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Industry 4.0 and lean management: a proposed integration model and research propositions

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ABSTRACT

Lean Management (LM) is one of the most widely used business strategies for the last three decades. Industry 4.0 shows all the promise of the fourth industrial revolution using automation technologies like cyber-physical systems, internet of things and cloud computing. The purpose of this paper is to propose an integration model of Industry 4.0 and LM. A summary literature review of Industry 4.0 and LM is carried out to construct a theoretical model of integration. The previous literature is used to develop and propose an integration model of Industry 4.0 and LM. The horizontal, vertical and end-to-end engineering integration model are integrated with LM methodology. Testable research propositions are proposed between Industry 4.0 and LM. The model proposed is novel and it raises the important issue of integration of LM with Industry 4.0. This is the first paper which proposes the integration framework of LM with Industry 4.0.

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Industry 4.0; lean management; model; lean automation; cyber-physical systems

1. Introduction

The advent of fourth industrial revolution has redefined the integration of physical world in the organization and the cyber world through technologies like artificial intelligence, analytics, cloud technology, internet of things (IOT), etc. (Bassi, 2017; Fonseca, 2018; Xu, Xu, & Li, 2018). The digital transformation has not only changed the manner in which an organization operates, but also the market is transformed into considering the full value chain (Oesterreich & Teuteberg, 2016). Industry 4.0 though initially introduced in 2011 in Germany, the official announcement as a strategic German initiative to revolutionize the manufacturing industry through the use of technology was officially unveiled in 2013 (Xu et al., 2018). Industry 4.0 is a current trend in manufacturing industry by use of automation technologies, such as cyber-physical systems (CPS), IOT and cloud computing (Hermann, Pentek, & Otto, 2016; Industry, 2016; Kagermann, Helbig, Hellinger, & Wahlster, 2013; Lasi, Fettke, Kemper, Feld, & Hoffmann, 2014; Lu, 2017; Rubmann et al., 2015; Xu et al., 2018). Many researchers have devoted considerable attention towards developing the concept of Industry 4.0 from its theoretical background to practical applications (Cheng, Liu, Qiang, & Liu, 2016; Fonseca, 2018; Kagermann, 2015; Kagermann et al., 2013; Lasi et al., 2014; Rubmann et al., 2015; Stock & Seliger, 2016;

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Weyer, Schmitt, Ohmer, & Gorecky, 2015; Yen et al., 2014). The previous studies have addressed several aspects of Industry 4.0 such as the context of application of Industry 4.0 (Jazdi, 2014; Oesterreich & Teuteberg, 2016; Zhong, Xu, Klotz, & Newman, 2017), several perspectives and viewpoints on Industry 4.0 (Brettel, Friederichsen, Keller, & Rosenberg, 2014; Saldivar et al., 2015; Schuh, Potente, Varandani, & Schmitz, 2014), application of Industry 4.0 in several sectors (Lu, 2017; Petrasch & Hentschke, 2016), the technologies in Industry 4.0 (Lee, Bagheri, & Kao, 2015; Rubmann et al., 2015) and numerous aspects related to the environment of Industry 4.0 (Bagheri, Yang, Kao, & Lee, 2015; Lee, Kao, & Yang, 2014) etc. Nevertheless, in addition, Industry 4.0 also incorporates several unexplored dimensions, like the integration of LM one of the most popular business strategy and Industry 4.0 (Kolberg & Zuhlke, 2015; Leyh, Martin, & Schäffer, 2017). The power of Industry 4.0 will not be materialized as an industrial revolution if it is not integrated into the LM theoretical framework (Rüttimann & Stöckli, 2016). The previous studies in Industry 4.0 were purely theory-oriented, and hence it is not readily adaptable for practical implementation in an organization. Also, there is lack of comprehensive framework which combines Industry 4.0 solutions with methods of LM Management (Kolberg & Zuhlke, 2015; Leyh et al., 2017). Thus, there is a need to develop a framework for the successful integration of LM and Industry 4.0 (Sanders, Elangeswaran, & Wulfsberg, 2016). Industry 4.0 and LM utilize decentralized control and aim to increase productivity and flexibility (Buer, Strandhagen, & Chan, 2018). There have been few studies on the importance of investigating the link between LM and Industry 4.0 (Buer et al., 2018; Kolberg, Knobloch, & Zühlke, 2017; Sanders et al., 2016; Sanders, Subramanian, Redlich, & Wulfsberg, 2017; Tortorella & Fettermann, 2018). In a recent study, Buer et al. (2018) suggest that area of LM and Industry 4.0 is yet immature and that is the reason why no implementation framework for integration of LM and Industry 4.0 is published yet. They further suggest a need to understand how these domains interact. In this study, it is intended to address the research gap by developing a theoretical integration model between LM and Industry 4.0. In addition, the research proposition will be developed so that future research can be guided in this direction. The theoretical background is elucidated in the next section, trailed by the proposed model and research proposition and subsequent discussion and conclusion are presented in this paper.

2. Theoretical background

2.1. Industry 4.0

Industry 4.0 is associated with the beginning of the fourth industrial revolution. It depicts the recent trend in automation technologies which is gaining popularity in the manufacturing industries. The main technologies which enable the revolutionary thinking in manufacturing are (1) CPS, (2) IOT and (3) Cloud computing. The main feature of Industry 4.0 is CPS production. This is based on heterogeneous data and knowledge integration (Lu, 2017; Zanero, 2017). The key roles of CPS are to achieve the agile and dynamic requirements of production. In addition, it should also aim to improve the efficiency and effectiveness of the complete organization. Industry 4.0 therefore comprises of many technologies, such as IOT, cloud-based manufacturing, Radio Frequency Identification (RFID), Enterprise Resource Planning (ERP) and social product development (Baur & Wee, 2015; Fonseca, 2018; Georgakopoulos, Jayaraman, Fazia, Villari, & Ranjan, 2016; Kube & Rinn, 2014; Lasi et al., 2014; Lin, Chen, Zhang, Guan, & Shen, 2016; Lom, Pribyl, & Svitek, 2016; Lu, 2017; Singer, 2015). Industry 4.0 is a development in technology from the earlier embedded systems to CPS. The embedded systems, semantic machine to machine communication, IOT and CPS are technological concepts that are connecting the physical world with the virtual world and this is the primary aim of Industry 4.0 (Xu et al., 2018). Also, the modern-day industrial systems should be capable deal with the complexity of the production process due ever changing customer needs by making use of the CPS (MacDougall, 2014). Therefore, such organization which integrates the cyber and physical systems is commonly termed as smart factory. The capabilities of smart organizations are immense and thus, we are on the brink of a fourth industrial revolution, wherein the world of production and network connectivity are connected through IOT and CPS to make the dream of Industry 4.0 a reality (Moeuf, Pellerin, Lamouri, Tamayo-Giraldo, & Barbaray, 2018; Xu et al., 2018). The smart devices within the smart organization complement IOT, CPS, cloud computing and Business Process Management. CPS is the main paradigm shift in the fourth industrial revolution. This paradigmatic shift is due to the technology revolution in Information and Communication Technologies leading to a shift from industrial electronics to industrial informatics. IOT revolutionizes existing manufacturing systems and is one of the most important enablers for Industry 4.0. The main function of IOT is to create networks that support the smart organization or factory (Trappey, Trappey, Govindarajan, Chuang, & Sun, 2017; Varghese & Tandur, 2014). The difference between third industrial revolution and Industry 4.0 is that third industrial revolution focusses on automation of machines and processes, however, Industry 4.0 focusses on end-to-end engineering integration & digitization and also the complete integration of physical systems with virtual systems (Tan et al., 2010). IOT is the main enabler for the Industry 4.0. This is because it transforms the operations and the role of other industrial systems due to digitization. IOT also helps to create virtual support networks to create a smart factory (Oesterreich & Teuteberg, 2016; Peruzzini, Gregori, Luzi, Mengarelli, & Germani, 2017). Cloud manufacturing will contribute significantly to Industry 4.0. It uses the network of resources in a highly distributed manner (Thames & Schaefer, 2016). CPS are the foundation for Industry 4.0. CPS are collaborating with computational entities that are in connection with physical systems and processes within the organization enabling data acquisition and data processing through the internet to meet the various goals of organizations. The physical and software components are intertwined with each other, operating in different spatial and temporal scales, however, interacting in different ways (Xu et al., 2018). With the introduction of CPS, machines will be able to communicate with each other and decentralized communication systems optimize the use of resources in the production process. In the modern day, the business must be efficient, productive and competitive to survive in the market, Industry 4.0 through informatization and digitization of the manufacturing achieves this goal. The long-term and short-term strategic impact of Industry 4.0 in the manufacturing and services in the global markets are immense in terms of meeting customer needs, in a most efficient manner. The industries around the world have responded effectively. Many firms like Siemens, Hitachi, ABB, Schneider

Electric, Emerson Electric, Bosch, Panasonic, Honeywell, Mitsubishi Electric, etc. have invested heavily in IOT and CPS type of projects (Xu et al., 2018).

2.2. Three kinds of integration of Industry 4.0

There are three kinds of integration possible in Industry 4.0. The horizontal integration, vertical integration and end-to-end engineering integration (Wang, Wan, Li, & Zhang, 2016). Horizontal integration is the integration of value networks to enable collaboration between corporations or organizations in the value chain (Foidl & Felderer, 2015). For the success of the business, more than one organization cooperates to deliver superior products and services (Sindi & Roe, 2017). By inter-cooperation horizontal integration of organizations through digitization, a new efficient digitized ecosystem is created. Vertical integration is the integration of various hierarchical subsystems within the organization to create a flexible and reconfigurable manufacturing system within the organization. The various informational subsystems within the organization are connected to the ERP system. This will enable a flexible and reconfigurable manufacturing system (Wang et al., 2016; Weyer et al., 2015). This integration results in smart machines within the organization autonomously configuring to adapt to different products. The big data management will enable to make this process a success. The end-to-end engineering integration results in integration which enables the creation of customized products and services across the value chain (Stock & Seliger, 2016). In a product-centred value creation process, a chain of activities is involved. E.g. customer needs analysis, product design and development, production, services, maintenance and recycling. By using power software tools these phases can be integrated to create customized, automated, self-organized product and services as per the customer requirement (Qin, Liu, & Grosvenor, 2016; Wang et al., 2016).

2.3. Lean management

Lean thinking or management is one of the most widely used business strategies in the last three decades. LM mean tools which are used to execute LM thinking. LM thinking is used to differentiates between waste and value within an organization. Waste is defined as 'any human activity which absorbs resources but creates no value'. The value on the other hand in the business sense is defined as 'a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer' (Womack & Jones, 1996; Womack, Womack, Jones, & Roos, 1990). LM, when practically applied in an organizations results in a process of continuous identification and elimination of waste from an organization's processes. Due to identification and elimination process, the by-product which remains in the organization is value-added activities in the organizational value stream (Rother & Shook, 2003). In a simpler language, LM within the organization deals with identification and elimination of waste. It originated from Toyota Motor Corporation. It is a fundamental substitute to the traditional method of mass production. The waste or Japanese equivalent 'MUDA' plays a major role in Lean. The initial waste identified by Taiichi Ohno (1) transportation (2) inventory (3) motion (4) waiting (5) overproduction (6) over processing (7) defects (Ohno, 1988). The eighth waste skills known as unused human talent was later introduced when LM was introduced in the western world (Liker, 2004). LM can also be defined by five principles (Womack & Jones, 1996). The five LM principles are (1) Specify the value desired by the customer. (2) Identify the value stream for each product/service providing the value customer. All the waste in the value stream can be challenged. (3) Make the product flow continuous. To make the flow continuous a remedy is to standardize the process around the best practices. Once the process is standardized it will allow more free time for the employees. This free time can be used for creativity and innovation. (4) Introduce the pull between steps where continuous flow is not possible. The customer demand should be the pulling force to trigger backward events. (5) Manage towards perfection and it will remove the non-value added activity from the value chain (Womack & Jones, 1996; Womack et al., 1990).

The benefits due to the removal of non-value added activities are a reduction in the number of steps, the time taken to manufacture the product and the information needed to serve the customer. In defining the five principles an underlying assumption is that organizations are made up of processes. The step-wise and sequential application of these five principles in organizations will add value to customers, reduce waste and continuously improve in an ever-repeating process called Kaizen (Radnor, Holweg, & Waring, 2012). Researchers have argued that focus should not only be on waste, but also on the other two elements Mura and Muri. Mura which relates to unevenness in the processes and argues for a less variation. To reduce Mura one has to standardize the processes. Muri means excessive strain. It calls for a good working condition that prevents injuries and strain on workers. There are three types of LM activities, which are (1) Assessment, (2) Improvement and (3) Performance Monitoring. Assessment is directed to assessing the existing state of organizational processes in terms of waste, flow or capacity to add value. Most commonly used tools are waste walks, value stream mapping etc. Improvement phase is the activities undertaken so that organizational processes are improved. The tools used are Rapid improvement events, 5S, etc. Though LM has many tools. The most commonly used tools Hoshin Kanri and planning, Value Stream Mapping, Lean Office, Lean Metrics, Push and pull systems, Kaizen events, Visual control and management, Takt time, 5S, One-piece-flow, SMED – quick change-over, Jidoka – automation, Kanban, Total productive maintenance and Asaichi – market morning -A3 report (Chiarini, 2011). Monitoring phase is where we measure the process & improvement made. Tools like visual management, SOP and performance data are the most widely used.

3. Industry 4.0 and LM integrative model

Industry 4.0 can be classified based on the principles of integration into vertical, horizontal and end-to-end integration (Wang et al., 2016). The five main principles for LM implementation is the overarching guideline for implementing LM (Womack et al., 1990). Waste must be eliminated before implementing three integration mechanism, else one will be automating the waste. With this principle in mind, the model proposes LM principles in all three forms of integration in Industry 4.0. Therefore, Industry 4.0 and LM integration model is as depicted in Figure 1. The vertical, horizontal and end-to-end engineering integration model and its integration with five principles are elucidated in the model.

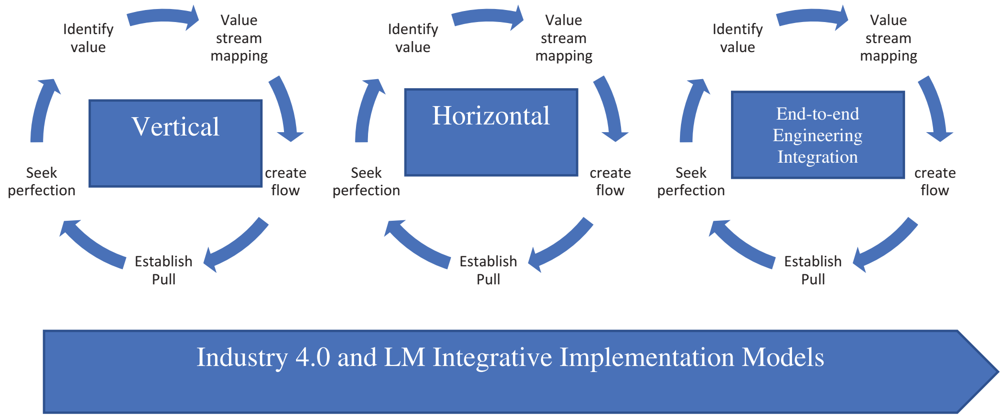

Figure 1. LM and Industry 4.0 Integration (Source: Author Constructed).

3.1. Vertical integration & lean

The vertical integration is the creation of flexible and reconfigurable manufacturing system by integrating various hierarchical elements within the organization through digitization (Foidl & Felderer, 2015; Wang et al., 2016). The integration of hierarchal subsystems within the organization must be well thought integration strategy to achieve strategic goals. LM can be used as a guideline to design the integration strategy. The first step in the design of vertical integration is to identify the value.

The value should be defined in terms of customer needs for a specific product or service the organization caters. Due to Industry 4.0, the customer needs are changing drastically, and new customer needs are emerging (Fonseca, 2018). A large amount of data on customer needs must be analysed through data analytics, before identifying the customer needs which can be met by the organization (Lee et al., 2014). The prime purpose of vertical integration is to meet the customer needs in an efficient manner using minimum resources.

Proposition1: *While designing the vertical integration architecture through Industry 4.0 for implementing Industry 4.0, defining the value in terms of customer needs for products and services will form the underlying principle for vertical integration.*

The second step in vertical integration is mapping the value stream for the organization products or services. Value streams are the steps or processes involved in converting the raw material to final products and services. The process could be design, production, manufacturing, purchasing, maintenance, etc. This step helps within the organization to identify value and non-value added activities (Womack et al., 1990). Before creating a flexible and reconfigurable manufacturing system, the process should have more components of value-added activities then non-value-added activities (Kolberg & Zuhlke, 2015). The wastes within the organizations could be identified and eliminated before designing strategic integration mechanisms. The process reengineering would also help before the strategic integration of various elements within an organization.

Proposition 2: *Value stream mapping of products and services before designing architecture for vertical integration thorough Industry 4.0 of hierarchical subsystems within an organization will help in removing waste in the integration of CPS which will represent all machines, products, and resources within the organization.*

The third step is to make the flow smooth within the organization. Removing various bottlenecks or delays or interruptions within the processes (Womack et al., 1990). This process to be successful it will require cross-functional cooperation between various elements in the organization (Singer, 2015). To promote the cross-functional cooperation to create smooth flow, the integration of various departments using CPS will be beneficial (Lee et al., 2015). In addition, data collection by placing strategically sensors at various points will help in the monitoring of the flow process within the organization.

Proposition 3: *The vertical integration of various hierarchical subsystems within the organization will create a smooth flow process leading to cross-functional cooperation between departments by integration of CPS within each department in a strategic manner using a self-regulated system.*

The fourth step is to improve the flow and the vertical integration of all departments will result in the reduction in time to deliver the product or service (Kolberg & Zuhlke, 2015). This leads to a pull system within the organization to create the atmosphere for just- in- time (JIT) philosophy. The JIT philosophy is a Japanese competition survival production philosophy. The main objective is reducing total production cost. It is done by minimizing waste and continuously improving the total product quality (Hutchins, 1999). Such a system will create an environment wherein the customer can pull the product from the organization as and when needed and the vertical integration of manufacturing, purchase and other function will deliver using the CPS.

Proposition 4: *The vertical integration though Industry 4.0 of hierarchical subsystems within the organization will drastically reduce the time taken to bring the product into the market enabling a customer created pull system.*

The last step is to create perfection within the system, by repeatedly visiting the above steps to create a perfect system (Womack & Jones, 1997). To do that one need a system which creates a continuous improvement culture within the overall integrating elements within the organization to improve value to the customer (Mann, 2010; Zarbo, 2012). It also means to create a culture within the organization which will vertically integrate the various subsystems within the organization. To create a culture of CPS em integration it requires more than technological integration, but a cultural shift in thinking in the organization.

Proposition 5: *The vertical integration of hierarchical subsystems should create a continuous improvement culture within the overall integrating subsystems within the organization to improve value to the customer.*

3.2. Horizontal integration and lean

The modern-day organization requires cooperation between various organizations in the supply chain to create value for the customer (Albino, Carbonara, & Giannoccaro, 2007). The supply chain for an organization is the system of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer (Christopher, 2016). In horizontal integration, all the organizations which participate in the value chain must play a role to meet the customer needs. The digitization of the entire supply chain will lead to improved benefits for the organization as well as for the customers (Auramo, Kauremaa, & Tanskanen, 2005). Due to the implementation of Industry 4.0, many new innovative business models are feasible and practically possible to be implemented in the marketplace to add value to the customer and also create a competitive advantage (Ivanov, Dolgui, Sokolov, Werner, & Ivanova, 2016; Kube & Rinn, 2014). To cite an example tracking of customer orders all along the supply chain by the customer is a feature which will add value to the customer in terms of last-minute orders, also, it will result in the personalization of products and services. Quality will now be the responsibility of the entire supply chain and with sensors monitoring the quality characteristics of interest, it will be very difficult for a poor-quality product reaching the customer (Foidl & Felderer, 2015). Horizontal integration cannot be implemented in isolation. LM can be used to design the horizontal integration. The first step in the design of horizontal integration is the identification of the customer value, which the supply chain or co-operating organizations are supposed to fulfil. Clear delineation of customer value will help in identification of various organizations role in the creation of value for the customer (Duarte & Cruz-Machado, 2017). Therefore, all the horizontally integrating organizations should agree on the customer value which the integrating strategy is supposed to fulfil.

Proposition 6: *Horizontal integration of various organizations is designed based on the common and mutually agreed perception of the customer value among the integrating organizations, which the commonly agreed integration strategy is supposed to accomplish.*

The second step in the horizontal integration is to map the value stream of the value added activities across each cooperating organization. This is an important step as it will help to understand the value each organization adds in the horizontal integration (Nash & Poling, 2011; Seth & Gupta, 2005). Due to the integration of various organizations through digitization, both upstream and downstream, there are huge opportunities to design innovative supply chain models (Ivanov et al., 2016).

Proposition 7: *The horizontal integration mechanism can be designed by incorporating VSM, to map the value to the customer by identification of waste (Muda) in the horizontal integration mechanism.*

The third step in the horizontal integration is to create a proper flow without any interruption or bottleneck (Womack et al., 1990). To create a proper flow among the various cooperating organizations for the horizontal integration, various coordination mechanisms using intelligent algorithms must be designed (Kolberg & Zuhlke, 2015). Monitoring of real-life data must be carried out for self-regulation throughout the supply chain to avoid any coordination issues for maintaining the smooth flow.

Proposition 8: *The horizontal integration mechanism using industry 4.0 will improve the flow across the cooperating organization to deliver value to the customer by incorporating smart coordination and regulation systems*

The customer will be directly connected to the various elements in the supply chain due to the horizontal integrating digitized mechanism. Based on customer needs appropriate response will be devised by all the subsystems or elements in the supply chain. Such a mechanism will result in delivery of personalized products and services based on the user needs that too in a shortest possible time (Douaioui, Fri, & Mabroukki, 2018; Ivanov et al., 2016).

Proposition 9: *The horizontal integration mechanisms using Industry 4.0 will enable the delivery of customized products and services in a shortest possible time based on customer created a pull system resulting in new industry level benchmarks.*

The horizontal integration will operate at an optimum level across the supply chain, when a culture of continuous improvement across all participating organization is formed. The steady state for the horizontal integration will be achieved when the continuous improvement is benchmarked across all participating organizations. If only a few organizations have this culture and others do not, then the benefits due to horizontal integration will not be realized (Hult, Ketchen, & Arrfelt, 2007).

Proposition 10: *Continuous improvement culture should be the benchmark across all the horizontally integrated organizations to create a perfect system to deliver optimum customer value by using minimum resources.*

3.3. End-to-end engineering integration

Product and services are important components for the success of Industry 4.0 (Leyh et al., 2017; Liao, Deschamps, Loures, & Ramos, 2017). The concept of the smart factory under Industry 4.0 is facilitating the automated, flexible, efficient production system that can be realized if the products and services are compatible for this unification (Lichtblau et al., 2015). The digital amalgamation of each stage of products life cycle enables new synergies and opportunities to optimize engineering along the entire value chain of the product (Kagermann et al., 2013). The product because it is smart, can store information about itself in terms as manufacturing, preceding operation, sub-seeding operation, the current state, circuit diagram or plan, assembly information, automatic path, among others more (Foidl & Felderer, 2015). The CPS thus covers every aspect from customer requirements to product architecture and manufacturing of the finished product. The first step in end-to-end engineering integration is identifying the value of the product in terms of customer requirements which should be further analysed from the CPS perspective.

Proposition 11: *End -to-end engineering integration requires identifying the value of the product in terms of customer requirements which are further translated into the* CPS *requirements.*

This will thus enable to manufacture cyber-enabled products, which are smart in nature. Products are assembled from smart workpieces which are modular and plug compatible (Axelsson, Fröberg, & Eriksson, 2018). These are equipped with sensors, RFID, communication interfaces, GPS, etc. to collect data from the environment and their own status about production. These data will be processed in the cyber systems to know their path in the production system. In addition, these paths, the cyber world will guide the production process in an autonomous manner without human interaction. Of course, all these happen in the real-time (Lichtblau et al., 2015; Saldivar et al., 2015). This integration of products, physical production systems, and cyber technology will enable monitoring, self-regulation, optimization of the resources to manufacture individual products (Bassi, 2017; Cheng et al., 2016). Such a viewpoint does not end with the production of the product alone, but rather, it moves beyond production to consumption by the customer. The concept of servitization was proposed as early as 1988 (Vandermerwe & Rada, 1988). This concept of customer focus should combine products, services, support and knowledge as the most important elements (Lee et al., 2014). Manufacturing servitization is defined as the innovation of organizational capabilities and processes, from product sales to integrated product services (Baines, Lightfoot, Benedettini, & Kay, 2009). It is a change in strategy for the organization wherein organization shift their capabilities and processes from selling of a product to selling an integrated product and service offering, that deliver value in use (Martinez, Bastl, Kingston, & Evans, 2010). Product-service system is a special aspect of servitization. It is a system of product, services, support networks and infrastructure, which is designed to be competitive in the market, meet the customer needs, and above all, it has less impact on the environment when compared with products of traditional nature (Mont, 2004). Therefore the marketing goal of the organization changes from not just selling a product, to satisfying customer needs by total service solution (Lerch & Gotsch, 2015). Such a concept to be a reality the integration of the CPS of the organization should integrate the usage of each product at the consumer end.

Proposition 12: *For end-to-end engineering integration the value stream of CPS system requirements using the product-service-system will help to identify the non-value added activities.*

As the smart products move through the organization in a self-guided manner, the smooth flow must be designed without any interruption or delays (Lichtblau et al., 2015). Each product will capture the various processing time parameters, which can be used to optimize the smooth flow during the end-to-end engineering integration (Nunes, Pereira, & Alves, 2017).

Proposition 13: *For end-to-end engineering integration the data from the smart products can be used to design the smooth flow using the* CPS.

The data within the smart products can be used to deliver the product in the shortest possible time within and external to the organization. The smart products will guide its way through smart supply chains in a pull system manner created by the customer (Nunes et al., 2017; Schmidt et al., 2015).

Proposition 14: *The data from the smart products can be used to create a pull system design using end-to-end engineering integration in a shortest possible time within and external to the organization.*

The self-regulating mechanism in the end-to-end engineering integration will create a culture towards perfection and continuous improvement through the smart algorithm which will acquire and process a large amount of data leading to technology-based continuous improvement culture (Bicaku et al., 2017; Burke, Mussomeli, Laaper, Hartigan, & Sniderman, 2017; He & Jin, 2016).

Proposition 15: *The self-regulating mechanism through smart data from the products in end-to-end engineering will create a culture of continuous improvement.*

4. Discussion & implication for research and practise

The purpose of this paper was to delineate the research gap in the current research and practice on LM and Industry 4.0, by presenting a proposed theoretical integration implementation model, which can be used for further empirical verification of three types of integration of Industry 4.0 and Lean. The overriding principle of our work is that LM can be used as a philosophical guideline for the design of architecture for the horizontal, vertical and end-to-end engineering integration for implementing Industry 4.0 within the organization. So far, there are few scholars who have examined the integration of LM with industry 4.0 (Axelsson et al., 2018; Leyh et al., 2017). Therefore, this study provides an addition, to the advancement of much-needed theory on LM and Industry 4.0. A major contribution of this study is that it provides the research propositions which can be tested in future empirical studies. Next, we discuss specific implications for research and practice. Vertical integration in Industry 4.0 is the integration of various functions within an organization (Wang et al., 2016). The underline principle of this integration should be aligned based on the five principles of Lean. Such an alignment of LM and vertical integration in Industry 4.0, will add value to the customer and the resources which are integrated will be utilized in the best possible manner. In addition, the integration mechanism can be tailored as per the individual organization based on the value it adds to the customer based on the product or service offerings. The vertical integration within an organization results in huge financial expenditure (Foidl & Felderer, 2015). By using LM principles as a guideline, the integrations of those functional subsystems may be carried out, initially, which adds value to the customer. This will thus serve as a guideline for the prioritization of integration of functional subsystems based on the five principles of LM. The horizontal integration is the integration of various organizations that add value to the customer (Stock & Seliger, 2016). The LM five guiding principles can be used as a guide for designing the horizontal integration strategy to add value to the customer by optimizing the various parameters within the horizontal integration. The five guiding principles can serve a cohesive mechanism for cooperation and coordination between all the different organizations within the horizontal integration framework (Martínez-Jurado & Moyano-Fuentes, 2014). The strategic data sharing, data management and self-regulation algorithm will also help in bringing transparency within the horizontal integrative elements. The horizontal and vertical integration based on the five principles of LM will result in a system which is very responsive and create a pull by the customer. End-to-end Engineering based integration is based on the information which gets stored on the smart products (Brettel et al., 2014; Stock & Seliger, 2016). The five guiding principles of LM can also act a means for designing self-guided optimum product path through various value-added streams in a most effective manner. The guiding principles of LM can thus be used by the organizations while implementing Industry 4.0 within the organization.

The future research should explore in detail the critical success factors for vertical integration based on LM five principles. The case studies will help to study the large number of variables which an organization has to consider while integrating various subsystems within an organization. The socio-technical elements (Trist, 1981) of vertical integration within the organization will help to unearth various factors other than technical factors which should be taken into consideration during the implementation of vertical integration within the organization. The future studies on horizontal integration and LM should also explore readiness factors of various organizations for the horizontal integration. The short-term and long-term algorithms which will solve the various issues of horizontal integrations like coordination, responsiveness, changing demands, quality and compliance, etc. may be needed to create self-regulating mechanisms within the horizontal integration. In end-to-end engineering integration and LM five guiding principles, research may be directed at algorithms which will help to optimize the self-guided path for products based on the five LM principles. Information acquisition, processing and decision-making models for the end-to-end engineering integration can be studied from LM principles to remove wastes.

4.1. Limitations

The study considers three forms of integration i.e. vertical, horizontal and end-to-end engineering integration and how it can be implemented with respect to LM five guiding principles. The theoretical model was based on recent literature in the field of Industry 4.0 and LM. The impact of the guiding principles and various types of integration will also be impacted by different types of organization e.g. small, medium and large-scale industries. This study has considered this variation between the types of industries to be constant. The review for building the theoretical integrative model is limited by the databases accessed, the search criteria's, method of searching, inclusion and exclusion criteria and the also time constraints.

4.2. Contributions to practise

The current trend in the modern organization is towards implementation of Industry 4.0. Organizations while implementing Industry 4.0 have to integrate it with LM for deriving optimum benefits (Buer et al., 2018; Rüttimann & Stöckli, 2016; Sanders et al., 2016, 2017; Tortorella & Fettermann, 2018). This study can be used as a practical framework for implementation Industry 4.0 and LM within an organization. Before designing the vertical, horizontal and end-to-end integration mechanism, the five LM principles may be applied to strategize the best possible combination sequence for integration. The implementation of integration is difficult to be implemented at once, however, the integration system evolves over a time with the cooperation of other subsystems in the integration. In other words, if LM principles should form the guidelines for designing & evolution of the integration mechanism to derive the optimum benefits from Industry 4.0. Further, implementing Industry 4.0 will require usage of a lot of organizational resources. LM integration using the 15 propositions suggested in this article will help the organization to better utilize the organization resources for deriving the intended benefits.

5. Conclusion

The fourth industrial revolution has resulted in Industry 4.0 being implemented by leading organizations and LM is one of the most widely used business strategies for the last three decades. LM can contribute towards the implementation of Industry 4.0, however, there is a shortage of studies which proposes the integration of Industry 4.0 with LM. This study proposes an integrative model of Industry 4.0 and LM. Vertical, horizontal and end-to-end engineering integration of Industry 4.0 with LM will help the organizations while implementing Industry 4.0. In addition, 15 research propositions are drawn which will help the future research to advance the integrative mechanism of LM with Industry 4.0.

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