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MES as an Enabler of Lean Manufacturing

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Abstract: Many firms have adopted Lean Manufacturing as a means of increasing productivity and reducing cost, often by focusing on the implementation of Lean best practices to identify and eliminate waste. This paper explores the application of Manufacturing Execution Systems (MES) to support the waste identification and elimination process. The majority of MES vendors have now incorporated Lean functionality in their software, but a comprehensive methodology that explains how MES can be used to enable and promote Lean Manufacturing is still lacking. This paper aims at filling this gap by presenting a Lean-MES framework. The proposed framework is validated and extended through a market analysis of MES software, identifying areas for further development for MES vendors.

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1. INTRODUCTION

Lean Manufacturing (LM) is widely recognized as a means to helping companies improve productivity, reduce costs and enhance flexibility (Womack & Jones, 2003). However, lean implementation still presents several challenges to companies (Liker & Rother, 2011). Indeed, research suggests only a small percentage of companies that adopt LM achieve the expected results (Ballé, 2005).

Recent studies have revealed that the integration of information technology (IT) with LM can support companies in overcoming such challenges (Powell et al., 2013). Within-firm and between-firm IT integration can help improve JIT practices, quality management and reduce delivery lead-times (Ward & Zhou, 2006). Moreover, production efficiency can be increased by integrating lean principles and advanced IT for manufacturing planning and control (Mo, 2009).

In this context, the introduction of Manufacturing Execution System (MES) brings new insights into the role of IT in LM. The real-time information flow of MES looks like a better fit for LM than any other production management software. By integrating lean tools and techniques with an MES, LM applications can benefit from real-time data analysis support.

More and more MES vendors have recently incorporated lean functions in their software solutions. However, specific lean challenges are not always considered when integrating so-called lean aspects into the MES functionality. A comprehensive analysis on how and to what extent MES functions should be integrated with LM is still missing (Cottyn et al., 2011).

This paper aims at filling this gap proposing a Lean-MES framework that seeks opportunities to effectively combine both strategies. The paper evaluates how an MES can support manufacturing firms overcoming the present-day challenges that often arise during LM implementation. The framework builds upon a literature analysis and is then extended through data elaborated from a market survey on current MES systems. The proposed framework validates and extends the theory and provides a useful tool for companies to analyse how to integrate MES in their existing IT structures. Furthermore, it provides a useful tool for benchmarking existing systems on the market.

The paper is organised as follows: Section 2 introduces the research methodology, while an in-depth analysis on the main characteristics of LM is reported in Section 3. Section 4 provides a detailed description on MES characteristics and introduces a general framework which explains how MES can support the implementation of LM. The analysis of the characteristics of existing MES software is reported and discussed in section 5 where an extension of the proposed framework is introduced. Finally, the last section concludes the paper, specifying its main limitations and suggestions for further work.

2. METHODOLOGY

This research relies on a three-step process. In the first stage, an extensive literature review was carried out taking into consideration scientific papers exploring MES and LM published in the period 2006-2017 and available in Scopus and ScienceDirect. The review process started with the analysis of LM literature to identify the main challenges in its implementation (Shah & Ward, 2003). The keywords adopted during this step were "Lean manufacturing", "Lean production", "TQM", "TPM", "SMED", "Just-In-Time", "Pull production", "Continuous improvement", "Kaizen" and "Customer involvement".

The first research phase was followed by a crosscheck analysis aiming at identifying which functionalities of MES can support companies to overcome their present-day challenges arising from LM implementation. Information coming from an extensive literature review on MES standards and functionalities were used to support the

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crosschecking activity, carried out by a panel of experts belonging both to industry and academia. The results were compared and a final general framework was agreed in consensus.
In the third phase of research the proposed framework was validated and extended through a market analysis of MES software, exploring existing solutions in both mechanical and electronics field. The analysis was carried out evaluating the vendors listed in MES Product Survey 2016 of CGI, one of the largest IT consulting service providers (CGI, 2016). To better identify how MES can support LM, the analysis was conducted in accordance with the taxonomy proposed by Arica & Powell (2017), which provides a framework for benchmarking MES based on two fundamental categories: i) business and manufacturing related factors and ii) technological factors. Three researchers with a theoretical and practical experience in lean manufacturing and production planning and control were involved to develop the analysis. The researchers operated independently by studying the information contained in brochures, presentations and websites of each software. Subsequent meetings allowed for the resolution of any discrepancies among the evaluations, thus leading to a common judgement.

3. LEAN MANUFACTURING

Lean Manufacturing (LM), which stems from research into the triumph of the Toyota Production System (TPS), is a human-centric management philosophy that focusses on engaging every individual in continuous improvement, everyday (Kaizen), by focusing on value-adding activities and removing waste (Womack & Jones, 2003). LM techniques are widely recognized as effective approaches to achieve flow, flexibility, stability and responsiveness (Womack & Jones, 2003). The following section describes the primary LM best practices, and the main challenges for their implementation according to Shah and Ward (2003). This is summarised in Table 1.

3.1 Continuous improvement (kaizen)

Kaizen is a Japanese philosophy that promotes continuous improvement as a result of continuous effort and employees' involvement (Imai, 1986). When implementing Kaizen, all the partners involved grow together, to create a lean environment throughout and across entire enterprises (Myerson, 2012). Even though many organizations understand the importance of Kaizen, not all companies succeed in its implementation because of inadequate communication channels, lack in knowledge sharing (Garcia-Sabater & Marin-Garcia, 2011) or inadequate deployment of organisational policies to all levels (Tortorella, Cauchick-Miguel & Gaiardelli, 2019).

3.2 Flow efficiency

The principles of continuous flow and pull production form the basic components of the Just-in-time system. Therefore the identification, reduction and elimination of those activities that do not add value to the process (Liker, 2004) can be considered the heart of the TPS. However, the complexity of modern organisations makes the implementation and improvement of these two basic principles a critical task. Disruptions in flow occur because of errors in inventory counting, capacity shortages and centralized controlling systems (Sanders, Elangeswaran & Wulfsberg, 2016). Moreover, the lack of communication between the parties leads to delays of scheduling as well as in the decision-making process, while the system flexibility is insufficient to deal with complex production environments (Hines, Holweg & Rich, 2004).

3.3 SMED

SMED is a methodology developed to improve setup time and optimise work rates, in order to support manufacturing adaptation to the constantly growing requirement for mass customization. When talking about SMED implementation, the main challenges are the reduction of time needed for setup activities and their standardization (Shingo, 1985).

3.4 Total Productive Maintenance (TPM)

The planning of equipment maintenance has always been a fundamental issue in manufacturing firms. Unexpected failures and machine breakdowns during production can lead to adverse effects on schedule, as well as on the employees' behaviour. Total Productive Maintenance (TPM) is defined as a set of activities carried out by small group of trained employees from top management to shop floor workers (McCarthy & Rich 2004) to maximize equipment effectiveness (Jangaler, R.S., Ranganath, 2016).

3.5 Total Quality Management (TQM)

Total Quality Management is the lean construct that includes tools developed to support companies with an organization-wide commitment to quality (Kiran, 2016). Its overall aim is to reduce costs and increase time-efficiency, releasing products that meet customers' requirements and needs (Reed, Lemak & Mero, 2000). By continually surfacing problems and fixing them as they occur, TQM techniques allow the elimination of wastes and the increase of productivity. As the challenges that manufacturing companies are facing are related to an incomplete or irregular record of quality-related information, in-depth monitoring along the production system is then required (Au & Choi, 1999).

3.6 Customer focus

As the true North of a lean enterprise, focusing on customer value represents the path to sustainable growth and profitability. In such a context, the takt time can be seen as the right LM tool to set the pace of a production system with the customer, rather than maximizing the production rate and factory utilization (Ali & Deif, 2014). As customer services differentiate companies from their competitors, but are characterised by high variance and complexity in processes, the main challenges for customer focus are mainly related to understand how standardization and adjustment of processes can be implemented to enhance lean services (Dombrowski & Malorny, 2016).

Table 1. LM present-day challenges

	Code
Continuous improvement (kaizen)	
Lack of communication and share	CI1
Limited resources and knowledge	CI2
Flow efficiency	
Tracking of product	FE1
Errors in inventory counting	FE2
Waste identification	FE3
Complex production scheduling	FE4
SMED	
Setup time reduction	SM1
Operation identification and standardization	SM2
Total Productive Maintenance (TPM)	
Control of machines breakdown	TP1
Management of maintenance activities	TP2
Education and training	TP3
Total Quality Management (TQM)	
Monitoring of process parameters	TQ1
Monitoring of testing tools	TQ2
Support operator in defect identification	TQ3
Automatic stop in case of defect / early detection	TQ4
Customer focus	
Standardize and customised services	CF1
Checking of customers' order status	CF2

4. MES INTEGRATION OF LEAN

In recent decades, companies have invested a huge amount of time and money to develop advanced technologies and production line automation on one hand, and to enhance their business management systems on the other. Manufacturing Execution System (MES) can be considered as a natural connection between these two layers (MESA International, 2007). Indeed, a MES is an IT tool developed around eleven function groups (MESA International, 1997) to support intermediation between the ERPs and the shop floors (Kletti, 2007). The integration of IT and LM has always been seen sceptically (Houy, 2005). However, by integrating lean tools and practices within MES, organisation can achieve several types of benefits, as indicated in the following and depicted in Table 2.

4.1 Continuous improvement (kaizen)

A MES provides data in real-time favouring the creation of useful information for continuous improvements efforts. As suggested by Unver (2012) integrating MES into LM supports the development of smart dashboards that elaborate KPIs and charts in real-time as well as provide the data needed for valuable PDCA analysis (D'Antonio et al., 2017). Moreover, integrating MES with PDCA reduces cycle time and improves process performances (Hwang, 2006).

4.2 Flow efficiency

By monitoring the processes in the shopfloor, a MES system can be used to identify the value stream and to support waste identification (Powell, Binder & Arica, 2013). The data collected can provide useful information to re-arrange the layout of the plant and the warehouse, as well as the position of machines In addition, through the adoption of RFID (Zhong et al., 2012) a MES system can be used to track every item in the production process, thus enabling a real-time visibility of products, improving material flow efficiency and minimizing inventory. Moreover, a MES can support advanced production planning, combining better operational management with plant floor connectivity (Cupek et al., 2016).

4.3 SMED

MES can play an important role to plan and optimize setup procedures. Indeed, the use of MES for setup leads to a reduction of setup time and a reduction of errors, due to automatic registration and data collection (Neves et al., 2015). Moreover, thanks to a direct connection between MES and machines operating in the shop floor, process data can be downloaded and uploaded automatically, leading to an efficient and effective monitoring and planning of setup activities (Theuer, Gronau & Lass, 2013).

4.4 Total Productive Maintenance (TPM)

MES can be deployed to improve TPM practices. Furthermore, maintenance management within MES can contribute to the achievement of quality targets. Adopting a MES to support maintenance operations, a wide range of documents and information can be linked and made available to the machine operators directly at the production terminals. At the same time, the maintenance tasks can be easily and quickly configured, planned, assigned and documented (Li, Wang & Huang, 2012). Again, a MES can provide all the data needed for the calculation of Overall Equipment Effectiveness (OEE), offering an integral instrument to monitor plant performances and thereby facilitating rapid and goal-oriented reaction (Unver et al., 2012).

4.5 Total Quality Management (TQM)

Integrating shop floor data with upper management system, a MES can be used to improve the effectiveness of TQM practices as well to support continuous improvement of quality standards (D'Antonio, Bedolla & Chiabert, 2017). In particular, MES provide real-time SPC analyses and reports on the relevant quality parameters. Using data and statistical evaluations, processes can be controlled in real time and out-of-specification production can be avoided. Moreover, different component parameters can be tracked at different production stages, while distinctive tests can be carried out to establish whether the parts have been produced in accordance with product and production standards (D'Antonio, Bedolla & Chiabert, 2017).

4.6 Customer focus

Literature showed that research on how MES can support companies to satisfy customers' requirements and needs is still lacking behind. Therefore, further studies are needed to evaluate which MES functionalities can improve customer focus and services.

Table 2. MES functionalities supporting LM challenges

MES functionalities	*LM challenges*
Real time data collection	CI1
PDCA Analysis	CI2
Real-time product monitoring	FE1
Inventory tracking	FE2
Real-time process monitoring	FE3
Advanced production planning	FE4
Setup planning	SM1; SM2
Automatic machine setup	SM1; SM2
KPIs calculation and analysis	TP1; TP2;
Autonomous maintenance	TP1; TP2;
Process control	TQ1; TQ2;
Quality data collection & analysis	TQ1; TQ2; TQ3
Defect traceability	TQ4
No functionality available	TP3; CF1; CF2

5. MES VENDOR ANALYSIS

In order to validate theoretical considerations developed from literature and provide an extension of existing knowledge about benefits that companies can achieve by integrating lean tools and practices within MES, a market analysis, considering the main 33 MES vendors of 2016 was carried out. According to CGI (2016), the industries considered were automotive, electronics, machinery and tooling, aerospace and defense, metals and semiconductor. The analysis was conducted starting from the taxonomy proposed by Arica & Powell (2017). The main results are showed in the following section and summarized in Table 3.

5.1 Continuous improvement

Existing MES can track and validate continuous improvement projects and develop functionalities, reports and applications to support change process. Continuous improvement escalation is supported by providing centralized knowledge systems and sustaining PLM process. Concerning problem diagnosis, MES provide integrated solutions for shop floor monitoring and reporting, based on KPIs calculation and reports. Energy consumption and emissions are also considered, by solutions able to calculate energy efficiency and define tolerance limits for emissions. Moreover, available MES provide dashboards to visualize and manage shop floor activities, providing transparency and visibility to the entire production process.

5.2 Flow efficiency

MES provides high-customizable control panel to track processes and products in real-time, to monitor energy consumption and to visualize the plant in real-time, collecting the data from the shop floor. Advanced production planning and scheduling modules within a MES are mainly based on Gantt charts, with reallocation of resources and order rescheduling in real-time. Moreover, MES supports operators' activities through the provision of electronic work and safety instructions and documentation that guide them throughout the production flow. Documentation is recorded in an electronic logbook to share knowledge and improve coordination.

MES provides real-time stock analyses and predictions, shipment and carriers tracking, as well as label management functionalities to support warehouse management. Labour management is also provided within MES, through the visualization of skills and certifications of individuals or crews, the displaying of personnel capacity and the monitoring of time and attendance.

5.3 Support SMED

MES support SMED activities providing automatic line setup procedures. Moreover, they can be used to define setup groups and allocate to the appropriate lines. Manufacturers can shorten setup times and increase machine utilization by automating machine setup and controlling it from the operation management level, with system-assisted equipment calibration.

5.4 Total Productive Maintenance (TPM)

The functionalities mainly offered by MES for TPM are related to maintenance process monitoring and overview, through visual aids, digital documentation and instructions. MES provides the essential capabilities for maintenance management, including the ability to schedule preventive maintenance programs, manage maintenance calendars, and calculate standard and customized KPIs. MES can also be used to automatically record and tag performances and maintenance history of each equipment, direct maintenance tasks, track the time and labour spent per each maintenance work order, as well as prioritize tasks and procedures by distinguishing the critical ones. The tool management is also supported by the adoption of MES, that provides information on tools and resources' technical status and availability. Furthermore, it can be used to track tools' utilisation and lifecycle, providing an electronic book to store all tools' history-related data.

5.5 Total Quality Management (TQM)

MES provide powerful tools to manage processes and product quality. In particular, it gives the opportunity to warning operators in case of deviations from configured standard, automatically monitor process conditions and provide early notifications of events. MES helps increase overall product quality providing SPC charts, measurement-related histograms and Pareto diagrams. It alerts operators when manufacturing process trends are out of control. Regarding defects' management, product traceability functionalities are provided by MES to identify where the defects are created and manage exceptions in case of irregularities. Storage and management of defect-related information is provided tracking the exceptions, in case the configured standards or SPC rules are violated. Again, MES provides visual support for quality-related activities, such as intelligent visualization of the product to map the defects and to conduct quality analysis. Moreover, it supports operators with checklists, documentation and instructions for inspections. It manages the inspection process, establishing sampling procedures and checking testing systems. Furthermore, MES monitors supply chain quality in real-time, releasing quality reports as well as analyzing and rating suppliers. Finally, it manages the quality inspections for incoming goods.

5.6 Continuous improvement

MES provides functionalities that can improve customer focus and customer-related services. It can record customer complaints and manage them investigating and reporting the root cause of the problems. Moreover, it manages manufactured material returned by a customer suggesting corrective actions and procedures. To manage customers' orders, MES can also track and fulfil orders either by assigning work-in-process material or finished goods. Furthermore, it tracks and manages automatically the shipment to customer, creating invoices and documents.

Table 3. MES tools functionalities for LM

MES functionalities	**(1)**	**(2)**	**(3)**
Real time data collection	TP	---	45%
Continuous improvement management	P	CI1	15%
PDCA Analysis	T	---	0%
Continuous improvement escalation	P	CI2	18%
Real-time product monitoring	TP	---	52%
Real-time process monitoring	TP	FE1	52%
Inventory tracking	T	---	0%
Warehouse management	P	FE2	36%
Advanced production planning	TP	---	48%
Setup planning	T	---	0%
Line setup optimization	P	SM1	3%
Automatic machine setup	TP	---	6%
KPIs calculation and analysis	TP	---	15%
Autonomous maintenance	TP	---	15%
Preventive maintenance	P	TP1	15%
Real-time maintenance monitoring	P	TP2	24%
Maintenance process overview	P	TP2	30%
Visual support for maintenance	P	TP3	24%
Process control	TP	---	30%
Supply chain monitoring	P	TQ1	21%
Inspection process management	P	TQ2	27%
Visual support for quality inspection	P	TQ3	30%
Quality data collection & analysis	TP	---	21%
Defect traceability	TP	---	30%
Return management	P	CF1	6%
Compliant management	P	CF1	3%
Customer order tracking	P	CF2	9%

(1) Still available in theory (T) or in practice (P)
(2) Additional LM challenge supported (based on vendor analysis)
(3) % of analysed MES software providing the functionality

MES software on the market can be also evaluated and ranked, according to their capability to support companies to overcome the identified LM challenges, as shown in Table 4, which also indicates that although the majority of existing MES are developed to support flow efficiency, there is often little consideration for quality management and customer service.

Table 4. Level of LM coverage of existing MES

# of not supported LM challenges	3/27
Max # of supported LM challenges	17/27
# of MES addressing more than 50% LM challenges	9%
# of MES addressing 100% of LM areas	0%
# of MES addressing 50% of LM areas	61%
# of MES addressing continuous improvement	58%
# of MES addressing flow efficiency	73%
# of MES addressing SMED	9%
# of MES addressing TPM	49%
# of MES addressing TQM	61%
# of MES addressing customer focus	12%

5. CONCLUSIONS

The proposed concept for a Lean-MES framework can be formed from Table 4, which structures the support of MES to the best lean practices and it is defined combining the frameworks obtained through the literature review and the analysis of MES vendors. The outcomes of the literature review reveal the theoretical integration of LM and MES. The analysis of MES vendors identifies the actual gap between theory and practice, showing how existent MES support best lean constructs.

The proposed Lean-MES framework aims to contextualize and formalize the integration of these two proven approaches, to improve efficiency and effectiveness. It provides a final insight of the functionalities of a MES supporting LM.

Moreover, the MES evaluation and ranking proposed can be useful to support MES developers in deriving and prioritizing improvement measures, focusing on MES capability to fully support a lean environment. The paper aims to provide a useful tool for companies to analyze which MES should be integrated in existing LM structure, to support the application and implementation of lean best practices. Furthermore, it can be used for benchmarking of existent MES on the market, which could be tested based on the framework.

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