Management and Production Engineering Review
Volume 11 • Number 2 • June 2020 • pp. 62–73
DOI: 10.24425/mper.2020.133729

AN OPEN SOURCE FRAMEWORK FOR THE STORAGE AND REUSE OF INDUSTRIAL KNOWLEDGE THROUGH THE INTEGRATION OF PLM AND MES

Giulia Bruno, Alberto Faveto, Emiliano Traini

Department of Management and Production Engineering, Politecnico di Torino, Italy

Corresponding author:
Giulia Bruno
Politecnico di Torino
Department of Management and Production Engineering
Corso Duca degli Abruzzi 24, 10129 Torino, Italy
phone: +39 0110907580
e-mail: giulia.bruno@polito.it

Received: 16 March 2020
Accepted: 6 June 2020

Abstract
Today, the changes in market requirements and the technological advancements are influencing the product development process. Customers demand a product of high quality and fast delivery at a low price, while simultaneously expecting that the product meet their individual needs and requirements. For companies characterized by a highly customized production, it is essential to reduce the trial-and-errors cycles to design new products and process. 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 to face new problems. In order to develop unique product and complex processes in short time, it is mandatory to reuse the acquired information in the most efficient way. Several commercial software applications are already available for product lifecycle management (PLM) and manufacturing execution system (MES). However, these two applications are scarcely integrated, thus preventing an efficient and pervasive collection of data and the consequent creation of useful information. The aim of this paper is to develop a framework able to structure and relate information from design and execution of processes, especially the ones related to anomalies and critical situations occurring at the shop floor, in order to reduce the time for finalizing a new product. The framework has been developed by exploiting open source systems, such as ARAS PLM and PostgreSQL. A case study has been developed for a car prototyping company to illustrate the potentiality of the proposed solution.

Keywords
Industry 4.0, PLM, MES, knowledge management, ARAS, PostgreSQL.

Introduction

In the era of Industry 4.0, the reality from H. Ford's view is changed completely. In 1909, a few decades after the Second Industrial Revolution, as stated in his biography, H. Ford observed: *"any customer can have a car painted any colour that he wants so long as it is black"*. In this short slogan lies the soul of mass production: maximum efficiency achieved with maximum standardization in order to reach the widest number of customers.

The production of the 21st century, on the other hand, focuses on the personal needs of the consumer, the companies innovate and introduce new products on the market led by the consumers, to anticipate their needs, lean development approaches are needed in order 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 for each customer. In this scenario the production line must become as flexible as possible, since an on-demand production is needed. In order to allow fast prototyping of products, modular architectures are used, since products have their foundations in a platform, common for a product family [1]. Product features are tested using finite element simulation (FEM), and designers could create virtual products and testing their ideas in a very fast and inexpensive way. Montecarlo Simulation and Discrete Event Simulation are also used to manage product portfolios supporting decision processes.

With new technologies of this revolution, meeting the demands of customers and innovating continuously are not only possible, but they are an essential requirement for any company, in particular small and medium sized, that wants to compete in the market [1–4].

In this context, the concept of reconfigurable manufacturing systems (RMS) has a great importance [5]. RMS goes beyond flexibility, and it allows to achieve responsiveness to market changes. It manages to change quickly both from the point of view of tools and machinery and form the point of view of information systems, in this way the production system is adapted to the requirements of the market. The RMS is designed using principles of modularity and integrability both software and hardware side in order to be scalable and convertible but also to handle real time quality control and product customization [6, 7].

The information technologies, including the sensors installed along the production line, make machines, operators and all the resources able to interact among each other and to collect data about their status and all the issues that happen during the production. The ability to store, integrate and use these data is an important feature to accomplish for a company of the fourth industrial revolution.

Industrial data integration can be seen from three different point of view: horizontal integration, vertical integration, and end-to-end integration [8]. Horizontal integration allows the flow of data through various business functions. Production data could be integrated with the company's resource data to make the process more efficient. Vertical integration requires the involvement of players and partners who interact with the company. Integrating the systems of various companies along the value chain is essential to allow a coordinated and efficient work. Finally, the end-to-end integration operates throughout the life cycle of the product and makes it possible to achieve excellent results that go further the production line and the supply chan.

To achieve system integration, it is necessary that IT platforms implemented in a company cover the process of product design, to allow innovation towards customer needs, and the production activity itself, to minimize costs and lead times. PLM systems are shared platform at disposal of designers to allow the interaction and coordination among people, thus enabling the knowledge exchange, transfer and reuse. MES system control and manage the daily production, providing real-time feedbacks of the whole process, right through to the completion of the order. MES, using data obtained by machines, operators and sensors, is able to create a digital copy in real time of the system. It is therefore possible to control the progression of tasks and compare it with the production planning.

Through the integration between PLM and MES, designers could observe what is happening in production, receive feedback and check where anomalies have occurred. This data can be reused at the design level so that this error does not occur again in the future. This data could be of great importance at the design stage of a new product, especially for OKP companies since, to design a new process, they usually need several trial-and-errors cycles before find the final one. For such companies, the knowledge of the trial-and-errors cycles that contribute to develop past products and processes, without the presence of a formalized and structured system, remains in the minds of the people, or, at best, transferred verbally, and then, over time, inevitably lost [9, 10]. Similarly, it is also difficult for a production manager to find information related to the checks to perform before and after the execution of an operation on a machine, and for an operator to report in a structured way the occurrence of problems and anomalies during the production.

Based on such needs, the aim of the paper is to propose a framework to integrate data coming from PLM and MES to reduce the number of trial-and-errors cycles to find the final production process of a new product. A specific attention will be given to the collection of data regarding anomalies occurring at the shop floor.

The rest of the paper is organized as follows. The Related works section summarizes the relevant literature available on the topic. The Method section describes the proposed framework, including the data model to integrate data coming from the PLM and MES systems. The Use case section presents the application of the framework in an Italian company producing car prototypes. Finally, the last section draws conclusions and states future work perspectives.

Related works

Previous works addressed the issue of structuring and formalising product-related knowledge [11–15], while several international research projects addressed the development of industrial knowledge sharing systems (e.g., amePLM [16], ICP4Life [17], Know4car [18], Manutelligence [19]). The benefits obtained by the symbiosis between design and manufacturing is highlighted in several papers [20, 21]. However, the practical use of tools for supporting sector knowledge management is still very low, and an integrated knowledge is still too far for many manufacturing companies. The GeCo Observatory (http://www.homeappliancesworld.com/2015/06/01/italian-manufacturing-innovation-is-possible) found, on a sample of more than 100 Italian manufacturing companies, that the most used methods to explicit knowledge remain the traditional verbal or written communication, while the use of more structured software systems is severely limited.

This lack in research on the integration between PLM and MES is also revealed by the recent increase of published papers on the topic. Figure 1 shows the result of a search in the Scopus database of papers about PLM-MES integration.

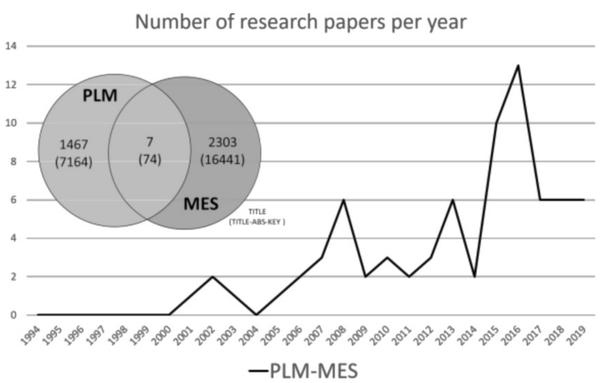

Fig. 1. Results of Scopus search: papers published on PLM-MES integration. Numbers in Venn diagram between brackets, as the trend graph, refer to a research carried out on title, abstract and keywords. Free numbers, instead, refer to a research only on the title.

The Venn diagram in Fig. 1 compares the number of papers addressing separately PLM and MES, and the number of papers addressing both. This last number is significantly low than the others: only 7 papers contain both PLM and MES words in the title (74 papers if the search is extended also to abstract and keywords). However, the interest for this topic is quickly growing, as shown by the line chart, which represent the distribution of the 74 papers among the years.

The oldest work between this seven [22] proves, also using simulation technique, that the business strategy of a company needs the information contained in a PLM-ERP-MES integrated system that has to include an informatic module to automatize this integration. This publication discusses methodologies and advantages of this integration. The most cited one [23] is a PLM-MES integration proposal that aims to overcome the problem of data heterogeneity by proposing a mediation system that takes into account also the ERP. In this work it is cited the ISA95-IEC62264 standard [24] of MES functions and MES-PLM data transferring, for which the author gives a classification in CAD model, plans, BOM, manufacturing process, work instructions and machine setup for the flow from PLM to MES, while from the MES is considered to receive reports about production problems. Furthermore, this paper introduced a mediation system based on ontologies to manage this integration. Another interesting article is a PLM-MES integration proposal for a collaborative design of a spur gear production [25]: an appealing case-study because the accuracy required for this product is very high with a consequential very high unitary cost. The same authors elaborated a PLM-MES integration applied on the automotive manufacturing [26], by focusing on how the real-time monitoring activity of the MES can improve the PLM. A survey submitted to a set of Italian companies to measure their digital maturity and their proneness in implementing further PLM and MES solutions and their integration was also presented [27]. The main results of this work are the awareness that none of the companies own both a PLM and a MES and that the half of them stated that a PLM-MES collaboration could be an advantage for their business. Another research activity in the intersection is an extension of the ISA95 standard [24] for manufacturing PLM integration with a data flow between ERP and MES [28]. The last article of the list describes the integration between product management and system monitoring by using ontologies [29]. The authors considered the ontology the most suitable tool to design the PLM-MES-ERP integration according a metric taken from the literature [30].

Our work addresses two lacks identified in the literature research. The first one is lack of an analysis related to highly customized and/or prototypal production, where the presence of many alternative routings and operations makes very difficult to manage all the manufacturing variables together, in an efficient way, without increasing wastes of time and costs. The second one is that there is not an explicit formalization of the structure designed for collecting data related to failures and anomalies occurring at the shop floor, and make them available for designers that can effortlessly learn past problems about designing new products and processes. The main technical innovations proposed by our work are the following: (i) an open source architecture for PLM-MES integration trough a central Knowledge Based System (KBS), (ii) an advanced data model to relate data from PLM and MES, and (iii) the allowance of storing data related to anomalies occurred during the production.

In this work, the efforts are focused on the PLM and MES integration. The ERP was not considered, but we plan to integrate it in a following step. This choice was made because, after having analysed the literature, the integration between PLM and MES is the least investigated and standardized. However, the information structure presented in this work was designed to easily accommodate the information from the ERP adding and connecting new entities in the data model.

Method

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. 2, this framework is based on a central database, called Knowledge based System (KBS), containing the subset of data relevant for both PLM and MES and acting as a bridge between the them.

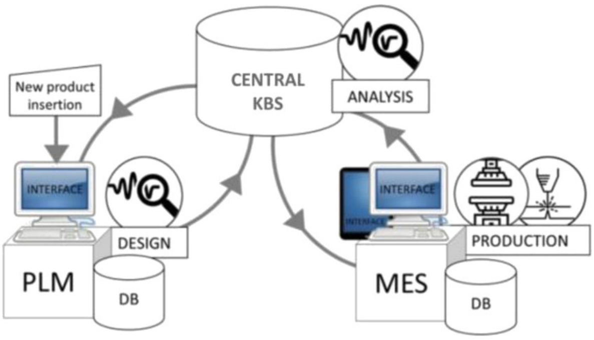

Fig. 2. Conceptual model of the integrated system.

Knowledge based system

The method we propose is to develop a central Knowledge based System (KBS), acting as integrator between PLM and MES. The proposed system 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 users, 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.

The information flows among PLM, KBS and MES is represented in Fig. 3. When a customer makes an order, it means that the company must define the sequence of production activities to obtain the required product. If the historical data regarding previous products are stored in the KBS, 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 similarity search is done through the similarity metric defined in [31].

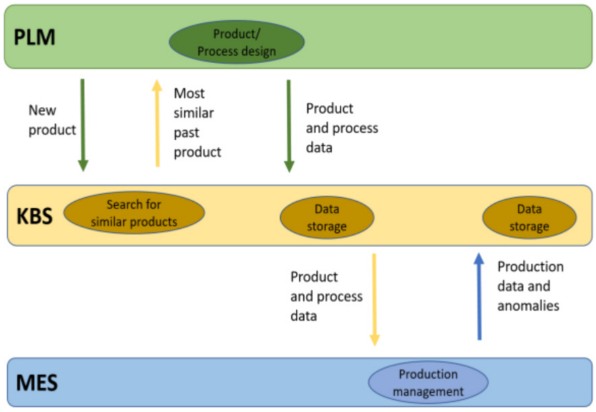

Fig. 3. Information flows among PLM, KBS and MES.

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 KBS 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 KBS 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.

KBS data model

Figure 4 shows the structure of the KBS through an entity-relationship model, inspired by the Core Product Model (CPM) [32], the Toronto Virtual Enterprise Ontology Model (TOVE) [33], the ADAptive holonic Control Architecture for distributed manufacturing systems model (ADACOR) [34] and the Almost Perfect Approach to Scheduling (TAPAS) [35]. Entities in green are the ones coming from PLM, whicle entities in blue comes from MES. There is one entity in yellow (ProjectInformation), which represent data usually coming from ERP, since it contains data related to customers and orders. Since in this work we do not address the ERP integration, we assume this entity also coming from PLM.

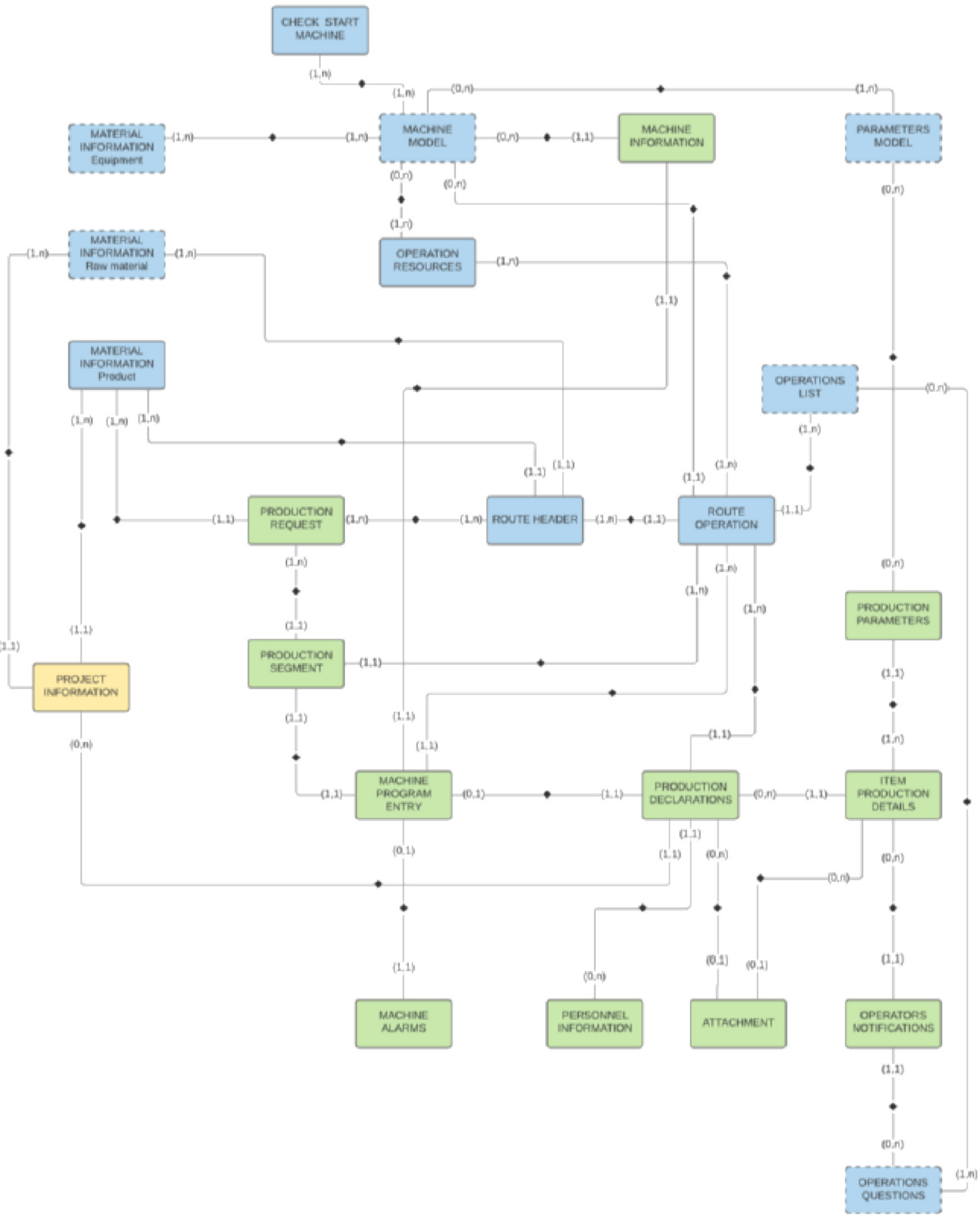

Fig. 4. UML class diagram of the data model of the KBS

The production of a product starts with the receive an order from a customer. ProjectInformation collects all this information and is directly linked to the product, represented by the entity MaterialInformation-Product. An order contains information about a single product, while a product can be made up of more than one order.

A product is linked to the production cycle (RouteHeader entity) with a relation (1,n), because a product can be produced through one or more manufacturing cycles. On the contrary, a production cycle is specific for a single product.

RouteOperation, in turn, is connected to the PLM system entities: OperationsList, MachineModel and OperationResources; and with the entities of the MES that control the productive cycle. The entity OperationsList is an operations record, where an operation can be linked to one or more sequences of operations. On the contrary, in a sequence of operations, the same operation cannot be repeated.

MachineModel is the entity that collects the main data about the equipment and machinery. The relation of RouteOperation with this entity is (1,1) since an operation can only be executed by a machine; while, a machine model may or may not be used in one or several operations. Likewise, MachineModel and MachineInformation are two highly related entities.

The relation of the machinery (MachineInformation) with the models of the machines (MachineModel) is (1,1) since every real machine will have an associated model. However, a model will not necessarily be related to a physical machine, so its relation will be (0,n). The main difference between these two entities, apparently so similar, is that the first, MachineModel contains the information required by the PLM system, while MachineInformation is the responsibility of the MES.

On the other hand, the MES entities that define the production cycle, ProductionRequest and ProductionSegment, are related to each other. A product or production cycle (RouteHeader) can be divided into one or several secondary orders (ProductionRequest) obtaining a relation of (1,n). The orders created by this entity will be planned by ProductionSegment. The same order can be formed by more than one operation to be planned, therefore the realization between ProductionRequest and ProductionSegment is (1,n). Otherwise, a planned operation is associated with a single order.

The main entity of the MES is ProductionDeclarations because it contains information about the progress of the production. This entity evaluates the data entries to the machinery one by one (MachineProgramEntry). Each one of this data entries can have associated at most one declaration (ProductionDeclarations) and one alarm (MachineAlarms).

ItemProductionDetails provides information about the production status of a set of products. This entity evaluates the statements saved in ProductionDeclarations every certain period, obtaining as a result the status of the articles declared: good, scrap or to be evaluated.

The two previous entities, ProductionDeclarations and ItemProductionDetails are connected to the entity Attachment with a relation (0,n) since operators can attach as many documents as they need for each evaluation performed. However, a document is unique to each statement, therefore, the relationship of the entity attachment with the other entities is (0,1).

Finally, the entities ProductionParameters and OperatorsNotifications delve into the progress of production, obtaining results with which the company can improve the production process and the PLM system implemented. For each final product, one or several parameters of the machinery have been imposed and will be stored in ProductionParameters, therefore, the relation of ItemProductionDetails and ProductionParameters is (1,n). In the same way, answers to a questionnaire (OperatorsNotifications) are collected for each evaluation of the production process, getting a relation (0,n).

By analyzing the data model, the data flow from PLM to MES results clear. Such flow can be divided in two sub-flows: an occasional and smaller flow and a continuous and larger one. The first flow refers to all information that is entered or updated in the PLM at irregular time intervals of the order of magnitude of the year or more. For example, if a new machine of the same type as those already present in the company was purchased, there would be nothing to update in the PLM and therefore no information that the PLM must make available to the MES. On the contrary, if the company decides to buy a new machine with some different characteristics from those already present (for example a press with a maximum power higher than the other machines) or if there is a need for new machinery to insert a new type of manufacturing activity in the plant, in the PLM it is necessary to update the entities related to machineries, activities and their characteristics. The continuous flow, instead, is the one related to the insertion of new production cycles. This flow is continuous because each new customer order corresponds to many new production cycles to be communicated to the MES as many prototype variants plus the final variant. Even if the purpose of this PLM-MES integration is to minimize this number of variants, the more orders are processed within the same production plant and the more unique they are, the more this flow from PLM to MES has to be considered continuous.

The data flow from the MES to the PLM contains all production monitoring data describing the success or otherwise of a variant defined in the PLM. Unlike the flow described above, all the data concerning a variant are interrogated all at once and by a human operator who oversees defining a new variant or validating the last one used in production. For this reason, it is necessary to compress this amount of data to minimize the cognitive load provided to the designer while providing him all the information he needs. Our framework allows the PLM to give to the designer only the general percentage of success of the variant with some adding information about a single activity which are provided to the designer in case he wants to deepen the analysis of a particular phase of work.

Framework implementation

The open source PLM software ARAS (www.aras.com) was exploited to digitalise and store the information related to the resources of the company and the production process of each product. Through an automatic procedure, the information related to the entities together with their relationships, are periodically extracted from the PLM system and inserted in the KBS, to make them available to the MES and ERP systems.

The KBS was implemented as a PostgreSQL database (www.postgresql.org), with the set of tables needed to represent the UML diagram of Fig. 4.

The commercial MES platform JPiano (https://www.aecsoluzioni.it/wp/en/jpiano-panoramica/jpiano-prodotti) was used to implement the MES system. Also, in this case, an automatic procedure allows the synchronization between MES and KBS.

Several graphic user interfaces were developed in ARAS in order to allow the users to insert the data corresponding to the structure represented in Fig. 1. As an example, Fig. 5 presents the user interface to insert the information related the Type of machine entity. Similar interfaces were created for Activities, Product, Check start and Check end. For each activity, the corresponding machine, check starts and check ends can be added by selecting them from the drop down menus created.

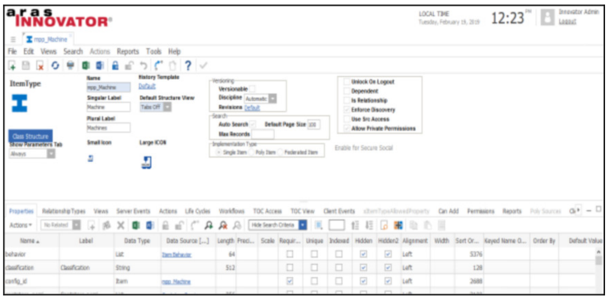

Fig. 5. Screenshot of the Aras PLM implementation of the MachineModel entity.

In ARAS, it is also possible to define a production process (i.e., the relationship between Activities and Product) by using the Process Plan module shown in Fig. 6. In order to populate a process plan, a designer/planner can easily add the activities by selecting the activities from 'list of Activities' created before.

The execution of each activity is then recorded by the MES, which insert the actual start and end date for each activity, so that a comparison between the planned dates and the actual ones can be performed.

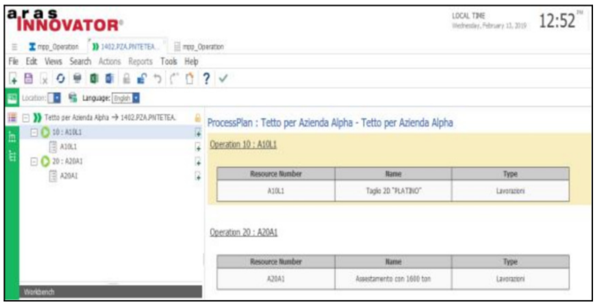

Fig. 6. Screenshot of the Aras PLM implementation of the ProcessPlan.

To replicate data from ARAS to the KBS, a merge replication [36] was implemented. Merge replication starts with a snapshot of the source database objects and data. Subsequent data changes and schema modifications made at the source database and at the destination database are tracked with triggers. The source synchronizes with the destination when connected to the network and exchanges all rows that have changed since the last time synchronization occurred. In this way, the content of the PLM and the KBS are continuously updated and synchronized.

ARAS also allows to attach reports to various objects. In the current framework, this functionality was used to summarize all the information coming from the MES about a production cycle. In this report, thanks the ItemProductionDetails table, data in ProductionParameters, ProductionDeclaration and OperatorsNotifications tables are aggregated and summarized to provide a general overview of process performance. At this point the operator can decide to access the window of a single activity of that production cycle to see in detail the different production parameters used in the line, any machine errors that have occurred, possible attachments (video or photo) entered by the operator on board the machine, the general information about the operator who has carried out this work and the answers that he has provided to the various checks proposed by the MES. Through these reports, therefore, the operator can make a conscious choice in order to decide whether the current variant of the production cycle is valid or which is the best further candidate to be valid.

Use case

The described framework was applied in an Italian company, which produces components for car prototypes. The main issue the company is trying to solve is that the information generated during the production process is not digitalized and it only persists in operators' memories.

Company description

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 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.

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.

Some of the problems faced by the company can be attributed to the separation between the design phase and the production phase. 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.

Another cause of problems 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.

Production process

The production process of the company is reported in Fig. 7 as an IDEF0 diagram. After the acceptance of the order of a component, the process starts 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.

Once the dies have been constructed, 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.

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.

Framework application

The developed framework was firstly initialized to address the company needs, and then used to store data regarding production cycles.

As previously discussed, one of the main potentialities of the framework is the capability of recording information about the criticalities occurring in the production activities. The entities used to store this information are the CheckStart and the OperationQuestions. Examples of CheckStart created for the use case are reported in Table 1. CheckStart represents the set of controls that the operators must do before starting the execution of an activity on a machine.

This list is set during the initialization phase in the PLM, and then automatically transmitted to the KBS, so that they are accessible by the MES. In this way, the MES can show the list to the operators when they start the execution of an activity. The operators can then notify if each control has been satisfied or not. This result is inserted in the MES, and thus automatically transmitted to the KBS, where they are at disposal of the designers.

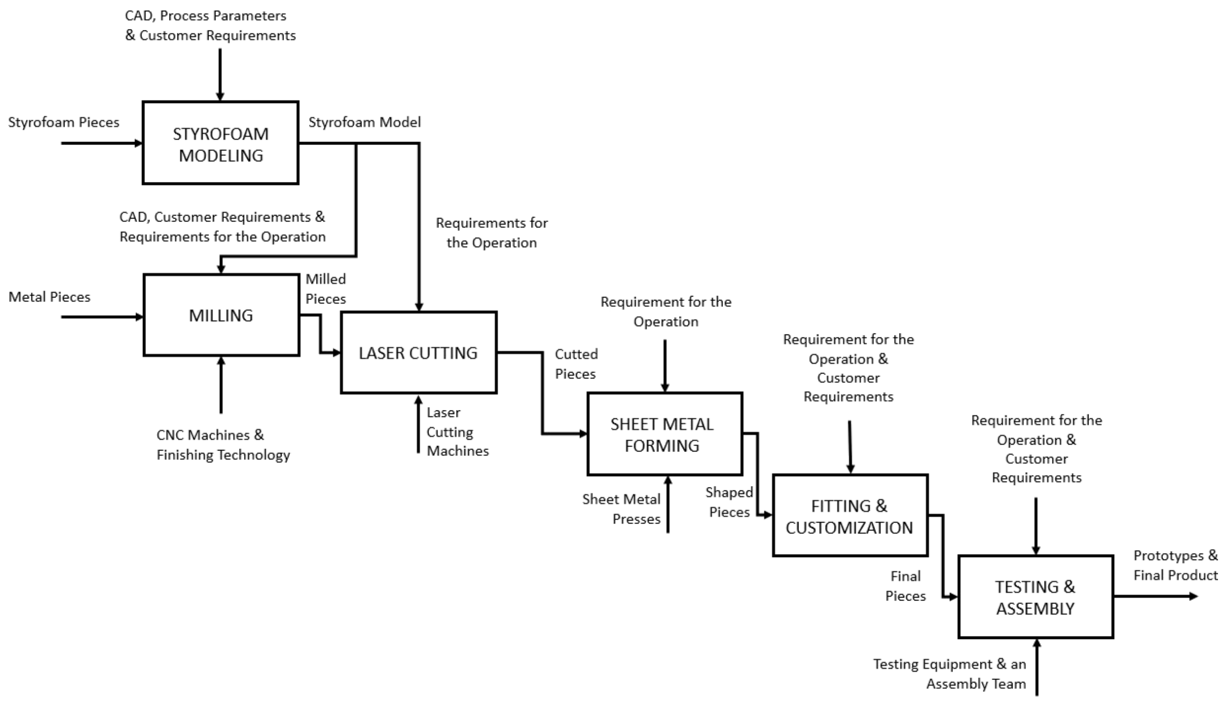

Fig. 7. IDEF0 diagram of the production process taken as use case.

Table 1
Examples of Check starts related to the Activities of the use case.

Activity	Check start
3D Laser welding	Presence of a dedicated head
	Presence of pincers for fixing the piece on the stand
	Set of self-learning programming mode of welding path
Press punching	Presence of the mold
	Presence of mold mounting brackets
	Presence of supports for handling sheet metal
Deep drawing	Presence of the mold
	Presence of mold mounting brackets
	Presence of supports for handling sheet metal
	Presence of nylon sheets
	Presence of oil
3D Laser finishing	Routes loaded with USB device
	Presence of U-bolts for positioning the sheet
	Presence of pincers for fixing the piece on the U-bolt
	Presence of reference holes
Manual molding	Presence of molds from the press department
	Presence of gauges and hammers

Similarly, also for the OperationQuestion, for each activity it is possible to specify which are the controls to do at the end of the operation. In the current version of the framework, the OperationQuestion is a free text where the operator could write if something went wrong during the operation. A more complex data collection, including the possibility of uploading a photo or a video of the anomalous results, is under development.

Benefits of digitalization and knowledge reuse

Through the exploitment of the proposed framework, it is possible to perform a dynamic and a historical management of data.

The first one improves the circulation of information between different departments of the company. In 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, since it stores process information and makes it dynamically available to the various operators, according to the task and responsibilities that each of them possesses.

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 KBS.

The Aras PLM 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, a link to the KBS will provide more details of what happened: what activities were repeated or added, the results of the check start and operation notification 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.

The choice of metrics and performance indicators is crucial to assess the success and the effectiveness of the integration process. There are some examples in the literature of metrics developed to analyse the effectiveness of a PLM for case studies [37] and works that seek to give a broad view of the problem by proposing various KPIs [38]. General indicators relating exclusively to PLM are the following [39]:

- number of new products per year,
- number of projects completed per year,
- number of defects per product family,
- return on innovation,
- time to market,
- level of part reuse,
- cost of rework,
- new product revenue.

Maintaining consistency between the defined indicators and the medium-long term strategic objectives of the company is essential. For this reason, in a following phase of the project, it will be necessary to discuss with the project stakeholders to define the main metrics taking into account the benefits expected from the integration between PLM and MES. Once the system will be running, it will be possible to evaluate the expected positive impact.

Conclusions

The objective of this paper is to propose a framework to integrate design and production data, since, especially in small manufacturing companies, they often remain separated and stored in two different systems: PLM and MES. The framework is based on a knowledge-based system, which collects and integrates two subsets of data, one from PLM and one from MES, making such data accessible by both systems. In this way, anomalies that occur at the shop floor during the production can be easily found by designers, who can use them to improve the process already defined or to define the production cycle for new products that have similarities with old ones. Furthermore, the proposed framework allows the data retrieval of previous products and its re-usage to define variants and changes to them.

Future works will consider on the one hand data analysis techniques for using the stored data in the KBS, and on the other hand a more comprehensive integration also considering the enterprise resource planning (ERP) system. The flow exchange between the three system will allows the management to have a better overview of the enterprise and will support the tactical-strategic decision making. Integration is not easy to achieve; it is necessary to understand what the three systems need to know about the other two. The information must be aggregated and easily accessible. We believe it is possible to introduce a new integration paradigm, the *outright enterprise system integration* (OESI), which represents a system integration that grows vertically among the company functions and along the product's life cycle in order to guarantee its management.

Furthermore, it is necessary the definition of a new metric, that maybe considers also quantitative key performance indicators, to evaluate the efficacy of the proposed framework in terms of reduction of process design time and process quality (like the number of refuses).

References

[1] Muffatto M., Roveda M., *Developing product platforms: analysis of the development process*, Technovation, 20, 11, 617–630, 2000.

[2] Wortmann J.C., Muntslag D.R., Timmermans P.J.M., *Customer-driven manufacturing*, Chapman & Hall, London, UK, 1997.

[3] Tu Y., *Production planning and control in a virtual one-of-a-kind production company*, Computers in Industry, 34, 3, 271–283, 1997.

[4] Dean P.R., Tu Y.L., Xue D., *An information system for one-of-a-kind production*, International Journal of Production Research, 47, 4, 1071–1087, 2009.

[5] Koren Y., Gu X., Guo W., *Reconfigurable manufacturing systems: Principles, design, and future trends*, Frontiers of Mechanical Engineering, 13, 121–138, 2018.

[6] Gola A., *Reliability analysis of reconfigurable manufacturing system structures using computer simulation methods*, Maintenance and Reliability, 21, 90–102, 2019.

[7] Wang G.X., Huang S.H., Yan Y., Du J.J., *Reconfiguration schemes evaluation based on preference ranking of key characteristics of reconfigurable manufacturing systems*, The International Journal of Ad-

vanced Manufacturing Technology, 89, 2231–2249, 2017.

[8] Vaida S., Ambad P., Bhosle S., *Industry 4.0 – A Glimpse*, Procedia Manufacturing, 20, 233–238, 2018.

[9] Bruno G., Antonelli D., Korf R., Zimmermann N., *Exploitation of a semantic platform to store and reuse PLM knowledge*, IFIP Advances in Information and Communication Technology, 438, pp. 59-66, 2014.

[10] Bruno G., Taurino T., Villa A., *An approach to support SMEs in manufacturing knowledge organization*, Journal of Intelligent Manufacturing, 29, 6, 1379–1392, 2018.

[11] Chungoora N., Young R., Gunendran G., Palmer C., Usman Z., Anjum N., Cutting-Decelle A., Harding J., Case K., *A model-driven ontology approach for manufacturing interoperability and knowledge sharing*, Computers in Industry, 64, 4, 392–401, 2013.

[12] David M., Rowe F., *What does PLMS (product lifecycle management systems) manage: Data or documents? Complementarity and contingency for SMEs*, Computers in Industry, 2015.

[13] Efthymiou K., Sipsas K., Mourtzis D., Chryssolouris G., *On knowledge reuse for manu-facturing systems design and planning: A semantic technology approach*, CIRP Journal of Manufacturing Science and Technology, 8, 1–11, 2015.

[14] Igba J., Alemzadeh K., Gibbons P.M., Henningsen K., *A framework for optimizing product performance through feedback and reuse of in-service experience*, Robotics and Computer-Integrated Manufacturing, 2015.

[15] Bruno G., Traini E., Lombardi F., *A knowledge-based system for collecting and integrating production information*, 20th IFIP Working Conference on Virtual Enterprises, PRO-VE 2019, Turin, Italy, 2019.

[16] Bruno G., Korf R., Lentes J., Zimmermann N., *Efficient management of product lifecycle information through a semantic platform*, International Journal of Product Lifecycle Management, 9, 1, 45–64, 2016.

[17] Elgamma A., Papazoglou M., Krämer B., Constantinescu C., *Design for customization: a new paradigm for product-service system development*, Procedia CIRP, 64, 345–350, 2017.

[18] Ebrahimi A.H., Johansson P.E.C., Bengtsson K., Åkesson K., *Managing product and production variety – a language workbench approach*, Procedia CIRP, 17, 338–344, 2014.

[19] Petrucciani M., Marangi L., Agosta M., Stevanella M., *A Platform for Product-Service Design and Manufacturing Intelligence*, [in:] Cattaneo L., Terzi S. [Eds], Models, Methods and Tools for Product Service Design. SpringerBriefs in Applied Sciences and Technology, Springer, 2019.

[20] Ming X.G., Yan J.Q., Lu W.F. et al., *Mass production of tooling product families via modular feature-based design to manufacturing collaboration in PLM*, J Intell Manuf, 18: 185, 2007.

[21] Pouchard L., Ivezic N., Schlenoff C., *Ontology engineering for distributed collaboration in manufacturing*, Proceedings of the AIS2000 conference, 2000.

[22] Joshi S., *ERP-MES-PLM integration-making information technology strategy compliment business strategy*, IADIS International Conference on Information System 2009, Barcelona, Spain, 2009.

[23] Ben Khedher A., Henry S., Bouras A., *Integration between MES and Product Lifecycle Management*, IEEE International Conference on Emerging Technologies and Factory Automation (ETFA'11), Toulouse, France, 2011.

[24] ISA-95, Enterprise Control System Integration, http://www.isa-95.com/, 2000.

[25] D'Antonio G., Sauza B.J., Chiabert P., Lombardi F., *PLM-MES integration to support collaborative design*, International Conference on Engineering Design, Milan, Italy, 2015.

[26] D'antonio G., Bedolla J., Genta G., Ruffa S., Barbato G., Chiabert P., Pasquettaz G., *PLM-MES integration: a case study in automotive manufacturing*, 12th IFIP International Conference on Product Lifecyle Management (PLM), Doha, Qatar, 2015.

[27] D'Antonio G., Macheda L., Bedolla J.S., Chiabert P., *PLM-MES Integration to Support Industry 4.0*, Springer International Publishing, 2017.

[28] Moones E., Kermad L., Vosgien T., El Mouloudi D., *PLM Standards Modelling for Enterprise interoperability: A Manufacturing Case Stady for ERP and MES Systems Integration Base on ISA-19*, Enterprise Interoperability 6th International IFIP Working Conference, IWEI 2015, Nîmes, France, Proceedings, May 28–29, 2015.

[29] Asmae A., Southail S., El Moukhtar Z., Hussein B., *Using ontologies for the integration of information systems dedicated to product (CFAO, PLM...) and those of systems monitoring (ERP, MES..)*, IEEE, 2006.

[30] Morel G., *Contribution de l'automatisation et à l'ingénierie des systèmes intégrés de production*, Habilitation à Diriger des Recherches de l'Université Henri Poincaré, 28, 1992.

[31] Bruno G., *Measuring product semantic similarity by exploiting a manufacturing process ontology*, International Conference on Industrial Engineering and Systems Management (IESM'15), 1251–1257, 2015.

[32] Fenves S.J., Foufou S., Bock C.E., Bouillon N., Sriram R.D., *CPM2: A revised core product model for representing design information*, Internal report nistir no. 7185, National Institute od Standards and Technology (NIST), 2004.

[33] Jin J., Fox M.S., Bilgic T., *A requirement ontology for engineering design*, Concurrent Engineering: Research and Applications, 4, 4, 279–291, 1996.

[34] Borgo S., Leitão P., *Foundations for a core ontology of manufacturing*, IntegratedSeries in Information Systems, 14, 1, 751–775, 2007.

[35] Moutarlier P., Geneste L., Grabot B., *Tapas: a modular framework to support reuse in scheduling software development*, Production Planning and Control, 11, 7, 648–659, 2000.

[36] Hammond B., *Merge replication in Microsoft's SQL server 7.0*, Proceedings of the 1999 ACM SIGMOD International Conference on Management of Data, 527, 1999.

[37] Alemanni M., Grimaldi A., Tornincasa S., Vezzetti E., *Key performance indicators for PLM benefits evaluation: The AlcatelAlenia Space case study*, Computer in Industry, 59, 833–841, 2008.

[38] Tomovic C.L., Ncube L.B., Walton A., Grieves M., *Development of product lifecycle management metrics: measuring the impact of PLM*, International Journal of Manufacturing Technology and Management, 19, 3–4, 167–179 2010.

[39] Stark J., *Product Lifecycle Management*, Vol. 1, 21st Century Paradigm for Product Realisation, p. 9, 2015.