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Logistics Response to the Industry 4.0: the Physical Internet

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Abstract: Today’s mankind and all human activities are constantly changing and evolving in response to changes in technology, social and economic environments and climate. Those changes drive a “new” way of manufacturing industry. That novelty could be described as the organization of production processes based on technology and devices autonomously communicating with each other along the value chain. Decision-makers have to address this novelty (usually named as Industry 4.0) and try to develop appropriate information systems, physical facilities, and different kind of technologies capable of meeting the future needs of economy. As a consequence, there is a need for new paradigms of the way freight is move, store, realize, and supply through the world (logistics system). One of the proposed solutions is the Physical Internet, concept of open global logistics system which completely redefines current supply chain configuration, business models, and value-creation patterns. However, further detailed research on this topic is much needed. This paper aims to provide a balanced review of the variety of views considered among professionals in the field of Physical Internet with the final aim to identify the biggest challenges (technological, societal, business paradigm) of proposed new logistics paradigm as a practical solution in supporting Industry 4.0.

Keywords: logistics efficiency; digitalization; logistics transformation; internet of things

1 Introduction

Maybe the key word of this century is digitalization. Digitalization is present in all spheres of human activities. When it comes to business activities then digitalization is a personification of the concept Industry 4.0. That is, words such as mechanization, electrification and informatization are key words for the first three industrial revolutions respectively, so is digitalization, which includes the use of integrated Cyber-Physical Systems, the key word for the fourth industrial revolution or the Industry 4.0. The term Industry 4.0 refers to a further developmental stage in the organization and management of the entire value chain process involved in manufacturing industry [1–3]. The Industry 4.0 assumes the formation of global networks which shall include product and storage facilities in the form of Cyber-Physical Systems which shall communicate independently, generate and control themselves. Thus improvements in design, production, distribution and exploitation shall be achieved. Every change in the production concept shall have an impact in the form of transformation of all goods, information and financial flows which represent the area of logistics. Logistics function was present in all developing phases of industry and only its purpose has changed (from firstly pure operative and supportive role to the role of strategic tools) as well as modes of realization of its activities. Therefore, as industrial concept was under development so logistics concept was also developing with the main characteristic of constant increase of complexity as the result of increase in requirements of producers for greater efficiency and customers for higher level of service. The current state of overall logistics efficiency is not ideal, and a new concept for logistics organization that challenges current and future industrial practice is needed. The solution could be in a new operational, organizational and management paradigm – the Physical Internet. This concept was first introduced by Professor Benoit Montreuil of Laval University of Quebec, Canada, and central idea is as follows [4, 5]: why not organize logistics activities in an open and shared network rather than in dedicated and specialized networks in a new era of interconnected logistics? This paper aims to pro-
vide a balanced review of the variety of views considered among professionals in the field of Physical Internet with the final aim to identify the biggest challenges (technological, societal, business paradigm) of proposed new logistics paradigm as a practical solution in supporting Industry 4.0.

2 Industry 4.0

2.1 Definition of the term Industry 4.0

The term “Industry 4.0” was initially coined by the German government, and it describes the organization of production processes based on technology and devices autonomously communicating with each other along the value chain [6]. The concept was derived from increase in production computerization where physical structures are integrated into information networks and as such it includes both horizontal and vertical integration of a large number of systems at all levels which lead to “end-to-end” solution (the solution with as less as possible intermediary layers). Vertical integration includes connection and networking of production systems with business processes of all connected participants, and horizontal integration assumes connection of information systems in different phases of production whether within one company or among different companies in a supply chain. These developments make the distinction between industry and services less relevant as digital technologies are connected with industrial products and services forming hybrid products which are neither goods nor services exclusively [6]. The Industry 4.0 is not the only term that appears in the context of increased digitalization, first of all production one, then come the rest of business processes. In [1] it is stated that in the United States and the English-speaking world more generally, some authors also use the terms such as the ‘Internet of Things’, the ‘Internet of Everything’, the ‘Internet of Service’, or the ‘Industrial Internet’. They further state that all of these terms and concepts have in common the recognition that traditional manufacturing and production methods are in the throes of a digital transformation. According to [6] the Internet of Things (IoT) refers to information technology (IT) systems connected to all sub-systems, processes, internal and external objects, supplier and customer networks that communicate and cooperate with each other through big data and cloud computing. It can be said that the Industry 4.0 fits in both IoT and IoS, that is, that it represents their application both in production and service industry as well as that it connects with other smart technologies. Other terms which are often cited in the literature concerned with Industry 4.0 are [6]:

- Industrial Internet, which refers that industrial and the internet revolution come together. The main difference between Industrial Internet and Industry 4.0 is that Industrial Internet goes beyond manufacturing to cover the wider adoption of the web into other forms of activity.
- Cyber-Physical Systems (CPS), which represent online networks of social machines that are organized in a similar way to social networks (they link IT with mechanical and electronic components that then communicate with each other via network). RFID represents early form of this technology, as is stated in [1].
- Smart Factory, term that exemplify some of the technical innovations such as integration of ICT in the production process and how these could play out in practice.

Hence, it could be concluded, like in [1], that all of those concepts together make an environment for Industry 4.0 (Figure 1).

2.2 The characteristics of the Industry 4.0

As it is stated in [6] the main features of Industry 4.0 are: interoperability (CPS allow humans and smart factories to connect and communicate with each other through IoT
and IoT); virtualization (capability to connect physical systems with virtual models and simulations); decentralization (decision making and management are performed independently and parallel in separate subsystems); real-time capability (adjustment with requirements in the real time is the key requirement for any kind of communication, decision making and management of systems in the real world); service orientation; modularity (systems of the Industry 4.0 should be maximally modular and capable for quick changes on the basis of automatic detection of a real situation). In the concept of the Industry 4.0 there are significant changes in relation to traditional technologies in the following elements: product (it comes to product personalization, local production, increase in flexibility with low prices and use of additional technologies); the process (the concept of networked production and formation of clusters which lead to reduction of barriers regarding knowledge and investments and increase in availability to both small and medium companies); business models (fragmentation of value chain occurs which makes possible for small players to become “global” players); competition (wider borders of the system in every respect); skills (essential is interdisciplinary view); globalization (decentralization occurs as well as increased flexibility in the sense of alternatives to the global presence). The main preconditions required for the successful implementation of Industry 4.0 is given by [6], and they are: standardization (of systems, platforms, protocols, connections, etc.), work organization; availability of products, new business models, know-how protections, availability of skilled workers, research, professional development, legal framework.

3 Logistics transformation

One of the main prerequisite for Industry 4.0 is digital transformation. Digitalization has been a major driver of changes throughout the value chain [6], and companies need to drive the digital transformation of their business to succeed in the new environment. According to [7], the five pillars will be critical for this transformation: companies’ ability to build digital capabilities; companies needs to enable collaboration in the ecosystem; managing data as a valuable business asset in the aim to secure crucial control points; companies needs to manage cyber security; and companies needs to implement a two-speed systems/data architecture to differentiate quick-release cycles from mission-critical applications with longer turnaround times [7]. The digital transformation and creation of connected digital single market is also one of the two first priorities for the EU with a view to foster growth, competitiveness, investments and jobs. On that way, use of digital technologies is therefore a priority task and a cross-cutting policy covering all sectors of the economy [8].

In logistics sector, vast amount of data and IT is available that could improve the use of existing resources. It has been already shown in papers [9–12] that some of the benefits that could be achieved through the IT application in logistics are improved analyzing, communicating, designing, understanding, and optimizing. Digitalization of logistics processes leads to “logistics transformation” or to creation of “smart logistics” solutions. Impact and the relationship between digitalization and logistics processes is explained briefly below. Namely, the final result (product) of logistics system is a logistics service. In traditional logistics systems, basic parameters according to which logistics service is selected (from the aspect of end users) are time and price (costs) [13]. However, due to all present globalization, increased competition pressure in the context of environmental protection and energetic efficiency, and initiative for new form of manufacturing industry based on exponential development of modern IT, the end user does not pay attention any more to time and cost only but also to sustainability of a logistics service (from environmental, economic and social aspect). Therefore, transformation of logistics includes changing of context of a “product” of logistics industry from the aspect of end users (Figure 2). Change of “product” context has impact on changes of the way of realization of logistics processes which are most frequently based on application of contemporary IT (digitalization).

On the basis of above stated it is inevitable that in the following period logistics transformation shall occur in the context of changing the way of realization of logistics processes in order to respond to requirements put forward to the logistics system by the new production context – the

![Figure 2: Transformation of context of logistics output (service), developed by authors.](image-url)
Industry 4.0. One of the proposals for direction of logistics transformation is Physical Internet as a completely new paradigm of planning, organizing, achieving and managing logistics processes.

4 The Physical Internet

4.1 Definition of the term Physical Internet

The concept of the Physical Internet (PI), introduced first by Professor Benoit Montreuil of Laval University of Quebec (Canada), is inspired on idea of transferring of metaphor of the (digital) Internet in the way we move, store, handle, realize, supply and use physical objects all around the world. After professor Montreuil, this idea was accepted also by researchers from other institutions worldwide (UQAM University Montreal, MINES Paris Tech, Georgia Tech Atlanta, Virginia Tech, ...), founding the group of more than 20 members and whose work is available publicly on the web page http://physicalinternetinitiative.org. The essence of the concept of PI, made as the result of that the current way physical objects are moved, handled, stored, realized, supplied and used throughout the world is not sustainable economically, environmentally and socially [14], is explained in two basic documents: Physical Internet Manifesto [15], and Physical Internet Principles [16].

What, in fact, PI represents is the most easily and shortly explained with the help of [14], where it is said that PI includes interconnected logistics in the sense of forming an efficient, sustainable, resistant, adaptable and flexible open global logistics web based on physical, digital and operational interconnectivity through world standard encapsulation, interfaces and protocols. The main PI building blocks are new modular load units (named \( \pi \)-containers), new supply chain interfaces: logistics centers (named \( \pi \)-nodes, \( \pi \)-hubs, \( \pi \)-stores, \( \pi \)-distribution centers) equipped with new handling and storage technologies (named \( \pi \)-movers and \( \pi \)-conveyors), and cooperative logistics networks. The general characteristics of all of those elements are “openness” (which means free of use by everyone).

The key word of the PI concept is universal interconnectivity, which should ensure full cooperation among all participants in a supply chain, full compatibility of all applied technical-technological resources and solutions and optimal realization of all operations. The key for establishing the universal interconnectivity is in the IT (digital interconnectivity), then in modular load units and interfaces (physical interconnectivity), and in protocols and procedures (operative interconnectivity). The PI is to transform logistics towards seamless and efficient universal interconnection all logistics networks, enabling users to think and act in terms of open global mobility webs and supply webs [17].

Physical interconnectivity includes forming of appropriate modular units (\( \pi \)-containers), which shall have the characteristic of “smart” ones and which shall enable full usage of load and storage capacities. These load units shall optimally move across logistics networks due to their capability to communicate with each other and with resources for transfer located in the logistics hubs (\( \pi \)-hubs), which is the result of digital interconnectivity. Therefore, digital interconnectivity shall enable encapsulation of goods in world standard „smart” green modular containers with possibilities to communicate between each other and with other elements in PI using all advantage of IoT (Figure 3). Operative interconnectivity includes application of certain protocols and procedures for defining domains and priorities when using information in planning, realization and management of modular units load flows.

Therefore, the PI exploits as best as possible the capabilities of smart \( \pi \)-containers connected to the Digital Internet and the World Wide Web, and of their embedded smart objects, where each \( \pi \)-containers has a unique worldwide identifier and smart tag as an element of the IoT [18]. The PI will try to use as best as possible the IoT to enable the ubiquitous connectivity of its \( \pi \)-containers and other \( \pi \)-systems (such as \( \pi \)-movers, \( \pi \)-hubs, etc.). However, the PI is a complex vision which assumes and involves the great technological changes. Because of that, paper [18] stated importance of understanding that the widespread development and deployment of this concept will not be achieved overnight in a Big-Bang logic, but
rather in an ongoing logic of cohabitation and progressive deployment.

4.2 A short review of theoretical and practical approaches, and main challenges

In text below a short review of papers and practical approaches to implementation of PI concepts is given. After that, and according performed review, a main challenge in further development and implementation of the PI concepts is identified.

In order to collect articles published in conference proceedings, journals and respected books and dissertation on the topic of the PI the short literature review has been conducted. After performing searching activities, about 40 papers were identified and for most of them full text version was collected. The biggest part of collected papers is published in proceedings and monographs regard several conferences. Only several papers are published in peer-reviewed journals which can be explained by novelty of the PI concepts. The main topics explored in identified papers are connected with the main building blocks of the PI concepts: \( \pi \)-containers, \( \pi \)-hubs and logistics web. The key enabler of the PI - \( \pi \)-containers is research topic in papers such as [2, 18, 19], and [20]. In all of those papers the key challenges regards \( \pi \)-containers are: sizing, design (from physical and information aspects) and problem of loading. The work of defining the precise sizes is to be of utmost importance [2]. Next key research issue is \( \pi \)-hubs, which is explored in detail in papers such as [21–24]. Logistics web as an interconnected open logistics network is researched in detail in papers such as [17, 25], and [26]. Generally, all of those papers explore how supply chain might work in a Physical Internet with standardized containers and a sharing of trailers and other resources across a network of facilities. The implementation of the PI concept can't happen over the night. As it have already stated in [18], there needs to be a smooth gradual transition starting with more strategic decision and planning phases, then moving toward more intensive and transformative phases. The PI can constitute itself progressively through the multi-level certification of: protocols, containers, handling and storage technologies, distribution centers and hubs, information systems, urban zones and regions, and inter-country borders [18]. From more practical point of view, project MODULISHA works on development a conceptual model for interconnected logistics. Key ideas will be the integration of the ISO modular logistics units into existing handling processes. In addition, this project addresses several issues to limit transaction costs by means of enhanced and standardized IT and planning approaches.

The PI has some advantages, and requires answers and solutions for different topics. As the main advantage of the proposed concept of PI could be creation and existence of an comprehensive framework which enables the great possibilities in connecting current research activities with the PI goals. It means that all logistics project could be more effective and efficient in situation that all of them have one main final aim-creating the PI. Hence, the PI could be a framework for enabling more consistent approaches for solving logistics issues. The biggest challenge of the PI concept could be awareness of “transfer of metaphor of Digital Internet”. Every characteristic of the PI needs to be further researched [18], and those researches could be divided on three levels:

- **Physical level** – due to the reason that major changes are expected to be in physical infrastructure, solving this kind of problem is first challenge. One of the issues which have to be solved is the problem of sizing and designing elements of physical infrastructures: \( \pi \)-containers, \( \pi \)-movers, \( \pi \)-nodes.
- **Information level** – the main challenge is how to make physical object smart at most efficient way. Future research should be focused on the strategic role of communications and information technology and its alignment with new business models.
- **Business level** – the PI redefines supply chain configuration, business models, and value-creation patterns, so the first step will be solving the problem with creations of new business models. Also, one of the questions could be how to measure performance of proposed new business models for the PI?

Probably the first challenge will be the final solution for standard size and design of \( \pi \)-containers, because there are a lot misalignments with the current system of load units such as pallets and ISO containers. What could be problematic is current logic used for defining \( \pi \)-containers. In analysis performed in reviewed papers, the starting position for defining standard size of \( \pi \)-containers is size of items (products). Maybe, the more logical solution will be to start from some bigger transport unit, such as ISO container or trailer?

5 Conclusion

The mission of this paper is initiation of wider research engagement on topic of the PI and its connection to the
concept of Industry 4.0. Industry 4.0 requires answers and solutions for different topics: man and labor, business and strategy examples, how to handle the data-overflow, cyber-security, standard and interoperability, medium sized businesses and users, etc. Industry 4.0 requires also a quite new organization of logistics activity, because the current is not in ideal state, which will support integration of services and freights. From that point of view, the PI concept could be appropriate solution. On other side, the PI cannot be realized without the widespread participation of industry, because large investments into loading units, handling and transportation assets is needed in order to achieve a critical mass of users. The both Industry 4.0 and the PI are complex systems which assumes and involves the great technological and business environment changes. It could be concluded, that those concepts are future and their further development will be gradual and in cohabitation.

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