Industry 4.0 and Lean Management – Synergy or Contradiction?

A Systematic Interaction Approach to Determine the Compatibility of Industry 4.0 and Lean Management in Manufacturing Environment

Adam Sanders(✉), Karthik R. K. Subramanian, Tobias Redlich, and Jens P. Wulfsberg

Institute of Production Engineering, Helmut-Schmidt-University, Hamburg, Germany
adam.sanders@hsu-hh.de

Abstract. Considering the ongoing trend of digitalization of the manufacturing industry to Industry 4.0, this paper assists in the transformation. The research work is focused on studying the possible impacts of Industry 4.0 on lean management (LM) tools which play a vital role to foster quality and reliability of products and services that are delivered to the customers. The LM tools which are impacted by the advent of Industry 4.0 and assisting in successful implementation of future smart factory will be investigated in particular focus. An interaction plot matrix is established to quantify the influence of LM tools on Industry 4.0. Interaction between these Industry 4.0 design principles and LM tools reveal several opportunities for achieving synergies thus leading to successful implementation of future interconnected smart factories. Overall, the research work serve as a guideline for industries that are under the transformation phase towards future smart factory and offers space for further scientific discussion.

Keywords: Industry 4.0 · Lean Management · Production Management

1 Introduction

Industry 4.0, the high-tech strategy initiated by the German government, is changing the way the products are manufactured which leverages the advancements of internet of things (IoT) and information and communication technology (ICT) to integrate digitalization into the production process. Businesses are in pressing need to respond to these evolving trends and develop the capability to produce highly customized products until the lot size of one in order to meet the rapidly changing consumer preferences thus managing to stay competitive in the today's dynamic market environment.

Manufacturing companies are looking for efficient means to accommodate the integration of Industry 4.0 concepts into the existing setup. Here, the complexity to effectively manage the implementation of new technologies arises and studies are required to find its impact on the existing shop floor practices. Particularly, the potential

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dilemma over the compatibility of lean philosophy and Industry 4.0 existing together in future smart factory arises owing to the reason that lean principles try to reduce complexity but Industry 4.0 increases the complexity. On the other hand Industry 4.0 can also be seen supportive for the idea of a lean production as the emerging transparency due to the introduction of intelligent networked systems will benefit the essential continual improvement process (CIP). This research aims for a broader understanding of the above mentioned impasse and for the identification of the impact of Industry 4.0.

2 Method

In this work, firstly a general overview about the topic of the compatibility of Industry 4.0 and LM is given. Then an interdependence matrix of the LM tools from Toyota's lean house and design principles for Industry 4.0 is formulated. The basic notion in framing this plot is to identify the LM tools which are getting benefited (beneficiary coefficient) from the induction of Industry 4.0 design principles into the existing production setup and also determine the cumulative support (supporting coefficient) that each Industry 4.0 design principle offers to the considered LM tools. This matrix is then used to solve the dilemma of whether Industry 4.0 and lean philosophy compliment or oppose each other by highlighting the basic LM tools that are required for Industry 4.0 implementation. The LM tools from TPS house are considered for detailed analysis about their functionality and applicability in Industry 4.0. Then by means of the interdependence matrix, the beneficiary and supporting coefficient scores are calculated and their interaction effects are explained in detail by considering specific scenarios inside the future smart factory.

3 Background and Literature Review

Lean production as a subfield of lean management can be defined as an intellectual approach comprising of a set of principles, methods and measures which when implemented provide waste elimination and competitive advantages [1]. Therefore, the lean production principles have been widely accepted by the companies in early 1990s [2]. Thus lean production with its simplicity, higher productivity, improved quality, reduced development time and inventory were able to capitalize on the decline of CIM and became the status quo of production [3]. However, lean production also has its limits with regard to addressing the futuristic highly volatile customer demands (until lot size of one) which lead to highly fluctuating work content. This acts against the lean production's aim of evenly flowing production [4]. Also the TPS forecasts demand based on the actual demand in the market which cannot be increased or decreased arbitrarily [5, 6]. Thus the suitability of lean production to assist Industry 4.0 for tackling the challenges of highly volatile customer demand and requirement of customized products with short life cycles (which Industry 4.0 is focused on) are put to question.

It can be understood that a skepticism prevails over the compatibility of Industry 4.0 and lean philosophy but there are also supporting aspects. The concept of lean automation was proposed in the 1990s whereby most of the tasks in auto assembly were automatized and the productions units were populated with highly skilled problem solvers whose responsibility was to ensure smooth and productive running of the production system [7]. This term was just a watchword in the last decades which was not paid much attention [2, 8]. However, [2] argues that in the context of Industry 4.0, automation and lean technology can be combined for realizing more benefits. Industry 4.0 can be considered as a logical evolution of lean principles which will assist to realize its complete potential. So on the first hand, the lean concepts and lean thinking can be embedded firmly into the business model for being able to build towards Industry 4.0 [9]. Further it is shown that research activities in Industry 4.0 even enable the philosophy of lean manufacturing [10].

A central difference between LM and Industry 4.0 lies in the strategic approach. Lean tries to reduce complexity for achieving simple solutions by simple means whereas Industry 4.0 simplifies the complexity from the view point of user by decentralized control and intelligent assistants. But still some questions remain about which lean methods supports Industry 4.0? Which lean tools benefit from the introduction of Industry 4.0? Will there be some principles that needs to be adapted? Moreover, which LM tools will become obsolete with manufacturing digitalization? This research will shed light to answer these questions.

4 Compatibility of Lean Management and Industry 4.0

In this section an interdependence matrix is formulated in order to solve the above questions and skepticism that is prevailing over the compatibility. The basic concept in building this matrix is to develop an individual two-way interaction between LM tools and Industry 4.0 design principles where each interaction is rated. Individual rating in each cell signifies the supporting and hindering effects of Industry 4.0 design principles on LM tools in the matrix. The support that each LM tool offers to Industry 4.0 is not rated but the basic lean elements for implementing Industry 4.0 are highlighted. To create this matrix the tools/principles of both lean and Industry 4.0 have to be defined.

4.1 Lean Management Tools

Employees influence the organization culture by means of their practices thereby each organization possess its own characteristics and dimensions [11]. Thus LM tools and practices are influenced by the organizational culture and varies between different business contexts [12]. This diversity led to creation of different versions of lean models [13, 14]. In order to provide a common and widely accepted source, the TPS lean house was chosen as it is the base for LM tools and techniques in practice [15]. While it comes in many variants the version in [14] is considered as the standard model for competitive manufacturing in this research work. This plethora of LM tools, techniques and methodologies aim at elimination of waste [16]. However, these tools possess multiple names and potentially overlaps with each other and could also have different methods of implementation by various researchers [17].

Based on the TPS-House, the technical requirements of lean practices to be adopted by the companies [18] and the LM tools which are addressed in a thorough literature review in [19] 14 LM tools (Fig. 1) are identified which will be the basis for further analysis.

Kaizen	Takt time
Total Productive Maintenance (TPM)	Value Stream Mapping (VSM)
Standardization	Heijunka (Production Smoothing)
Forms of wastes (Muda)	Autonomation
5S (sort, set in order, shine, standardize, sustain)	Andon (Visual Control)
Total Quality Management (TQM)	Poka Yoke
Kanban (JIT/Pull)	Single Minute Exchange of Dies (SMED)

Fig. 1. Lean management tools

4.2 Industry 4.0 Principles

In order to assist in successful implementation of pilot projects of Industry 4.0, six design principles are derived from independent Industry 4.0 components (CPS, IoT, IoS, Smart Factory) by means of extensive literature review to identify the central aspects of Industry 4.0 [20]. These principles are used in this paper as the Industry 4.0 principles for further analysis (Fig. 2).

Real-Time Capability	Decentralization
Modularity	Interoperability
Service Orientation (SOA and IoS)	Virtualization

Fig. 2. Lean management principles

4.3 Interdependence Matrix

Using the identified lean and Industry 4.0 design principles, the interdependence matrix can be formed by inserting the LM tools in vertical direction and Industry 4.0 principles in the horizontal direction (Fig. 3). Each Industry 4.0 design principle has a benefiting effect, hindering effect or no effect on each of the identified LM tools and these effects are represented with scores ranging from 10 to −10. The interaction scores are allocated based on literature and on the authors' perception.

The interdependence matrix portrays a two-way interaction between LM and Industry 4.0 principles: (i) To what extent the Industry 4.0 design principles are supporting LM tools (represented by beneficiary and supporting coefficient) (ii) The basic

		Industry 4.0 Design Principles					
	Beneficiary Coefficient	Real- Time Capability	Decentrali-zation	Modularity	Interoperability	Service Orientation (SOA and IoS)	Virtualization
Supporting Coefficient		6.6	6.1	3.1	6.2	4.7	6.1
Lean Management Tools							
Kaizen (PDCA)	5.3	10	5	0	10	0	7
TPM	9.5	10	10	7	10	10	10
Standardization	2.8	5	0	0	7	0	5
Forms of wastes	7.3	10	10	7	5	5	7
5S	2.5	5	7	0	3	0	0
TQM	4.7	7	7	0	7	0	7
Kanban (JIT/Pull)	7.0	10	10	5	10	0	7
Takt Time	-8.0	-7	-10	-10	-7	-7	-7
Value Stream Mapping	4.7	10	5	0	3	0	10
Heijunka (Smooting)	7.7	10	7	5	7	10	7
Autonomation	7.0	5	10	3	10	7	7
Andon	4.0	5	7	0	5	0	7
Poka Yoke	4.7	3	8	3	7	0	7
SMED	6.0	10	3	5	10	3	5

Legend										
	Value	10	7	5	3	0	-3	-5	-7	-10
	Degree of influence	Full support	High support	Moderate support	Limited support	No impact/ neutral	Limited hinderance	Moderate hinderance	High hinderance	Full hinderance
	Range	9.1 to 10.0	6.1 to 9.0	3.1 to 6.0	0.1 to 3.0	0	0.1 to 3.0	-3.1 to -6.0	-6.1 to -9.0	-9.1 to -10.0

Basic lean tool for Industry 4.0

Fig. 3. Interdependence matrix (color figure online)

LM tools which assist Industry 4.0 implementation (no scoring, colored blue). The beneficiary coefficient implies the extent to which each single LM tool getting benefitted from the Industry 4.0 design principles. It is calculated by summing up the scores for each interaction and dividing it by the total number of Industry 4.0 design principles. On the other hand, supporting coefficients imply the degree of support that each Industry 4.0 design principle gives to all the LM tools. It is calculated by summing up all the values except for the fields which have no impact and dividing it by the total number of LM tools that has a score value other than 0 [21]. This is done to negate the neutral effect of LM tools on the overall score. The other way interaction is represented by the cells which are highlighted in blue. It signifies that they are the basic lean elements that serve as a foundation and support successful implementation of Industry 4.0 (detailed in Sect. 5.3).

5 Discussion of Results

The matrix displays that most of the LM tool interactions with Industry 4.0 design principles receives either a supporting or at least a neutral effect. Only exception is the takt time which encounters a hindrance effect. This signifies that the concept of takt time will be eliminated in future smart factories. On the other hand, TPM had benefited the most from the Industry 4.0 design principles with a beneficiary coefficient score of 9.5. Since these two LM tools are lying at the opposite extremes on the scoring scale, they are considered for detailed explanation in the following. With regard to supporting coefficient, real-time capability is offering the highest support to the LM tools with a score of 6.8. Rest of the Industry 4.0 design principles are offering high to moderate support. The other way interaction (LM tools that support Industry 4.0 design principles) is highlighted in blue. It indicates the basic LM tools which are essential for successful implementation of Industry 4.0.

5.1 Interaction of TPM with Industry 4.0 Design Principles

TPM receives a comprehensive support from all the stated design principles of Industry 4.0. TPM will execute its functions more effectively in the future smart factory with assistance from Industry 4.0 techniques. The interaction of TPM and real-time capability yielded a score of 10 due to the fact that machine and plant conditions can be monitored in real time (e.g. energy consumption, machine breakdowns, output quality, OEE). By means of intelligent algorithms, failure patterns can be predicted in advance and concerned personnel can be notified which in turn makes the maintenance planning, forecasting, spare parts logistics more easy and efficient.

After failure detection, maintenance engineers will be notified with the location of the component in which failure is imminent. They can then use the machine history and detailed step by step 3D troubleshooting procedures which promotes high autonomy problem solving. Augmented reality and interactive 3D trouble-shooting guidelines on smart devices assist to carry out maintenance activities. On account of such highly decentralized activities, the interaction of TPM and decentralization was awarded with a score of 10. In case of a bigger malfunction, others machines can be contacted via M2M to find their availability for taking over the workload. Alternatively, the service availability of CPS and CPPS devices in other plants can also be verified via IoS to transfer the production orders to other units. After rectification, the solution is stored into the cloud. This along with failure pattern can be communicated with other machines which can then learn the mistake and prevent it from happening again. TPM highly benefits from interoperability and service orientation principles that the score of 10 is awarded.

If a failure demands a part to be replaced, then the new spare part can be printed using 3D printer. Parts of the machines are made modular for easy plug and play changeover, which enables maintenance replacement of the newly manufactured part. This often exclude parts which are more complex and require precise machining. So a score of 7 is given to the TPM and modularity interaction. CPS and CPPS devices perform data collection (e.g. tool wear) and data analysis. This data is compared with the stored standard reference models, its own historical performance data and performance data of other machines in the cloud to determine the current operating performance. Thus TPM and virtualization interaction is granted with a score of 10. TPM tool will serve as an important enabler for successful functioning of a connected industry [22].

5.2 Interaction of Takt Time with Industry 4.0 Design Principles

The interaction of takt time with Industry 4.0 design principles range from high to full hindrance. Decentralization was evaluated with a full hindrance score of −10 owing to the fact that decision about production planning, takt time calculation is made centrally with the help of forecasted demand and product variants. So rush orders cannot be easily integrated into the production with fixed takt times which is completely contradictory to the Industry 4.0 objective of decentralization and autonomy. Modularity also cannot be enforced as production schedules, product variants and the takt time are fixed. Real time product demand fluctuations cannot be accommodated into the production line which is a complete hindrance. Communication with other machines about delay and quality issues are of less importance if the takt time and work steps are already determined and it has to follow only a fixed production sequence. Also, takt times will not allow flexible capacity planning thereby blocking the services of machines and workers to other participants. Even data collected from the physical process cannot be used for implementing an immediate change in the production of successive products owing to limited flexibility, variants and output, which are already determined by the takt time. Changes can be implemented only during the next production cycle. Because of all these reasons, a high hindrance with a score of −7 is assigned to their interactions with takt time. In summary, takt time will be an obsolete LM tool in the future smart factory. This conception is also supported by various industry statements [23, 24].

5.3 Basic Lean Elements for Industry 4.0 Implementation

Some of the LM tool interactions (like modularity vs. standardization, decentralization vs. SMED) might have scored less with regard to the beneficiary coefficient but these LM tools in turn assist successful implementation and functioning of Industry 4.0. The most important of which is muda (waste). It is very much essential, that most of the waste in the factory and entire business process must be removed before digitalization. Standardization is also equally important for achieving modularity and interoperability as all the CPS and CPPS devices in a smart factory should have a standard protocol (e.g. OPC UA) for communication. To enable Plug&Play principle for flexible interchanging machine modules different manufacturers of the module should adopt standards for integration. It is important for virtualization to maintain consistent data standards for further processing. Likewise, SMED assists Industry 4.0's target of reduced batch sizes for achieving a lot size of one by reducing the setup time. The value streamed data is fed into cloud and machines access it continuously via IoT. The present status of value stream is monitored and if there are any discrepancies, it reacts independently to solve the problem without central control.

6 Summary and Outlook

This paper provides an explanation to the co-existence of lean management and Industry 4.0 in future smart factories via an interdependence matrix. The results of the matrix show the existence of numerous synergies between the considered LM tools and Industry 4.0 design principles. From the two-way interactions, LM tools like TPM, Kanban, production smoothing, autonomation and waste elimination benefit the most by the introduction of Industry 4.0. Real-time capability, decentralization and interoperability design principles offer highest support to the LM tools. Furthermore, it is shown that the concept of takt time will no longer be needed for production lines in future smart factories. The other way interaction shows that LM tools like SMED, VSM, standardization and waste elimination are supporting and represent the prerequisites for upgrading towards Industry 4.0. As a result, integration of Industry 4.0

modules in a lean manufacturing environment will add considerable value to a company. The authors are aware of the subjectiveness of the scores and therefore this paper aims for further discussion in the scientific community

Finally, it can be concluded that the concept of lean management will not fade away with the advent of Industry 4.0 but it is likely to become more important for successful implementation of Industry 4.0. The provided interactions between lean management and Industry 4.0 serve as basis for further research regarding the implementation of the lean philosophy into the future smart factory.

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