Implementation and Evaluation of MES in One-of-a-Kind Production

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Abstract: Customers are demanding more and more a product of high quality and fast delivery at a low price, while simultaneously expecting that the product meets their individual needs and requirements. For companies characterized by a highly customized production, it is essential to optimize the use of machines and reduce the production cycle. The aim of this paper is to develop and evaluate how a MES is able to collect data from the machines and use such data to perform a real time planning of production activities. The system has been implemented in an Italian company that produces metal sheet components for prototypes and small series in the automotive sector, which is characterized by a production with high complexity and high mix of products. The obtained results show that the system provides several benefits in term of reduction of times.

1 INTRODUCTION

According to a McKinsey study, the benefits of adopting new digital technologies will bring significant gains, eg. 10-40% reduction in maintenance costs, 10-20% reduction in quality cost, and 30-50% reduction in total machine downtime (McKinsey Digital, 2016). However, despite the improvement in connectivity and computing power, only three percent of companies are ready for large-scale deployment of solutions for smart manufacturing. For many of them it is not clear how advanced analytics will streamline their operations. This leads to many pilots in the industry and a lot of data which is not contextualized and properly used at all the levels in the organization. A flexible approach to contextualize data and use it in the real-time planning for generating automated decision-making process could overcome this barrier.

In the market, three main groups of systems are available, addressing different issues: (i) manufacturing execution systems (MES), focused on process interlocking solutions, (ii) production planning systems, which plan activities based on demand and availability of the resources on long time spans, and (iii) industrial IoT solutions, which collect real-time time data from machines with little contextualization (in fact, machine data can't describe completely what is actually happening on the production floor).

The proposed framework incorporates all the key aspects from these different solutions. Based on a system that is already able to deal with complex and heavy regulated industries, such as the pharmaceutical ones, where it provides all the data required by regulations for electronic batch records, the aim is to demonstrate how the real-time planning is able to offer alternatives and intelligence in an automated way to plan the production in the most optimal way.

Such system is most needed especially because the production of the 21st century is mostly focused on the personal needs of the consumer, and the companies that innovate and introduce new products on the market need new approaches to quickly test the products and reduce the time to market. The past decades have been characterized by this trend which can be summarized with the concept of mass customization. This concept reaches its extreme with the One-of-a-Kind Production (OKP): every single product is different because it is produced for a different customer (Wortmann et al., 1997). In this scenario the production line must become as flexible as possible, since an on-demand production is needed.

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Thus, a big opportunity exists now in the market, because several of the challenges involved in optimizing production are not well addressed or not addressed at all. Especially the part of aggregating data from the shop floor and use it for real-time high-level automated decision making is not addressed.

The aim of this work is to provide intelligent decisions in real-time in order to increase flexibility, efficiency and predictability in manufacturing. The expected outcome is to build a real-time planning solution that works in a production scenario with high complexity and high mix of products.

2 RELATED WORKS

Traditional scheduling approaches in production involve the creation of schedules prior to beginning of the production process. In this case, uncertainties that are not expected nor taken into account at the planning phase can cause delays of these schedules (Suwa et al., 2012). Common uncertainties that occur in a manufacturing system include machine operator absence, material shortages, and machine failure (Snyman et al., 2017).

In such scenarios, the manager has to react by manually selecting a new or revised schedule to ensure that production continues while maintaining the required performance level. All these challenges lead to poor utilization of resources, delays in deliveries and sometimes chaos in production.

The innovation of real-time scheduling is to address the shortcomings of the traditional approaches by performing scheduling concurrently with the production process. Furthermore, based on the analysis of historical data, it is possible to predict maintenance activities and include them in the scheduling. This new approach can help industries to better plan activities (e.g., reduce waste, improve productivity) and mitigate the risks of non-delivering, especially in OKP companies in which the uncertainties are more frequent.

The characteristics of OKP make production scheduling and control extremely difficult (Tu et al. , 2000). The main featuresof the OKP production are: high customization (each product is designed and manufactured based on customer requirements), complicated and dynamic supply chains, great uncertainties in production control and dynamic production systems (Luo et al., 2011). In OKP manufacturing, due to high customization, the productive cycle does not repeat and the productive tasks do not have fixed times (Tu et al., 2000).

In addition to the dynamics just mentioned, there are also other disturbances such as stochastic customer orders or emergency orders, and frequent engineering changes, that make highly complex the productive activities planning (Lu et al., 2006).

The proposed framework is a MES (Manufacturing Execution System), i.e., a software product able to manage factory floor material control, and labor and machine capacity, and to track and trace components and orders, manage inventory, optimize production activities from order launch to finished goods (Helo et al., 2014). A similar study was proposed by Wang et al. (2012), who developed an application of a RFID enabled real-time manufacturing execution system for OKP manufacture of radial tire mold. This study demostrated that the atomatic workshop control system largely improves the machines' utilisation rate and thus the production efficiency. In this way, the production potentials of the company can be exploited fully though the real-time information, instead of being directed arbitrarly by managers.

Furthermore, our proposed system schedules activities through the product input data and changes the planning depending on the unexpected events to respect, anyway, the deadlines. It also controls the tasks status, the downtimes (due to breakdown, maintenance, etc.), the operations in production support (material handling, program loading, quality control, etc.). It can also compute, through the analysis of data, the KPIs relative to the production.

3 MES SYSTEM FRAMEWORK

The developed framework consists of several software applications and hardware components, produced by the Octavic PTS company (https://octavic.dk/). The framework is useful for bridging data from operators with machine data to offer contextualized data (human driven data) for all the levels in the organization. This approach gives better insights about the root cause of the problems, actions that have been made and provides real-time feedback for the decision makers.

The machine data is automatically communicated to the system (IOT technology). A practical example of integrating operator data with machine data is when the machine is stopped for the loading of new equipment. In this case the operator communicates the start and the nature of downtime to the system while the end is automatically recognized by the system thanks to the machine information. These last report to the system when the spindle stops or moves.

The framework consists of a web application which provides advanced analytics, real-time feedback using flexible escalations levels, predictive KPIs (OEE) etc.

The data is collected from machines using a device with a touch screen that is interfaced with the machines and guides the operator through a flexible UI flow to input data at certain stages during the production process. In this way the data collected from the machines is contextualized using the knowledge from the operator.

Data gathered is presented in a relevant format on large screens for each level of decision making in the organisation. The web solution responsible to manage, present and store the data is developed using .NET technology. For the planning solution, the GoogleOR-Tools which as an advanced framework for constraints programming.

The flexible UI application which is running on the device with a touch screen is built in QT (c++). The system is very easy to install, configure (all the configuration is done using the web interface) and connect to any type of machine.

4 APPLICATION

The framework has been applied to an Italian company, which manufactures car body prototypes. The use case company is a tier 2 supplier for worldwide known automotive manufacturers. The strength of the company relies in its ability of developing complex manufacturing processes in short time to provide prototypes and pre-series products. The company is a perfect example of the OKP approach to produce customized products based on requirements of individual customers.

The OKP companies use flexible manufacturing systems to efficiently produce unique batches (P.R. Dean et al., 2009). So the production of metal sheet prototype components for a high variety of customers requires a flexible production system. The objective of the paper is to estimate the improvements od production activities planniing , before their start, by using a MES system. According to this goal, the first step is to analyze in detail the process of die production.

The equipment to form metal sheet components are made in cast iron or in resin; the last-mentioned material is cheaper but less resistant, so it is used for small volume orders. To minimize costs, the company realize more equipment from a single foundry blank (for example designs punch and blankholder together) and only in the end separates them.

The structure of the milling cycle, necessary to transform the foundry blank in the finished piece of equipment, is in common for all the equipment. The structure is composed by the sequence of three main tasks: (i) face milling and roughing, (iii) finishing, (iv) cutting.

The tool paths and all the milling support operations (such as crane transport, fastening, metal swarf control on blank surface, blank line up, utensil resetting, cleaning etc..) make up the milling cycle. The details of the activities, necessary to carry out, depend from the piece of equipment to be produced.

The smoothing, roughing and cutting operations are carried out on the roughing machines (suitable for removing more material and supporting higher stresses on the tool) while the finishing operations are carried out on finishing machines (with high rotation speed and feed, very accurate and with automatic tool change).

Each developed equipment is unique. However, is essential to find a method of classification of equipment through which the variety of system input data can be reduced. Thanks to this reason, the equipment are classified according to the production cycle. The equipment have in common the production cycle structure but what varies for each of that is: (i) the duration of the activities, (ii) the necessary activities and (iii) the allocation of activities / machines. According to how the variables individually affect the cycle, it is possible to combine these effects and find all the possible customizations of the cycle. Consequently, a new equipment in production can be classified by associating it with one of these customizations.

Until now, the company management planned the milling activities thanks to the experience accumulated over the years regarding the expected times and the recommended machines for the equipment in production.

Relying on experience is not always the right choice. If the production manager does not define any planning rules and does not use a calculation tool, he could be in serious difficulty when the amount of activity is high.

OKP companies have highly flexible production systems, which allows numerous chances to produce an equipment. Choosing the best among these for a high quantity of equipment inevitably increases human error. In addition, the customer could request design changes even in the production phase and a lot of other uncertainties could be happen such as breakdowns, maintenance, absence of operators, delay in delivery of raw materials etc...

All these variables complicate the role of production manager, which often has to pay workmen overtimes thus increasing costs and reducing earnings. Moreover, in this worry scenario the manager stress increases and makes worse the quality of staff work. This effect inevitably affects current and future performance of the production process.

The aim of this work is to evaluate the benefits that the use of a real-time planner involve already in the design phase in a mold manufacturing company. To this aim, the system planning results have been compared with the manual ones through some indicators. The details of the production process, the method implementation and the description of the obtained results are reported in the following sections.

4.1 Process Description

The company manufactures and assembles sheet metal and aluminium components for prototypes and small series of cars and other road vehicles. The customers are car manufacturers, that usually, in the design phase of a new vehicle, need some models to perform assembly and safety tests (the so-called crash-tests) but for them the production of a small volume of components is not convenient so they commission these activities externally. The strength of the company in fact relies in its ability of developing complex manufacturing processes in short time.

The customer imposes to the company different progressive deadlines for components and gradually assembles and tests them. If the tests on prototypal components is negative, the customer can ask for company to modify them. It is a well-known fact that without a flexible production system, the company could be in trouble to pass quickly these unexpected events and respect the deadlines.

The greatest difficulties in this type of business are the strict budgetary and production time limits and the need of a highly flexible production system. The earliest project deadline is 7/8 weeks form the order of which more than 3 weeks are necessary only to complete the equipment to forming and cutting the metal sheet components. The remaining limited time is used for all the other project phases.

The production process of the company is reported in Fig.1. It starts from the acceptance of the order of a component with the delivery by the costumer of the CAD models needed for production. The CAD models are received by the technical office, where the designers define the production process and the dies needed by the pressing machines.

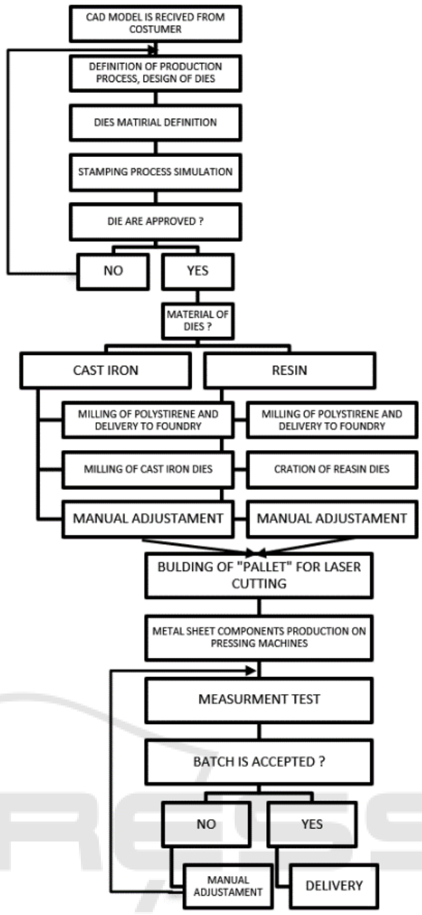

Figure 1: Production process of the company.

In prototypal production the pressing machines are mainly used for drawing and flanging metal sheet. Drawing metal is taking a flat or partially formed sheet metal blank and forming it into a desired shape.

Flanging metal is the act of swiping sheet metal in a direction contrary to its previous position. These pressing operations are performed with a punch and a die. In a basic example of metal sheet forming, the punch has the shape desired for the metal sheet component and it's locked on press machine ram (the moving of reciprocating member).The sheet metal blank is placed over the die, which is locked on press machine bolster plate. During the closing operation of the pressing machine, the blankholder, that surrounds the punch, firstly comes into contact with sheet metal blank and applies pressure to the entire its surface (except the area under the punch) to hold it against the die while the punch travels towards the blank. After contacting the sheet metal blank, the punch forces the sheet metal into the die cavity, forming its shape.

At the end of the production process design, the equipment CAD projects are used by the CAM

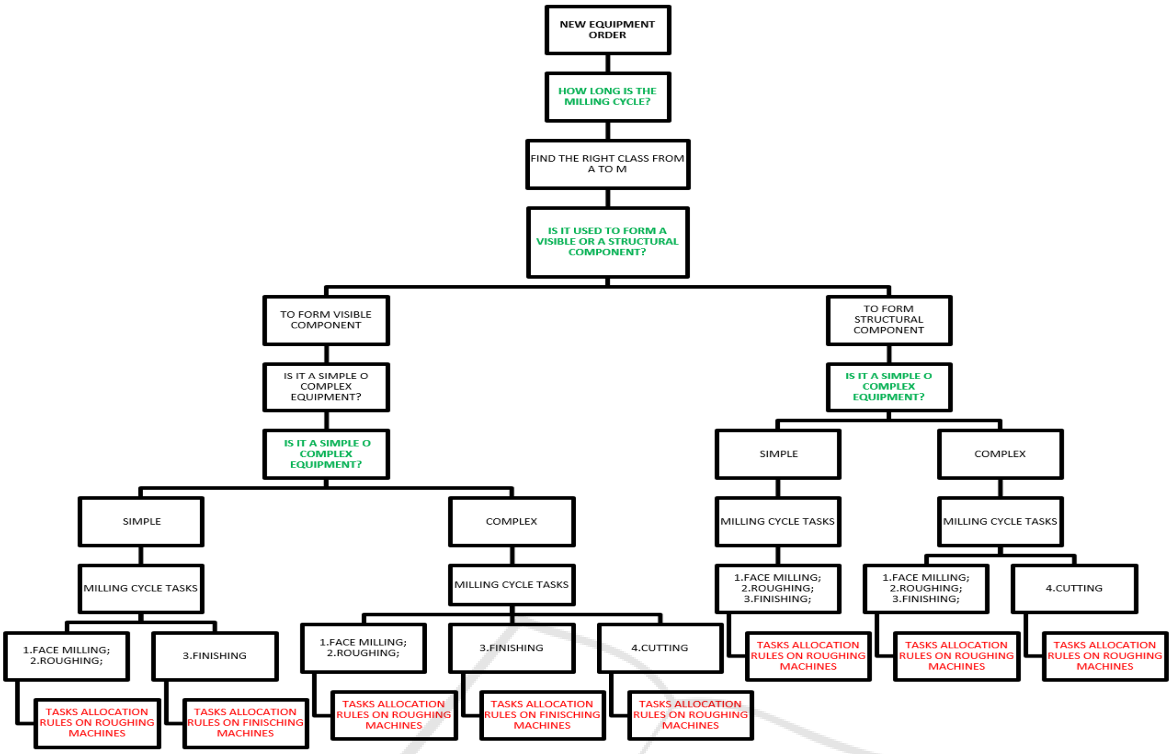

Figure 2: Flow chart.

department to define the tool paths both for the polystyrene model and, subsequently, for the milling of the foundry blank.

The foundry receives the equipment polystyrene models and give back the cast iron ones. After this phase, the cast iron blanks are milled and manually overhauled by skilled workers.

Once the sheet metal forming operations are finished in the press sector, the components are laser cut with specific pallets (obtained previously by copying the shape of the punch), checked by skilled workers and send to the costumer.

4.2 Implementation

The high product customization introduces a high planning complexity. In order to implement the real-time planning system to the dies productive process, a method to group the equipment by budget hours and type of milling cycle has been defined, in order to reduce the complexity.

The system implementation complexity is in the input data variety. Each piece of equipment is unique and therefore also its production cycle. According to this reason, it looks like impossible to implement the system in the way that it can know the production activities depending on each equipment.

So, to reduce the input data complexity, the equipment have been classified by means of the production cycle. Starting with a production cycle structure common to all the equipment, its customization variables have been identified.

Starting from a production cycle structure common to all the equipment its modification variables have been identified and their effects have been combined to find all customizations.

The variables are: (i) the duration of the activities, (ii) the necessary activities and (iii) the allocation of activities / machines. The changes that each of them apports to the production cycle can be identified through three questions:

1. How long is the milling cycle?
   The answer identifies that each activity has a different duration depending of the equipment.
2. Is the equipment used to form a visible component or a structural component?
   The answer identifies if the roughing and finishing activities carry out in sequence on a roughing machine (structural component) or if they carry out respectively on the roughing machines and finishing ones (car-body visible component).
3. Is the equipment simple o complex?

The equipment is complex when more pieces are realized from the single foundry blank (such as punch and blankholder designed and manufactured together).
If the answer to this question is "yes" then the last activity of the cycle is the cutting one otherwise is the finishing one.

The combination of modification options 2 and 3 entails four production cycle types.

The last variable to manage is the duration of the activities depending of the equipment. In order to consider it, eleven classes have been defined, from A to M, and a range of milling hours has associated in ascending order to each of them. For each class there are four production cycle types and their activities are linked to a percentage of the class hours range: 55% for a finishing activity, 44% for a roughing activity and 1% for the cutting one.

The flow chart representing this process is reported in Fig.2.

4.3 Order Loading

Upon to the arrive of a new equipment in production, the order is loaded into the system. The new equipment is linked to the right production cycle by choosing one of the four types of orders: (i) the production of a simple equipment used to form car-body visible components, (ii) the production of a complex equipment used to form car-body visible component, (iii) the production of a simple equipment used to form car-body structural component, and (iv) the production of a complex equipment used to form car-body structural component.

In the order loading phase, it is important to specify one of the 11 classes in addition to the typology. In this way, the system is going to automatically recognize the necessary activities and their duration. So, it is going to plan them correctly.

Regarding the allocation of activities to the machines, the system is going to respect the following rules:

(i) For the first type of order, one change of machines is allowed. Firstly, the face milling and roughing activities carry out in sequence on roughing machine then the finishing tasks on finishing machines.

(ii) For the second type, two changes of machines are allowed. Firstly, the face milling and roughing activities carry out in sequence on roughing machine, then the finishing task on the finishing machines, and finally the cutting task on roughing machine.

(iii) For the third type, no machine changes are required because all the milling tasks are carried out on a roughing machine.

(iv) For the fourth type two machine changes are needed because the cutting activities, although carry out on roughing machine as the previous ones, are not immediately done after the finishing tasks.

The company machines are divided in finishing machines and roughing machines. In particular, the company has four roughing machines and three finishing machines, but some machine-activity allocations are preferable to others depending of the equipment. In addition to the mentioned rules, the roughing and finishing machines have been associated with the corresponding activities with an increasing priority. In particular, the system is going to firstly occupy the machines with the highest priority and then those with the lowest priority.

During the introduction of a new order, the operator in addition to the class and typology (through which the system recognizes the right milling cycle) has to report the coming date from foundry and the deadline date from the customer.

5 RESULTS AND DISCUSSION

In order to show the system planning efficiency, we compared the manual planning of activities with the automatic planning defined by the system. An example of the planning generated by the system is reported in Fig.3.

Figure 3: Planning of activities on the machines.

The considered period covered the orders of 39 equipment, for which a total of 73 activities were executed. In the original planning, the time period started in the 48th week of 2019 and ended in the second week of 2020.

The comparison was made accordingly to the following three indicators:

1. waiting time, i.e. the time between the coming date of the item from the foundry and the starting date of the first activity;
2. production time, i.e. the time between the start of the first activity and the end of the last one;
3. deadline gap, i.e., the time between the end of the last productive activity and the deadline set by the customer.

For each equipment, the three indicators were computed both for the original planning and the automatic one. The results showed that, with the automatic planning, the 97% of the equipment present less or equal waiting time, the 82% of equipment present less or equal productive time, and the 77% of equipment present a higher deadline gap.

The results show the benefits of using the system to plan the activities before their starts. Instead, the use during the production process allows to collect high amount of data on it.

The company gain are several benefits dufrom e the data collection during the production, such as (i) the ability to know the causes of uncertainties during the production process and so quickly react to them, (ii) the possibility of analyzing such data at the end of the production process to reconstruct the past events (descriptive analysis), find the cause-effect link of the events (diagnostic analysis), predict what will happen with the future orders (predictive analysis) and design the improvements that will influence the future results (prescriptive analysis), and (iii) the possibility to collect the product managing strategies. The built database is essential to help managers to take the future choices and estimate better the future quotes.

6 CONCLUSIONS

The objective of this paper is to propose a framework to collect data and perform a real time planning of production. The benefits of using such framework are demonstrated in a real case of an Italian manufacturing company.

Future works will address the further benefits of using the developed framework also in case of breakdowns and downtimes, to automatically recalculate the planning of activities.

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