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Current Status of Industry 4.0 in Material Handling Automation and In-house Logistics

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Abstract**—**In the last decade, a new industrial revolution seems to be emerging, supported -once again- by the rapid advancements of Information Technology in the areas of Machine-to-Machine (M2M) communication permitting large numbers of intelligent devices, e.g. sensors to communicate with each other and take decisions without any or minimum indirect human intervention. The advent of these technologies have triggered the emergence of a new category of hybrid (cyber-physical) manufacturing systems, combining advanced manufacturing techniques with innovative M2M applications based on the Internet of Things (IoT), under the umbrella term Industry 4.0. Even though the topic of Industry 4.0 has attracted much attention during the last few years, the attempts of providing a systematic literature review of the subject are scarce. In this paper, we present the authors' initial study of the field with a special focus on the use and applications of Industry 4.0 principles in material handling automations and in-house logistics. Research shows that despite the vivid discussion and attractiveness of the subject, there are still many challenges and issues that have to be addressed before Industry 4.0 becomes standardized and widely applicable.

Keywords**—**Industry 4.0, internet of things, manufacturing systems, material handling, logistics.

I. Introduction

MATERIAL handling incorporates the movement, storage, protection and control of materials and products throughout the complete lifecycle of manufacturing, warehousing, distribution and disposal. The material handling process includes a wide range of manual, semi-automated and automated equipment and systems supporting logistics and making the supply chain work. The material handling systems and processes of a company are established to enhance customer service, decrease inventory, shorten shipping times and decrease general production, distribution and transportation expenses.

The term Industry4.0 which first appeared at Hannover Fair in 2011, refers to the Fourth Industrial Revolution which is characterized by the need to attain a higher level of operational efficiency and productivity, but also a greater level of automation as well. The primary characteristics are digitization, manufacturing optimization and customization; automatic data sharing and communication; enhanced human-machine interaction; automation and adaptation; and value-added services [2]. Consequently, the result of all the above is to build "smart" factories. Factories that are able to adapt quickly to modifications in order to satisfy leadership objectives, use resources at the greatest level, and do all this autonomously, without the need for human intervention [3].

Material handling incorporates the movement, storage, protection and control of materials and products throughout the complete lifecycle of manufacturing, warehousing, distribution and disposal. The material handling process includes a wide range of manual, semi-automated and automated equipment and systems supporting logistics and making the supply chain work. The material handling systems and processes of a company are established to enhance customer service, decrease inventory, shorten shipping times and decrease general production, distribution and transportation expenses.

Key technologies of Industry 4.0 are IoT including Industrial Wireless Networks (IWN) that can sense, identify, process and communicate [4], Cyber-Physical Systems [2], Cloud Computing [5], Robotics [6], Big Data analytics [7], Augmented Reality [8], Artificial Intelligence and Machine Learning [9], Digital Twins and Simulation [10] and Additive Manufacturing [11]. The more these trends converge (i.e. adoption of such technologies by people and companies), the bigger the effect becomes. Each of these technologies and trends disrupts almost every aspect of our lives, our society, the economy and all industries and countries with an exponential pace and impact. The more devices, machines, production modules and products that can connect and exchange data independently, the more actions will be generated between them, and a more linked and intelligent environment for production and services will be developed [12].

Although there is increasing interest in Industry 4.0, literature on how this new technology revolution affects supply chain activities and intralogistics and material handling has been restricted up to now. This paper seeks to determine the current Industry 4.0 state of the art, study its main applications in the area of in-house logistics, analyze its impact and potential consequences and identify grey research areas and shortcomings in the current state of the art. Therefore, the objective of this paper is to contribute to improving knowledge of Industry 4.0 in relation to material handling and in-house logistics.

This paper is organized in four discrete sections. The current one introduces the basic concepts and states the objectives of this paper. Section II presents the detailed analysis of the collected material. Section III discusses the review of collected material and Section IV concludes the

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review, by presenting the research contributions and limitations of this study.

II. Analysis

The authors provide an analysis and discussion of the impact and potential consequences of Industry 4.0 on material handling & contemporary in-house logistics. In doing so, the authors focus on supply chain & logistics and discuss how Industry 4.0 technologies and digitalization affect the different elements of material handling and in-house logistics through the reviewed literature.

According to [13], developments of Industry 4.0 have a heavy impact on logistics. These developments, lead to improvements in different areas of logistics, such as better efficiency, increased traceability and improved responsiveness to customers, which in turn impact the basic elements of businesses. In other words, this new “version” of logistics provides opportunities to significantly change business models that companies operate with. Technologies such as IoT and Cyber-Physical Systems (CPS) are able to tackle challenges of traditional supply chains and logistics by monitoring and synchronizing information between physical processes and cyber computational space [13]. Based on [14], within the procurement, transport logistics, warehouse and order fulfillment functions, results showed that the areas most affected by the launch of Industry 4.0 are order fulfillment and transport logistics. It is evident from the same analysis that the application of specific techniques, such as Virtual Reality, Augmented Reality, simulation and 3D-Printing, has favorable outcomes for the logistics tasks under research. Big Data Analytics, cloud computing, IoT, RFID, cybersecurity, robotics, drones, and BI, on the other hand, could have both beneficial and negative consequences for organizations. The clear advantages of Industry 4.0 application are enhanced flexibility, quality standards, efficiency and productivity [14].

Reference [15] mentions the fields of transportation and warehousing as areas impacted by digitization and Industry 4.0 techniques. CPS will be the primary initiator of change in the field of warehousing. In the intelligent warehouse of the future, individuals, machines and resources will all interact easily and continually with each other, which literally implies that standard warehousing activities will totally alter as products are uniquely recognizable, can be located at all times and know their own history, current status and alternative paths to attain their target state. In [16], the authors discover a correlation between Industry 4.0 technologies and improved operational efficiency in transport services and warehousing facilities. They demonstrate that technologies such as IoT, automation, Cloud computing, Big Data Analytics, simulation and Augmented and Virtual Reality can be applied with beneficial effect on logistics and material handling. Furthermore, they also recognize five significant technological elements that will lead to future logistics tasks being fully automated, being: intelligent robots & autonomous vehicles, RFID technology & Quick Response Codes, sensors & conveyors, smart devices, and lastly CPS [16].

Another region that Industry 4.0 technologies could assist in the supply chain is the optimization of issues and processes for factories and warehouses. Logistic systems demand a shorter delivery cycle, reduced inventory levels, fewer working hours, and more on-time manufacturing and distribution in the context of Industry 4.0. The range and level of logistics planning within the prism of Industry 4.0 is therefore more comprehensive than in traditional logistics planning [17]. According to [18], broader logistics sector, including material handling and in-house logistics, is a suitable application area for Industry 4.0, with significant impacts expected.

According to [19], digitalization in logistics is based on cooperation, connectivity, adaptiveness, integration, autonomous control and cognitive improvement. Industry 4.0 technologies play a crucial role on the implementation of these characteristics and they enable the ability for integrated planning & execution systems, logistics visibility, autonomous logistics, smart procurement, smart warehousing and intralogistics, and advanced analytics among others. The characteristic of adaptiveness is also vital for intralogistics operations, since it allows systems to be able to change its components and their relations over time in order to be influenced by events outside of its system boundaries [19].

Reference [20] uses the term “Smart Logistics”, which is the same that is used also for defining “Smart Products” and “Smart Services”. A Smart Logistics system is one that can increase flexibility by bringing the business closer to client requirements and adapting to market modifications. An effective and powerful Logistics 4.0 should use and depend on the following four technological apps, according to [20]: 1) Smart Warehouse Management Systems to transform warehouse operations according to future demands in compliance with the paradigm of Industry 4.0. 2) Advanced transport management systems capable of providing better end-to-end visibility of the supply chain by using IoT technology. 3) Intelligent Transportation Systems (ITS), an area that interacts with distinct fields of transport systems, such as transport management, control, operations, infrastructure, policies and methods of control and finally 4) Information Security is, crucial and challenging requirement in Logistics 4.0, since dependence on technology is increasing [20].

On a more detailed level, Industry 4.0 will trigger changes that affect material handling and in-house Logistics, through improvements in materials and information, robotics and cloud technologies, RFID, Autonomous Guided Vehicles (AGVs) and autonomous decisions and configuration of material handling systems. According to [21], future warehouses and factories will have all of their components represented as individual agents in the cloud. All devices such as AGVs, industrial robots and operators, through their smart tablets or PDAs, will be interconnected and also have the ability to make their own decisions. Through the cloud architecture, the current hierarchical control structures will be replaced by decentralized web-like control architectures, which will offer additional services like data storage and outsourcing computational power.

Reference [22] describes that automated systems comprised by AGVs or some form of freely autonomous robots allow the warehouse area to become far more flexible than with the use of a fixed automation system, such as a conveyor. Extensions or modifications to such systems can be quite quick and cost adequate, which is one of the most important aspects during our times, where trends change quickly and future can be much different than the present. Another advantage of fleets of freely autonomous robots is that they are able to deal with dynamic changes, such as obstacles in the environment, and when a route is blocked, they can find a way to navigate around in order to continue their task [22]. Reference [23] describes the advantages of using AGVs in industrial environments, whether they are warehouses, container terminals, or manufacturing facilities. They state that according to the 2016 Material Handling Industry Report, which documents the utilization of AGVs in supply chains, the role of robotics and automation is catalytic in disruptively shaping competitive advantages. Reference [24] also explains the positive impact of mobile robots in material handling, through the different solutions they have provided. Todays' smart manufacturing systems rely on intelligent machines and devices in order to meet the challenges of consumer demands. They present a solution to the problem of mobile robot Artificial Intelligence programming in smart manufacturing systems. According to [25], cloud computing can be of great help in robotics, since it helps to manage data flow more efficiently. Within a warehouse, each individual robot does not have to keep its massive data storage, since combined data pools can help to use and update data on the basis of individual capability. Transferring computational and data analysis load to the cloud releases robot resources and enhances their capacity for executing tasks at the shop floor level [25].

According to [26], RFID technology can be of great assistance in a warehouse environment. Other than tracking inventory items, it can be used on storage equipment too, which allows for real-time response. Reference [26] introduces a concept of flexible warehousing, which is based on real-time decision support system that is enabled by RFID generated data. In this concept, all racking and inventory items are RFID enabled, which permits their visibility at any time. The outcome of such a system is that depositing and picking trips within the warehouse can be greatly reduced, which in turn reduces costs and lead time [26]. According to [27], in order to navigate a warehouse or a factory, some form of information regarding the mapping of the facility is required. Reference [28] also mentions the positive effects of RFID on AGV systems. In their paper, they introduce an AGV system for smart factories which uses RFID in order to create a flexible and intelligent environment. What they found out is that RFID enables smart decision making for the AGVs, it improves fixed form guidance methods and remains flexible in case of future reconfigurations of warehouse or factory space [28].

Reference [29] describes another way that Industry 4.0 technologies could help in material handling. They say that based on technological advances, like intelligent industrial robots and M2M communication, new possibilities open up in order to reduce throughput losses in case of equipment failure. Machines have become intelligent enough in order to reconfigure themselves automatically in case they detect a failure in the overall system. In [29], they consider a planning of configuring automated flow lines that allows for downstream stations to perform the operations of failed stations in addition to those operations that were initially assigned to them, in the event of a failure [29].

Reference [30] describes the importance of knowing the abilities and overall effectiveness of material handling system, and therefore they discuss about the Overall Equipment Effectiveness (OEE) standard and simulation and show how these two techniques can help identify possible problems. The paper designs and studies the execution of an intelligent material handling system for material distribution with utilizing an agent-based algorithm as control architecture. A time based methodology is applied to evaluate the OEE. On the second stage, each of the optimization solutions is implemented on the simulation model in order to verify and validate the effects of the OEE percentage [30].

III. Discussion

Through a detailed evaluation process of the selected papers, four dominant literature categories were identified. A discussion for each one of these categories follows in the remainder of this section.

Industry 4.0 Applications for General Supply Chain & Logistics

This category includes papers that study Industry 4.0 technologies and their impact on logistics in general. Their main outcome shows that the shift towards Industry 4.0 will result in a profound change in the related information flow, affecting the entire logistics distribution system. This will inevitably lead to a deeper integration of logistics in business operations and create a shift toward service-oriented logistics on demand. According to the literature reviewed, the key organizational change in logistics sector will be the higher autonomy of decision-making accessible to logistics partners. This implies that decentralized decision-making promotes leaner planning of logistics, as connectivity guarantees that the actors have access to a virtual process model. Therefore, a thorough knowledge of upstream and downstream procedures enables a close integration of logistics into the value network.

Industry 4.0 Applications for Material Handling and Its Support by Information Flows

This category includes papers related to information flow and the intensified ability that Industry 4.0 has provided through technologies such as the IoT. With thousands of different kinds and forms of products being stored in today's average warehouse, every square meter of warehouse room needs to be optimally utilized to guarantee that particular products can be retrieved, processed and supplied as quickly as possible. Industry 4.0 promises a technology-driven, high-speed environment allowing executives to know what happens in a warehouse or factory space at a specified time; machine performance, environmental conditions, energy consumption, stock status or material flow. Key technology of papers in this category is undoubtedly RFID, which by using active and passive readers, can provide precise localization of mobile devices in indoor environments. At the same time, sensors can also be incorporated into the infrastructure of the warehouse itself. Smart warehouse energy management connects various utilities, including connected lights and ventilation systems in order to optimize energy consumption, which in turn results in lower costs and lower carbon footprint of the facility. Finally, preventive maintenance is another key use case of IoT once data analytics is involved, and this is particularly critical in a warehouse or factory environment. This can have significant consequences in terms of OEE, a main metric of production productivity.

Industry 4.0 Applications for Material Handling Physical Activities

In this category, we classified papers that discuss about Industry 4.0 technologies and their impact on physical activities of material handling, such as picking, packing, storage and retrieval among others. Therefore in this category papers mention and analyze subjects that refer to CPSs, AGVs, picking robots, mobile robots, swarm intelligence, wearable devices and AR and VR. Material handling equipment and packaging are increasingly equipped with information technologies, which makes assets such as forklift trucks able to autonomously identify themselves, determine their present location and collect data on their status and the products being transported. Another point that was addressed on the examined literature is the human-to-machine interaction. In the near future, workers will join the IoT environment and through connecting via their smartphones, scanners, tablets and wearables, such as smart glasses and other AR and VR devices, they will possibly elevate human-to-machine interaction within the warehouse even further. The advent of connected workforce offers innovative possibilities for monitoring workers' health and fatigue, tracking workers' specified process routes and analyzing, where warehouse executives can enhance walkways or alter a process to make the work of employees easier and safer.

Industry 4.0 Applications for Material Handling Managerial & Strategic Planning

This category includes papers focusing in Industry 4.0 technologies and their impact on managerial and strategic planning of material handling, with subjects such as big data analytics, simulation and digital twins being in the center of discussion. It is often still the case that very little information is gathered for tasks such as production, logistics and services, even in centralized operations. Moreover, in many cases the data captured can only be seen or accessed by a limited number of people who can decrypt and understand the respective domain systems. The fact that warehousing facilities, transport units and autonomous vehicles are fitted with sensors and are connected to systems that share and organize their produced data creates a digital shadow of the real world. Thus, by employing analytics to sensor data, not only imminent issues, but possibly hazardous developments can be predicted well in advance. Therefore we see that as time progresses, logistics decisions are becoming more data based, in order to allow continuous process improvement and the efficacy of these data based decisions is guaranteed by the systematic use of information technology and systems.

IV. Conclusions

Logistics have developed from just an activity providing services, i.e. delivering the right goods to the right place at the right time, to become a key driver of digital and societal change. Topics like autonomous driving, IoT and Big Data are closely intertwined with logistics today. In this process, logistics both as a science and an economic sector drives both the application and the development of basic methods, algorithms and technologies. Therefore, Logistics plays a key role in the all-encompassing digitization of the economy and society. This means it is even more essential as a subject of research than was already the case, because Logistics is the backbone of developments concerning Industry 4.0. The goal is to create flexibly interconnected, complex and distributed material handling and in-house logistics systems based on a continuous and autonomous exchange of data and information between human actors and physical, technical objects [31].

In this paper, an analysis of Industry 4.0 technologies is presented in an attempt to understand their effect on material handling and in-house logistics. The study of literature reveals that Industry 4.0 is currently populated by small-scale test installations that try to depict real-life situations, thus lacking large-scale applications of its technologies in material handling and in-house logistics. Therefore the impact of Industry 4.0 in the studied areas in terms of efficiency, flexibility and availability has not yet been tested in detail. In addition, existing studies on the impact of automation in terms of human employees and the future qualifications and competencies needs of the workforce are scarce and relatively limited in their empirical findings. Finally, we have to note down that the choice of language limits the results of our study, since it is anticipated that a substantial number of publications is using a language other than English, especially in German where the Industry 4.0 term was firstly introduced.

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