereira – 7 citations – present reflections regarding adequate requirements and issues enabling organizations to be efficient and fully operational in the Logistics 4.0 context (Barreto et al., 2017). Hompel and Kerner – 6 citations – present the question of changing the paradigm in the fourth industrial revolution according to the vision of Logistics 4.0 (Hompel & Kerner, 2015).

Of the 19 identified articles, only 2 of them are strictly thematically related to warehousing:

1. Technical potentials and challenges within internal Logistics 4.0 (Schmidtke et al., 2018),
2. Proceedings, GOL'2018: the 4th IEEE International Conference on Logistics Operations Management (GOL, 2018).

Schmidtke, Behrendt, Thater and Meixner present the impacts of changes on the logistics sector within Industry 4.0 as well as on technical potentials for internal logistics (Schmidtke et al., 2018). Proceedings, GOL present technical potentials and challenges within internal Logistics 4.0 (GOL, 2018).

In the literature query, attention was also drawn to three other articles, which although are not directly related to warehousing, may have significance for this field of logistics:

1. Ethanol loading and dispatch operation: A discussion on management practices and Logistics 4.0 (Jacintho et al., 2018),
2. The development of telematics in the context of the concepts of “Industry 4.0” and “Logistics 4.0” (Bujak, 2018),
3. Logistics 4.0 – A challenge for simulation (Timm & Lorig, 2016).

Jacintho, Da Silva, Do Nascimento, Poveda, Cevoli and Ribeiro present a new model of loading and dispatch operation of an ethanol plant based on management within Logistics 4.0 (Jacintho et al., 2018). Bujak indicates trends and directions of changes in the implementation of the latest telematics solutions (Bujak, 2018). Timm and Lorig discuss two integrating approaches to simulate decision makers and logistic processes in the context of Logistics 4.0 [Timm & Lorig, 2016).

2.2. Logistics 4.0 in the Web of Science Database

Based on the search criterion “logistics 4.0” as of 1.12.2018, only 7 potential articles were identified in the Web of Science database that have this term in their title, abstract or keywords. All 7 articles were analysed further: 5 articles are the same articles that appeared earlier in the Scopus database, 2 articles are new – they are only available in the Web of Science database.

The distribution of the number of articles about Logistics 4.0 is as follows: 2015 – 1, 2016 – 1, 2017 – 2, 2018 – 3. The most cited authors are: Polak-Sopinska A., Wisniewski Z., Wrobel-Lachowska M. – 2 articles each. The most important research centres where the concept of Logistics 4.0 is discussed are: Lodz University of Technology and Norwegian University of Science and Technology – 2 affiliations

each. From the national perspective, Logistics 4.0 first of all is discussed in: Germany (3 articles), Norway (2 articles) and Poland (2 articles). Logistics 4.0 is most often located in the following fields: Engineering (3 articles), Computer Science (2 articles), Operations Research Management Science (2 articles). Publications about Logistics 4.0 most often take the form of proceedings papers (6 articles), the form of articles is rare (1 article). The most important title in the Logistics 4.0 topic is Advances in Intelligent Systems and Computing (2 articles). All 7 articles are published in English.

Of the 7 identified articles related to Logistics 4.0, the subject of education and theory of information dominates (which is not the matter of interest for this article). From general papers devoted to the concept of Logistics 4.0, the article entitled “Logistics 4.0 and emerging sustainable business models” (Strandhagen et al., 2017) – 1 citation – is repeated. Among the papers related specifically to warehousing, the article entitled “Technical potentials and challenges within internal logistics 4.0” (Schmidtke et al., 2018) is repeated – this is the only paper in the Web of Science database that deals with the subject matter of logistics within the framework of Logistics 4.0. Other papers, although not directly related to warehousing, may have significance for this field of logistics. The article entitled “Logistics 4.0 – A challenge for simulation” (Timm & Lorig, 2016) – 1 citation – is repeated.

In the context of the subject of this article, among the two new papers (appearing only in the Web of Science database), the article by Wang – Logistics 4.0 Solution New Challenges and Opportunities (Wang, 2016) – draws attention. Wang presents the outline of the vision of “Logistics 4.0” – the definition and proposition of some basic technical components of Logistics 4.0 with two laboratory cases how to implement the technologies in Logistics 4.0 (Wang, 2016). The second of the new papers concerns education (no relation to the subject of this article).

2.3. Logistics 4.0 in the Industry 4.0 stream in the Scopus and Web of Science Database

In connection with the resulting low number of identified articles devoted to Logistics 4.0, the author decided to carry out a preliminary, broader literature search. The search was also conducted on 1.12.2018 and consisted in an attempt to specify the defined criteria in titles, abstracts or keywords. The adopted search criteria included: 1 – “logistics*”, 2 – “warehouse*”, 3 – “industry 4.0”. The results of the literature search are presented in Table 1.

Table 1. Number of articles dedicated to logistics (1), warehousing (2) and Industry 4.0 (3) – compilation based on the Scopus Database and the Web of Science Database

Query	Scopus	Web of Science
1	451 590	325 151
2	31 264	16 748
3	3 526	2 157
1 + 2	3 435	1 907
1 + 3	187	130
2 + 3	35	29
1 + 2 + 3	17	12

Source: own study

It has been observed that logistic issues, thematically related to warehousing, are also indexed within the Industry 4.0 term (as a historically earlier concept). Thus, Logistics 4.0 (although not mentioned directly from the label) also has its great achievements within the Industry 4.0 stream. Therefore, a more thorough search was carried out on 10 April 2019 by specifying the defined criteria in titles, abstracts and keywords. The adopted search criteria included: “warehouse*” and “industry 4.0”. The results of the literature search are presented in Table 2.

Table 2. Literature trends about warehousing within the Industry 4.0 stream based on the Scopus Database

Topics / Year	19	18	17	16	15	14	13
robots	1	8					
RFID	1	3	2		1		1
modelling, optimization, simulation	1	3	1			1	
cyber physical systems		2	3	1			
data warehouse		3	2				
Big Data	1	2			1		
autonomous vehicles		1	2		1		
Internet of Things		1	2	1			
multi agent systems	1	1	1				
general, concept		2		1			

Source: own study

Based on 52 articles, warehouse intralogistics 4.0 is shaped by several trends, with two being predominant: robotics and RFID (Table 2). The analysis of the publication points out that within the scope of warehouse intralogistics 4.0, special interest focuses primarily on the possibilities offered by solutions related to autonomous automatization. For this reason, in the next practical part of this article, a case study of the automatization of warehouse processes will be discussed in detail, which shows the implementation of the concept of Logistics 4.0 in practice.

3. CHARACTERISTICS OF PROMAG S.A.

The subject of the case study is a company PROMAG S.A. (<https://promag.pl>, 07.12.2018), which has been operating on the market since 1982. For over 30 years, by combining extensive experience with modern solutions, PROMAG has been setting standards in Polish internal logistics. The mission of PROMAG is “to be an advisor and preferred business partner for our customers in the field of comprehensive warehouse equipment”. The vision of PROMAG is contained in the following words: “to optimize our customers’ warehouse space according to the most recent technical achievements in order to make it safe, ergonomic and efficient”.

The structure of the PROMAG company consists of: headquarters in Poznań, 10 customer service branches in Poland (Bydgoszcz, Bytom, Gdańsk, Kraków, Lublin, Łódź, Poznań, Szczecin, Warszawa, Wrocław), e-commerce sales via the online store www.e-promag.pl, a logistics centre with the area of 24 thousand square metres in

Koninko near Poznań, own production facilities with the area of 13 thousand square metres in Bolechowo near Poznań.

PROMAG, as a producer and integrator of comprehensive warehouse equipment, supports clients in the field of internal logistics by: logistics audit, technical consultancy, measurements and design, integration and production of storage systems and internal transport equipment, delivery and assembly of offered systems, notification of equipment to UDT, service and inspections, training in safe work in the warehouse.

The PROMAG offer is comprehensive and includes: automatic storage and transport systems in the warehouse, racks, forklifts, hoisting equipment, loading systems, packaging equipment, metal furniture, complementary storage equipment.

PROMAG actively supports the development of Polish intralogistics. In 2015 a cyclical forum “WAREHOUSE OF THE FUTURE” was initiated. The leading topics have so far been: “Warehouse of the future – how to reduce the costs of your business?”, “The future of business in the era of automatization and robotization”, “Warehouse 4.0 – digital integration of processes in intralogistics”, “Logistics 4.0 – evolution or revolution in warehouses?”.

In 2015 in Poznań, at the PROMAG Warehouse Technology Centre, which is the only such centre in Poland, a multimedia and practical exhibition “WAREHOUSE OF THE FUTURE” was opened (<https://www.magazyn-przyszlosci.pl>, 07.12.2018). The aim of the exhibition is to present interactively trends and the most modern solutions related to intralogistics. The central part of the exhibition is a fully automated transport line, picking, palletizing and storing in the warehouse where the latest technologies and solutions in the field of robotics and automation and product identification are applied.

A distinctive feature of PROMAG on the Polish intralogistics market is their look into the future, consisting in professional taking into account currently prevailing trends and using modern technologies.

4. CHARACTERISTICS OF THE AUTONOMOUS AUTOMATIC WAREHOUSE AUTOMAG MOVER

The AutoMAG Mover warehouse is a fully autonomous and automatic storage system, a development of semi – automatic dense storage system using AutoMAG Shuttle trolleys with an AutoMAG Mover transfer trolley and AutoMAG Lift vertical conveyors (<https://www.automag-system.pl>, 14.12.2018). The aim of this solution is to completely eliminate forklifts from the goods storage area and increase the efficiency and safety of warehouse processes.

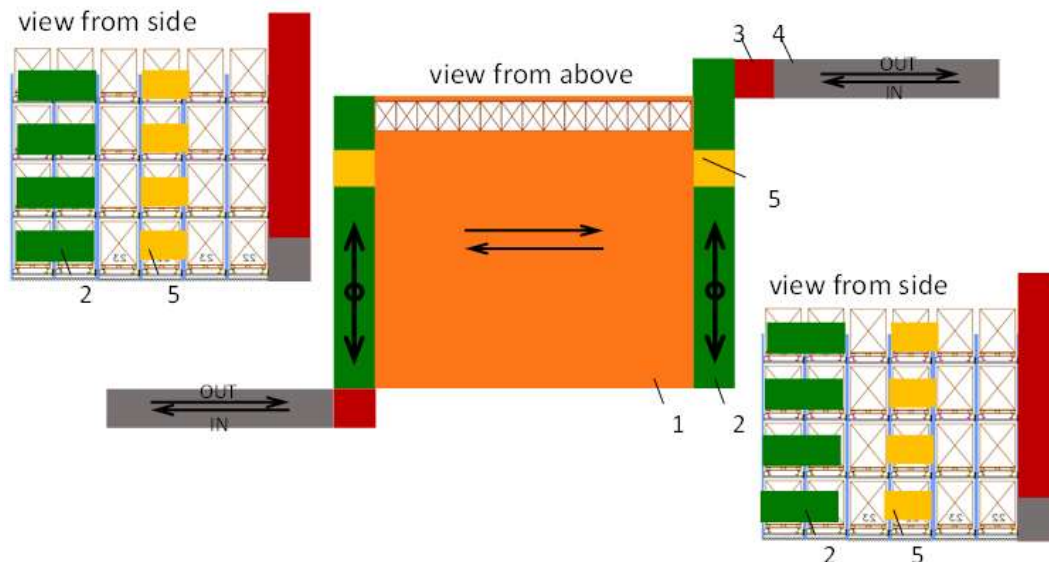
The AutoMAG Mover system works as follows:

- step 1: delivery of a pallet load unit (PLU) to an automated system by a horizontal conveyor,
- step 2: transfer of a PLU from the horizontal conveyor to the AutoMAG Lift vertical conveyor,
- step 3: PLU transport by the AutoMAG Lift vertical conveyor to the required level in the rack block,

- step 4: loading of a PLU on the AutoMAG Mover transfer trolley along the shelf block to achieve the location of the designated rack channel,
- step 5: moving a PLU with the AutoMAG Shuttle trolley to the inside of the rack channel,
- step 6: return of the AutoMAG Mover transfer trolley to the AutoMAG Lift vertical conveyor in order to load the next PLU (steps 5 and 6 cannot be carried out simultaneously, because the AutoMAG Mover is not a pallet carrier, the pallet carrier is the AutoMAG Shuttle; so the AutoMAG Mover can only return for a pallet when the AutoMAG Shuttle is on it; so in step 5 the AutoMAG Shuttle transports the pallet to the rack channel and goes back to the AutoMAG Mover).

The AutoMAG Mover system offers a number of configuration variants. This article presents only two selected solutions: the flow of goods according to the FIFO principle in fast – moving warehouses (Figure 1) and the implementation of the flow of goods according to the LIFO principle for low – capacity warehouses (Figure 2).

Figure 1. Diagram of the flow of goods according to the FIFO principle in fast – moving warehouses

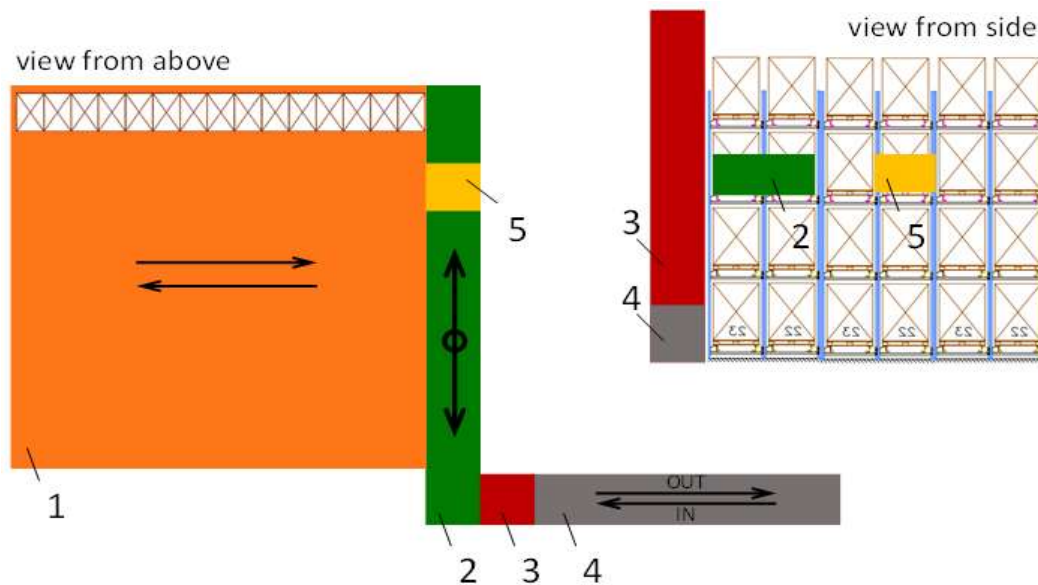


Legend: (1) dense storage shelves, (2) transfer trolley AutoMAG Mover – 1 piece in each level of storage, (3) vertical conveyors AutoMAG Lift – 2 pieces, (4) horizontal conveyor – 2 pieces, (5) shuttle trolley AutoMAG Shuttle – 1 piece in each level of storage.

Source: own study

Regarding Figure 1, when reversible conveyors are used, loading and unloading can take place on both sides of the rack block, but it is more often the case that on one side there is loading and on the other unloading.

Figure 2. Diagram of the flow of goods according to the LIFO principle for low – capacity warehouses



Legend: (1) dense storage shelves, (2) transfer trolley AutoMAG Mover – 1 piece, (3) vertical conveyors AutoMAG Lift – 1 piece, (4) horizontal conveyor – 1 piece, (5) shuttle trolley AutoMAG Shuttle – 1 piece.

Source: own study

In low – capacity warehouses, the platform of the AutoMAG Lift vertical conveyor enables movement between levels in the rack block of not only a pallet load unit but also of the AutoMAG Mover transfer trolley and the AutoMAG Shuttle trolley. While in high – capacity warehouses, vertical conveyors collaborate with the AutoMAG Mover located at each level of storage in the rack block, guaranteeing high efficiency of work. The management of such a system is carried out using the WMS class software.

The main benefits that can be achieved by implementing the AutoMAG Mover system include: total automatization – eliminating forklift trucks from the area of goods storage, the ability to work 24 hours a day, increasing the efficiency of warehouse processes, fast and quiet pallet movement, shortening the time of warehouse operations, reducing fixed costs in warehouses, reducing the average storage cost of a pallet unit, high utilization coefficient of warehouse, constant control and inventory update, increased work safety, elimination of errors resulting from manual warehouse management.

The autonomous AutoMAG Mover system is used in fast and slow – moving warehouses (criterion – throughput), with a relatively small diversified range of goods. The AutoMAG Mover automatic system also works well in cold stores due to the high utilization coefficient of the warehouse volume, which allows to reduce the operating costs of such an object. The AutoMAG Mover system by PROMAG is therefore a flexible, versatile and modular solution.

5. CONCLUSION

At the moment the number of articles devoted to Logistics 4.0 is very small – Scopus (19), Web of Science (7). However, the dynamics of the growth of the number of articles is very rapid (year to year) – Scopus (200%), Web of Science (100%). In correspondence with the number of articles, also the number of citations of articles about Logistics 4.0 is very small – Scopus (8 articles), Web of Science (2 articles). The average citation for Scopus is 3.625 (with a citation range from 1 to 7), for Web of Science 0.429 (with a citation range from 1 to 1). Thus, the broader (number of articles) and more prestigious (number of citations) knowledge base on Logistics 4.0 is Scopus.

The most common practice is to put the “logistics 4.0” term in the title, abstract and keywords (Scopus 10 from 19 articles, Web of Science 4 from 7 articles). From the remaining articles in the Scopus database 1 article has the search term in the title and abstract, 1 in the abstract and keywords, 1 only in the title, 3 only in the abstract, 4 only in keywords. From the remaining articles in the Web of Science database the search term only in the title, only in the abstract or only in the key words, is always included in only 1 of 3 articles. Therefore, the most effective publishing strategy is to put the “logistics 4.0” term wherever possible.

The most cited authors are: Polak-Sopinska A., Wisniewski Z. and Wrobel-Lachowska M. However, their papers concern the educational trend (no direct connection with the subject of this article). Logistics 4.0 is mainly the topic of interest in such countries as: Germany (mainly Otto von Guericke University of Magdeburg), Poland (mainly Lodz University of Technology) and Norway (Norwegian University of Science and Technology). Logistics 4.0 is most often located in the following fields: Engineering and Computer Science. This shows that Logistics 4.0 deals very much with modern technical and technological issues.

As part of Logistics 4.0, warehouse intralogistics enjoys niche interest. As part of the wider Industry 4.0 stream, the interest in Logistics 4.0 focuses primarily on storage systems, especially in terms of their autonomy and automatization. So, most papers about warehousing in Industry 4.0 / Logistics 4.0 present some form of an automated warehouse. In this context, this article presents a case study from the Polish market of warehouse intralogistics 4.0 – an autonomous and automatic storage system AutoMAG Mover by the PROMAG company. There is evidently a strong trend towards autonomous and automatic functioning of facilities in the storage area, as well as more widely throughout the entire warehouse (all areas).

Articles about Logistics 4.0 usually take the form of proceedings or conference papers with English as the dominant language. The leader among journals publishing about Logistics 4.0 is, without a doubt, “Advances in Intelligent Systems and Computing”. Therefore, at the moment the most up-to-date knowledge about Logistics 4.0 can be collected by participating in dedicated conferences.

More extensive knowledge about Logistics 4.0 can be found in other databases of scientific articles (of lower rank) e.g. Google Scholar. The articles e.g. “Logistics 4.0 – a new paradigm or set of known solutions?” (Szymańska et al., 2017), also confirm the existence of a deficit of publications devoted strictly to Logistics 4.0.

To sum up, Logistics 4.0 is a young concept, functioning only for several years. Within Logistics 4.0, two distinct trends of interest can be distinguished: processual – focusing on the organization and efficiency of logistics activities and technical-technological – focusing on providing modern tools that facilitate the physical implementation of the flow of goods. Previous experience of the author of this article with Physical Internet (PI) (Domański et al., 2018) confirms that such a dichotomy is a characteristic feature of new logistic concepts emerging today.

The added value of this article is a summary of the development of Logistics 4.0 at the current stage of its evolution. The literature analysis draws attention to the main topics, trends, people, research centres, countries, fields of science and journals. The analysis of the practice shows that business implementations of Logistics 4.0 are very advanced relative to scientific concepts. In the future, the author plans to deepen the analysis of the articles contained in section 2.3 (Table 2) and conduct surveys on Logistics 4.0 among Polish intralogistics companies.

Automated storage (retrieval) systems have existed since 1970. Therefore, automated systems alone should not be identified as intralogistics (warehouse) 4.0. So what else should Logistics 4.0 contain? There is still no reference definition of Logistics 4.0.

6. ACKNOWLEDGMENT

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