Smart Logistics in Industry 5.0

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Given the importance of human centricity, resilience, and sustainability, the emerging concept of Industry 5.0 has pushed forward the research frontier of the technology-focused Industry 4.0 to a smart and harmonious socio-economic transition driven by both humans and technologies, where the role of the human in the technological transformation is predominantly focused on. The core elements of Industry 5.0 show that following the technology-centric transition of Industry 4.0, the societal, environmental, and human perspectives require more attention, which will yield significant impacts on logistics operations and management. For instance, the personalization of demands implies a personalized delivery system. Incorporating customers into the design requires highly intelligent CPS and system integration. Human–machine interaction triggers the interaction of various topics such as safety, human behavior, etc. Thus, there exist various challenges and approaches to addressing smart logistics issues in Industry 5.0.

Keywords: Industry 5.0 ; Industry 4.0 ; smart logistics ; sustainable logistics ; bibliometric analysis ; literature review

1. Introduction

Industrial revolutions, throughout history, are primarily driven by disruptive technological breakthroughs that change the manufacturing paradigms and the way of customer demand satisfaction. With the increasing adoption of advanced manufacturing technologies, digitalization, and information and communication technology (ICT), Industry 4.0, also known as the fourth industrial revolution, aims at achieving a higher level of automation and intelligence [1]. Through leveraging the effectiveness and efficiency of manufacturing processes, Industry 4.0 predominantly emphasizes the paradigm shift led by new technologies, but less attention has been paid to the human aspects [2][3][4]. This is, however, argued as a threat to the sustainable development of humans and society [5], which requires more attention and effort from both industrial practitioners and academia [6]. Although this concern can be partially addressed by incorporating Industry 4.0 within the context of sustainability [7], circular economy [8], green supply chain [9], and so forth, it is still important to have a systematic conceptual development to fill the missing points of Industry 4.0. Thus, given the importance of human centricity, resilience, and sustainability [10], the concept of Industry 5.0 is proposed to complement the existing Industry 4.0 [11] in order to better meet the industrial and technological goals without compromising the socio-economic and environmental performance [2][3]. Among others, personalization, human–machine collaboration, bioeconomy, and sustainability are the most important pillars in Industry 5.0 [12]. As argued by Di Nardo and Yu [13], the increasing adoption of Industry 5.0 technologies will not hinder human value, but rather promote a dual integration between human intelligence and machine intelligence in a collaborative environment [14].

Logistics, as a key function of a company or a supply chain, has been significantly affected by recent technological advancements and innovation [15]. Smart logistics operations are enabled by the increasing use of new technological solutions, which lead to the emergence of intelligent warehouse management [16], smart transportation [17], digital twin [18], and so forth. By comparing the development of logistics operations with the four industrial revolutions in history, Wang [19] proposed the concept of Logistics 4.0, which integrates Industry 4.0 technologies into various logistics operations to improve smartness and automation. This concept is further developed to adapt to the characteristics of specific industries, e.g., food logistics [20] and forest supply chain [21].

Even though significant research effort has been given to understand the impacts of new technologies on smart logistics operations and management, no effort has been directed to the human and environmental aspects brought by Industry 5.0. A recent literature review has put forward the concept of supply chain 4.0 to supply chain 5.0 [4], but no research has been done to provide a comprehensive understanding of the implications of Industry 5.0 for smart logistics. To fill this gap, this entry presents a comparative bibliometric analysis to show the connection and differences between Industry 4.0 and Industry 5.0 and smart logistics. A thorough content analysis is then given to illustrate the features of smart logistics in Industry 5.0 concerning four areas, namely intelligent automation, intelligent devices, intelligent systems, and intelligent materials. Finally, a research agenda is proposed for identifying future research directions of smart logistics in the era of Industry 5.0.

2. The Three Key Elements of Industry 5.0

As rooted from Industry 4.0, Industry 5.0 embraces similar technologies and a clear distinction between these two industrial revolutions is thus of significance. The official introduction of Industry 5.0 underpins the evolution of this novel paradigm with respect to a trinary concept to pinpoint its corresponding core values [22]: human-centricity, resilience, sustainability.

- **Human-Centricity.** Conveys the fact the production and logistics system must be improved with solid attention to human benefits and needs, by which the human is transformed from ‘cost’ to ‘investment’ [2]. From the operational aspect, this urges the promotion of hybrid alternatives in response to the industrial challenges, where the human power and human brain are involved not only in maintaining the surveillance but also in incorporating more intelligence and innovation and, to some extent, making decisions [3][23]. Industry 5.0 emphasizes research and development (R&D) activities to translate information into knowledge and meet sustainable social goals by upskilling humans through formal education or training schemes [2][6][24][25][26]. From the social and economic point of view, Industry 5.0 shapes the ground to not only prevent the elimination of human labor engaged in the manufacturing industry but also create more job opportunities in the supportive industries, which provide technological solutions, i.e., robot manufacturing, sensor manufacturing, etc. [3][24][27]. Hence, based on these objectives, Industry 5.0 is a human-centric paradigm that transfers the human back to the center of production cycles.

- **Resilience.** Represents the flexibility and agility that a production plant needs to maintain in response to market change [24][28]. Today, customers are strikingly bombarded with high-tech innovations and products, and according to the constant changing in the market, personalized demands are one of the most significant challenges to the manufacturing industry [23]. To a larger extent, manufacturing systems are expected to transform from mass customization to mass personalization [24]. From a tactical perspective, this is realized by incorporating the customers into the design phase to build up the personalized product from scratch [27][29]. To improve the operational flexibility in this regard, human–robot collaboration has significant potential, which conducts versatility of fabrication in a more efficient time [24][30]. It is worthwhile to highlight that while the main task is accomplished by the robot, human collaboration facilitates the problem solving of the work and process flows, and improves intelligence and innovation [23][30].

- **Sustainability.** The concept of sustainable development was initially introduced by Brundtland in 1987 and defined as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [31]. While the social- and human-related issues are an integral part of this concept, they are merely discussed within human-centricity in the context of Industry 5.0. This approach emphasizes reverse logistics [32][33], circular economy [2], value chains, and so forth [34]. Sustainable development seeks the protection of the environment through sustainable products and logistics systems to approach the zero waste objective [27]. In addition to waste prevention, the manufacturing processes must be environmentally friendly—for example, by using renewable resources and green computing [30].

3. Smart Logistics in Industry 5.0

The core elements of Industry 5.0 show that following the technology-centric transition of Industry 4.0, the societal, environmental, and human perspectives require more attention, which will yield significant impacts on logistics operations and management. For instance, the personalization of demands implies a personalized delivery system [25]. Incorporating customers into the design requires highly intelligent CPS and system integration [30]. Human–machine interaction triggers the interaction of various topics such as safety, human behavior, etc. [23]. Thus, there exist various challenges and approaches to addressing smart logistics issues in Industry 5.0. With a focus on the interaction between technology and humans in smart logistics, researchers present discussions through a quadripartite intelligence framework [3][24], namely intelligent automation, intelligent devices, intelligent systems, and intelligent material.

3.1. Intelligent Automation

The major focus of Industry 5.0 is human-centricity, which, from a pragmatic aspect, puts forward the presence and high importance of the human in a system. However, there is a trade-off between human integration and automation to satisfy the goals of Industry 5.0, and this concern resides in the context of intelligent automation [23][24], e.g., human–robot collaboration. It impacts the resilience of a logistics system and thus requires special attention and intelligence to achieve a lean collaboration [35][36][37]. The human's role in a logistics system was initially investigated in 2016 under the concept of 'Operator 4.0′, which aims, by taking advantage of technological advancements, at maximizing the human's contribution from three functional aspects [38][39], namely assisted work, collaborative work, and augmented work. The first function highlights the tasks that are mainly completed by human operators with the help of assisting technologies. The second requires collaboration between machine/robot and human. The last relies on technologies that could extend the human's physical and visional capabilities. Considering logistics operations at different stages, e.g., production, warehousing, etc., material handling and information flow are two operational categories that significantly benefit from these applications [40].

Industry 5.0 paves the way to extending this framework by considering both resilience and human-centricity. Romero and Stahre [41] introduce the concept of 'Operator 5.0′ as "a smart and skilled operator that uses human creativity, ingenuity, and innovation empowered by information and technology as a way of overcoming obstacles in the path to create new, frugal solutions for guaranteeing manufacturing operations sustainable continuity and workforce wellbeing in light of difficult and/or unexpected conditions". In the context of Industry 5.0, this paradigm encourages technological development in two main directions: self-resilience and system resilience. Self-resilience emphasizes human sustainability from biological, physical, cognitive, and psychological dimensions and focuses on human-centricity in the technological transition, i.e., work ethics, social impacts, legal issues, etc. [42][43][44][45]. System resilience, however, signifies the functional collaboration between humans and machines in terms of sharing and trading control [46].

Human–robot collaboration in Industry 5.0 also plays a vital role in reacting to highly unexpected events, e.g., the COVID-19 pandemic, which requires high production agility and flexibility to fulfill the rapidly increasing demands of medical supplies [41][47][48]. In this regard, collaborative robots (cobots) are one of the most discussed enabling technologies in Industry 5.0. However, two important issues, namely the human skills and the behavior of cobots, need to be taken into account when cobots are integrated into a production or logistics system. As the main lever of Industry 5.0, through proper training, humans must be capable of working together with cobots [45][49][50][51][52]. For this purpose, the use of several supportive technologies, i.e., virtual reality, augmented reality, and simulation, has been extensively investigated [3][48][53]. For instance, operators can learn and understand the cobot motions under specific conditions without compromising safety measures and productivity [3][48]. On the other hand, cobots can be programmed or trained to establish a lean collaboration with the operators, which may lead to an increase in the productivity and efficiency of the workflow [54]. Human–robot collaboration not only requires hardware capabilities, i.e., sensors, etc., but also implies the essence of cognitive and intelligent behaviors of the cobot [54]. In this regard, the latest computation methodologies, i.e., machine learning (ML), deep learning (DL), clustering, regression, etc., have become increasingly important for the development of versatile applications [3][48][55][56][57][58][59].

3.2. Intelligent Devices

Machines, robots, and other facilities that are used in the production and logistics systems must be improved and equipped with smart technologies to maximize functionality and performance through physical and cyber connections with high monitoring and controlling capacities [60][61][62][63]. Considering the scopes of Industry 5.0, this objective signifies the interaction between humans and robots/machines. On the one hand, these intelligent devices, e.g., intelligent machines, smart robots, cobots, etc., require cognitive capabilities for decision-making by themselves to not only perform operations alongside the humans but also actively prevent undesired incidents. On the other hand, due to the operators' inherent physical and intellectual limitations, the shortcomings for accessing the information flow and augmented functional abilities can be resolved by intelligent devices [50]. The collaboration between robot and operator raises concerns about human constraints as opposed to machines, which requires extra effort to resolve their integration issues. In this regard, operators' conditions need to be constantly traced with capture motion and eye-tracking devices, wearable biometric equipment, etc., under various workload conditions from both physical and cognitive perspectives [64][65][66]. This helps to facilitate a resilient workplace in which the environment adaptability can be improved in varied conditions [65].

In addition, Industry 5.0 emphasizes human-centricity through the use of technologies and hardware to improve and support the operators' performance in logistics systems and supply chain operations. In this regard, human wearable devices that boost cognitive and operational capacities are increasingly being utilized and improved in manufacturing industries [66]. Exoskeleton refers to augmenter equipment that gives extra strength and physical capabilities to protect the operator from the adverse effects of heavy workloads [67][68][69][70]. Benefiting from virtual technologies, i.e., smart AR glass, spatial AR projector, etc., are viable and novel gadgets that facilitate flexible operations and technical guidance through information transmission and virtualization [41].

Moreover, the latest improvements in unmanned aerial vehicles (UAVs) have radically altered the intralogistics and material handling systems in a highly novel manner, and this additionally represents significant potential for personalized delivery systems [25][71][72]. Furthermore, Auto Identification (Auto-ID) and RFID have been extensively investigated in smart logistics and supply chains, which support traceability, warehouse operations, and inventory management [51][73].

3.3. Intelligent Systems

The systematic approach of Industry 5.0 requires information transmission for individualized and case-based tasks in the production system and enhanced interaction with better decision-making processes throughout the whole supply chain [74][75][76][77][78]. This characteristic urges improved data and information exchange among different stakeholders, which largely affects the agility and intelligence of a smart logistics system. This aim can be realized by a network of data interoperability, where sensors exchange and process information in a big data environment [3][25][79][80][81][82]. In the context of Industry 5.0, a Smart Cyber–Physical System (SCPS) can be established for promoting data transmission and the sustainability of production and logistics systems [83][84]. This digital transformation, however, must be energy-efficient by taking into account green procedures, i.e., green production, green recycling/disposal, green IoT (G-IoT), etc., to facilitate a lean circular economy (CE) [85][86].

A digital transition to Industry 5.0 and Society 5.0 triggers the development of blockchain computing [27][87][88][89][90][91]. In addition, it benefits the supply chain by enabling demand customization and personalization through recommender systems, which capture customers' preferences using social networks, text recognition, and analytical techniques [92]. Benefiting from internet-based connectivity, the transparency of information and manufacturing traceability can be drastically enhanced [25][51]. Real-time decision-making and high-quality visualization form the foundation of a virtual smart logistics system in Industry 5.0 [93], which facilitates the emergence of the smart digital twin for logistics systems [3][81][94][95][96].

3.4. Intelligent Materials

One of the revolutionary improvements in Industry 5.0 is the development of smart materials. The characteristics of these new materials may significantly impact the supply chain activities by serving multiple functionalities and capabilities under certain conditions. For example, manipulating the shape and properties of the material and/or product according to varying physical conditions, e.g., temperature, light, stress, etc. [96][97][98][99]. The primary implication is related to additive manufacturing, where the 4D printing method strongly benefits from smart materials [24]. Compared with traditional 3D printing, 4D printing employs similar technology that fabricates parts and components through the layer-wise adhesion of a corresponding material. However, the major difference lies in the material type [97][98][100][101]. By using smart materials, the products can maintain various shapes and functionalities according to the environmental condition to improve the durability, adaptability, and reliability of the product. Various examples exist in medical science, aerospace, semiconductors, etc.

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