The Role of Manufacturing Execution Systems in Supporting Lean Manufacturing

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Abstract. In order to deal with global competition and increased customers expectation, companies must improve the efficiency of their manufacturing processes. Mainly, two approaches are available: the implementation of lean manufacturing practices and the deployment of information tools for data analysis. For a long time, these two strategies have been considered mutually exclusive; recently, it was understood that information concerning the manufacturing process is mandatory for the effective implementation of lean practices. This work aims at showing how Manufacturing Execution Systems (MES) can support the lean manufacturing paradigm into a medium size enterprise. The case study of a company in the supply chain of automotive components is presented to provide evidence about the role of MES and to highlight possible criticalities occurring during its implementation.

Keywords: Manufacturing Execution Systems, Lean Manufacturing, Information tools.

1 Introduction

Today enterprises are driven by a challenging market: on the one hand, companies have to deal with competitors spread all over the world, operating in a variety of different conditions. On the other hand, the expectation of customers is increasing: product with enhanced quality, innovative features and higher customization level must be delivered in shorter times and at a lower cost. Hence, to maintain and improve their competitive advantage, leading organizations in different industrial sectors need to improve process optimization and efficiency.

One of the initiatives that a company may undertake to improve its competitiveness is the implementation of *Lean Manufacturing* practices; this term has been first introduced by Womack [1] to describe the working philosophy deployed in Japanese companies, with particular concern for Toyota. The essence of this methodology is the elimination of waste and non-productive process, in order to focus on value added operations and produce high-quality products, at the customers demand pace, with little waste.

Another approach is the deployment of automation and Information Technology (IT) tools, which allow to improve process planning and control, as well as to enhance the performance of each step of the manufacturing process. The landscape of the existing software classes and their purposes has been changing over the years, and is still evolving at a high pace. Today, beside the improvement of existing tools, huge efforts are made for the integration and the communication between different information tools and among systems deployed by different companies (for example, among firms belonging to the same supply chain).

For several years, Lean Manufacturing has been considered as opposed to the deployment of IT tools and their integration within and between firms [2, 3]. On one side, the philosophy of lean is “less is better”: inventory, variability, material handling, options and choices must be reduced as much as possible to improve the performance of a company. Conversely, the philosophy of IT is “more is better”: IT tools allow to better manage large amount of data, with increased flexibility, functions and features [2].

According to Ward and Zhou [2], the two classes of instruments are complementary both in the concept and in the application: IT tools can be considered a kind of higher-level planning system, while lean practices were related to shop-floor control and execution activities.

Nevertheless, in order to define improvement strategies and assess their impact, the collection and analysis of information is mandatory: the deployment of methodologies for Lean Manufacturing cannot exclude the use of IT tools. Hence, in the last years, IT instruments have been widely adapted, upgraded and expanded to deal with process monitoring and control activities.

The focus of this paper is on the role of Manufacturing Execution Systems (MES) – a class of IT tools – to support the implementation of Lean Manufacturing practices. The remainder of this paper is organized as follows: in Section 2 the Lean Manufacturing paradigm is introduced and some basic knowledge concerning MES is provided. In Section 3, the role of MES to support Lean Manufacturing is discussed. In Section 4, the case study of MES implementation into a medium size enterprise and the support in achieving Lean Manufacturing are presented. In Section 5, conclusive remarks and hints for future developments are discussed.

2 Background

2.1 Lean Manufacturing

Muda is a Japanese word meaning “waste”: it is referred to any human activity that needs dedicated resources, but does not create value. Taiichi Ohno, a Toyota executive, introduced the concept of *muda* in manufacturing, to label all the activities that require resources to take place, but do not add value to the process or to the product [4]. In particular, he defined seven classes of waste that typically affect a manufacturing process. Namely: (i) Overproduction; (ii) Waiting; (iii) Transport; (iv) Extra processing; (v) Inventory; (vi) Motion; (vii) Defects.

These wastes do not add value to the product, hence customers are not willing to pay for them. Manufacturers have to become less wasteful in order to be more profitable and improve their competitiveness. A systemic method to eliminate *muda* is Lean Manufacturing [5]. It is an approach inspired by Japanese management methods, in particular by the Toyota Production System. The effectiveness of this approach led to interest among European and American companies. The first attempts in exporting Japanese production methods have been made in the 1970s [1]. At that time, the experience was not successful; according to the prevalent opinion, this was due to cultural differences and to the unique social context of Japan. Nonetheless, in the early 1990s, deeper empirical and theoretical research has been performed and the basis for the first definition of lean manufacturing has been provided [1, 6]. This approach is structured in the following 5 principles: (i) Specify value; (ii) Identify the Value Stream; (iii) Flow; (iv) Pull; (v) Perfection.

At the state of the art, the interaction between lean practices and information tools has not yet thoroughly studied. A research performed by Moyano-Fuentes et al [7] showed that companies need to increase the degree of use of IT tools in order to implement lean manufacturing practices. Riezebos et al. [8] reviewed the role of IT in achieving lean production over three strategic topics: production control systems, computer aided production systems and maintenance processes. Powell et al. [9] analyzed ERP implementation processes and proposed a framework for ERP-based lean implementation, with particular concern for Small and Medium Enterprises (SMEs) [10].

2.2 Manufacturing Execution Systems

Manufacturing Execution Systems are IT tools commonly deployed in companies involved in traditional manufacturing. A MES enables information exchange between the organizational level, commonly supported by an Enterprise Resource Planning (ERP), and the control systems for the shop-floor, usually consisting in several, different, highly customized software applications [11]. A schematic of MES positioning in the framework of information tools supporting manufacturing is provided in Fig. 1.

The tasks in charge of a MES were proposed by Mesa International [12] in 1997, and then defined through the standards ISA95 [13] and IEC62264 [14]. A MES has two principal purposes. First, the system has to deal with the top-down data flow: the requirements and the necessities provided by the organizational level must be transformed into an optimal sequence planning meeting such targets. This sequence must be identified by best exploiting the available resources (such as staff, machines, materials, inventory) and taking into account the constraints of the process, such as processing and setup times, and workstations capacity.

The second aim of a MES is to manage the bottom-up data flow. Data concerning process performance and product quality can be gathered at the shop-floor level; the role of MES is to collect such data, analyze it through appropriate mathematical techniques, and extract a synthetic information to provide the business level with an exhaustive picture of the current state of the process. Possibly, the analysis should be performed in real-time, in order to make decisions to control the process with the

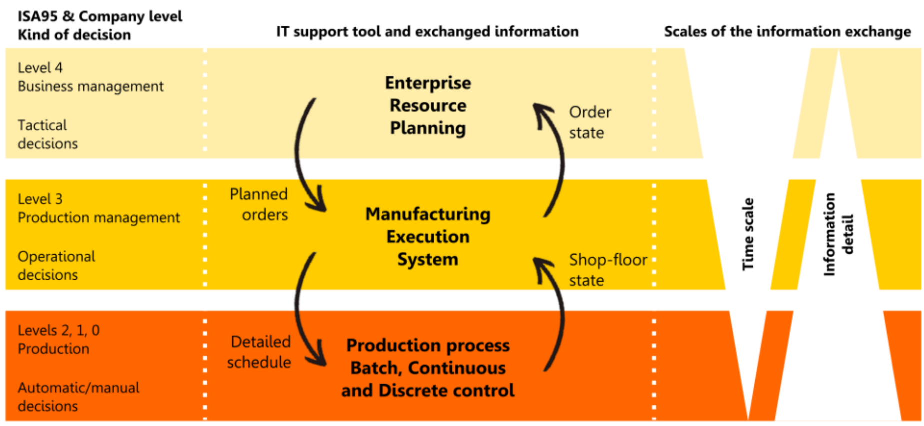

Fig. 1. Positioning of MES within an industrial framework.

necessary rapidity. Recently, the development of low-cost, small, easily available sensors led to a great diffusion of monitoring systems to assess product quality and process performance, and to support the improvement of production process.

MES were initially deployed in industries focused in the fields of chemistry and pharmaceutics; then, the spread of such systems increased, but for long time this tool has been considered useful only for large industries. In recent years, it was understood that the benefits provided by a MES can profitably support even smaller companies [15]. According to a recent survey [16], in Europe SMEs represent around the 99% of the enterprises; thus, the potential of MES application is very huge. However, in the implementation of a MES, SMEs and large companies have to face different issues. In Section 4, the attention will be focused on the SME perspective.

According to the last report of Markets and Markets [17], the MES turnover is expected to reach USD 12.6 Billion by 2020 at a CAGR[1] of 10.85% between 2015 and 2020. For a long period, Europe has been the main market for MES; nevertheless, in recent times the Asia Pacific region has superseded Europe as the biggest regional market. North and Latin America are, respectively, the 3rd and the 4th market [18]. The major players in the MES market include ABB Ltd. (Switzerland), Andea Solutions (Poland), Dassault Systemes SA (France), Emerson Electric Co. (US), General Electric Co. (US), Honeywell International Inc. (US), Rockwell Automation, Inc. (US), SAP AG (Germany), Schneider Electric SE (France), Siemens AG (Germany), and Werum IT Solutions GmbH (Germany).

3 MES support to Lean Manufacturing

As stated in Section 1, for a long time the deployment of IT tools and the lean practices have been considered mutually exclusive. However, recently, the importance of deploying MES to support continuous improvement techniques has been shown. Cottyn [19] developed a framework for the integration of lean objectives

[1] Compounded Average Growth Rate

into MES. He defined an automatic Value Stream Mapping (aVSM) methodology: the aVSM benefits from the information provided by the MES, since it is a rich source of information and historical data useful to define continuous improvement actions. On the other side, MES benefits from aVSM because it does not contain information concerning the value flow. The framework is validated through the case studies of a furniture firm and a food and beverage company.

A further recent work [20] aimed at the definition of a methodology for the development of MES-oriented tools to support the path towards Lean Manufacturing. It consists of three steps: (i) identification of the wastes to be eliminated; (ii) identification and description of all the components and resources involved in the process at stake; (iii) description of the analysis technique to be integrated into the MES (data source, mathematical algorithms, information to extracted). The methodology enabled to deal with both the top-down and the bottom-up data flows in charge of MES, and was applied to case studies in heterogeneous fields, such as subtractive and additive manufacturing processes, automated warehousing and automated transport of items through a manufacturing line. The research results provided evidence that the deployment of information-based techniques enables to develop adaptive strategies for waste reduction and achievement of lean manufacturing. The research also showed that an effectively implemented MES is, by itself, a lean tool: appropriate techniques must be implemented to transform the acquired data into the right amount of information, to be delivered at the right person, at the right time; ineffective tools lead to wastes such as useless effort in understanding data or oversized infrastructures for data transmission.

The findings presented in this and the previous Sections encourage the deployment of MES to improve the control of the process and to have a complete and updated picture of the manufacturing flow. In particular, MES can enable the identification of wastes and criticalities, and provide information to support decision aiming at overcoming such issued. The impact of SMEs in the European manufacturing has also been presented. Thus, in the following Section a MES implementation into a SME is presented: the aim of this case study is to show how this system can be implemented into a small size company, the implementation issues that may be faced and the support that it can provide in approaching lean manufacturing.

4 A case study in a SME

The mission of the industrial partner involved in this project is to design and produce interior components for buses, coaches and trains. Although it is a medium size enterprise, the company is composed of five subsidiaries, located in Europe, Middle East, Asia and America. Namely, the firm produces and assemblies lighting systems, handrails, ceiling panels, pillar coverings and luggage racks. Given this high variety of products, the company deploys a wide range of materials including HPL, plastics (PVC, ABS), metals (mainly aluminum), fiberglass, and textiles. The whole manufacturing process is composed of several operations such as cutting, bending, shaping, turning, milling, welding, assembly, surface coating, painting, and punching. Each product has its own manufacturing process. In this project, the Italian plant has been involved to test the implementation of a MES. This shop floor consists of 21 machines; among them, two are equipped with a PLC.

The need for a MES. Before starting the project, data concerning the production were manually registered on paper sheets by shop-floor operators. Then, the same operators manually entered such data into the company's ERP. The information was used to evaluate performance indicators, such as machines utilization and overall process efficiency. Data concerning failures were collected into specific forms and managed without the support of ERP. This practice resulted in non-standardized data collection and imprecisions; further, in some cases data acquisition was missed. Although not efficient, this approach for data collection is still common for SMEs. Nonetheless, the lack of appropriate information tools may lead to issues such as missed, redundant, or discordant data. For these reasons, the industrial partner decided to introduce a MES into the company.

MES implementation. The industrial partner had not yet installed any information systems in the shop-floor. Thus, to implement the MES two main issues have been dealt: (i) the acquisition of data; (ii) the infrastructure for data transmission to the central unit.

As stated, the shop-floor is composed of a heterogeneous variety of machines. Among them, only two are equipped with a PLC: so, data concerning work instructions, start and finish time, as well as the error codes related to possible failures are directly taken from the controller; the operator only has to log in the system before starting the operation. However, the majority of the machines is not equipped with a PLC and data must be manually entered. To support a profitable deployment of MES, manual machines have been equipped with a set of tablets connected with the central unit. Such devices are used as an interface between the operators and the MES.

Data transmission is performed through wireless connection: the installation of a cable network would have been more expensive and would have provided a lower flexibility.

MES functionalities. Given the motivations leading to MES installation, the developed system aims at solving issues concerning the traceability of the performed operations.

From the shop-floor operators' perspective, the MES is a digital, standardized support to collect the information that was previously handled manually. Before starting an operation, the operator has to log in the system, by scanning a personal bar code or by entering his ID. Then, he must input the number corresponding to the production order at stake, as well as the work code. This step enables to extract the list of operations to be performed; the operator has to select the specific phase he is dealing with from a drop-down menu and the work instructions are shown. At this stage, all the data necessary to uniquely identify the operation have been introduced in the system. To begin working, the operator clicks a Start button: in this way, the system is aware that some resources are busy and cannot be allocated elsewhere. Similarly, when the operation is finished, a Stop button must be clicked. In the PLC-equipped machines, the last two steps are automatically performed. Data concerning the involved resources and the time took by the operation are saved for further analytics. The operator also has to input information concerning issues: a list of possible failures and quality defects is available to shorten the time spent in this task and to standardize the sent information. A free text field is also available for unexpected issues.

From the business level perspective, the interface of the MES enables to take snapshots of the shop-floor state at different time scales. First, the present utilization of the resources can be extracted at any time. Second, analytics concerning arbitrary time spans can be extracted: the average values for the utilization of the equipment, the overall efficiency of the process, the impact of defects and failures can be extracted. Further, the cost of processing a part or a lot can be evaluated. The traceability of the product through its manufacturing process enables to define a product passport [21], i.e. a document containing the whole chronology of the manufacturing steps experienced by each part.

The support to Lean Manufacturing. The deployment of the presented MES enables to collect data concerning the events taking place at the shop-floor, the repartition of times, the utilization of the resources and the flow of items through the process. These data are collected through the interface provided to the operators; then, data analysis and aggregation are performed to support the decision making process at the business level. Such decisions must be aimed at the elimination of wastes, in order to focus the efforts on the operations that add value to the product and which a customer is willing to pay for. Given the classification of wastes provided in Section 2, the functionalities of the implemented MES enable to:

- Trace the impact of *Defects*: whenever a (semi-)finished item does not match the required quality level, the operator inputs an issue message into the MES. The analyses performed by the system enable to identify the classes of product or the operations mostly affected by defects. The tracking capability is an effective tool to support the identification of the ultimate reasons leading to poor product quality.
- Trace the impact of *Inventory* and *Waiting*: the capability of extracting the instant overview of the shop-floor enables to evaluate the number of items idle into the shop-floor. Inventory minimization is desirable, since idle parts require room to be stocked and represent money already spent which is not yet producing income. Waiting is the counterpart of inventory, since it represents the time that items spend without being processed or transported; this time is mainly due to not synchronized flows of materials. The information collected by the MES enables improved planning of operations and allocation of resources, aiming at minimizing waiting.
- Trace the impact of *Transport*. The chronology of the events experienced by the items enables to identify their path through the shop-floor. Thus, data collected over large time intervals can provide useful hints to re-arrange the layout of the plant, the position of the machines and the placement of warehouses in order to reduce the impact of transport: beside a time waste, transport is also a potential risk, since the items may be damaged.

5 Conclusions and further developments

In this work, the implementation of a MES into a medium size company has been presented. The work has been focused on the improvement of shop-floor data collection, aiming to enhance the quality of process knowledge and to support decision making processes. The system is still in a start-up phase: it has been successfully installed into the company, and beta test have been performed to ensure its correct deployment. The MES is now starting to be heavily used, hence a quantification of the advantages concerning will be available in the next months. The presented case study also represents a pilot test for the company, which consists of five plants spread in different geographical areas. The company aims at developing and setting a complete MES system into the Italian plant; after its validation and the evaluation of benefits, the MES will also be installed into the other plants.

The support that such system can provide to achieve Lean Manufacturing has been described in the previous Section. The current spread and the expected trends for MES diffusion in the next years have been presented in Section 2. Given these two concepts, it can be stated that in future a higher diffusion and support of information tools for setting up and tuning lean practices is expected.

However, the experience gathered through this case study showed that some criticalities may occur. A MES cannot be considered as a plug and play system: a robust system for data acquisition and transmission is necessary. The interaction between machines and MES can be managed by the PLC: the information collected during an operation can be sent to the system and stored. However, in the present case study, the majority of the machines was not equipped with a PLC. Thus, alternative ways to collect data had to be identified. The issue was tackled through the deployment of mobile devices, such as tablets: today, such devices provide a huge calculation capability at a low cost. The heterogeneous fleet of machines presented in this case study is not rare: the majority of companies all over the world can be classified as a small-medium enterprise. For this kind of companies, the turnover of machines occurs slowly, so a low-cost solution for the integration of information tools to trace the events occurring in the shop-floor and to improve process knowledge is desirable. In this case study, the cost necessary to develop the software, to equip the shop-floor with a wireless infrastructure for data transmission and to buy the mobile devices was in the order of 40k€.

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