Exploring the Role of Industry 4.0 on Global Logistics: Challenges in Big Data and IoT

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***Abstract*—The globalization of the economy and consumers' increasing demand for customized products have led to a rise in the complexity of global logistics chains. In response to these challenges, the integration of logistics with the Internet of Things (IoT) and Big Data, known as Logistics 4.0, offers opportunities for more efficient planning, control, and adaptation of logistics processes. Industry 4.0, with its emphasis on IoT and Big Data analytics, significantly influences the logistics sector, making it a pioneer in the digital transformation of the entire economy. This paper seeks to review and analyze the role and impacts of Industry 4.0 on global logistics, while also addressing the main challenges related to IT security, data protection, and successful implementation of Big Data Analytics in the supply chain. Additionally, it aims to explore the changes in work systems within companies due to digital transformation in logistics.**

Keywords—Industry 4.0, Internet of Things (IoT), Big Data Analytics (BDA), Logistics 4.0, Cyber-Physical Systems, Cloud Computing

I. INTRODUCTION

The increasing complexity of global logistics makes it increasingly difficult to combine a flow of goods with the associated flow of information. But the central prerequisite for well-functioning logistics is the synchronicity of material and information flows [1]. With the Internet of Things (IoT), it is now possible to identify objects and observe them along the entire supply chain. Every object is always localizable and can provide both historical data and data in real-time. This generates a whole new dimension of data, so-called Big Data. As defined by many researchers, IoT and the generation and analysis of Big Bata are the central technologies of the fourth industrial revolution, Industry 4.0 [2].

The merging of the physical and digital world in logistics through the IoT opens the potential for increasing efficiency, optimising the performance of systems and processes, as well as for automated decision-making based on Big Data Analytics (BDA). If implemented successfully, both companies and consumers can benefit from this Logistics 4.0. In this regard, this paper examines the role and impact of Industry 4.0 on Global Logistics and the challenges that Logistics 4.0 must overcome.

II. LITERATURE STUDIES

The literature review of the paper focuses on the critical aspects of the role and impacts of Industry 4.0 on Global Logistics. To ensure the quality of the research process, several publications have been analysed with keywords such as 'Industry 4.0', 'Internet of Things (IoT)', 'Big Data Analytics (BDA)', 'Logistics 4.0', 'Cloud Computing', 'Cyber-Physical Systems'.

A. Logistics 4.0 as an application domain of Industry 4.0

Industry 4.0 is directly related to the digitalisation of industrial production. To understand this fourth industrial revolution, it is helpful first to look at the past three industrial revolutions. The four industrial revolutions are concisely summarised in Figure 1.

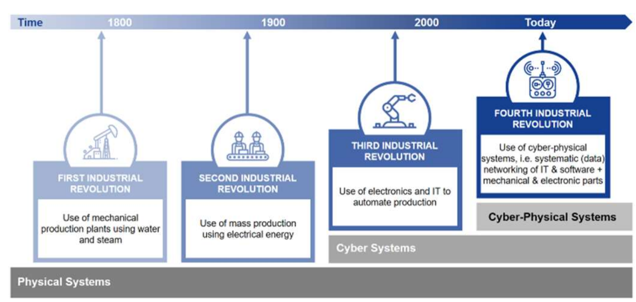

Fig. 1. Development from Industry 1.0 to Industry 4.0 [3].

The invention of the steam engine is seen as the trigger for the first industrialisation. The discovery and economical use of petroleum, the invention of the combustion engine and the utilisation of electricity made the use of assembly lines for mass production possible from the beginning of the 20th century and thus triggered the second industrialisation. Around the middle of the 20th century, the third industrial revolution started, which meant an automation of the production. This was caused by information technology (IT). The fourth industrial revolution is currently underway when it was triggered by the networking of physical things, which is known as the Internet of Things. With this, these things become data carriers. By integrating software and digital components, data can not only be generated and collected but also transmitted and analysed. These large amounts of data are referred to as Big Data. On the way from the first industrial revolution to Industry 4.0, logistics took on similar developments to production. This is shown in Table 1.

TABLE I. Development Stages of Production and Logistics.

	Industry 1.0/2.0	Industry 3.0	Industry 4.0
Supersystem	Analogue Communication	Internet and Intranet	Internet of Things
System	Neo-Taylorism	Lean Production Lean Logistics	Smart Factory Cognitive Logistics
Subsystem	Mechanisation	Automation	Virtualisation

Logistics 4.0 is based on the comprehensive networking of physical objects and the creation of a digital image of the real processes [4]. Accordingly, Logistics 4.0 stands for the comprehensive informatization of the logistics industry, which includes its actors and objects.

B. Cyber-Physical Systems and Cloud Computing

In a Cyber-Physical System (CPS), information technology units work together via a communication network, which in turn control physical objects [5]. CPS are objects, devices, buildings, means of transport, as well as production facilities and logistics components, which contain embedded systems that have been made capable of communication [6]. These systems can communicate over the Internet. CPS capture their environment directly with their sensors, evaluate them with available data, save them and then act on the physical world via actuators. Figure 2 shows how a CPS is constructed.

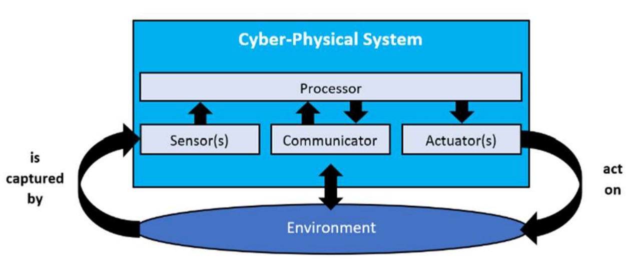

Fig. 2. Construction of a Cyber-Physical System (CPS)

Humans, in turn, are connected to these CPS via multimodal, so-called human-machine interfaces and can operate them, for example, via touch displays or voice [7]. CPS can network, which enables them to autonomously build peripheral networks. They are also able to optimise themselves. In coordination with humans, CPS can solve problems independently. An example of a CPS in logistics are self-controlling, automated guided vehicles in intralogistics.

Cloud computing is a possible solution to meet the continually growing need for computing power and storage capacity of information systems. Clouds can appear in various forms, such as private, public or hybrid clouds [8]. Also, clouds can either be managed in-house, only within the company or obtained from third parties outside the company. Clouds and cloud services are, therefore, a primary factor in successfully mastering the challenges of technological progress. There are three levels of abstraction from cloud services. One service level is Infrastructure-as-a-Service (IaaS). IaaS focuses on the dynamic allocation of IT resources, such as memory, processor, and network capacities, through virtualisation [9]. Another level of service is Software-as-a-Service (SaaS), which provides standardised applications for end-users [10]. The software is provided directly by a service provider over the Internet, which means that no local installation of the software is necessary. To use SaaS services, users usually only need Internet access and a web browser. The third service level, Platform-as-a-Service (PaaS), is closely related to SaaS. However, PaaS is less aimed at end-users than at application developers and system architects [11]. These are provided with a platform on which software can be both tested and executed. In logistics, in particular, advantages arise from the use of IT resources from the cloud. Along the supply chain, there is a need for regularly updated data and information. The cloud supports logistics, especially when it comes to high demands on flexibility and quality, as well as when deadlines are tight. The cloud also enables companies to meet challenges posed by future technologies, such as 3D printing, robotics, or the Internet of Things, by adapting and expanding logistics services.

C. Identification and Location Technologies in the Context of Internet of Things (IoT)

The Internet of Things is the basis for the fourth industrial revolution [12]. Hereby, the IoT is expanding the classic Internet by networking from and with everyday objects. These then have the option of making their physical context information, such as their location or state, available as information on the Internet. This largely eliminates the separation of physical and virtual worlds, which is the central paradigm of Industry 4.0 [13]. The central idea is the amalgamation of the physical world and its digital models in computers. This enables them to transfer their information about themselves and their environment to other IT systems at times that are relevant for the application. For the implementation of the Internet of Things to take place, technologies are required that enable the identification, recording and communication of physical objects. Barcodes are a widely used technology to identify objects in the logistics area. In the case of barcodes, data is presented in graphic form and can be read using a barcode scanner. Common types of barcodes are, on the one hand, the commercial bar code (EAN) and, on the other hand, stacked codes such as the 2D Quick Response (QR) code [14]. Besides, a 3D code is also standard, the third dimension of which is based on the color [15]. Another technology to identify objects in the logistics area is the RFID technology. This is a procedure with which binary-coded data are recorded and transmitted without visual and touch contact. With this technology, data is exchanged using inductive coupling or electromagnetic waves. Components of such an RFID system are transponders, also called tags, and read/write stations [16]. A vital advantage of the RFID technology compared to that of barcodes is that, unlike barcodes, RFID tags do not rely on an optical connection, and the reading process can be carried out much faster. Also, the error rate with RFID is significantly reduced compared to manual reading processes. Another great advantage over the barcode system is that the transponders can be rewritten since, in addition to simple reading processes, they also allow writing processes [17].

The RFID technology is, therefore more than a kind of modern barcode since RFID evaluations can provide information about where the object is currently located when the object was last located, and what condition it is in. For this, sensor technologies are combined with the RFID chip. This makes it possible to perceive and thus monitor parameters such as speed, temperature, or air humidity. The RFID technology can, therefore, be seen as a critical technology of the IoT [18]. As a result, the processes along the supply chain can be significantly accelerated and made more secure. In addition to identification, the localization of objects also plays a vital role in the coordination of material and information flows along the supply chain. One technology for this is the Global Positioning System (GPS). These are satellites orbiting around the earth at an altitude of 20,000 kilometers. Each of these satellites emits signals that enable the precise location of objects. The reception of these signals is mainly used for the localization of means of transport in the aviation, shipping, and road traffic. At least three satellites are required for precise location and at least four satellites for three-dimensional localization. Corresponding signals can be received by devices equipped with GPS receivers, which at the same time enable mobile navigation [19].

D. Business Intelligence (BI) and Big Data Analytics (BDA) in the Context of Big Data (BD)

Big Data means the ever-increasing amount of available data itself [20]. Besides, this also means the possibility of discovering relationships and integrating forecasts through different data sources and their analysis. On the one hand, this targeted evaluation of Big Data enables manufacturing companies to optimise production systems. On the other hand, this allows customers and market developments to be better understood and forecast reliability to be increased in general. Even vast amounts of data, both internal and external, can now be analysed. The challenge, with this, is to localize data. This is especially true for internal data that is often not used even though it is available. The next step is then to statistically prepare and integrate the data so that it is permanently converted into retrievable knowledge. As shown in Table 2, the data type of Big Data is often characterised by the three 'V': Volume, Velocity and Variety [21].

TABLE 2. Characteristics of Big Data.

Big Data			
Character	Variety	Volume	Velocity
Specificity	Structured Semi-Structured Unstructured	Yottabytes Zettabytes Exabytes Petabytes Terrabytes Gigabytes	Real-Time Milliseconds Seconds Minutes Hours

Hereby, 'Volume' stands for the ever-increasing amount of data. The speed at which the data can be analysed is referred to as 'Velocity'. It also refers to the rate at which the data can change itself. 'Variety' describes the heterogeneity of the structures of the digital data. Business Intelligence (BI) is mainly based on structured data that is available in relational databases. Big Data Analytics, on the other hand, is based on unstructured, rather text-based, format and description-free data formats [22].

Descriptive Analytics are methods for descriptive analysis, which aim at general descriptions or summaries of a situation. Diagnostic Analytics can be used to analyse causes and answer the question of 'why'. To answer the question of 'what' is currently happening, real-time analytics design the systems in such a way that current data is available for analysis without any significant delay. These are then carried out in the shortest possible time. Predictive Analytics goes one step further, and it is intended to provide a look into the future. And the highest form of decision support in a company is Prescriptive Analytics. This analysis method is used to answer the steps required to achieve a business goal optimally. Similarly, one research study identified that the adoption of new technologies are best placed analysing types of data sets and their cost-effective capabilities within the organisations [23].

E. Impact and Potentials of IoT and BDA

With the spread of the use of IoT and BDA technologies, promising logistics potential can be leveraged. Both companies and end-users can benefit from the IoT. The efficiency of business processes, as well as the customer experience, are affected by the IoT. It will also develop entirely new business models. The possibilities created by IoT are succinctly outlined in Figure 3.

With IoT technology, assets and people along the entire supply chain can be observed and controlled in real-time (Monitoring/Controlling). It is possible to measure the extent to which these assets perform certain services. As a result, current and future activities can then be influenced (Measuring). Business processes can be automated to avoid manual intervention, improve quality and predictability, and reduce costs (Automating). The interplay of people, systems and assets can be optimized, and their activities can be coordinated (Optimising). Ultimately, forms of BDA can be applied to the entire supply chain to identify extensive opportunities for improvement and best practices (Learning).

Fig. 3. Potentials for Logistics Processes through IoT [24].

The added value through IoT therefore takes place by capturing data that arise through the networking of assets, strictly speaking, from the knowledge resulting from this data. The IoT, sensors and RFID tags thus can transform the physical world into a virtual world [25]. When these physical objects also communicate with each other, a massive volume of unstructured data is generated in real-time. For this reason, the use of BDA is essential. The enormous increase in data generated, which has been made possible by advances in IT, makes the extraction of useful information from this data a decisive competitive advantage for companies. The power of BDA can be used by companies to formulate business strategies and reduce business risks. BDA, therefore, plays a vital role in improving the performance of a supply chain [26]. Studies identified that some of the technological developments, as IoT and BDA could be used to create a focused service value as the firm's development and attainment strategies to achieve competitive edge within the market [27].

F. *Critical Challenges for IoT and BDA*

IT security and data protection represent a critical success factor for IoT and BDA technologies [28]. Creating security and maintaining confidentiality is of crucial importance for every Big Data system. For example, information about prices should be confidential, even among partners in a supply chain. It will also be important that storage systems offer security against unauthorized access, regardless of whether aggregated data is stored by cloud service providers or privately because there is a risk that data will be stolen and sold as an economic asset. If you consider that machines and vehicles are connected via the IoT and are controlled based on data, manipulating this data can have drastic effects. However, too many data protection guidelines also limit the possibilities and advantages that BDA applications offer [29].

Another critical challenge for IoT and BDA technologies are the extensive changes within a company's work system that they bring about [30]. A comprehensive digital transformation requires the activities to be integrated into the socio-technical triangle of a company consisting of people, technology, and organisation. Since the future of IoT will primarily focus on the interaction with technological systems, as well as the precise evaluation and interpretation of data, the qualification should focus on data management. The aim here is to achieve both in-depth IT know-how and a thorough understanding of the process. For the internal organisation, the IoT enables a more robust network of employees and thus promotes a more agile way of working, which focuses on innovations. For this, it is essential to focus on a way of thinking and working that emphasizes potential and not problems. An open error culture should encourage employees to enjoy experimenting. The IoT and Big Data technologies enable managers to focus less on subjective decision criteria than on the existing database. But it is also necessary for managers to develop a deep understanding of the technologies, data, and processes to assess the possible effects of data-based decisions.

III. RECOMMENDATIONS AND CONCLUSIONS

This paper provides an overview of the fundamental requirements of Logistics 4.0 within the context of Industry 4.0. It emphasizes how the integration of IoT and Big Data Analytics enables more efficient planning, control, and adaptation of global logistics processes. The challenges related to the extensive use of these technologies are also discussed.

The paper acknowledges the need for further research to quantify the benefits and costs of implementing BDA and IoT for companies. It suggests exploring what data should be shared within supply chains and addressing concerns about sharing Big Data. Additionally, the suitability of various IoT identification technologies and specific BDA applications for different areas along the supply chain should be investigated in future studies.

The evolution of Industry 4.0 involves the intelligent networking of production, logistics, and infrastructures. The paper highlights the role of IoT in real-time monitoring and control of objects throughout the supply chain and the potential for automating business processes. BDA can be applied to the entire supply chain, leading to significant improvements and best practices. A key finding of the research is that optimizing logistics processes goes beyond merely collecting data; it requires converting data into actionable knowledge using BDA, providing a competitive advantage for companies.

Furthermore, the paper emphasizes the main challenges of logistics 4.0 and the critical success factors of IoT and Big Data technologies, such as IT security and data protection. The digital transformation necessitates changes in the work system within companies, including identifying required competence profiles and providing training in data management and IT expertise. Agile working methods and an open error culture are promoted, and managers are encouraged to base decisions on objective data. In conclusion, the combination of logistics and IT through IoT and Big Data technologies offers numerous synergies for all aspects of Global Logistics and stakeholders along the supply chain. However, successful implementation requires overcoming various challenges and adopting an open attitude towards digital transformation.

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