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Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing

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Abstract:

Purpose: Lean Manufacturing is widely regarded as a potential methodology to improve productivity and decrease costs in manufacturing organisations. The success of lean manufacturing demands consistent and conscious efforts from the organisation, and has to overcome several hindrances. Industry 4.0 makes a factory smart by applying advanced information and communication systems and future-oriented technologies. This paper analyses the incompletely perceived link between Industry 4.0 and lean manufacturing, and investigates whether Industry 4.0 is capable of implementing lean. Executing Industry 4.0 is a cost-intensive operation, and is met with reluctance from several manufacturers. This research also provides an important insight into manufacturers' dilemma as to whether they can commit into Industry 4.0, considering the investment required and unperceived benefits.

Design/methodology/approach: Lean manufacturing is first defined and different dimensions of lean are presented. Then Industry 4.0 is defined followed by representing its current status in Germany. The barriers for implementation of lean are analysed from the perspective of integration of resources. Literatures associated with Industry 4.0 are studied and suitable solution principles are identified to solve the above mentioned barriers of implementing lean.

Findings: It is identified that researches and publications in the field of Industry 4.0 held answers to overcome the barriers of implementation of lean manufacturing. These potential solution principles prove the hypothesis that Industry 4.0 is indeed capable of implementing lean. It uncovers the fact that committing into Industry 4.0 makes a factory lean besides being smart.

Originality/value: Individual researches have been done in various technologies allied with Industry 4.0, but the potential to execute lean manufacturing was not completely perceived. This paper bridges the gap between these two realms, and identifies exactly which aspects of Industry 4.0 contribute towards respective dimensions of lean manufacturing.

Keywords: production management, lean manufacturing, industry 4.0, cyber physical systems, internet of things

1. Introduction

Manufacturing in the current century witnesses enormous shifts and changes from its original version. Ever since the evolution of the first industrial revolution, the sector has been growing in all its facets, acquiring more and more technologies in the process. With the western world employing automation and computer-integrated technologies to improve its manufacturing, the Japanese industries devised a customer-value focussed method of manufacturing called Lean Manufacturing. Toyota Motor Corporation successfully implemented lean manufacturing and showed remarkable increase in productivity and decrease in wastes in its firm. Since then, industries around the world have attempted to make their production factories lean to reap the associated benefits. Notable rewards have been reported by European firms through this effort, not only in manufacturing sectors, but also in service fields such as retail, healthcare, travel and financial services (Piercy & Rich, 2009).

Germany's manufacturing is mainly driven by small and medium scale enterprises (SMEs), many of which are family owned firms. These medium sized companies, of which some are world market leaders in their fields, employ lean manufacturing along with technical expertise to prosper as successful players in global trade (Venohr & Meyer, 2007). Nevertheless, the road towards making a factory lean has never been straightforward and some of the SMEs still struggle with implementing desired lean tools. Numerous challenges and roadblocks hinder the effective path to attaining lean. Several industries have tried in vain or only with partial success. Hence it is essential to find a route to solve these problems and aid the industries in a non-traditional and employee-friendly manner. And the answer comes in the name of Industry 4.0. Industry 4.0 is German Government's recent initiative to gain stronghold in global manufacturing. By advanced application of information and communication systems in manufacturing, the entire factory environment becomes smart and enables mass customisation. Many research activities are carried out by academia and industry on the technologies and processes concerned with Industry 4.0. The link of these technologies towards various aspects of lean manufacturing is identified in our research. It is inferred that Industry 4.0 is equipped with high-end solutions which possess the necessary tools to implement lean. However, it is an inevitable fact that financial investment required for such high-end digitisation is quite intensive. So not all SMEs are enthusiastic to dive into Industry 4.0 (Schröder, Schlepphorst & Kay, 2015), and the question whether it is worth the effort always remains. The approach used in this paper answers a significant part of this question, and illustrates that lean manufacturing and Industry 4.0 are not mutually exclusive; they can be seamlessly integrated with each other for successful production management. This paper analyses the researches and publications concerned in the field of Industry 4.0, and identifies how they act as supporting factors for implementation of lean manufacturing.

2. Methodology

The course of actions performed in this research is described as follows. Initially we carried out an extensive study in the field of lean manufacturing. Since various definitions and perceptions exist across different academia and industrial researchers, we formulated an appropriate definition for lean manufacturing and conceptualised into different dimension groups. Then we introduced the term Industry 4.0 and discussed its current status. The challenges factories face to implement lean due to lack of resources such as proper communication, monitoring, integration etc. are analysed according to these dimensions. Then literatures associated with Industry 4.0 are broadly studied and explored regarding their functionalities and outcomes. Independent researches in various fields concerned with Industry 4.0 hold the potential for solutions for the above mentioned barriers for lean implementation even if the primary focus of the research is usually another. We extracted these solutions and represented according to the dimensions as the enablers for implementation of lean manufacturing. The proposed methodology is illustrated in Figure 1.

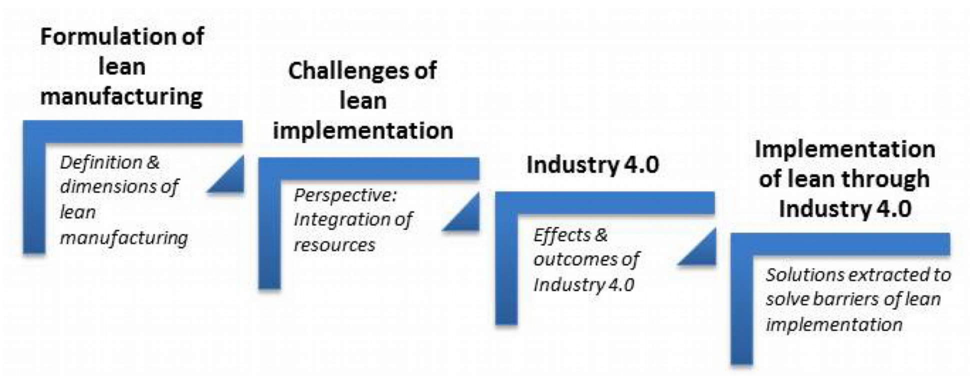

Figure 1. Approach

3. Lean Manufacturing

Lean Manufacturing can be described as a multi-faceted production approach comprising a variety of industrial practices, directed towards identifying value adding processes from the purview of customer and to enable flow of these processes at the pull of the customer through the organisation (Shah & Ward, 2007; Womack, Jones & Roos, 1990). It evolved from the conceptualisation of Toyota Production System (TPS) by Taichii Ohno's initiatives at Toyota Motor Company (Ohno, 1988). The central thrust of lean manufacturing is to create a streamlined flow of processes to create the finished products at the required pace of customers with little or no waste (Shah & Ward, 2003). Shah and Ward (2007) performed a comprehensive, multi-step approach based study to identify the dimensional structure of lean manufacturing and developed reliable scales to signify them. They quantified the conceptual definition and measurement of lean manufacturing in ten factors, as mentioned below.

1. *Supplier feedback:* Critics and performances of products and services received from customers to be periodically communicated back to suppliers, for effective transfer of information.
2. *Just-In-Time (JIT) delivery by suppliers:* Only required quantity of products to be delivered by suppliers at the specified time when customers require them.
3. *Supplier development:* Suppliers to be developed along with the manufacturer, to avoid inconsistency or mismatch in competence levels.
4. *Customer involvement:* Customers are the prime drivers of a business, their needs and expectations should be given high priority.
5. *Pull production:* An initiation of need from the successor through kanban should enable the flow of production from the predecessor, signified as JIT production.
6. *Continuous flow:* A streamlined flow of products without large halts should be established across the factory.
7. *Setup time reduction:* Time required to adapt resources for variations in products should be maintained as least as possible.
8. *Total productive/preventive maintenance:* Failure of machines and equipment should be avoided by effective periodical maintenance procedures. In case of failure low rectification time is to be maintained.
9. *Statistical process control:* Quality of products is of prime importance, no defect should get percolated from a process to a subsequent one.
10. *Employee involvement:* With adequate motivation and entitlement, employees are to be empowered for an overall contribution towards the firm.

The research work by Shah and Ward (2007) provides a theoretical definition for the term 'lean manufacturing' and validated it by an extensive survey of lean practices in manufacturing industries (Hasle, Bojesan, Langaa-Jensen & Bramming, 2012). It provides an explanation of underlying principles and a clear definition for lean manufacturing in a socio-technical approach (Staats, Brunner & Upton, 2011). This model of ten elements includes people and process elements, as well as internal and external factors, which had limited focus in past research (Dora, Van Goubergan, Kumar, Molnar & Gellynck, 2013). Hence these widely accepted ten dimensions of lean manufacturing are used in our research and are validated for attainability through Industry 4.0 technologies. These ten dimensions are grouped into four major factors, depending on the entities involved in each of the dimensions. Accordingly, the factors as depicted in Figure 2 are:

- Supplier factors
- Customer factor
- Process factors
- Control and human factors

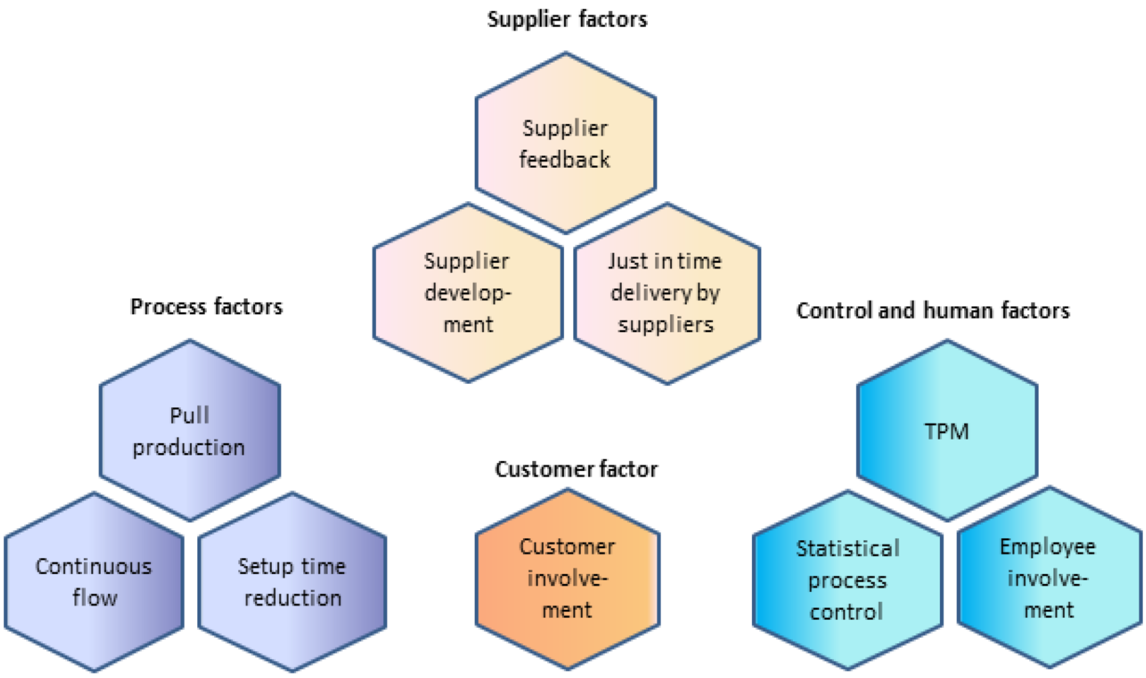

Figure 2. Grouped dimensions of lean manufacturing

The supplier factors are concerned about integrating with the suppliers in the business, and comprise the dimensions supplier feedback, supplier development and JIT delivery. The customer factor is focussed about involving customer into the business processes. The process factors focus on the operations and sequence of the processes, and consist of the dimensions pull production, continuous flow and setup time reduction. The human and control factors, as the name suggests, are concerned about the controlling system and employees. Total productive/preventive maintenance, statistical process control and employee involvement fall under this category.

4. Industry 4.0

Industry 4.0 is the fourth industrial revolution applying the principles of cyber-physical systems (CPS), internet and future-oriented technologies and smart systems with enhanced human-machine interaction paradigms. This enables identity and communication for every entity in the value stream and leads to IT-enabled mass customisation in manufacturing (Lasi, Fettke, Kemper, Feld & Hoffmann, 2014; Posada et al., 2015; Valdez, Brauner, Schaar, Holzinger & Ziefle, 2015). The term was first coined in 2011 at the Hanover Fair followed by formation of a working group chaired by Siegfried Dais (Robert Bosch GmbH) and Henning Kagermann (Acatech). The Internet of Things and Services enables to network the entire factory to form a smart environment. Digitally developed smart machines, warehousing systems and production facilities enable end-to-end information and communication systems-based integration across the supply chain from inbound logistics to production, marketing, outbound logistics and service (Kagermann, Helbig, Hellinger & Wahlster, 2013). Industry 4.0 also ensures creation of better cooperation between employees and business partners.

Industry 4.0 significantly influences the production environment with radical changes in the execution of operations. In contrast to conventional forecast based production planning, Industry 4.0 enables real-time planning of production plans, along with dynamic self-optimisation. Though embedded with latest technologies and intelligent algorithms, the smart factory allows itself to be built on the foundations of the classical Toyota Production System (Bauernhansl, Hompel & Vogel-Heuser, 2014). The introduction of information and communication systems into industrial network also leads to a steep rise in the degree of automation. Intelligent and self-optimising machines in the production line synchronise themselves with the entire value chain, right from order or materials from suppliers to delivery of goods to customers (Spath, Ganschar, Gerlach, Hämmerle, Krause & Schlund, 2013). Simulation of inventory, logistics and transport, and usage history of products also help to positively influence the production processes (Wan, Cai & Zhou, 2015).

In Germany industries are evaluating their readiness towards implementing Industry 4.0. At least 41 percent of German firms are aware of the theme and have started some concrete initiatives. But it is a long way to go and for some industries the topic is still unknown. This applies in particular to small scale industries where 44 percent of them are unaware of Industry 4.0; on the other hand it is well known in larger companies, where only 17 percent are found to be ignorant of the term. There also exists a lag in implementation plans of Industry 4.0 between big industries and SMEs. Nearly 20 percent of original equipment manufacturers have solid implementation strategies, whereas even with the huge volume of SMEs in Germany, only 17 percent are equipped with implementation strategies (Weiss, Zilch & Schmeiler, 2014). These industries need to explore the possibilities and benefits associated in integrating all their factory operations. This does not only concern technical issues but also raises important management questions (Sanders & Wulfsberg, 2015). The initiative is widely spread across the world, called by different names in different countries. Hence the findings of this research are applicable to Internet of Things (IoT) based manufacturing control practices in any country.

5. Integration of Lean Manufacturing and Industry 4.0

Integrating both the spheres of lean manufacturing and Industry 4.0 is an important research field to be extensively explored. With the advent of computer integrated manufacturing, there was a speculation that factories of the future would operate autonomously without the requirement of human operators. Though such a statement proved to be infeasible in a practical scenario, it gave rise to the concept of lean automation, where robotic and automation technologies are employed to achieve lean manufacturing. Taichii Ohno's Toyota Production System is based on two pillars: Just in time and autonomation (Ohno, 1988). Autonomation refers to automating the manual processes to include inspection; i.e. when a problem occurs, the equipment should stop automatically and not allow defects to further proceed through the line. Only when a defect is detected would a human intervention be required. Hence automation in production has played an important role right from the inception of lean manufacturing, and Industry 4.0 can be considered as advancement in this field.

In the following sections, the ten dimensions of lean manufacturing from the four grouping factors according to Shah and Ward (2007) are discussed and how the technologies and concepts of Industry 4.0 act as enablers to these dimensions is evaluated.

5.1. Supplier Factors

The supplier factors are concerned about the flow of goods and information from the suppliers to the manufacturer. It is necessary for every entity in the supply chain to get synchronised with the changes in business processes of the manufacturer. Accordingly, the dimensions supplier feedback, supplier development and JIT delivery are discussed, and the impact of Industry 4.0 on these factors is shown in Figure 3.

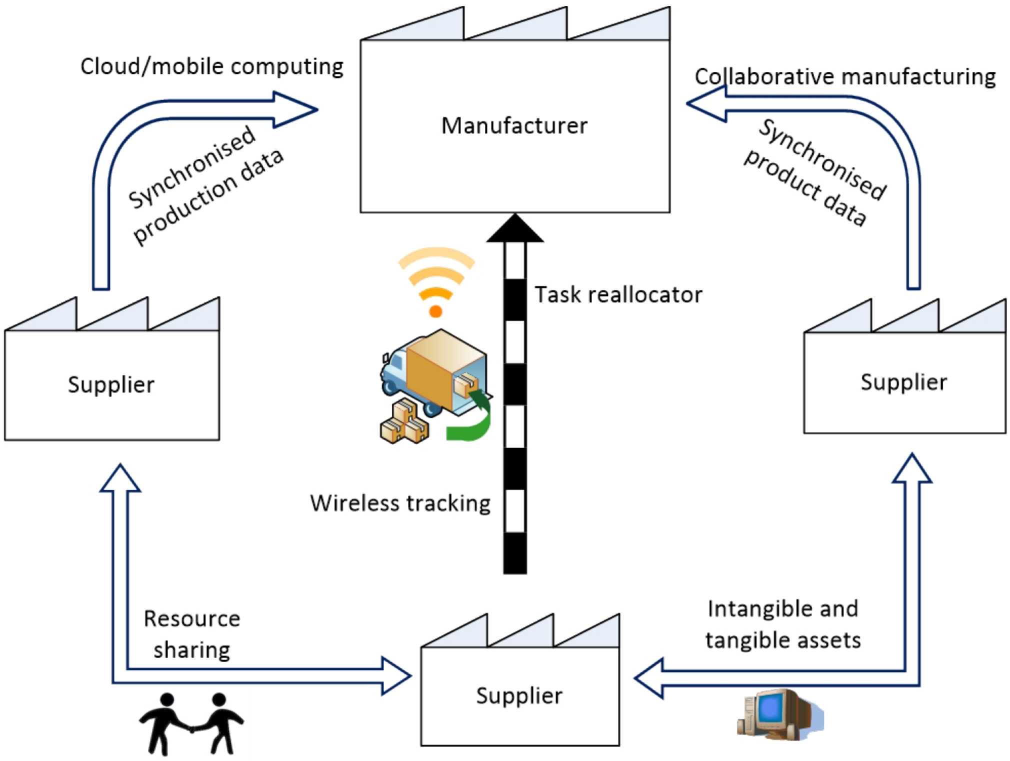

Figure 3. Impact of Industry 4.0 on supplier factors

5.1.1. Supplier Feedback

Inappropriate transfer of information between manufacturers and suppliers is a significant source of waste, with respect to the process as well as the product. Suppliers need to be regularly informed about the status and condition of the products and services provided by them. This paves way for immediate response and adequate action in case of any discrepancies. But difference in business models, operation, and data maintenance practices between the manufacturers and suppliers do not allow manufacturers to easily communicate information with other business partners. Every industry cannot have expertise and resources in all the required fields. Industry 4.0 provides the necessary tools to achieve immediate and automatic feedback to suppliers, to overcome bureaucracies and inadequate communication channels.

Collaborative manufacturing and development environments in the context of Industry 4.0 adequately serve these purposes, especially for SMEs with limited resources. The combined expertise of collaborated firms expands the horizons of business, along with beneficial risk mitigation in case of catastrophes. Data of products and production processes is shared beyond the boundaries of individual industries, enabling them to be highly synchronised (Brettel, Friederichsen, Keller & Rosenberg, 2014). The traditional communication mechanisms between the partners in a business are renovated through cloud computing and mobile computing services. Just through smartphones and tablets connected to the internet and common cloud, easy integration and better relationship could be maintained between the business partners (Schmidt, Möhring, Härting, Reichstein, Neumaier & Jozinović, 2015). Thus collaboration, synchronisation and better communication mechanisms serve as enablers to maintain effective supplier feedback.

5.1.2. Just-In-Time Delivery by Suppliers

The just in time philosophy popularised through the Toyota Production System calls for an inventory level of value zero. Only the required number of products should reach the manufacturer at the right time, without the need of storing them before being used. But in present logistics systems, this timely delivery is not always possible due to reasons such as incomplete status of goods being shipped, mismatch between the required and transported goods and unexpected time delays during transfer of goods. Internet of Things is equipped with different integrated devices for communication, which manage information about goods transported. Every item already stored with a delivery note, would be tracked wirelessly about its origin, destination as well as the current status. Tagging every item ensures sending of right products to the correct destinations and reduction of lead times of distribution. This ensures not only timely delivery of the items, but also optimisation of the travel routes and reliability in logistics. A supplier is empowered to comment when exactly his goods would reach the customer, thereby enhancing credibility and adding value to customers (Bose & Pal, 2005; Caballero-Gil, Molina-Gil, Caballero-Gil & Quesada-Arencibia, 2013). In case a timely delivery is not possible due to some unforeseen traffic jam or any other constraint, a smart task allocator would initiate a simulated trading process, where an order is reallocated to satisfy the demanding time constraints (Fischer, Müller & Pischel, 1996). Therefore tagging every item, wireless tracking and smart reallocation of orders are observed to significantly promote just in time delivery of goods by suppliers.

5.1.3. Supplier Development

To create a lean ecosystem and to continuously improve it, all the partners in the supply chain have to develop along with the manufacturer. If only the manufacturer strives to implement lean manufacturing and suppliers keep following legacy operating practices, it might create a mismatch of goods and information flow and lead to adverse effects. Inadequate resources and expertise hinder growth of suppliers on par with manufacturers. Through Industry 4.0, technological networks are established between different cooperating partners. These networks assist in the sharing of intangible assets such as research and knowledge in the form of data and information, as well as tangible resources such as machines, equipment and human experts. These resources are part of different organisations but act towards achieving a common goal. Such virtual organisations benefit the supplier firms in different aspects with not just the business model of outsourcing, but more synergetic cooperation from product development until production and sales. In this environment, the emphasis is heavy on information management for development of suppliers and to become on par with manufacturer (Tepeš, Krajnik, Kopač & Semolič, 2015). Compatibility issues of hardware and software between suppliers and manufacturer is also an important drawback for collaborative development. Incompatible data formats between two different service providers preventing seamless information flow, though avoidable, exist due to individuality reasons. Global standardisation institutes are standardising the interfaces between equipment, which support vendor-specific hardware and software. Many automation technology solution providers are willing to standardise their individual entities and communication protocols, thereby cooperating towards the common goal of Industry 4.0 (Weyer, Schmitt, Ohmer & Gorecky, 2015). Hence through virtual organisations and standardised interfaces, professionally lean empowered suppliers get synchronised with manufacturers.

5.2. Customer Factor

The customer factor focusses on catering to the needs of customer and integrating them with the business process, in order to achieve lean manufacturing. The dimension customer involvement is discussed in the following section.

5.2.1. Customer Involvement

Against the widespread trend of directly just providing products and solutions to customers, customers' involvement has to be established right from product development stages. Customers are the crux for a business to survive and hence their association should be considered of high importance. But once the specifications are set for manufacturing, customers are provided with very little flexibility to alter them at a later stage. Through intelligent systems in manufacturing, the start of freeze period, i.e. the period at which manufacturing parameters are frozen and cannot be changed, can be elongated until the point where unchangeable parameters are incorporated into the product. This is achieved quite effortlessly by the integration of different systems such as manufacturing execution system, B2C applications, etc. This provides a system for customers to be kept informed about the actual production stage and expected completion of the order (Cannata, Gerosa & Taisch, 2008). No more can the old 'sell and forget' mentality be found in the minds of manufacturers. Business models are getting converted into providing products along with services. Enhanced services such as upgrade and refurbishment discover new customers while increasing experiences of existing customers (Ganiyusufoglu, 2013).

Industry 4.0 also employs intensive techniques for customer analysis and market research areas. Traditional analysis tools such as quality function deployment (QFD) have limitations on the quantity of customers' requirements and their relationship with product design requirements, besides the problem of acquiring exact needs of customers. Big Data facilitates extreme complex calculation and processing of relationship between needs and functions for large volume of data (Li, Tao, Cheng & Zhao, 2015). Even the products developed and sold to customers are termed as being smart, which mean that they are integrated with devices which track usage data and send to smart factories. The manufacturer then collects and analyses data from these devices from different categories of customers, which enables him to better identify customers' needs and behaviours in order to provide more sustainable products and solutions (Shrouf, Ordieres & Miragliotta, 2014). As a result elongated freeze period, enhanced services for products, large volume QFD and usage analysis allow firms to understand and serve customers better.

5.3. Process Factors

The sequence of operations performed in the shop floor and the flow of products right from the stage of raw materials to the finished goods are significant factors to be considered to implement lean. These factors are discussed below, and an illustration depicting the impact of Industry 4.0 on these factors is shown in Figure 4.

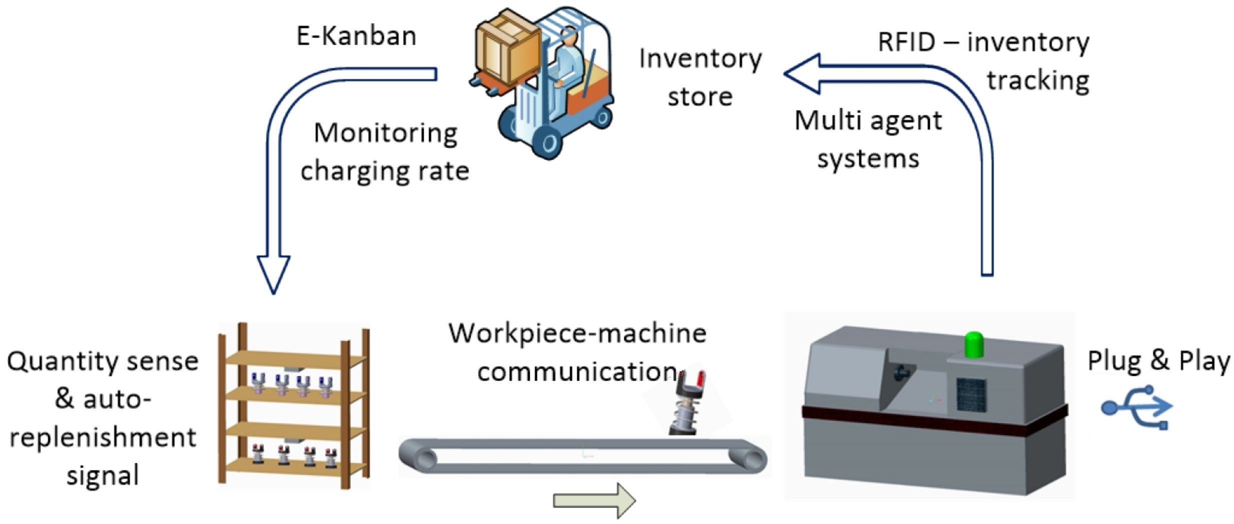

Figure 4. Impact of Industry 4.0 on process factors

5.3.1. Pull Production

An operation in an industry should be performed only when it is demanded for. The demand should arise from the customer, based on which a production order should be created. It means that every subsequent operation has to initiate the operation of its predecessor. A normal push production would lead to extra inventory, unsold goods in the factory and in turn leads to extra costs of manufacture, maintenance etc. (Monden, 2011). Improper track of quantity of materials supplied to the production line and alterations in schedule after material supply severely affect the pull production system. Kanban is one of the best methods of implementing pull production, in which a successive station generates kanban cards to initiate operation for a particular station. By using information and communication technologies, an e-kanban system recognises missing and empty bins automatically via sensors and triggers replenishment. The charging level of the bin also can be monitored and data can be transmitted wirelessly to an inventory control system in real time. As long as real inventory and value in manufacturing execution system matches, faults in production control can be avoided due to lost kanban (Kolberg & Zühlke, 2015). Wireless information and communication systems perform these tracking operations through radio frequency identification (RFID) tags to monitor the status, number and location of material batches. The changes in schedules can also be continuously monitored and kanban parameters can be updated through these technologies (Kouri, Salmimaa & Vilpola, 2008). So the overall production flow is made into pull system through automatic material replenishment monitoring, schedule tracking and kanban updating facilities of Industry 4.0.

5.3.2. Continuous Flow

The flow of raw materials, semi-finished and finished goods need to be continuous according to a determined value stream. As a major concept of just in time manufacturing philosophy, materials should arrive only at the time of manufacturing and should not be kept waiting for long periods or stored as inventory. Every process needs to add value and result in a streamlined flow of operations. In many cases a disruption in flow arises due to errors in inventory counting, capacity shortages and centralised controlling systems leading to delays in decision making. Industry 4.0-solutions employing RFID technology help to eliminate errors associated with inventory by real-time exact tracking of inventory. An error-free inventory status aids maintaining a low inventory level and timely ordering of goods (Raki, 2014). Networked enterprises of the modern era also facilitate for subcontracting, thereby they receive resources and assistance when needed, which helps to manage capacity shortage. Integrated scheduling and planning of production is possible among the subcontracted industries. For example, a manufacturer can track the capacity and progress of orders of a supplier, and adjust his own production accordingly in case of delays. (Wiendahl & Lutz, 2002). With the advent of holonic manufacturing, employing multi-agent systems for material handling, planning and control, the system gets more modularised and decision making gets shifted from centralised hierarchical structures to decentralised agents (Lewandowski, Gath, Werthmann & Lawo, 2013).

Wan, Zhu, Mu and Yu, (2014) proposed a material distribution method based on Internet of Things in a JIT production environment for a mixed-model assembly workshop. A mathematic model for material distribution based on the production layout and material information in each station is built. An intelligent optimisation algorithm was developed to solve this model and resulted in an optimised material distribution plan. It eliminates interruption, & waiting in the manufacturing line and delays in schedule, enabling a continuous streamlined flow. In this way real-time inventory tracking, subcontracting and decentralised decision making leads to a continuous streamlined flow in the production line.

5.3.3. Setup Time Reduction

As the needs of customers get diversified, the variants of products delivered also get increased. Toyota popularised the concept of 'Single-Minute Exchange of Die' where it demonstrated drastic reduction of changeover times. But manufacturing multiple variants with least changeover time has always been a challenge. Modern manufacturing is proceeding towards mass customisation and cannot afford for high setup times between variants. Process adaptations are generally done by humans based on previous knowledge. With Industry 4.0-technologies, plug and play and distributed systems are equipped with self-optimising and machine learning behaviour, which enable firms to adapt machines according to products and produce small batch sizes. The operations to be performed on a part are initially loaded into the part through RFID tags. As the part reaches its respective machine, it directly communicates with the machine through RFID receivers. This results in quicker changeover of machine parameters according to the instructions read from the part (Brettel et al., 2014). Consequently setup time in organisations is substantially reduced through self-optimisation of machines and workpiece-machine communication.

5.4. Control and Human Factors

The factors responsible for control of quality and equipment along with work environment are considered in this category. Control and human factors consist of the dimensions total productive/preventive maintenance, statistical process control and employee involvement. An illustration of impact of Industry 4.0 on these factors is shown in Figure 5.

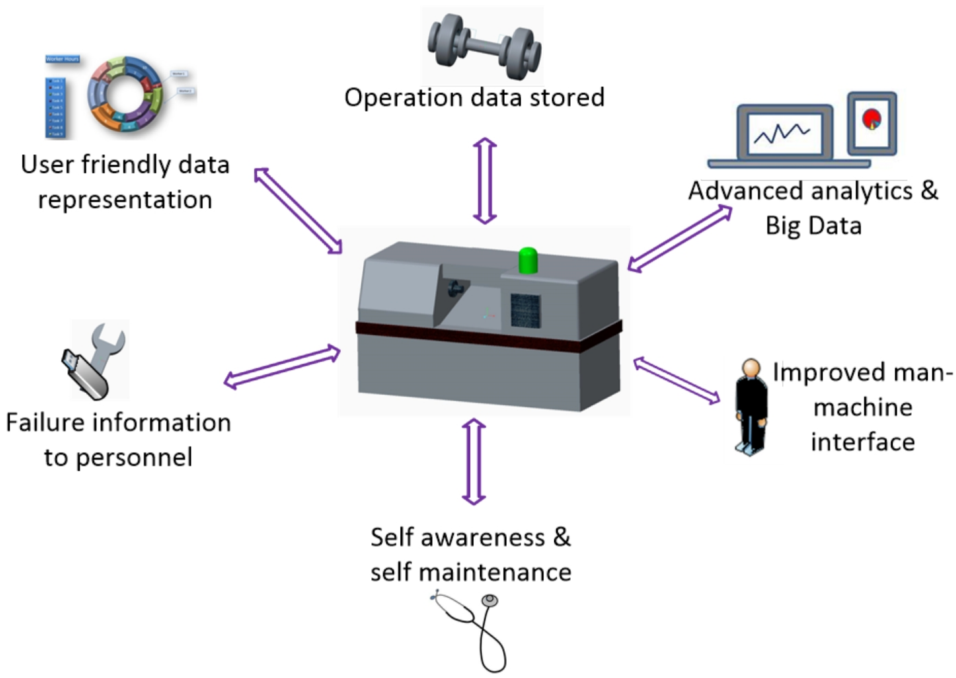

Figure 5. Impact of Industry 4.0 on control and employee factors

5.4.1. Total Productive/Preventive Maintenance

Faults or failures of machines during production lead to adverse effects on schedule of production as well as morale of the employees. Companies take efforts through preventive and periodical maintenance schedules but failure of machines are not always under control. Production gets disrupted in case of a machine breakdown, and often considerable time is spent to find the root cause and solve the problems. In a smart factory with machines interconnected with information and communication systems, when a machine breaks down, it sends error notifications to respective shop-floor and maintenance personnel. The maintenance worker then checks the error code for solutions and gets necessary tools and parts for repairing. Meanwhile the manufacturing execution system can reschedule the jobs to mitigate the impact of breakdown (Lucke, Constantinescu & Westkämper, 2008). With more advanced analytics and big data environment, machines are equipped to be self-aware and self-maintained. Such machines assess their own health and degradation and utilise data from other machines to avoid potential maintenance issues (Lee, Kao & Yang, 2014). The ability to anticipate potential breakdown and identify root cause needs to be developed in the control systems. For example, enterprise resource planning systems have included comprehensive frameworks for predictive maintenance. It integrates between machine data, ERP data, sensory data and predictive algorithms (Haddara & Elragal, 2015). So machine-worker communication, self-maintenance assessment and predictive maintenance control system notably improve the total productive and preventive maintenance in the factory.

5.4.2. Statistical Process Control

The quality of products is of prime importance in any manufacturing industry. The processes have to be always under control and several techniques have been developed in the field of quality management to evaluate processes. But decreasing product lifetime, decreasing development time, competitive pricing and increasing product complexity push process control under high risk. Ignorance of operators performing an operation and inability to track the process for variations contribute significantly for quality defects in products. In the scenario of Industry 4.0, smart products come with details about the operations to be done on them. The sequence of operations to be performed on a product is already loaded onto the carrier of that product. This information is already passed on to the machine for automated operations, and shown with better visualisation interfaces for manual operations. Improved man-machine interfaces also present information in a more appealing manner, and avoid possibility of making mistakes in the production processes (Schuh, Gartzen, Rodenhauser & Marks, 2015). RFID enables automatic sensing of processes for variations by reading the respective information stored in RFID tags. IoT assists in integration of different value adding processes by combining information and data from different machines. Advance analytics combines business intelligence along with management of process workflows, by computing meaningful trends and relationships from the available data. These three technologies together contribute to the macro phases of Six Sigma through their characteristics such as traceability, visibility, memory and localisation (Nicoletti, 2013). Thus workpiece-machine communication, improved man-machine interfaces and process tracking, integration and management ensure that defect-free products are produced and sold to customers.

5.4.3. Employee Involvement

Lean manufacturing emphasises heavily on the empowerment of employees. The employees are responsible for actually working and creating products and services, hence they should be given adequate flexibility and importance of acknowledging their ideas and suggestions. Incorrect allocation of employees to different tasks, improper performance evaluation and training and monotonous work are significant contributors for poor morale in work environment (Sanders & Wulfsberg, 2015). In many cases, workers also find it difficult to portray their suggestions and feedback in current workplaces. In the work environment of Industry 4.0, production workers provide immediate feedback of production conditions via real time data through their own smart phones and tablets. Everyone is equipped with a smart handheld device, which is integrated with the company's network. This presents an extremely comfortable environment for employees to record their concerns and feedback right at the workplace (Schuh, Gartzen, Rodenhauser & Marks, 2015). The assignment process of employees for different operations based on their availability is assisted by CPS, making use of social media irrespective of spatial and temporal availability of the decision maker. The manager is able to check the availability and allocate the workers to different operations through the handheld smart devices (Spath, Gerlach, Hämmerle, Schlund & Strölin, 2013). This highly eases the manager's efforts in coordinating and maintaining workforce. Evaluation of workers in terms of speed, accuracy, performance and motivational factors are also simplified through specialised worker support systems. They contribute towards developing better interfaces or specialised training processes for employees (Brauner & Ziefle, 2015).

One of the most significant factors for dissatisfaction of employees is monotony and performance of routine activities. Smart devices acquire real time data, autonomously execute routine tasks, and represent as figures and graphs. Cognitive acquisition of this information and improved man-machine interface disburden the workers from routine tasks and help to focus on diversified work and learning tasks. Monotonous and non-skilled activities are automated leading to a shift of nature of work, ie., workers are trained to work on calibration, data processing and other such non-repetitive tasks. (Schuh, Gartzen, Rodenhauser & Marks, 2015; Schuh, Potente, Wesch-Potente & Hauptvogel, 2013). Employees utilise their own smart devices for interconnectivity; therefore Industry 4.0 would be motivated by employees themselves, rather than being forced by the management (Schuh, Reuter, Hauptvogel & Dölle, 2015).

Thus smart feedback devices, worker support systems and improved man-machine interface facilitates better empowerment and involvement of employees in the organisation.

6. Summary

The findings of the previous chapter establish the presence of a positive correlation between lean manufacturing and Industry 4.0. A summary of the ten dimensions of lean manufacturing, challenges to implement lean with existing factory resources and solutions to overcome them through Industry 4.0 are tabulated in Table 1. Every problem for implementation of lean manufacturing from the perspective of integration has a solution in the technologies associated with Industry 4.0. Executing these technologies solves these barriers in all factors – supplier, customer, process and control & human factors. Hence the research clearly confirms that by embracing Industry 4.0, industries are capable of becoming lean without the need to maintain conscious and persistent 'striving-for-lean' efforts. Conception, operation and maintenance of a manufacturing industry are improving considerably through the technologies of Industry 4.0. With advanced information and communication systems in place along with a lean operating structure, an industry has the potential to expand into new horizons at ease.

As per the conventional aspects of lean manufacturing, it is a well-accepted fact that as a factory becomes lean, the flow strengthens, and the non-value added activities or 'waste' decreases. Decrease in waste means decrease in costs as well. So any effort to decrease this waste pays off in terms of reduction of operating costs. Now this effort comes through digitisation and integration of resources, in the name Industry 4.0. By implementing Industry 4.0, besides the stated benefits of making the factory smart, financial benefits would be realised as well due to the reduction or elimination of redundant wastes. Hence though cost-intensive, enforcing Industry 4.0 proves to be worth the investment for its unforeseen benefits, and the research affirms that reluctant industries can positively venture into this fourth industrial revolution.

Dimensions of Lean Manufacturing	Challenges for lean implementation from integration perspective	Solutions provided by Industry 4.0
Supplier feedback	Limited expertise and resources	Collaborative manufacturing
	Difference in business models, operation and data maintenance practices	Better communication mechanisms
		Synchronisation of data
JIT delivery by suppliers	Incomplete goods' shipping status	Item tagging
	Mismatch in quantity of transported goods	Wireless tracking of goods
	Unexpected delays during transportation	Smart reallocation of order
Supplier development	Inadequate resources and expertise	Standardised interfaces
	Equipment compatibility between organisations	Virtual organisations - synergetic cooperation
Customer involvement	Little flexibility for product alteration	Elongated freeze period
	Relationship between needs and functions	Large volume QFD
	Acquiring exact customer needs	Usage analysis
Pull production	Improper track of supplied material quantity	Material replenishment monitoring
	Changes in production schedule	Schedule tracking and kanban updating
Continuous flow	Errors in inventory counting	Real-time inventory tracking
	Capacity shortages	Subcontracting
	Centralised control systems	Decentralised decision making
Setup time reduction	Human experience-based process adaptation	Self-optimisation & machine learning
		Workpiece-machine communication
Total productive/preventive maintenance	No control of machine breakdown	Machine-worker communication
	Unknown problem solving time	Self-maintenance assessment
		Predictive maintenance control system
Statistical process control	Ignorance of operators	Workpiece-machine communication
	Inability to track process variations	Improved man-machine interface
		Process tracking, integration & management
Employee involvement	Improper feedback mechanisms	Smart feedback devices
	Performance evaluation practices	Worker support systems
	Monotony in work	Improved man-machine interface

Table 1. Summary of lean dimensions, challenges and solutions

7. Conclusion and Outlook

Industries across the world strive to achieve lean manufacturing, but not every organisation is successful in perfectly implementing and achieving the benefits of it. Though conceptualised initially for manufacturing industries, lean philosophy is being adapted even by service and maintenance sectors. This paper presented a comprehensive framework of barriers and challenges for lean implementation from an integration perspective and evaluated how lean manufacturing can be implemented through the technologies of Industry 4.0. Through integrated information and communication systems, the shortcomings of conventional practices can be overcome to improve productivity and eliminate wastes. It implies that industries now have the combined benefits of real-time integration of the entire factory along with assurance of minimal waste generation. The research alludes that SMEs in Germany can positively commit into Industry 4.0 with the perspective of making their production shop-floors lean. However, there is a demand for further research to emphasise the importance on continuous improvement over the dimensions of lean manufacturing. Increase of computing power and decrease of size results in nonstop evolution of new technologies. Improvements or adaptations of evolution of these new technologies need to be analysed over their influence on lean manufacturing. Moreover some researches in Industry 4.0 were purely theory-oriented, not readily adaptable to an application. Application-oriented research need to be developed pertaining to the criteria of implementing lean manufacturing. Future research needs to be focussed on creating a conceptual framework and cyber physical working system, integrating these parameters in a fully functional production environment.

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