Integration Between PLM and MES for One-of-a-Kind Production

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Emiliano Traini, Giulia Bruno, Ahmed Awouda, Paolo Chiabert, Franco Lombardi

Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy
{emiliano.traini,giulia.bruno,ahmed.awouda,paolo.chiabert,franco lombardi}@polito.it

Abstract. Despite the amount of research addressing the formalization of product-related knowledge, the practical use of tools for knowledge management is still very low at the corporate level. Several commercial software applications are already available for product lifecycle management (PLM) and manufacturing execution system (MES). Unfortunately, these two applications are scarcely integrated thus preventing an efficient and pervasive collection of data and the consequent creation of useful information. This is more critical in One-of-a-kind Production (OKP), where each product is unique, the process is not completely defined at the design stage, but it is continuously improved at the shop floor level by skilled operator. In such situation most of the company's knowledge relies on the lessons learnt by operators in years of work experience, and their ability to reuse this knowledge in order to face new problems. Because OKP must develop unique product and complex processes in short time, it is mandatory to reuse the acquired information in the most efficient way. It is therefore necessary to collect all the data from the shop floor and transform them in information that will be used in the development of the next product and process. The aim of this paper is to design a framework able to integrate data, from both design and manufacturing phases. To this aim, a framework has been designed to structure and relate information from the PLM and the MES systems. A case study has been developed for a car prototyping company to prove the efficiency of the proposed solution.

Keywords: Industry 4.0, PLM, knowledge management, OKP.

1 Introduction

Product innovation and customization are the main weapons in the hands of small and medium sized companies to compete in a market characterized by high volatility and quick dynamics. Customization strategies can be particularly observed in companies whose manufacturing processes are dedicated to the manufacture products so much customized as to be considered unique specimens, known as "one-of-a-kind production", OKP [1,2]. This production method is characterized by a very high level of product customization, a strong variability in the production process, a complex and dynamic supply network, and a versatile and dynamic production plant, often controlled in an empirical way [3]. Several Italian and European SMEs meet this definition and many of them are able to compete with larger companies, offering products (and services) highly personalized, with more content of a large delivery company and higher quality standards used for similar products (possibly "custom") from global companies.

Effective collaboration and knowledge sharing among experts and technicians at all levels is the “secret strategy” for OKP systems. OKP decision making mainly relies on the long-life human learning process based on product case-histories, which enables operators to react autonomously and adapt and/or recover the manufacturing process, or even suggest product modifications to improve the manufacturability.

In recent years, embedded technology, connected devices, and Internet of Things (IoT) have been introduced in industrial environments, to provide sensors, actuators and networks able to interact with the working processes in real time and giving rise to the so-called “fourth industrial revolution” (Industry 4.0). Currently, the usage of IoT data is limited to analyze shop floor behavior by monitoring environment parameters. However, the most significance challenge is to integrate IoT data with data generated in the product design phase, in order to increase the knowledge about products and infer correlations among product geometrical features, product manufacturing process parameters and product failures. This challenge is even more important in OKP, where the knowledge of previous failures of similar products would improve the design of the process of a new product by reducing the time spent for trial-and-error.

Several commercial software applications are already available for product lifecycle management (PLM) and manufacturing execution control (MES). PLM systems make at disposal of designers shared product databases. The fact that PLM systems are accessible by different people and departments allows the collaborative development of products, enabling sharing and reuse of information. However, PLM systems are not integrated with the manufacturing execution systems (MES), which took control of the factory operations, from production order release testing of the finished product. MES systems are used to control in real time the progress of orders and to associate to each production order the information about the parameters and results of the operations. Through the real-time monitoring, it is therefore possible to release and/or modify work orders, to intervene promptly in case of unforeseen, and to rebalance workloads of machines and operators.

The full exploitation of PLM and MES systems is limited by two factors: first, the lack of integration between them, thus requiring a third application of interconnection, and second, the need of deriving more explicit knowledge from the data generated in terms of correlations of events and prediction of future criticisms. The lack of a formalized, structured and effective knowledge management system to capture and represent the tacit knowledge makes such knowledge remain in the minds of the people, or, at best, transferred verbally, and then, over time, inevitably lost [4,5].

To catch such knowledge, there is the need of using more advanced systems to store and correlate all the information coming from the plant. The aim of the paper is to develop a framework to integrate knowledge coming from the design and the execution phases in manufacturing.

The rest of the paper is organized as follows. Section 2 summarizes the relevant literature available on the topic. Section 3 describes the proposed framework and the definition of the data model to structure the product and process knowledge. Section 4 presents the application of the framework in the use case of an Italian company producing car prototypes. Finally, Section 5 draws conclusions and states future work perspectives.

2 Related works

In the last ten years, several research papers were published, which addressed the issue of structuring and formalising product-related knowledge, mainly related to modelling product geometrical features and manufacturing process parameters [6,7,8,9]. Also, several international research projects addressing the development of industrial knowledge sharing systems were recently founded (e.g., amePLM [10], ICP4Life [11], Know4car[12], Manutelligence[13]). However, the practical use of tools for supporting knowledge management is still very low at the corporate level. A study conducted in 2013 by the GeCo Observatory (http://www.homeappliancesworld.com/2015/06/01/italian-manufacturing-innovation-is-possible), on a sample of more than 100 Italian manufacturing companies, found that the most used methods to explicit knowledge remain the traditional verbal communication, the practices based on paper, and the basic IT supports for collaboration such as shared folders, forums, and intranet portals. It is also severely limited the use of more structured software systems.

Two lacks can be identified in both current scientific literature and research projects. The first one is that they did not address specifically the OKP domain, where the presence of many alternative routings and operations makes very difficult to manage all the manufacturing variables together, in an efficient and profitable way, without increasing wastes of time and costs. The second one is that there is no overall view of IoT architecture (in terms of kinds of data to be measured at plant level, together with the kind of sensors need to measure such data) and also on processing intelligence to analyse such data in a efficient way. It is therefore essential, both for industrial efficiency and for customer satisfaction, the development of an integrated knowledge management system, able to take systematic tracks of the experience accumulated over time through the manufacturing activities.

3 Framework

The proposed framework is a knowledge management system able to collect and store data both form product design and process execution. As shown in Fig. 1, this framework is based on a central database (DB) containing the subset of data relevant for both PLM and MES and acting as a bridge between them.

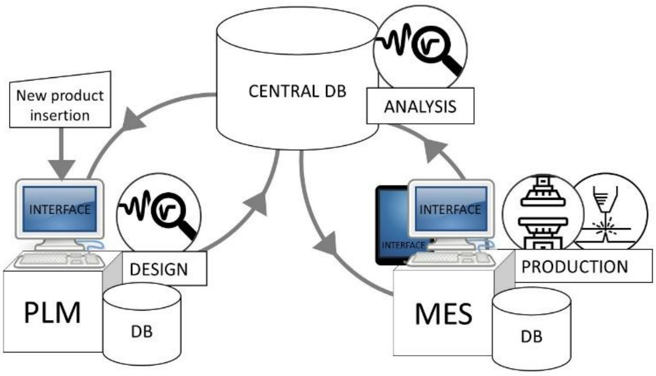

Fig. 1. Conceptual model of the framework.

The proposed framework will allow (i) to collect all the information regarding the critical realizations of new components in a structured way, so that the added values of the experience breakthrough, as well as other useful tips, could be provided to the end-user, and (ii) to reuse the knowledge, i.e. help designers to define more reliable processes for new products, reducing the "trial-and-error" cycles in the development of forming processes.

In fact, when a customer makes an order, it means that the company must define the sequence of activities to obtain the required product. If the historical data regarding previous products are stored in the central DB, it can be used to find the closest product already produced in the past that needs less changes to be adapted to the new shop order. The chosen product is then found in the PLM platform where the needed changes can be done. The information associated to the new product is sent to the central DB and made accessible to the MES. The MES uses the product information to manage the production and, when the production is finished, it reports in the central DB the information related to the execution of each activity and the success or failure of the product. In case of failure, the company can check the intermediate results reported for each activity and decide how to proceed to obtain a better solution.

The content of the central DB and the data flow between it and PLM and MES are described in the following subsections.

3.1 Data from PLM

Through the PLM, in the design phase, the following data regarding the product and its activities are generated and sent to the central DB.

- *BOM*. This is a list of the raw materials, sub-assemblies, intermediate assemblies, sub-components, parts, and the quantities of each needed to manufacture an end-product.
- *CAD file*.
- *List of activities.* This is not a typical information stored in PLM. Practically, this is an ordered list of all required activities to obtain the final product.

- *Activities description.* It is related to the company department where the activity must be done, the specification of the activity, the need or not of a machine and, in case of need, which is the machine.
- *Check start*. It regards the necessary condition for the beginning of the activity. If the considered activity is manual, all the tools and raw materials needed by the operator are included. If the activity needs a machinery, the set up and all the necessary tools are included. Furthermore, the condition on the semi-finished goods need to be added (the operator needs to be able to see error that comes from the previous activities).
- *Check end*. It is related to the production and product quality check. The operator needs to be able to know the necessary parameters to discern accordant products from the other. Related to the process, the operator can have information about not only the product lifecycle but also about the CAD files related to it.
- *Machine description*. It is the list of available machines, characterized by the type and other parameters, so that when an activity has to be executed, the operator knows which type of machine he must use and which specific ones are available.

To allow the retrieval of similar products, it is also useful to define a classification of products in groups of similar objects. The selection of good classification parameters is fundamental for the analysis, and the more these parameters are, the more accurate the classification for a future shop order will be. The following three classification parameters were used:

1. *Family.* The first classification parameter generates a macro-division of products, which considers the major differences in production process and material (e.g., structural elements, non-structural elements, panels).
2. *Subfamily*. Once divided into families the products are classified according to their use and their shape (e.g., the panel family is further divided into the subfamily of doors, sides, trunks, fenders and roofs).
3. *Complexity.* The last parameter discriminates products that belong to a very homogeneous group, by considering more complex the products in which an activity is repeated several times to achieve a better degree of refinement.

3.2 Data from MES

The role of the MES is the production monitoring, thus it sends to the Central DB the information related to the process of a specific shop order. The production information to be collected is the following:

- *Check start results*. If it is not possible to start a new activity, the MES needs to be able to receive information about the causes.
- *Check end results*. It is fundamental to collect information regarding the problems occurred during the process at the end of the activity.

- *Machine failure*. In the OKP it is fundamental in addition to the production also the monitoring of the machine failures. In fact, knowing this information it is possible the improvement of the machine assignment to different activities in order to minimize downtime.
- *Activity information*. The MES platform need to be able to record information related to the performed activities. Among these parameters, main ones are the actual cycle time, the machine set up and the time waiting for the operator.

This structure, able to accommodate a prefixed type of information, risks not being enough to capture all the knowledge generated during the production. To overcome this problem, the MES must be thought out and developed in order to allow to receive unforeseen information about the production. A basic example is the possibility for the operator to freely write a description of the incident or to use cameras in the production sector.

In the OKP the MES needs a last degree of freedom: the possibility of changing the activities of the product to production in progress. In fact, this kind of manufacturing companies are still very dependent on the experience of their operators. For this reason, it often happens that the operators take decisions in slight contrast to the ones of the Analyst Office that remain a-priori and non-dynamic decisions. Then the MES must be able to communicate to the central DB that the production cycle has been modified for a single shop order.

3.3 Knowledge DB

The central DB is structured to receive and integrate data coming from both PLM and MES, and to make them available for further analysis.

Fig. 2 shows the structure of the central DB through an entity-relationship model. The product entity contains information about the classification, the CAD file, the BOM and other general characteristics of the products. The amount of the semi-finished product is connected to it, which identifies the status of the semi-finished products specifying the next activity to be carried out. This is the reason why there is also the activity entity that characterizes the particular activity, explaining the check start, the check-ends and the machines necessary to carry it out. All the physical machines available in the company are then associated to the corresponding type. This information is provided by the PLM and is subsequently used by the MES.

To the entities associated with the PLM activity are added entities that model the data provided by the MES, i.e. the data coming from the production. The fundamental entity is the one related to the shop order. In the central DB all the shop orders taken in charge and on which the company has worked are stored. This entity is obviously connected to the product, as each shop order concerns a single and specific product, so a single and specific product lifecycle. The shop order is also connected to the activity carried out, connected itself to the verification checks. It models the data structure from which we can extract the history of all the activities divided by shop order and consequently by product and results obtained.

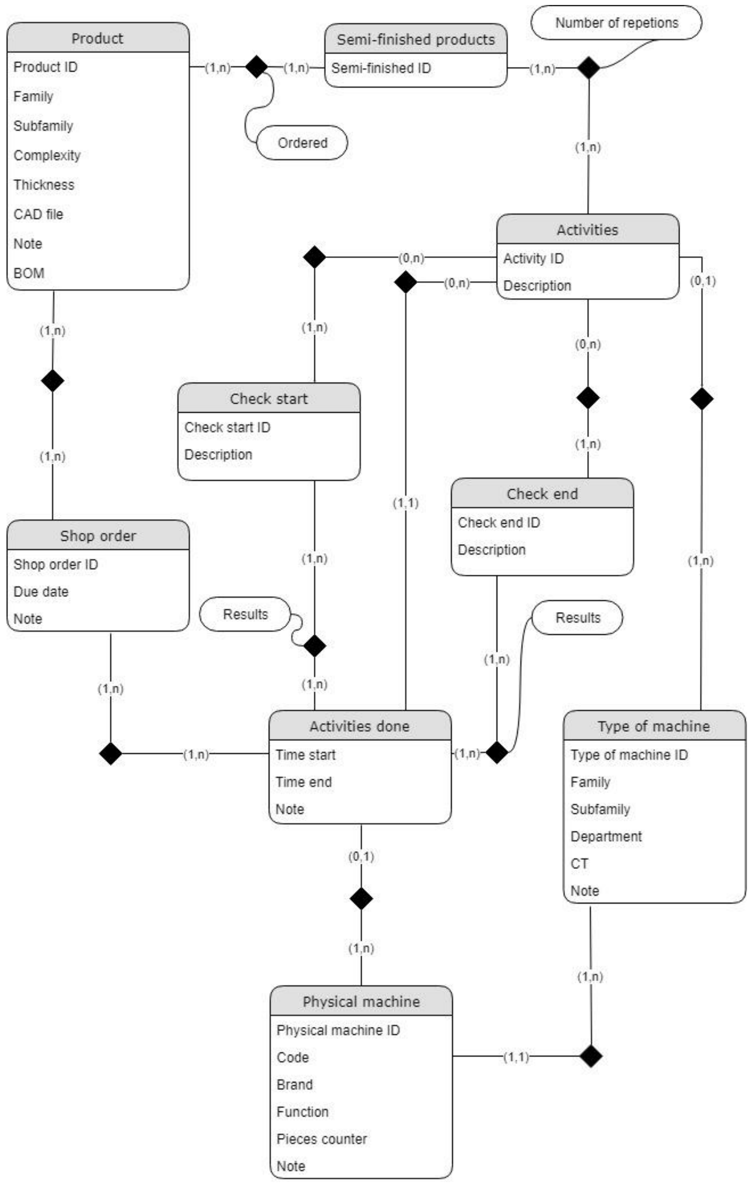

Fig. 2. Entity-relationship model of the knowledge DB.

4 Use case

The study was conducted in an Italian company that operates in the automotive sector, producing prototype bodywork components for passenger cars and other kinds of vehicles. The 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 providing prototypes and pre-series products. According to this goal the company is a perfect example of the OKP approach to produce customized products based on requirements of individual customers.

4.1 Complexity of the OKP process

Due to the production nature of the company, it is difficult to forecast the production trend, and there may be problems and mishaps that prevent the plant from having a linear production. Unlike series production, the production of prototypes is characterized by an extremely variable production rate, with high material waste. The problems faced by the company can be attributed to two main aspects. The first is the separation between design phase and production phase (i.e. the separation between product design and process design). When the design of the dies is approved by the responsible person, his role is over, and the designer does not receive any feedback on possible problems caused by the dies during production. Furthermore, the shop floor operators do not receive the results of the simulation that should theoretically indicate which zones of the piece are the most critical.

This lack of bidirectional information flow impedes the process of continuous learning for both parties: the designer who, without receiving feedback on his work, cannot modify his work methodology or make the simulation more reliable. For the operators, the lack of information about the results of the simulation makes their job harder, since they do not know what the outcome of their work should be. The second aspect is the absence of data collection during production. The only relevant data is the quantity of pieces produced at the end of the shift. No data is collected about the exact quantity of defectives or of material waste. No information is stored, about the main problems that the operators had to face during the shift: such information, if available, is found only in the minds of experienced operators, this lack of a structured knowledge management system results in production mishaps and delays when such key employees are absent and creates a dependency on specific personnel which is not efficient for a production plant.

4.2 "As is" situation

The industrial process for the realization of a prototype bodywork component starts with the delivery, by the costumer company, of the CAD model of the requested piece. The CAD model is received by the technical office that defines the production process, the design of the dies and the material to be used. After that, the model is sent to the CAD office in order to be validated via simulations. If the simulation does not highlight critical issues, the models of the dies are approved and sent to the CAM department, where the toolpaths for the milling machines are studied and defined in order to start the dies construction.

Once the dies have been constructed and ready the metal sheets used to make the body part are sent to the Laser office where the metal sheet is trimmed using a two-dimensional laser to obtain the appropriate shape outline. After the sheets have been cut, they are transported to the presses area where they undergo the first press operation (also known as drawing). The semi-finished items are then returned to the laser section where 3D lasers cut the metal sheet according to specific laser paths obtaining the final measures of the piece and creating slots and holes. Depending on the complexity of the piece a redrawing operation may be required where the piece is pressed again and trimmed by the 3D laser to obtain a component that perfectly satisfies the requested dimensional and geometric tolerances. All the information generated during the process is only written in paper, thus over time, inevitably lost.

4.3 "To be" situation

In the "to be" situation, essentially the process remains the same but with a different management of the information. There are a dynamic and a historical management of the data.

The first one improves the circulation of information between different departments of the company. In the OKP, in fact, an efficient communication between offices with different manages is necessary to respond to the continuous process changes made during the production itself. The MES is the main proponent of this management. It stores process information and makes it dynamically available to the various operators, according to the task and responsibilities that each of them possesses. As explained above, the MES extracts the product and production indications from the central DB previously filled by the PLM.

The second management of data consists in the digitization of the company know-how. In this way, the technicians responsible for defining the product life-cycle insert the information into the PLM. It automatically makes this information available to the MES in the central DB. In this case Aras PLM platform was chosen to develop the PLM. Aras solution meets all the needs for the management of the OKP, including the possibility of adding a report to a shop order that allows analysts to know that products have encountered problems or changes, and to get an initial description of these. At this point to deepen the analysis of the problems, there is a link to the central DB which will provide more details of what happened: what activities were repeated or added, the results of the check start and check end and all that is related to that shop order. In this way, the company has a detailed history of production and above all of what has not worked, to understand what changes to make for a current shop order and to be more accurate about future ones.

5 Conclusion and future works

This paper aims to present a methodology to build a framework to integrate design and production data. Besides the storage of product and process knowledge into a structured archive, the proposed framework is a tool which allows the data retrieval of previous products and its re-usage to define variants and changes to them. Changes in the production operations or parameters can be done more easily starting from the knowledge of a previous product instead of redoing from scratch.

Some limitations of the work are that it is focused on the knowledge related to the production phase of products, without considering other important aspects related to customers or maintenance. Furthermore, the model also lacks additional information, such as the cost, time and quality associated to the operation, which can be inserted to allow more complex reasoning.

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