A Survey of Research on Industry 4.0 in Intralogistics

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This paper presents the research, development and application of Industry 4.0 in Intralogistics in the last five years. The progress made in Intralogistics, using Industry 4.0, is presented. An overview of the basic principles and elements of Industry 4.0 as well as its impact in the field of Intralogistics is given. Intralogistics is a field that is still being researched and has great potential for further development. Finally, the aim of this paper is to focus on sustainability parameters, technology and elements that still need to be worked on.

Keywords: Industry 4.0, Intralogistics, Sustainability parameters, technology and elements

1. INTRODUCTION

For humanity, continuous development and progress is necessary in all fields, including industry. Modern societies have higher expectations, so continuous development is essential. Throughout centuries, the industry has developed by applying scientific knowledge and achievements. So far, the industry has gone through four different revolutions:

- 1st Industrial Revolution (Ca. 1750),
- 2nd Industrial Revolution (Ca. 1900),
- Digital Revolution (Ca. 1970),
- Industry 4.0 (today).

The new technology that will be applied in the industry must be sustainable in order to be successful and applicable worldwide. Sustainability and implementation means that economic, social and environmental aspects must be fulfilled. This is possible through further research and better utilization of these aspects and contributions of Industry 4.0 in the field of Intralogistics. Smart intralogistics will lead to increased flexibility and productivity in the future. All possibilities must be taken into account when accepting the changes brought by (Intra) Logistics 4.0.

A certain group of scientific papers, journals and catalogs dealing with this topic was analyzed. These scientific papers provide us with a complete insight into previous research.

The following is an overview of published works in the previous five years (Figure 1), covered by this paper.

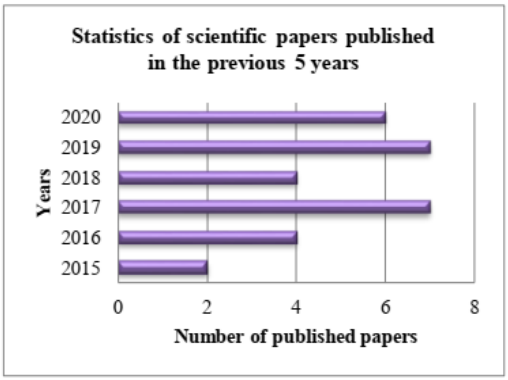

Figure 1: Statistics of scientific papers published in the previous 5 years (which are covered in this paper)

Below is an overview of the countries in which the paper was published, according to the main author (Figure 2). Statistics are given according to papers from references.

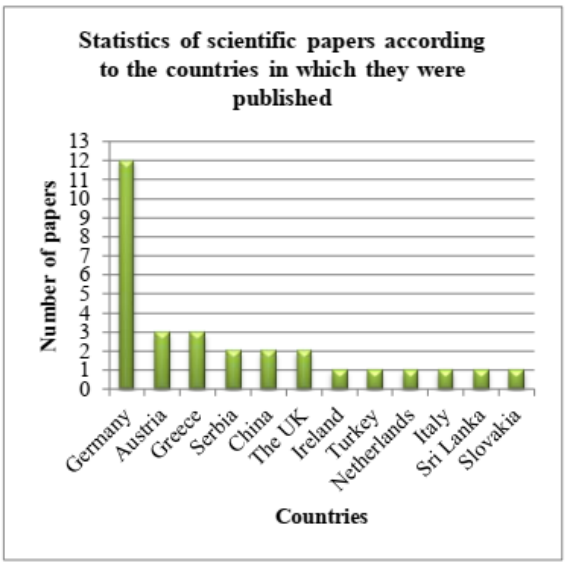

Figure 2: Statistics of scientific papers according to the countries in which they were published

2. INDUSTRY 4.0

Industry 4.0 is coined as the Fourth Industrial Revolution, hence the '4.0'. To understand this terminology, a brief summarization on the earlier three revolutions is necessary (Figure 3).

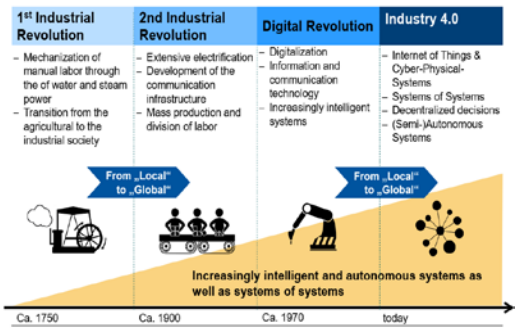

Figure 3: Illustration of Industrial Revolutions (adapted from [2])

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The first Industrial revolution was characterized by the introduction of the steam engine, which provided mechanical motion for labor activities and resulted in the transition from hand production to machine production. The second revolution was characterized by the mobilization of people and information due to improvements of infrastructure facilities as railroads and telephone lines. Technological innovations, as the factory electrification and the development of the production line, enabled mass production. In the Third revolution, the rise of computers and communication systems occurred. [1]

This has improved the collection, processing and analysis of information, as well as enabled automated production.

It should be noted that accelerated development in all fields is yet to come, so expectations for the future are high.

The term Industry 4.0 was first introduced in 2011 in Germany, but in the same time other European countries began to make major changes. Then came the terms "Smart Factory", "Industrial Internet of Things (IIoT)" or "Smart Industry" that we use today.

The concept of Industries 4.0 implies connecting machines, products, systems and people that can share information and manage themselves and each other. In such a model, all objects are smart entities that have the ability to autonomously manage, control and communicate with the environment. Industry 4.0 understands complete automation and digitalization of business systems and their connections with the environment. This leads to the existence of a virtual reality model in which it is possible to monitor and manage all processes and activities. ICT, software applications and information platforms have the biggest role in the concept of Industry 4.0 because they provide connecting the virtual and physical business system. [3]

In [4] the concept of Industry 4.0 is presented using a theoretical framework with the application of technology and its functionality.

The main elements of Industry 4.0 are Cyber-Physical Systems (CPS), Internet of Things (IoT), Industrial Internet (Industrial Internet of Things), Internet of Services (IoS), Cloud Computing, Internet of Energy (IoE), Big Data, Artificial Intelligence (AI), Augmented Reality (AR), 3D printing, Blockchain. Each of these elements is presented in [5].

The Industry 4.0 distinguishes four key principles [1].

- ***Interoperability between cyber physical systems***, which emphasized the collaboration between the different cyber-physical systems via the Internet of Things
- ***Information transparency***, which accentuates the large amounts of data that are processed into information and are shared, in order to establish an open and transparent business environment
- ***Technical assistance to humans***, is providing the user with systems that are able to assist in the performance of complex tasks within for example production activities
- ***Autonomous decision-making of the cyber-physical systems***, through the increasing quality of transparent information available for these systems, and their improving programming, autonomous decision making by cyber physical systems is becoming more developed.

The fields in which the influence of 4.0 Industry may bring improvement [6]:

- **Productivity improvement**: Industry 4.0 provides several improvements such as automation, real-time inventory management, and continuous optimization that lead to productivity enhancement.
- **Increased quality**: ongoing monitoring and control of production allows for improved quality of products and services.
- **Increased flexibility**: with a customer-centric approach, Industry 4.0 allows manufacturing flexibility through automation and robotics.
- **Increased speed**: with enhanced product life cycle management and physical-digital integration, the speed of production is enhanced.
- **Safer and better working conditions**: with increased automation, real-time monitoring of incidents, better-designed workstations, and enhanced work structuring, workers have safer and better working conditions.
- **Improved collaboration**: as the availability of data is enhanced, and digital layer and physical layer are integrated the intra- and inter-organization collaboration is improved.
- **Sustainability**: optimized use of resources, reduction in defects, and other environmental improvements make operations more sustainable.
- **Innovation**: Industry 4.0 leads to new ways of creating value and new forms of employment, for example through downstream services.

3. LOGISTICS 4.0

The term Logistics 4.0 appeared in 2011 within Industry 4.0. Everything within Industry 4.0 related to logistics (Transportation, Warehousing, Packaging, Distribution, Loading/Unloading and Information service) will be now Logistics 4.0.

A feature of Logistics 4.0 is smart process management.

The most important technologies and applications used in Logistics 4.0 are Wireless Sensors Networks, Internet of Things, Automatic Guided Vehicle, 3D Printing, Drones, Cloud Computing, Big Data, Blockchain, Robotics and Automation, Augmented Reality. Each of these elements and technologies is presented in [3]. We can see that there is an overlap of elements in Industry 4.0 with Logistics 4.0, which is logical considering that Logistics 4.0 comes from Industry 4.0.

Table 1 provides an overview of the applied technologies and applications used in Logistics 4.0 as well as the personal impression of the authors on their importance and contribution.

Table 1: The applied technology and the corresponding elements with the sources in which they are processed as well as their use

Technologies and elements	Source	Utilization
Wireless Sensors Networks	[3], [5], [7], [8]	++
Internet of Things	[1], [3], [5], [6], [7], [8], [9], [10], [11]	+++
Automatic Guided Vehicle	[1], [3], [7], [8], [12], [13], [14]	+++
3D Printing	[1], [3], [5], [10], [15]	++
Drones	[3]	n/d
Cloud Computing	[3], [5], [7], [8], [9], [10], [11], [13]	+++
Big Data	[3], [5], [8], [10], [11]	+
Blockchain	[1], [3], [5], [16]	+
Robotics and Automation	[3], [9], [13], [1], [10], [5], [8],	+++
Augmented Reality	[3], [9], [10], [5], [8]	++

Utilization: n/d not enough data yet, + less / bad, ++ moderate, +++ high / excellent

4. INTRALOGISTICS

Intralogistics is a subset of Logistics 4.0. The history of Intralogistics dates back to the immediate post-war period, when economic and industrial development was mainly driven by manufacturing. Transportation at the factory initially relied on simple equipment such as bag carts, other trolleys and overhead cranes. The goods were stored at ground level, as stacking the blocks in height led to poor visibility and accessibility. [17]

Since 1950, Intralogistics has been evolving. In Figure 4, we can see significant features in Intralogistics shown according to years of development.

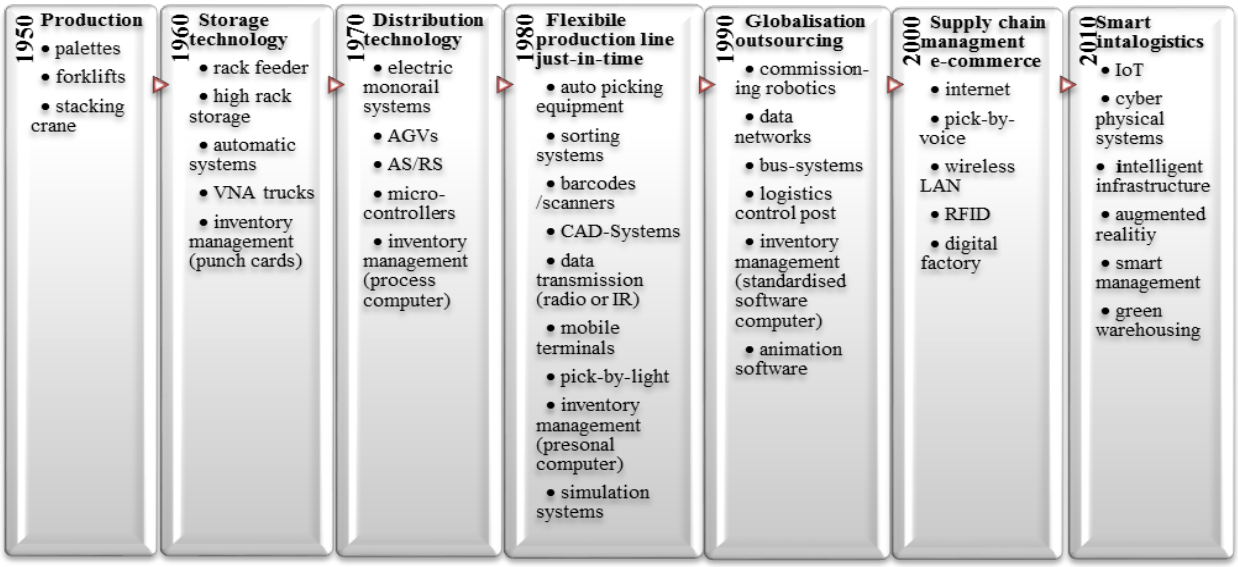

Figure 1: History of Intralogistics (the paper [17] complemented)

Definitions of Intralogistics [18]:

The new term "Intra-Logistics" describes the organization and optimization of internal material flow and logistic technologies as well as the goods transshipment in industry, trade and in public institutions by means of technical components, partial and full systems and services.

- Intralogistics as a brand describes the organization, realization and optimization of internal material flows in industrial and trading companies as well as in public institutions by means of technical systems and services.
- Under “Supply Chain Management”, Intralogistics controls the flow of materials along the entire value chain.
- Intralogistics describes the internal flow of materials between different "logistics hubs" - from the flow of materials in production, distribution centres, airports and seaports - as well as the associated flow of information.
- Intralogistics is part of a trend-setting industry which consists of thousands of companies in in Germany (e.g. from manufacturers of lifting and crane devices, forklifts and storage technology, to

developers and suppliers of complete systems).

Megatrends will determine the development of Intralogistics in the future.

In order to get acquainted with the subject of research and examination in Intralogistics, an overview of the fields with a description and the corresponding reference is given, Table 2.

Table 2: The subject of application in Intralogistics is presented in the papers

Subject of applying	Description	Source
Logistics 4.0 Application and DB Schenker Application Results	• Blockchain • AVs • Electronic market platforms • 3D printing - reduction of storage space • Interview with DB Schenker	[1]
Autonomous mobile robots in smart Intralogistics	• Ability to maintain flexibility • The role of AMR application • Connection, automation and fast information exchange • Comparison of AMR and AGV • Impact of AMR application	[13]
Automated Storage and Retrieval Systems (AS/RS)	• Solution of the collection problem using Shuttle vehicle • Mechanical solutions, technical characteristics, design and specification of Shuttle vehicle • Requirements and problem improvement • Creating a subsystem	[19]
Smart Warehouse	• Better information exchange • Sensors • Wireless communication • New design warehouse and fewer workers • Smart management systems • Efficiency that contributes to reducing mistakes • Opportunities and challenges in Sri Lankan	[20]
Application of AGV and other technologies to increase flexibility	• Flexibility - a variety of assessments, tasks and resources • Assessment and dimensions of flexibility • Application schemes	[21]
Smart Conveyor	• Control of conveyor belts • Conveyor belts as cyber - physical systems • Roller as a source of information • Controller drum drive unit	[22]
Intelligent infrastructure, Sensor system at the forklift truck, Celluveyor - Omnidirectional Cellular Conveyor	• Production combination • Forklifts with tablet • Increasing security • Design and application of Celluveyor - Omnidirectional Cellular Conveyor	[23]
AGVs in industrial environments	• Impact of AGV and increase productivity • Operation plans • AGV Ecosystem • Software for AGV • Proposed layout of the warehouse and the path for the movement of vehicles • Eco-indicators	[24]

As mentioned in the introduction, sustainability will justify the application of Industry 4.0 in Intralogistics. It consists of the following factors: economic, social and environmental aspects (Figure 5).

As already stated, these aspects represent sustainability.

Sustainability should reflect the following:

- **Economic:** An affordable system that works efficiently, offers common solutions, is financially stable and supported. Selects and supports the local economy.
- **Social:** The basic needs of individuals / communities to be met in a safe way and to support good living conditions as well as safety at work, on an equal footing within the collective.
- **Environment:** Reducing the consumption of non-renewable resources, reduced greenhouse gas emissions, as well as taking into account pollution and waste. Use of technology that reuses energy and recycles certain components.

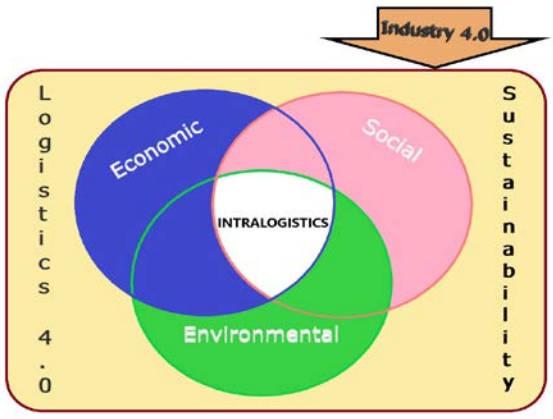

Figure 5: Illustration of interrelationship in Intralogistics

To indicate the importance of sustainability factors in the field of Intralogistics, Table 3 provides an overview of scientific papers in which this factor is (more or less) described.

Table 3: Assessment of fulfilment of Sustainability factors described by papers

Source	Description	Sustainability factors		Level of meeting criteria
[1]	• Reduction of storage space and problematic supply of raw materials in 3D printing • Company DB Schenker efficiency and safety	Economic	✓	+
		Social		/
		Ecological (Environmental)	✓	+
[5]	• Application in various industries • Man-centered management model	Economic	✓	++
		Social	✓	++
		Ecological (Environmental)		/
[6]	• Real-time progress monitoring, enhanced quality and safety, and improved communication between stakeholders is the contribution of the application	Economic	✓	+
		Social	✓	+
		Ecological (Environmental)		+
[10]	• Contributes to Sustainability Factors • Perspective for customers, production, employees • Opportunities, threats and the biggest problems	Economic	✓	+
		Social	✓	++
		Ecological (Environmental)		/
[13]	• Comparison from an economic and technical perspective • Price chart analysis and impact of flexibility and productivity • Direct impact of AMR	Economic	✓	+++
		Social		/
		Ecological (Environmental)		/
[15]	• Industry 4.0 and its impact on ecological sustainability • Resources, Recycling - Extending the product life cycle, 3D printing • Energy – Smart management, Smart Meter • Reduction of costs • Environmental Protection	Economic	✓	++
		Social		/
		Ecological (Environmental)	✓	+++
[17]	• New environmental challenges for ports and terminals • Environmental aspects • Forms of environmental impacts	Economic	✓	+
		Social		/
		Ecological (Environmental)	✓	+++
[21]	• Analysis of the novelty of the method relies in the possibility of evaluating the virtual systems of systems, equipped with the needed functionalities, before its actual development (process requirements, assessing factors: feasibility, development costs, market potential and effective impact on the current processes)	Economic	✓	++
		Social		/
		Ecological (Environmental)		/
[23]	• Intelligent infrastructure • Sensor system at the forklift truck	Economic		/
		Social	✓	+
		Ecological (Environmental)		/
[24]	• Increase productivity and reduce environmental impact • Reduction of energy consumption • Eco - indicators (AGV emission measurement)	Economic	✓	+
		Social		/
		Ecological (Environmental)	✓	+++

[26]	• Smart factory production system opposite Traditional production line • Beneficial Outcomes, Flexibility, Productivity, Resource and Energy Efficiency, Transparency, Promoting Integration, Profitable, Friendly to Staff with application demonstration	Economic	✓	++
		Social	✓	+
		Ecological (Environmental)	✓	+
[27]	• Market offer with faster, safer (less damage) equipment • Safe handling • Optimization of consumption of raw materials, resources, energy • E - sales	Economic	✓	+
		Social	✓	+
		Ecological (Environmental)	✓	+
[28]	• Reduction: transport costs, resources, energy consumption • Green Warehousing • Investments and recommendations • Numerical experiments	Economic	✓	+++
		Social		/
		Ecological (Environmental)	✓	+++
[29]	• Lean management • Supplier factors, Customer factor, Process factors, Control and human factors	Economic		/
		Social	✓	+
		Ecological (Environmental)	✓	+
[30]	• Life cycle assessment of all parts • Climate change • Graphical display of results	Economic		/
		Social		/
		Ecological (Environmental)	✓	+++

Level of fulfillment of criteria: / unexplored, + less/poor, ++ moderate, +++ high/excellent

From the previous table (Table 3) and the mentioned scientific papers, it is noticeable that the economic factor is most represented in as many as thirteen papers, then the environmental factor in ten, while the social factor is represented in seven papers. Thus, it is concluded that the greatest importance was given to the economic factor, while other factors gained less importance. Therefore, we came to the conclusion that it is necessary to identify other factors in order to achieve adequate representation.

The level of fulfilment of the criteria is a personal assessment of the author of this paper and gives us an insight into the importance that the author has given to a certain factor in his work.

5. CONCLUSION

The idea of this paper is to provide an overview of the research, development and application of Industry 4.0 in Intralogistics.

By developing the industry over the years, i.e. centuries, we come to today: Industries 4.0.

In the introduction, the authors give a statistical overview of the processed papers by years and countries of publication, in order to get the best possible impression of the time and places of research that are described. At the beginning we can get acquainted with the origin of Industry 4.0 and its concept.

The most significant elements that define Industry 4.0 at its core are:

- Big Data,
- Smart Factory,
- Cyber Physical Systems,
- Internet of Things (IoT),
- Interoperability.

This paper provides references that deal with each of these elements. Four key principles of development are given, as well as the area of application in which Industry 4.0 can bring improvement.

To understand the concept of Intralogistics, we need to get acquainted with Logistics, of which it is a subset.

In this particular case, Logistics 4.0 (which was created by the implementation of Industry 4.0), has its own technologies and related elements that it applies, Table 1. The given table shows the use of technologies and related elements in the mentioned scientific papers. All of the above technologies and elements must be further developed in the future in order to make progress. Intralogistics has developed gradually, throughout history, in accordance with the development of storage technology, market needs, as well as the needs of distributors and customers (users). That's how ‘Smart Intralogistics’ came about.

In this paper, new definitions of Intralogistics are presented. Emphasis is placed on monitoring megatrends and the current method of application.

In order to better understand mentioned term, a table with paper dealing with the application of "Smart Intralogistics" of its elements and technologies is given, Table 2. We notice that in the last 5 years the list of published scientific papers on a given topic is deficient (30 papers in the period from 2015 to 2020), but also that in recent years that has changed for the better (13 papers in the period from 2019 to 2020). We emphasize what has already been mentioned in Industry 4.0 and what is important for this part: Sustainability.

The factors that make up Sustainability are:

- Economic,
- Social and
- Ecological (Environmental).

Since the paper is based on research, a table is given describing the presence of these significant factors, Table 3.

After processing the collected data, we can conclude that Intralogistics with the application of Industry 4.0 is still in development, not only in practice, but also in scientific research.

In the future, intralogistics will continue to monitor and apply scientific knowledge. This will result in opportunities for improvement during development. Consideration would be reduced not only to a scientific basis, but also to its application in the industry practice.

Countries around the world understand the benefits of switching to "Smart Intralogistics", while countries in the region, including Serbia, will need more time to embrace and implement it.

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