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Using Industry 4.0 Capabilities for Identifying and Eliminating Lean Wastes

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Abstract

This paper conducts a review of the literature to identify associations in operations between Industry 4.0 capabilities such as Additive Manufacturing, Augmented Reality, Autonomous Robots, Big Data, Cloud Computing, IIoT, Simulation, and Systems Integration with the commonly identified lean manufacturing wastes of Transport, Inventory, Movement, Waiting, Overproduction, Overprocessing, Defects, and Underutilized skills. The paper documents research that links various capabilities and wastes, including how IIoT can be used to reduce defects in manufacturing, and how it can mitigate overproduction across industries. There is also evidence that big data implementation in manufacturing has positive effects on reducing waiting times across the manufacturing process and delivery, and that cloud computing techno logies guarantee better estimates for product and predicted inventory amounts. The research finds impacts on the social aspect of manufacturing by how augmented reality tools are increasingly used in the manufacturing sector to improve workers' knowledge, skills, and abilities, and that simulation software applications are capable of decreasing operator motion wastes. The paper concludes that there is a clear benefit for SMEs in using Industry 4.0 in lean implementation journeys, and it supports the efforts of manufacturing organizations to become leaner using Industry 4.0 capabilities and solutions.

Keywords: Lean Manufacturing; Industry 4.0; Wastes; Operations Management

1. Introduction

The operations function exists to create and deliver services and products [1], and operations management is the practice of management decision-making and systems design that covers the input-process-output cycle. The flow of operations – materials flow, or information flow – from the supplier to the customer, constitutes the most important task for manufacturing companies and, through its link to cash flow, it is one of the areas of management with the highest impact on business results [2]. Time is one of the most valuable resources with respect to business effectivity, where the minimization of production time ensures higher client satisfaction [3]. Eliminating wastes of both time and resources helps improve manufacturing systems [4]. Moreover, the reduction of operational costs while preserving a product's full value is crucial to defining lean manufacturing [5]. Lean Manufacturing is amongst the most researched topics in the modern area of operations management [6]. The origins of lean have been traced back in time far beyond the automotive era yet is commonly associated with the power of the Toyota Production System (TPS) and lean models of operational management.

Lean manufacturing is evolving to become a method of maximizing a company's efficiency and reducing its waste with respect to digital and physical business processes [7]. Any actions or resources that don't benefit the customer or client

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directly are considered waste [8]. There are seven commonly identified types of manufacturing waste which are defects, overproduction, waiting, transportation, overprocessing, and inventory. Moreover, "underutilized skills" have been added to the manufacturing waste category by various authors [9.10].

Beginning in 2011, the digitalization of manufacturing has impacted the industrial revolution, allowing business processing to happen in real-time [11, 12]. The fourth industrial revolution, also known as Industry 4.0, is a group of technological advances used to increase business digitization and to enable businesses to be a part of an interconnected world [13]. Industry 4.0 is often categorized by nine enablers, these are the Internet of Things (IoT), Big Data, Autonomous Robots, Additive Manufacturing, Cloud Computing, Simulation, Cybersecurity, Augmented Reality, and Systems Integration [14]. Research suggests that businesses will see bigger benefits with the introduction of Industry 4.0. However, Small & Medium-sized Enterprises (SMEs) can suffer from the introduction, due to high investment costs and incorrect scope and planning within its implementation [15].

Industry 4.0 has been attributed to increased levels of manufacturing productivity, decreased lead times, and improved efficacy due to growing amounts of technology in the industrial and manufacturing fields [16, 17, 18]. It has also been found to support the implementation of Just in Time systems through the digitalizing of the supply chain to enable timely and accurate communication regarding inventory location and levels [19] and detecting bottlenecks to ensure continuous flow [20]. Industry 4.0 capabilities and technologies can also be used to support the implementation of lean manufacturing through the identification of manufacturing wastes in the manufacturing system [21]. Lean manufacturing waste can be defined as the non-use, loss, or over-use of digital and physical business technologies. This includes but is not limited to simulations, virtual models, and data analytic systems [7].

The relationship between Industry 4.0 and lean manufacturing is increasingly explored in the operations management literature [22, 23, 24, 25]. Although different in many ways, both concepts share the same goal or increasing added value [26]. Previous studies have explored how JIT can be supported by a digital supply chain [27], that Jidoka can be improved via enhanced information sharing using the Internet of Things [24], and Quality can be enhanced by digitizing the quality control process [28]. This paper sets out to answer the question of 'what are the associations between lean manufacturing waste and Industry 4.0', and to explore how the various Industry 4.0 capabilities can be used to identify and eliminate the different types of lean wastes in manufacturing. Identification of the wastes will generate more targeted and efficient approaches in the lean implementation journey, and the elimination will further enhance the value provided from within the manufacturing system. The following section explains the methodology applied, which is followed by the research Findings section, and finally the Conclusions section.

2. Methodology

The literature review performed for this paper used SCOPUS as the database to identify the relevant studies. Combinations of the following keywords were used to identify the pool of papers to be screened, "lean manufacturing", "wastes", Industry 4.0", and "digital". An excess of 200 papers were identified and screened at the abstract stage. A total of 53 papers, published between the years of 2008 and 2021, were chosen as relevant for this study to explore how Industry 4.0 capabilities can be used to identify and eliminate lean wastes in manufacturing systems. Despite of the great interest in the concept of Industry 4.0 worldwide, there is no one formally respected definition for it [29], and although there are many technologies and capabilities directly related to the digitalization of manufacturing there still is a lack of agreed upon classification in the literature. As such, the key Industry 4.0 capabilities identified and used in this research are the Additive Manufacturing, Augmented Reality, Autonomous Robots, Big Data, Cloud Computing, the Industrial Internet of Things (IIoT), Simulation, and Systems Integration. Whereas the lean manufacturing wastes identified and included were Defects, Overproduction, Waiting, Transportation, Overprocessing, Inventory, Underutilized skills, and Motion. The following section describes the different types of lean wastes and how the various Industry 4.0 capabilities can support in their identification within manufacturing systems.

3. Findings

3.1. Defects, IIoT, and Autonomous Robots

Defect waste is producing any product that is not suitable for use for whatever reason such as defective materials and components or produced not per specification [30]. The Industrial Internet of Things (IIoT) reduces information defects and increases product traceability [31, 32]. In the steel industry, Cao et al. [33] tested the use of a blockchain platform that allows producers, logistics services providers, and consumers to participate in information certification on improving steel products' information integrity and traceability. Results indicated that stakeholders in the steel industry were able to certify steel products, and express confidence in the information provided on the platform helping them reduce existing information defects. The authors suggested the universalization of blockchain technology in other complex industries to mitigate the information deficiency and defects problem. Potyrailo [34] proposed an IIoT based sensing technology for detecting gases in industrial and clinical environments. Advanced sensors that read many variables, and act autonomously can reduce risks of gases leaks or unexpected overflows. The author concluded with the suggestion that the sensors allow manufacturers to maintain smooth production without dealing with defective manufacturing environments. Velandia et al. [35] investigated the problem of defects in crankshafts manufacturing. They proposed a feasible solution capable of reducing process and product defects along the assembly line. The authors recommended the placement of radio-frequency identifiers on bolts along the assembly line. They also suggested the placement of a reading antenna on the gantry overlooking every step of the manufacturing process line. A reading of bolts will be taken at every stage, and immediate corrections will be made once any deviation is detected and flagged by the automated system. The Industrial Internet of Things (IIoT) capability has shown to have a clear impact on the identification of defective products and components at the various stages of production. Whereas the use of autonomous robots on the floor, which are machines programmed to achieve a task or a collection of functions in the manufacturing process [36], increases standardization and mitigates the occurrence of errors and defects on the production line, and stations. This helps the manufacturer achieve a better integration level, as well as flow improvement [37, 38].

3.2. Overproduction and IIoT

Overproduction waste is manufacturing extra products that are not required or have no customer demand [30], it is a major cause of other types of manufacturing wastes including inventory and waiting. Ghouat et al. [39] suggested that Industry 4.0 carries significant improvements on the production systems of manufacturers. First, the use of IIoT increases the real-time data collection of customer needs making the manufacturing of only desired products realized. Second, the enhancement of machine-to-machine communication increases optimal production generating only needed amounts requested by customers. Xu and Chen [40] proposed an IIoT based framework to enhance the implementation of Just-in-Time manufacturing, and thus avoid overproduction. The authors identified the frequently cited challenges surrounding the application of JIT in manufacturing settings. Then, the authors proposed a solution to address these challenges based on IIoT technologies. The proposed framework is celebrated to enhance lean manufacturing production and reduce excessive communication among varying departments in the enterprise. Korchagin et al. [41] used ARENA to simulate the effects of IIoT technologies on the lean production of the aviation industry in Russia and China. Based on a Boeing case study, the authors concluded that the use of IIoT results in the lean manufacturing of safe and quality aircraft products. The authors suggested that this application is profitable, and implementable across countries, and industries. The use of the Industrial Internet of Things has been associated with the identification of overproduction, as well as the implementation of JIT which aids in the reduction of overproduction.

3.3. Waiting and Big Data

"Waiting" waste is the delay time for employees such as equipment downtime, delay in processing, being out of stock of materials, or production equipment not ready [30]. Kho et al. [42] integrated big data analytics solutions to decrease lead time in the manufacturing process. Within a manufacturing shop floor, the authors proposed a radio frequency identification-based solution to track time at each stage of the manufacturing process. Results indicated that manufacturing time at each phase of the batch input manufacturing decreased since the big data solution suggested needed changes in the process. Big data analytics improves manufacturer's ability to build to order systems. Consumers may channel their preferences along the manufacturing process allowed by intelligent data systems that integrate consumers' desires in the manufacturing process of products [43]. Ye et al. [44] concluded that big data analytics decreased waiting time in tracking products, their locations, and features. The authors suggested that manufacturers increase their supply chain efficiency by relying on intelligent big data transportation systems. The use and the analysis of big data capabilities have shown to have an impact on the identification of waiting wastes and on increasing the operators' productivity.

3.4. Transportation, Big Data, and Systems Integration

Transportation waste is the movement of components and products between stations that aren't required to reach customers' needs [30]. Big Data applications in transportation manufacturing sectors carry a wide range of positive benefits [45]. The authors surveyed 320 manufacturers across industries and reported positive gains on their supply chain sustainability performance because of implementing big data analytics. Specifically, big data analytics helped manufacturers improve their circular economy practices, and sustainable supply chain activities, which resulted in efficient lean transportation. Bag [46] concluded a positive relationship between the implementation of big data and sustainable supply chain practice among South African engineering companies. The author suggested that big data applications improve real-time knowledge about problematic routes, equipment, vehicles, personnel, and suppliers making manufacturers correct their choices to guarantee smooth transportation quickly. Moktadir et al. [47] demonstrated how big data analytics is an important element in the establishment of robust transportation systems in the manufacturing field. The authors reported that once the data types are known to the manufacturer and a big data tool is specified, waste in the supply chain phase will be minimized. Similarly, the use and the analysis of big data capabilities has shown to have an impact on the identification of transportation wastes and on increasing the transporters' productivity. System integration refers to the increased connectivity and linking of cyber-physical systems in the manufacturing operation. The more connected the systems are within an operation, the easier the detection of waste sources, and customers' needs, which aids manufacturers in providing further value to their customers – which is the core concept of lean [48]. On the other hand, the more diverse systems are, and the more technically advanced they are, the harder their integration is. Therefore, it is best for manufacturers to standardize their systems and tools to guarantee higher degree of integration, which will result in enhanced continuous flow and improvement at all levels of the operation [49, 50].

3.5. Overprocessing and Big Data

Overprocessing waste is the addition of unrequired processes to produce a product or utilizing a more capable machine when a simpler one would be sufficient for the task at hand [30]. The application of big data analytics in the manufacturing process is a promising practice enhancing lean manufacturing outcomes [51]. Abell et al. [52] applied big data to manufacturing process control and proposed a new method to improve quality assurance called process monitoring for quality. The authors implemented their new proposed assessment method in the battery industry and found significant improvements in process streamlining and standardization. Big data tools could be linked with machines to autonomously correct any deviations from standardized processes using the information generated and recommended by the intelligent data-based systems [33]. Majeed et al. [53] proposed a framework for integrating big data analytics for optimizing manufacturing processes. Applying the framework in 3D printing company, the proposed application resulted in benefits for products manufacturing. Big data analytics helped automated machines identify customers' needs and integrate them into every phase of the manufacturing process.

3.6. Inventory and Cloud Computing

Inventory waste is all the materials, components, or products in storage for a longer than necessary [30]. Cloud computing technologies guarantees better estimates for product and predicted inventory amounts compared to traditional software downloads on personalized computers [54]. Cloud computing increases the cost-effectiveness of inventory handling by eliminating the need for servers, as well as human-related services rendered in inventory management on-site. Inventory amounts could be accessed anytime, anywhere, and from any device with a high degree of accuracy. This saves time spent on updating computer software and systems used to estimate inventory, as well as manage it [55]. Most importantly, cloud computing allows manufacturers to centralize inventory management activities. All processes relevant to inventory organization, arrangement, and ordering could be handled in one location, the cloud, where every stakeholder has access to the needed information [56].

3.7. Underutilized Skills and Augmented Reality.

Underutilized skills waste is the failure of tapping into employees' skills and knowledge to make improvements [30]. Augmented reality tools are increasingly used in the manufacturing sector to improve workers' knowledge, skills, and abilities in lean manufacturing and Industry 4.0 applications [57]. Augmented reality tutorials, programs, and workshops could be delivered to demotivated individuals who are not utilizing their skills to achieve lean objectives at the workplace. Augmented reality could be used to teach managers how to reward hard work, recognize employees, and stimulate innovation [58]. Augmented reality could open new horizons and avenues to the application of technical skills endowed by manufacturers' personnel [59]. The technology could be used in demonstrating additive manufacturing processes or simulated optimized systems [60]. Moreover, employees could utilize their existing knowledge to achieve the desired future states of optimized quality products and processes [61].

3.8. Motion, Simulation, and Additive Manufacturing

Motion waste is the unnecessary human movement, whether on the shop floor or micro-movement within a workstation [30]. Simulation software applications have been shown to have the capability of decreasing motion wastes [62]. Lean manufacturing experts could design optimal workstation layouts, and physical environments and assess their efficiency by using simulation software. Simulation software could eliminate wastes in the production planning phase [63] by the evaluation of alternative planning strategies to determine the optimal course of action. Simulations allow the design of process maps and the test of insertion or deletion of different phases to generate the most effective and efficient results desired. Manufacturing simulations allow manufacturers to integrate siloed operations within the general system by eliminating excess resources, people, or equipment. Moreover, simulation platforms allow manufacturers to evaluate the performance of their process designs [64, 65]. Additive manufacturing refers to the creation of high-dimensional objects by the disposition of materials like 3D printing [66]. Additive manufacturing saves large amounts of resources and minimizes the waste of operator motion, resources, costs, and energy used in production [67], this helps manufacturers achieve the objectives of lean manufacturing.

4. Discussion and Conclusions

The literature review has shown how Industry 4.0 capabilities and their different applications have a significant and growing role in the successful implementation of lean manufacturing initiatives, as shown in Fig. 1.

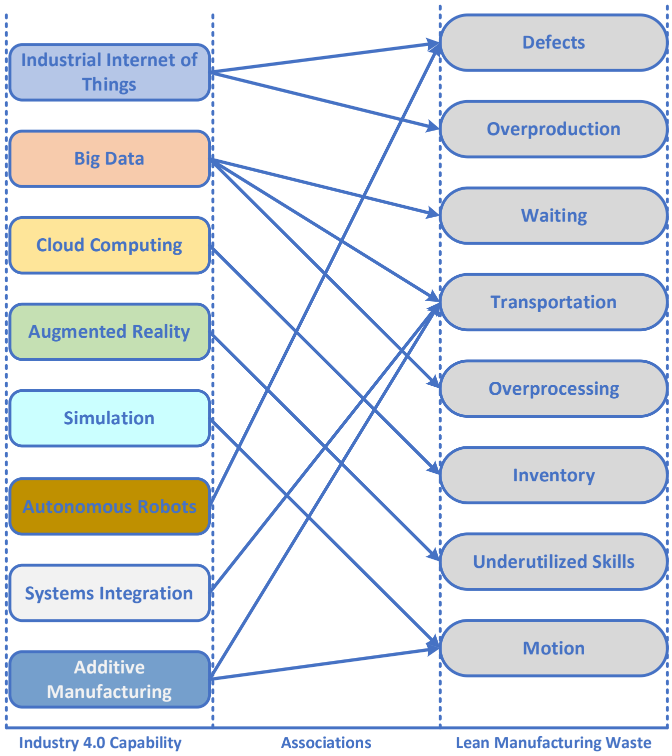

Fig. 1. The associations between the Industry 4.0 capabilities and lean wastes

The different solutions provided by these capabilities can be used in the process of identifying and eliminating lean wastes. The identification of the lean wastes will have a clear benefit for SMEs, as they typically operate on small transformational budgets related to the lean implementation journeys, therefore having digital capabilities that improve the identification of waste and will ensure that the transformational budgets are allocated effectively. This will result in successful lean journeys that deliver more efficient and productive manufacturing systems.

It can be concluded that all lean manufacturing wastes can be identified, as well as eliminated, using various digital tools that are considered part of Industry 4.0. This research has shown how IIoT mitigates overproduction across industries, and how its implementation is associated with a lower process and product defects. Moreover, the implementation of big data in manufacturing has been found to have positive effects on reducing waiting times across the manufacturing process and delivery, as well as transportation of parts, and the need for overprocessing. Studies have also shown how instant access to records stored on the cloud can reduce inventory, and how augmented reality can be used for upskilling of operators and in the identification of unutilized skills. Finally, how simulation and digital modelling has been extensively used in the identification and reduction of motion. Further research that builds on this work would seek to understand the relationships between Industry 4.0 and lean manufacturing, such as the associations linking Industry 4.0 capabilities with lean manufacturing metrics, and how Industry 4.0 can improve the lean manufacturing tools.

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