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ORIGINAL ARTICLE

Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries

M. Ghouat, A. Haddout and M. Benhadou*

Laboratory of Industrial Management, Energy and Technology of Plastic and Composites Materials
Hassan II University – ENSEM Casablanca, Morocco

ABSTRACT – Industrial companies looking for permanent performance are facing challenges of reducing production costs, reducing customer delivery delays and improving their quality products. These lead them to improve their responsiveness and flexibility to meet the varying needs of customers to cope with these constraints. Several industrial companies have adopted the lean manufacturing (LM) concept based on the Toyota production system to reduce wastage according to a methodical and structured approach that has given this proof for several years. This approach currently finds its limits, since it is based on static data. A dynamic approach, real-time data on customer needs and production performance will readjust the levers of lean manufacturing to improve its efficiency. This paper aims to show that the concept Industry 4.0 incarnates the lean manufacturing approach by feeding a real-time data and a real-time analysis of Big Data in a Cyber Physical Production System (CPPS), in order to improve decision-making and re-adjust real time levers of the lean manufacturing approach.

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INTRODUCTION

Nowadays companies adopt several management models to improve their competitiveness; the most used models are those which draw on the principles of lean manufacturing. However, other levers of industry 4.0 provide support for this approach which has given his proofs. In this article, it is necessary to evaluate the data relating to real-time collection capture of manufacturing needs, real-time management of work in progress, real-time adjustment of the production schedule, real-time management of production capabilities, real-time scheduling of production, real-time management of machine configurations, real-time report of production and real-time management of machine maintenance, in order to highlight their influences on the key lean manufacturing performance indicators that are the result of Industry 4.0 technologies. On the other hand, a list of Industry 4.0 technologies has been chosen to assess each technology in relation to its impact on key performance indicators. Matrices are provided for assessment of potential impacts of Industry 4.0 technologies on the indicators: Takt time, the cycle time of production, lead time, work in progress, finished product inventory level, waiting, motion time, the one-piece flow rate, the SMED change over time, the workload, the OEE, availability index, Cadence index and quality index.

In a previous paper [1], the authors show that the ongoing development of communication technologies requires organisations to facing respond to challenges. Customers increasingly demand very short response times to their customer requests. On the other hand, the requirements for increase customisation needs and high complexity of products increased [1]. The study recommended that before the Industries 4.0 concepts are implemented, the process-learning factory based on digital visualisation of the process allows identifying lean manufacturing levers along the value stream.

Organisations must put in place a process of continuous improvement of their competitiveness based on several strategic axes such as production costs, product quality and innovation in order to meet the individual requirements of the customers. The flexibility of the tool of production becomes one of the major axes for development of production. This flexibility based partly on communication between the various machines of production [3]. According to the authors [2], the main boundaries to the flexibilities is shown in the study regarding the theory of performance frontiers and asset frontiers; the additive manufacturing technology represents an alternative for short lifecycle products.

In order to ensure real-time communication between production machines, the organisms have seen an increasing multiplication of the connections of these production machines in a Cyber-Physical Production System (CPPS). The cornerstone of Cyber-Physical Production System (CPPS) is the digital representation of each product (Digital Representative DR). This digital representation contains information about the specifications of the product and all its production phases. This information is mainly used to coordinate production through continuous adaptation of production planning data to increase responsiveness and optimise production [4].

In this context, the most popular method for optimising production is the value stream mapping (VSM) of the Toyota Production System. It is used for visualising the production process and reducing the 7 wastes (Muda) that are due to inventory/work in progress, transportation, motion, waiting, over-processing, over-production, and defects [4]. The main objective of VSM is to reduce the lead time and meet the customers' need by eliminating the 7 wastes (Muda) in the value

*CORRESPONDING AUTHOR | M. Benhadou | ✉ mariambenhadou@yahoo.fr

chain of the product by reducing the activities to non-value-added (NVA). In this perspective, the concept Industry 4.0 supports the LM approach by feeding information in real-time [5].

There is a strong dependence between LM principles and the Industry 4.0 concept; the dependence is strongly materialised in waste avoidance and data visualisation. This dependence has also been demonstrated by experiments based on the tutorial factory to sensitise participants to the potential of digital technologies for supporting LM principles and provide LM guidance in manufacturing organisations. The principles of the Industry 4.0 concept are also a way of simulating and optimising LM principles [6-8]. The traditional LM approach consists of eliminating non-value-added activities by eliminating wastes at all levels of the value chain, stabilising production cycles, machine rates and standardisation of work through a value chain analysis based on value stream mapping (VSM) analysis. When digitising certain processes, this allows an instantaneous capture and analysis of the information and real-time visualisation of the performances, that will allow thereafter real-time interventions to stabilise production. For industries, it is an opportunity to evaluate the potential for improvement offered by LM, digitisation and Industry 4.0 on key performance indicators of the LM (Takt time, OEE, cycle time, lead time, workers and work in process) and sustainable development [9 -12 -30].

Industry 4.0 technology has been shown to have a positive impact on key indicators in the supply chain. The technologies involved are virtual and augmented reality, additive manufacturing and 3D printing, simulation, big data analytics, cloud technology, cybersecurity, internet of things, miniaturisation of electronics, automatic identification and data collection (AIDC), Radio Frequency Identification (RFID), robotics, drone and nanotechnologies, machine-to-machine communication (M2M), business intelligence (BI). [13- 30].

This paper has been aimed to demonstrate how technologies related to the Industry 4.0 concept impact the key performance indicators of production. For this purpose, it is necessary to determine the most relevant indicators that have a close relationship with the performance of the production systems. Figure 1 below illustrates the interactions between the various stakeholders in the organisation with the organisation's data hosted in the cloud.

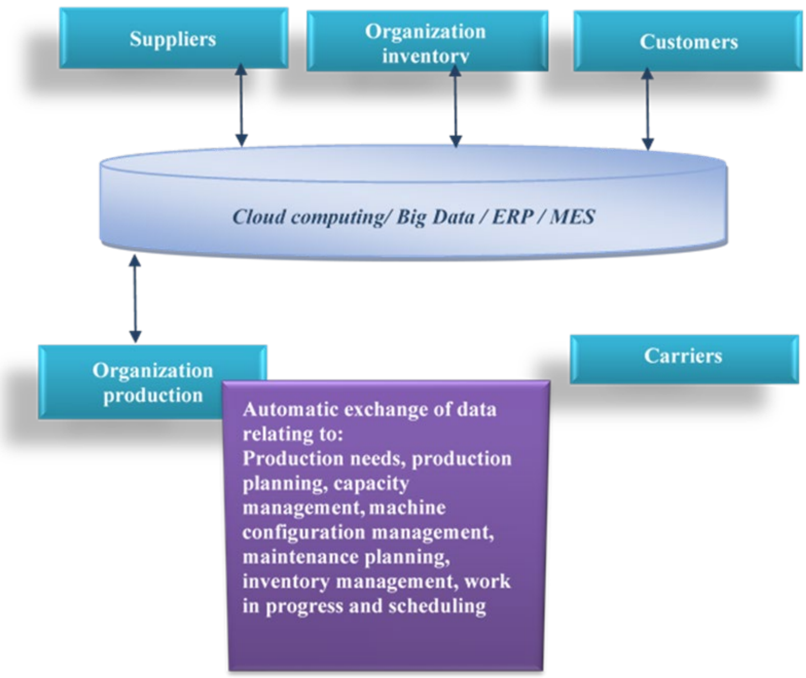

Figure 1. Interaction mode between the interested parties and the organisation in the industry concept 4.0.

METHODOLOGY

Nowadays, the relevant and fast decision making is efficient when all interested parties exchange data into a cloud computing system which provide in real-time relevant information; from customers related to customer needs and order scheduling, from suppliers related to material availability, from carriers related to shipment scheduling, from ERP (enterprise resource planning) related to material requirement, inventory management, work in progress and production scheduling, from EMS (execution manufacturing system) related to cycle time performance, quality performance, machine availability and from big data analytics related to customer needs prediction and production performance prediction. We focused on the following exchange of data to demonstrate the relationship between Industrial 4.0 concept and levers of lean manufacturing. The real-time capture of manufacturing needs are:

i. Real-time capture of manufacturing needs,
ii. Real-time management of work in progress,
iii. Real-time adjustment of the production schedule,
iv. Real-time management of production capabilities,
v. Real-time scheduling of production,
vi. Real-time management of machine configurations,

vii. Real-time report of production,
viii. Real-time management of machine maintenance.

Process of Exchanging Data in a Big Data:

People, machines and sensors can exchange a multitude of data with different formats and produce other data with increasing volumes. This phenomenon called Big Data is the result of the development of the information and communication technologies (ICT), sensors, machine control systems and production systems [14]. All these technological advances have enabled the Industry 4.0 concept to create and exploit the data exchanged in a cyber-physical system. Figure 2 favoured by the development of the Internet of Things (IoT) [15], cloud computing, mobile devices, information security, additive manufacturing insertions, Manufacturing Execution Systems (MES), Enterprise Resource Planning (ERP), Business Intelligence (BI) and sensors. In this cyber-physical production systems, the interoperability of the different components is a necessary condition to ensure real-time communication [19]. The five most important segments of interoperability include security features, data representation, communication outside the cyber-physical production systems, communication of things inside the cyber-physical production systems as well as an application addition section to reinforce the capabilities [16].

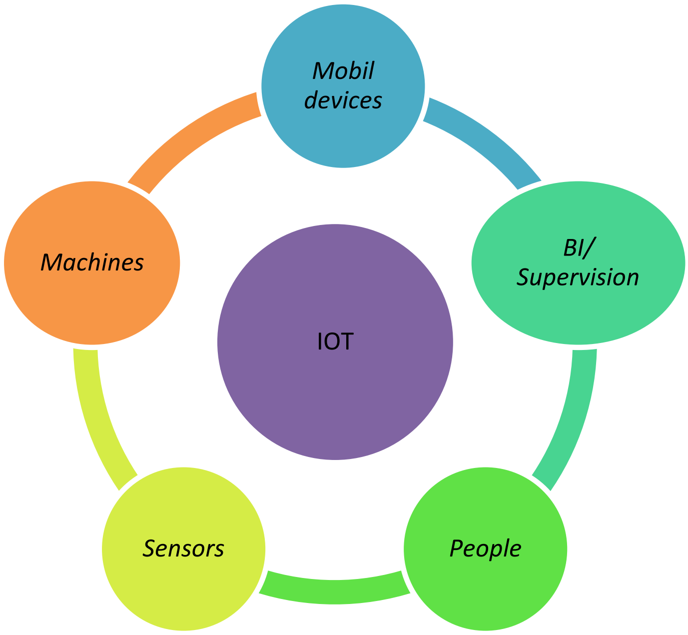

Figure 2. Cyber-physical production system.

Data Analysis between Production and Cloud Computing

Real-time capture of manufacturing needs

Figure 3 shows the data exchanged with cloud computing in a cyber-physical production system. Manufacturing requirements are closely linked to sales orders (SO), production work in progress (WIP) and available stock (S). The Enterprise Resource Planning (ERP) based on Material Resource Planning (MRP) II method, calculates in real-time. The net need (NN) of production is according to these data, using NN = SO-S-WIP [17]. Sales orders (SO) are fulfilled in real-time by the sales department on the ERP or directly by the customer on mobile applications that communicate in real-time with the ERP, so only the real needs of the customer are taken into account. Consideration for production, which leads us to consider in the Lean Manufacturing approach the waste 'MUDA' due to overproduction. So the production is synchronised with the customer demand represented by the indicator Takt Time. It is important not to produce in full load but to align the production with the strict demands of the customers [12].

Real-time work in progress management

Work in the progress inventory is the intermediary stocks between transformation processes. The real-time work in progress management makes possible optimisation of stock level and reducing the waiting times in the intermediate stages of production. It has been proved that Takt time is used to reduce the work in progress inventory (WIP), which leads us to consider in the lean manufacturing approach the 'MUDA' wastes relating to storage and waiting.

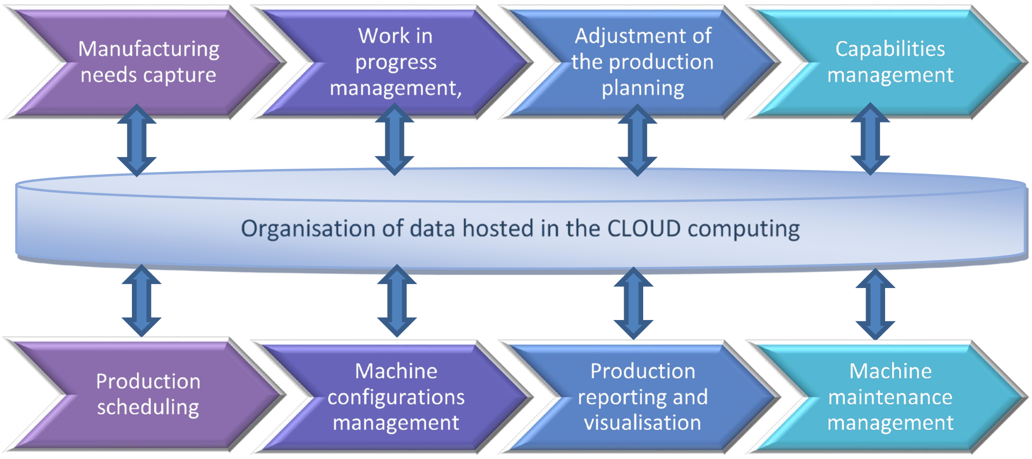

Figure 3. Data exchanged in a cyber-physical production system.

Real-time adjustment of the production schedule

The real-time adjustment of the production schedule increases the responsiveness of finished product manufacturing face to the instantaneous variation of customer orders (CC), variation of finished product inventories (S) and variation of work in progress [17]. Work in progress inventory can be common to several finished products. So, the real-time adjustment of the production schedule for semi-finished products and the components; that make up these work in progress inventory, makes it possible to optimise the changeover times for series and products and reduce waste due to start-up and shutdown of production. These lead us to consider in the lean manufacturing approach the waste MUDA relating to the waiting time due to the machine adjustment times and the MUDA relating to rejects [9].

Real-time manufacturing capabilities management

The real-time manufacturing capabilities management is an essential component of production planning, based on machine availability data. The production planning is automatically adjusted according to the actual production rates and according to machine hazards, which can be micro stops or scheduled maintenance stops. This capability management allowed us to instantly re-adjust the work in progress inventory of upstream or downstream of production processes. The capability has undergone an instantaneous variation in order to maintain the 'one-piece flow' approach which leads us to consider the MUDA relating to the inventory in the lean manufacturing concept.

Real-time scheduling of production

The real-time scheduling consists of executing the production program on a short-term deadline, the allocation of resources (was done through an analysis of the Big data relating to the production rates), the estimated dates of end of manufacturing in progress, the planned start dates of the preparations of the machine adjustments and the estimated dates of the changes in the series. These taking into account real-time changes made in the production program and the result of the short-term capability management, that will impact the Overall Equipment Effectiveness (OEE) and MUDA, relation to waiting time in the lean manufacturing concept [12].

Real-time machine configurations management

The real-time management of machine configurations consists of capturing and monitoring the various machine parameters according to the changes in the production environment and the quality of the products manufactured. The analysis of Big Data by a BI [14, 18] allows us to visualise the most optimal machine parameters, in order to reduce the time required for the settings. This leads us to consider the MUDA relation to the waiting time due to the machine settings.

Real-time reporting and visualising

The real-time monitoring of each machine's production consists of recording data relating to the quantities produced, the quantities discarded, the production rates, the productive times, the unproductive times, the resources and the energy consumed. The analysis of these data hosted in the cloud through BI allows us to view and monitor machine performance and continuously compare them to the optimal performance.

Real-time management of machine maintenance,

The real-time machine maintenance management is based essentially on the manufacturer data for preventive maintenance according to the running time of the machines. The BI predicts the date of the stop of a machine for preventive maintenance according to the recommendations of the provider. A coupling can be done with computer-assisted maintenance management (CMMS) to predict the launch date of spare parts purchases. Real-time maintenance management can be based on data related to the analysis of certain parameters read by sensors, which are stored in the big data. The BI can be based on the statistic processing control (SPC) to calculate the natural limits of these parameters, to follow variations on a control card and predict the date of intervention for preventive maintenance. Of course, the production schedules take into account the real-time maintenance schedules, that leads us to consider the MUDA relation to the waiting time due to machine maintenance [14,18].

RESULTS AND DISCUSSION

Impact of Lean Manufacturing (LM) Concept on Manufacturing Performance

Several studies have shown that adopting an LM approach has a positive impact on the sustainable development of manufacturing organisations. By adopting an LM approach on processes and equipment, product design, supplier relationships and relations with customers, we obtain a significant impact on 61% of the sustainable performances of the industries [20]. The financial performance of organisations is improved by adopting a reduction in waste. The LM culture reinforces the positive impact on the sustainable performance of organisms, the impact is even more marked when the LM culture is well anchored in the organisation [20]

It has also been shown that the reduction of inventories in the LM concept has a positive impact on the financial indicators of the manufacturing companies. The digitisation makes it possible to surpass the limits of the LM by increasing the capacity to treat the complexity and to increase the flexibility. The model was developed to identify the potential for digitisation in an LM production system [21-22].

Digitisation in cyberspace of production systems also has an impact on environmental performance, particularly on electricity consumption [23]. The impact depends on the configuration of the chosen cyber-physical production systems before launching a new production line. The computer simulation of the target architecture that results from a target VSM has a positive impact on the future performance of the new production line since malfunctions can be detected before implementing the production line [24].

On the other hand, in the social sector, technologies related to the Internet of Things have an impact on the improvement of workers' conditions through the monitoring of the health of workers, the conditions of the work environment and the way in which the work is carried out. The sensitisation of workers through the tutorial factory integrating the Industry 4.0 concept, makes it possible to ensure change management and the creation of decent working conditions in an Industry 4.0 environment [25 - 26].

Key Performance Indicators of Production

From the analysis of production data hosted in Cloud Computing and part of the cyberspace of production systems, the analysed real-time data are used to make real-time decisions to improve production performance. There is a strong correlation between the performance of the Industry 4.0 concept and the performance of the LM concept. In other words, the contribution of Industry 4.0 technologies can impact the MUDA of the LM concept [27]. Key performance indicators of production can be reflected in the performance indicators of an LM approach. Therefore, it is appropriate to conduct an impact analysis of Industry 4.0 technology on the key indicators of LM concept by further shelling these indicators to make their exploitation easy [28]

Certain industry 4.0 principles related to data acquisition and processing, machine-to-machine communication, and human and machine interface (HMI), which have a positive impact on the just-in-time principle of the LM concept [29]. The principle of the LM concept is to synchronise production with customer demand represented by a Takt time indicator [11,12]. The objective is to approach the cycle time (TC) which is closely dependent on lead time (LT) to the Takt time, by identifying non-value added activities and eliminating them. These wastes are 7 +1 Muda that are: overproduction, stock, waiting, moving, transportation, improper process, waste and inappropriate human potential.

Principle of Impact Evaluation of Industry 4.0 Concept

Through the study of the literature, the main question that arises is; 'How the Industry 4.0 concept impacts the key performance indicators (KPIs) of the industries?' and 'What is the relevant KPI to assess?' According to the literature, the most relevant key indicators of performance regarding the LM principle are: Takt time, cycle time, lead time, waiting times, motion time, OEE (with its components: availability index, cadence index and quality index), finished product inventory levels, work in progress levels and machine capability indicator (with its components: SMED 'series changeover time', one-piece flow and work load rate).

The key indicators identified in Table 1, 2, 3 and 4 were evaluated according to the impact of a technology related to the Industry 4.0 concept. A small potential impact is marked (+), a possible impact means is marked (++), a strong potential impact is marked (+++) and (0) when the technology has no impact on the indicator. Table 1 shows the potential impacts of Industry 4.0 technologies on Takt time capturing and cycle time of production indicators. Table 2 shows the potential impacts of Industry 4.0 technologies on the lead time with its components indicators; the work in progress and finished product inventory level, waiting and motion time. Table 3 shows the potential impacts of Industry 4.0 technologies on the indicators such as the utilisation rate of the theoretical production capacity with its components (one-piece flow rate, SMED change over time and the workload. Table 4 shows the potential impacts of Industry 4.0 technologies on OEE with its components indicators: availability index, Cadence index and quality index.

Table 1. Impact of Industry 4.0 Technologies on Takt time capture and cycle time.

Technologies related to Industry 4.0 concept	Takt time capture Real-time tracking of customer demand	Production cycle time The average time elapsed between two products
1. Enterprise resource planning (ERP)	0	+
2. Manufacturing execution systems (MES)	+	++
3. Business intelligence (BI)	+++	+
4. Cloud technology	+	0
5. Big data analytics	0	++
6. Machine-to-machine communication (M2M)	+++	0
7. The internet of things	+++	+++
8. Automatic identification and data collection (AIDC)	+	+
9. Radio-frequency identification (RFID)	++	0
10. Virtual and augmented reality	0	+
11. Additive manufacturing and 3D printing	++	+++
12. Simulation	++	0
13. Cybersecurity	+++	+
14. Miniaturisation of electronics	+	+
15. Robotics, drone and nanotechnology	0	+

Table 2. Impact of Industry 4.0 technologies on lead time.

Technologies related to Industry 4.0 concept	Lead time	
	Work in progress and finished product inventory	Waiting, motion and transport time
1. Enterprise resource planning (ERP)	0	0
2. Manufacturing execution systems (MES)	+	+
3. Business intelligence (BI)	+++	+++
4. Cloud technology	+	+
5. Big data analytics	0	0
6. Machine-to-machine communication (M2M)	+++	+++
7. The internet of things	+++	+++
8. Automatic identification and data collection (AIDC)	+	+
9. Radio-frequency identification (RFID)	++	++
10. Virtual and augmented reality	0	0
11. Additive manufacturing and 3D printing	++	++
12. Simulation	++	++
13. Cybersecurity	+++	+++
14. Miniaturisation of electronics	+	+
15. Robotics, drone and nanotechnology	0	0

Table 3. Impact of Industry 4.0 technologies on capacity management.

Technologies related to Industry 4.0 concept.	Capacity Management		
	One piece flow	SMED series changeover time	Work load rate
1. Enterprise resource planning (ERP)	+	+	+
2. Manufacturing execution systems (MES)	++	++	++
3. Business intelligence (BI)	+	+	+
4. Cloud technology	0	0	0
5. Big data analytics	++	++	++
6. Machine-to-machine communication (M2M)	0	0	0
7. The internet of things	+++	+++	+++
8. Automatic identification and data collection (AIDC)	+	+	+
9. Radio-frequency identification (RFID)	0	0	0
10. Virtual and augmented reality	+	+	+
11. Additive manufacturing and 3D printing	+++	+++	+++
12. Simulation	0	0	0
13. Cybersecurity	+	+	+
14. Miniaturisation of electronics	+	+	+
15. Robotics, drone and nanotechnology	+	+	+

Table 4. Impact of Industry 4.0 Technologies on the OEE.

Technologies related to Industry 4.0 concept	OEE		
	Availability index	Cadence index	Quality index
1. Enterprise resource planning (ERP)	++	++	++
2. Manufacturing execution systems (MES)	+	+	+
3. Business intelligence (BI)	0	0	0
4. Cloud technology	++	++	++
5. Big data analytics	0	0	0
6. Machine-to-machine communication (M2M)	+++	+++	+++
7. The internet of things	+	+	+
8. Automatic identification and data collection (AIDC)	0	0	0
9. Radio-frequency identification (RFID)	+	+	+
10. Virtual and augmented reality	+++	+++	+++
11. Additive manufacturing and 3D printing	0	0	0
12. Simulation	+	+	+
13. Cybersecurity	+	+	+
14. Miniaturisation of electronics	+	+	+
15. Robotics, drone and nanotechnology	+	+	+

CONCLUSION

Through the study of the production environment, a global analysis of the interaction between the Industry 4.0 concept and the Lean Manufacturing approach has been conducted. It has been shown that there is a strong interaction between the concept of Industry 4.0 and the levers constituting the lean manufacturing approach. Indeed, the concept of Industry 4.0 supports the principle of the lean manufacturing where the technologies related to this concept make it possible to improve the flow of information exchanged by ensuring the interconnection of the machines, things and people. Real-time analysis of the data allowed improvement of decision-making in cyber-physical production systems. To improve the effectiveness of the levers of lean manufacturing approach, key performance indicators derived from this concept have been identified. They are well impacted by technologies related to the Industry 4.0 concept and the impact levels must be validated by the survey.

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REFERENCES

[1] Wank A, Adolph S, Anokhin O, et al. Using a learning factory approach to transfer Industrie 4.0 approaches to small- and medium-sized enterprises. Procedia CIRP 2016; 54: 89-94.

[2] Brettel M, Klein M, Friederichsen N. The relevance of manufacturing flexibility in the context of Industrie 4.0. Procedia CIRP 2016; 41: 105-110,

[3] Tantik E, Anderl R. Integrated data model and structure for the asset administration shell in Industrie 4.0. Procedia CIRP 2017; 60: 86-91.

[4] Tantik E, Anderl R. Industrie 4.0: Using cyber-physical systems for value-stream based production evaluation. Procedia CIRP 2016; 57: 207-212.

[5] Mayr A, Weigelt M, Kuhl A, et al. Lean 4.0 - A conceptual conjunction of lean management and Industry 4.0. Procedia CIRP 2018; 72: 622-628.

[6] Dombrowski U, Richter T, Krenkel P. Interdependencies of Industrie 4.0 & lean production systems- A use cases analysis. Procedia Manufacturing 2017; 11: 1061-1068.

[7] Bauer H, Brandl F, Lock C, Reinhart G. Integration of Industrie 4.0 in lean manufacturing learning factories. Procedia Manufacturing 2018; 23: 147-152.

[8] Uriarte AG, Ng, Moris MU, Supporting the lean journey with simulation and optimisation in the context of Industry 4.0. Procedia Manufacturing 2018; 25: 586-593

[9] Meudt T, Metternich J, Abele E. Value stream mapping 4.0: Holistic examination of value stream and information logistics in production. CIRP Annals - Manufacturing Technology 2017; 66: 413–416

[10] Büyüközkan G, Kayakutlu G, Karakadılar IS, Assessment of lean manufacturing effect on business performance using Bayesian Belief Networks. Expert Systems with Applications 2015; 42(19): 6539–6551.

[11] Helleno AL, Isaias de Moraes AJ, Simon AT. Integrating sustainability indicators and Lean Manufacturing to assess manufacturing processes: Application case studies in Brazilian industry. Journal of Cleaner Production 2017; 153: 405-416.

[12] Ali RM, Dief AM. Dynamic lean assessment for Takt Time implementation. Procedia CIRP 2014; 17: 577-581.

[13] Tjahjono B, Esplugues C, Ares E, Pelaez G. What does Industry 4.0 mean to supply chain? Procedia Manufacturing 2017; 13: 1175–1182,

[14] Santos MY, e Sá JO, Andrade C, et al. A Big Data system supporting Bosch Braga Industry 4.0 strategy. International Journal of Information Management 2017; 37: 750–760.

[15] Ahuett-Garza H, Kurfess T. A brief discussion on the trends of habilitating technologies for Industry 4.0 and Smart manufacturing. Manufacturing Letters 2018; 15: 60–63.

[16] Tantik E, Anderl R. Integrated data model and structure for the asset administration shell in Industrie 4.0. Procedia CIRP 2017; 60: 86-91.

[17] Segerstedt A. Cover-time planning/Takt planning: A technique for materials requirement and production planning. International Journal of Production Economics 2017; 194: 25–31.

[18] Shi Z, Wang G. Integration of Big-Data ERP and business analytics (BA). Journal of High Technology Management Research 2018; 29: 141–150.

[19] Liao Y, Ramos LFP, Saturno M, e al. The role of interoperability in the fourth industrial revolution era. IFAC-Papers OnLine 2017; 50(1): 12434–12439.

[20] Iranmanesh M, Zailani S, Hyun SS, et al. Impact of lean manufacturing practices on firms' sustainable performance: lean culture as a moderator. Sustainability 2019; 11(4): 1112.

[21] Meade DJ, Kumar S, White B. Analysing the impact of the implementation of lean manufacturing strategies on profitability. The Journal of the Operational Research Society 2010; 61(5): 858-871.

[22] Hoellthaler G, Braunreuther S, Reinhart G. Digital lean production – An approach to identify potentials for the migration to a digitalised production system in SMEs from a lean perspective. Procedia CIRP 2018; 67: 522-527.

[23] Thiede S. Environmental sustainability of cyber physical production systems. Procedia CIRP 2018; 69: 644-649.

[24] Antonelli D, Stadnicka D. Combining factory simulation with value stream mapping: a critical discussion. Procedia CIRP 2018; 67: 30-35.

[25] Gregori F, Papetti A, Pandolfi M, et al. Improving a production site from a social point of view: an IoT infrastructure to monitor workers condition. Procedia CIRP 2018; 72: 886–891.

[26] Reuter M, Oberc H, Wannöffel M, et al. Learning factories' trainings as an enabler of proactive workers' participation regarding Industrie 4.0. Procedia Manufacturing 2017; 9: 354-360.

[27] Stock T, Seliger G. Opportunities of sustainable manufacturing in Industry 4.0.Procedia CIRP 201; 40: 536-541.

[28] Mrugalska B, Wyrwicka MK. Towards lean production in Industry 4.0. Procedia Engineering 2017; 182: 466 – 473.

[29] Wagner T, Herrmann C, Thiede S. Industry 4.0 impacts on lean production systems. Procedia CIRP 2017; 63: 125-131.

[30] Brusa E. Synopsis of the MBSE, Lean and Smart Manufacturing in the product and process design for an assessment of the strategy "Industry 4.0". In: Proceedings of the 4th INCOSE Italia Conference on Systems Engineering, Rome, Italy; 28-30 November, 2018.