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Industry 4.0 Application in Lean Manufacturing- A Systematic Review

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Abstract. For several years Lean manufacturing has been adopted by industries in improving the operational performance of the firm. However, Lean manufacturing is associated with fixed production sequence and slow responsiveness, which limits its capability of meeting the constantly changing customer demand, product variability & customisation. This can inhibit its adaptability in the digital era. Meanwhile, Industry 4.0 technologies support the mass production of highly customisable products by being modular and flexible. Although Industry 4.0 technologies can meet the demands of the digital era, they are considered as a solution provider with little scope for organisational process improvement. Hence, an integration of both approaches will lead to a competitive advantage in the digital era. This paper aims to explore and evaluate the work done by researchers in identifying the link between lean manufacturing and Industry 4.0 technologies, through a systematic literature review to understand if lean manufacturing and Industry 4.0 technology can be integrated effectively.

Keywords. Lean Manufacturing, Industry 4.0., Systematic Review

1. Introduction

Today, manufacturing companies are facing diverse challenges which can be characterised as changing customer expectations, intense competition, globalisation, financial crisis, and economic downturn [1]. Under these challenging environments, companies need to adopt the most effective techniques and methodologies to stay competitive. Several such methodologies have been developed for companies to stay competitive such as Lean Manufacturing, Six Sigma, Lean Six Sigma, etc. Furthermore, for the organisation to be competitive, it must constantly adapt to the latest technologies and processes to maintain the sustainability of the process [2]. Industry 4.0 is the latest advancement in the industrial process, which is also termed as "fourth Industrial Revolution". It signifies a confluence of various technologies ranging from digital to material and process technologies. However, Industry 4.0 has been presented as a solution to ensure the productive sector success in the digital area, but with a little scope for organisational process improvement, such as those associated with Lean Manufacturing [3]. Lean Manufacturing developed during the third revolution is a management philosophy that focuses on improving the organisation's efficiency, implemented across different sectors of industries [4]. Lean Manufacturing is one such methodology that can significantly improve the quality, reduce cost, reduce lead time,

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and improve the productivity of the firm [5]. The widespread adaptability of Lean Manufacturing is due to the fact that it's easy to apply and provides effective results [6]. Although lean manufacturing is associated with fixed production sequence and slow responsiveness, against the changing customer expectation and product variability and customisation, Lean Manufacturing may not be able to meet the demands of the digital era, and its sustainability for the future can be limited [7]. So, one of the important aspects here is if Lean Manufacturing can be effectively integrated with Industry 4.0 to reap benefits from both digital technology advancement and organisational process improvement. Lean manufacturing and Industry 4.0 have similar goals, which correspond to improved quality, productivity, elimination of waste, and customer-oriented [8]. Although there are similarities, it is interesting to note that lean manufacturing is associated with the empowerment of employees and is considered a Low-tech approach, contrary to the implementation of higher automation levels in Industry 4.0, which leads to a reduction of manpower. This paper aims at exploring the existing research on integrating Lean Manufacturing principles with Industry 4.0 technologies that have been published in academic journals by systematically reviewing the literature.

2. Research Methodology

This research work contributes to the systematic literature review (SLR) on the application of Industry 4.0 technologies in lean manufacturing in a manufacturing context. According to [9], SLR is a methodology that identifies the existing work done by researchers, selects and assesses the contribution from various researchers, analyses and synthesises the data, and produces the results in such a way that there is a clear summary of what is known and what is not. As shown in figure 1, this study follows

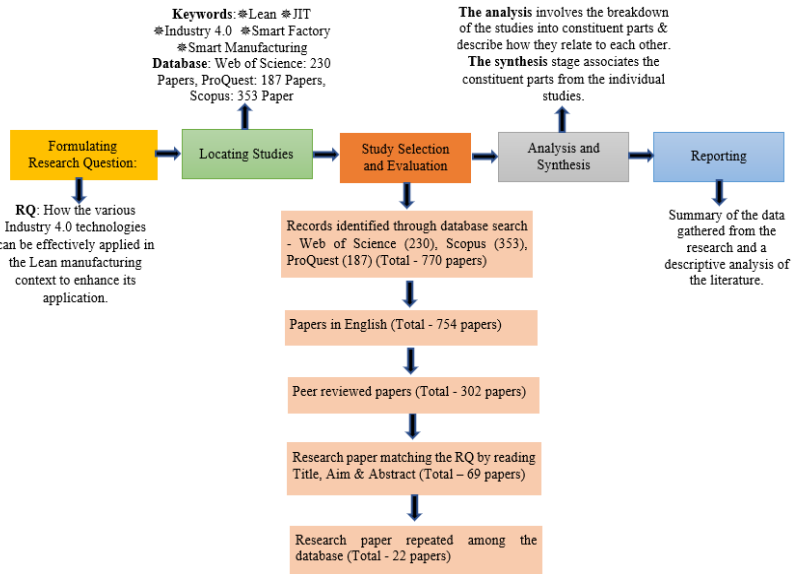

Figure 1: Research methodology

a typical five SLR steps proposed by [9] consisting of 1) Question formulation; 2) Locating Studies; 3) Study selection and evaluation; 4) Analysis and Synthesis; 5) Reporting and using the results.

3. Findings

3.1. Bibliometric Analysis

In the 22 papers shortlisted, the first paper was published in the year 2016. Since then, there is a continuous rise in the number of publications depicting the interest of researchers and academicians in this area, with the highest publication of 13 in the year 2020 and five publications already in the first quarter of 2021. Concerning the contribution of Journals, the 'International Journal of Production research', 'Production planning and control' and 'Sensors' had two publications each, and all other journals have one publication each.

When the shortlisted papers were filtered from the country origin, Italy had the highest contribution with four papers, followed by Germany, UK, and Malaysia with three papers each. China had two papers and seven other countries had a contribution of one paper each. The contribution to the research from a developed country is 64% and from developing countries is 36%. This signifies that even developing economies have shown tremendous interest in the field and have tried to adopt the latest technology. Globalisation has also contributed, as the companies from the developing economies have expanded globally with affiliate companies all over the world which has contributed to the development of the manufacturing sector in the developing countries.

On analysing the results of the research paper, nine industry 4.0 technologies were identified which were discussed by the authors in the research papers. The results depicted that IoT technology was the highest quoted by authors with 7 papers, Cyber-Physical System appeared in four papers, Machine Learning and Cloud Computing appeared in three papers each, and remaining technologies were discussed in one paper each.

3.2. Industry 4.0 tools supporting Lean Manufacturing

IoT (Internet of Things) technologies such as RFID (Radio Frequency Identification) and LPWAN (Low Power Wide Area Network) are utilised to enhance digital traceability and to provide real-time information which can be effectively applied in Lean Manufacturing to identify and eliminate the waste [10-11]. IoT has also been used in integrating machines in the shop floor and also to connect to the machines with Andon systems to enhance the decision support system for process improvement [12-13]. IoT has also been applied to transform the traditional JIT (Just-In-Time) into dynamic JIT, which successfully addresses the challenges of traditional JIT by integrating modules integrated with IoT technologies into the Manufacturing Execution System (MES) [14]. IoT application is also shown to benefit the concept of SMED (Single Minute Exchange of Die), by providing embedded information to the product that can be directly communicated to the machine that requires a changeover, ensuring shorter changeover time through direct communication [15]. IoT has also shown effective synchronisation between the production and logistics by providing the logistic operator with real-time

requirements and also proposes optimum travel routes to improve the process efficiency [16].

Machine learning (ML) is used to enhance the decision support system in JIT delivery performance by providing flexibility for the operator with re-scheduling options in case of production issues through the use of a human-machine interface [3]. ML contributes to the continuous improvement philosophy, in targeting specific performance indicators of complicated data-driven processes, by choosing the best improvement pathway under dynamic changes of production, which otherwise would have been a tedious task doing it manually [17]. ML also reduces the process lead time and has been effectively implemented in an additive manufacturing environment by accurately predicting the cooling time [18].

Cobots are also implemented effectively in the lean manufacturing environment. It promotes automation through careful gripper design to comply with safety norms to integrate the simultaneous operation of operator and robot [19].

Augmented Reality (AR) plays a vital role in ensuring Poka-Yoke or Jidoka systems. Kumar and Chiarini [20] quote examples from the survey where AR is used as Poka-yoke and ensuring that the operator follows a standard operating procedure. In an instance, the operator has to tighten critical-to-safety bolts wearing smart 3D glasses. The glasses visualise a green light on picking the right critical bolt and facilitate the operator in choosing the right wrench. The glasses also ensure that the operator tightens the bolt with the right torque and will then carry out the next task. This example depicts the effective combination of the Industry 4.0 tool with the Lean principle giving optimum results.

Virtual Reality (VR) has been used to create a digital twin of the manufacturing process before the actual installation. It allows the manufacturing team to confirm the virtual world's design and ensure rectification of the problems before the installation [21]. This integration of VR in the confirmation process ensures a reduction in the rework and reduces the lead time of the project by ensuring fewer problems after installation.

Artificial Intelligence (AI) with the use of electroencephalography sensors is utilised to characterise and discerning between various types of behaviour. This practice is carried out on a balanced scorecard and hoshin kanri tree and conveys the unique characteristics observed by the process operator and the leader [22]. These devices are effective in imparting the training of the lean principles on the shopfloor and valuable feedback can be given by differentiating the systems and better understanding the thinking patterns.

Cyber-Physical Systems (CPS) are used to create real-time scheduling and dispatching system that runs on dynamic value stream map. It can monitor the flow of the products and spot the discrepancy between the physical and virtual world caused by Lean waste [23]. CPS is also deployed by integrating with pull production strategy to reduce the cost involved in the implementation by striking a balance between the extent of CPS implementation and the performance through an appropriate pull control strategy [24]. CPS is also used in implementing the Jidoka system in determining the optimum time for the tool wear in a CNC process and also initiate automatic tool change by reducing the need for the operator to perform the repetitive task [25].

Cloud Computing (CC) is implemented in dashboard-type monitoring of the process, enabling managers to make effective decisions [26]. CC along with RFID is used to grasp the real-time production records of production operators and the production equipment's for a labour-intensive production company [27]. CC is integrated with ERP (Enterprise Resource Planning) system to create a cloud ERP system that supports electronic Kanban,

real-time monitoring of production volumes promoting JIT, FMEA (Failure mode effect analysis) of process, and supports preventive maintenance, spare part management, and tracking machine breakdown history [28].

Big Data Analytics (BDA) is effectively integrated with various guidelines of value stream map (VSM) to enhance and benefit the VSM design. It enables real-time takt definition, effective decision making in selecting finished goods strategy. BDA can successfully permit the re-dimensioning of supermarket policies and along with remote production process management would allow instant updates regarding fluctuations and variations which can halt interval achievement [29].

4. Conclusion

This research work contributes to the systematic literature review on the relation between Lean Manufacturing and Industry 4.0 technologies in a manufacturing context. As Industry 4.0 is associated with a list of technologies and is not a definitive set of technologies, nine technologies have been identified which were prominent in the research field. These Industry 4.0 technologies were then linked with different Lean Manufacturing principles and tools through the literature review and have been described in the main findings. It is also observed that Industry 4.0 technology has enhanced lean manufacturing tools through technology advancement, digitalisation and the use of the internet. The Industry 4.0 technology also has specifically improved on the challenges faced by traditional Lean tools and the combined effect has proven to provide the potential for the organisation to tackle the challenges of the digital era.

A bibliometric analysis of the literature review results also brings many insights into the research. The prominent insight derived is that the research area is a young research area with an increasing trend of interest from researchers and academicians in the field. Interestingly, Italy dominated with the maximum research papers in the field followed by Germany, UK, and Malaysia. This can be attributed to the search string keywords which were broadly focused on 'Lean manufacturing', 'Industry 4.0', and 'Manufacturing' sector.

This research by depicting the application of the Industry 4.0 technologies in Lean Manufacturing through systematic literature review methodology provides a foundation that can inspire further research efforts. Due to space limitation, the discovered future roadmap in this area will be presented at the conference.

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