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Interaction between product life cycle management and production management: PLM-MES integration

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Abstract. This paper presents and discusses an analysis of the interoperability between engineering and manufacturing steps within the Product Life cycle Management (PLM) context. Initially, PLM was focused almost exclusively on the product design, but nowadays, it tends to cover all the stages of the product life cycle. In the same time, the industrialization and the manufacturing are not sufficiently integrated into the PLM solutions. Actually, there is much to be gained by extending the coverage of PLM to production stage in order to lead to interaction. The main purpose of this paper is to study how to realize interaction between PLM and production management that is ensured by the Manufacturing Execution System (MES).

Keywords. Product Lifecycle Management, Manufacturing Execution System, production management, interoperability.

1 Problem statement/Objective of the thesis

Our research is based on the extension of PLM in order to interact with production management. Our main objective is to contribute to the enhancement of PLM by integration with production management that executes all production operations in the shop floor.

Enterprises are facing global competition, more suppliers and more governmental regulations. Several challenges face these enterprises such as shorten innovation lead-times, reduction of time to market, reduction of costs, improving quality, mass customization demands, more complex products, geographically dispersed design teams, inventories subject to rapid depreciation and rapid fulfillment needs [1]. The

need of deploying PLM system becomes more and more important in order to tackle these challenges. The PLM system is a business strategic approach that applies a set of business solutions to support the collaborative creation, management, dissemination, and the use of product definition information across the extended enterprise from concept to end-of-life. It integrates people, processes, business systems and information together [2]. The expected improvements and benefits lead the change within the company's processes [3]. In the PLM context, product lifecycle consists of three main phases: beginning of life (BOL) including design, industrialization and production; middle of life (MOL) including logistics (distribution), use, service, and maintenance; and end of life (EOL) including reverse logistics, remanufacturing, recycle, and disposal [4]. PLM system tracks and manages information through the product lifecycle. The problem is that data contained in PLM applications has been lost during the product lifecycle [5]. For enterprises, looking at life cycle beyond design through production and maintenance, there are some limitations that must be addressed [5]. Indeed, PLM lacks of production information from the shop floor. PLM system needs to connect between the product design and analysis processes and the production and processes as well as Product Data Management (PDM), Enterprise Resource Planning (ERP), MES and others. The only benefit of PLM is to help these different systems integrated [6]. The integration between engineering as a high-level information and production management as a low-level information becomes important. Therefore, we should study the necessity and feasibility of integration between the two levels. When talking about interaction between PLM and production management, we need to deal with some particularities:

- First of all, it is important to study the necessity of integration.
- Secondly, there are vast amounts of intellectual property that are not effectively conveyed to the shop floor because conventional PLM tools are confined to engineering [5].
- Thirdly, the combination of design solutions with production automation systems can create seamless environment of two-way information flow [7]. Besides, it is important to identify and manage the information sharing between PLM and production management and the product data model that exists in those two systems.
- Finally, it's necessary to choose the best technique allowing an optimized integration

Regarding to these particularities, the lack of interoperability across PLM and production management is large. Therefore a study and development for the interoperability solution is needed.

2 Theoretical background and research gap

2.1 Product lifecycle management

PLM supports the modeling, capturing, manipulating, exchanging and using of information in all product life cycle and supports consequently information feedback to each product lifecycle phase [6]. During BOL, the information flow is quite complete because it is supported by several Information Systems (IS) like CAD (Computer Aided Design) and PDM [4]. However, these systems need information

from production, use and disposal to optimize and enhance design and industrialization. The feedbacks of product information from production, use, maintenance and recycle or disposal become important in order to allow each lifecycle stage to make decisions while having visibility to others lifecycle stages. All information flows in whole product lifecycle are illustrated in Fig. 1.

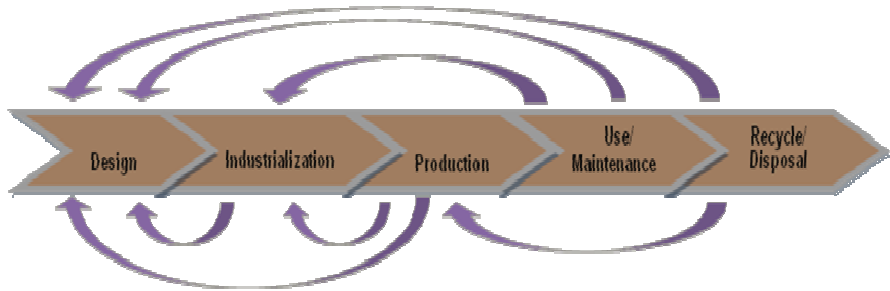


Fig. 1. Information flows in whole lifecycle

In the case of production stage, we have identified three information streams as input and three output flows that allow production to have all relevant data that affect a product throughout engineering and recycling. It also provides to design, industrialization, use and maintenance all production status encompassing product and process data. The input and output information of production stage are illustrated in Fig. 2.

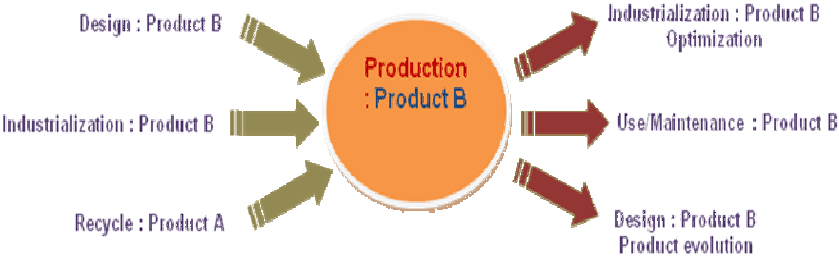


Fig. 2. Input and output information of production stage

In fact, with the increasingly demand of complex products and the advancements in Computer Aided Engineering (CAE) technology, more and more data are being generated. These data are related to the development of products such as CAD drawings, 3D models and the documentation related to the requirements management and development [8]. Since the last decade, design and industrialization consist of the most developed product life cycle stages. This development allows PLM to cover requirements analysis, design and industrialization almost total way, while

production, use, maintenance and recycle or disposal are poorly covered or not covered at all. PLM focuses mainly on virtual product and process development. The expansion into factory automation provides an opportunity to share and key product-related information from both the physical and virtual environments [7].

2.2 Production information systems

In order to control production operations in the enterprise, we distinguish three control levels. The first is the ERP that is the strategic level. The second level is the MES that executes production according to the ERP orders. Finally, the shop floor that is the physical world of production so the operative level. The information granularity and execution time is different between the different levels.

Today, the production information is provided to PLM from ERP. This is not sufficient and dynamic real-time shop floor data and also need to be gathered for consideration. Shop floor data is captured only by MES [9]. Currently, the ERP obtains this information from MES and provide it to PLM. The PLM obtains production information directly from ERP and MES via ERP. Indeed, the interaction between PLM and production IS cannot be totally established without directly interaction between PLM and MES because these systems are often used in the enterprise separately without data exchange which causes several problems. The requirement today is to interact PLM with MES in order to accelerate things like faster transfer of Engineering Bill of Material (EBOM), Manufacturing Bill Of Material (MBOM) and supporting manufacturing process of new product introduction.

MES aims at executing manufacturing plans; it builds a bridge between plan management level and bottom layer control. The MES is found on the intermediate level between Computer Numerically Controlled (CNC) machine tools and Programmable Logic Controllers (PLCs) on the lower level and the ERP system on the higher side [10]. The origins of the MES concept can be found in the data collection systems of the early 1980s. The various disciplines in corporate management such as production, personnel, and quality assurance were furnished with dedicated data collection systems [11]. It supplies operators, administrators with current state of the plan's execution, track as well as all resources (person, equipment, material, customer demand and so on). MES can carry through optimization management during the entire production process from the issue of production order to the completion of product. When real-time events occur in the factory, MES can promptly make response to them, restrict and process them with current accurate data [12]. MES has eleven functions defined by Manufacturing Execution System Association (MESA) [13]: Resource Allocation and Status, Operations/Detail Scheduling, Dispatching Production Units, Document Control, Data Collection/Acquisition, Labor Management, Quality Management, Process Management, Maintenance Management, Product Tracking & Genealogy and Performance Analysis. In practice, the MES exchange information with ERP in order to inform the latter about production information and status.

ERP system encompasses a wide range of software products supporting day-to-day business operations [14]. ERP serves many industries and numerous functional areas in an integrated fashion, attempting to automate operations from supply chain management, inventory control, manufacturing scheduling and production, sales support, customer relationship and so on [15]. The production planning modules has one from the highest degree of customization. ERP ensures production process optimization control, optimization operation and optimization management technology that takes production synthesis index as the target [12].

2.3 Current IS integrations

Several problems appear when IS share information within a complex global network whose topology could change rapidly. For instance, the ERP functioning leans on sufficient and up-to-date data about production status communication from MES system. Several researches and works for IS integration have conducted what leads to the development of standards. Considering the case of ERP and MES integration, the correct information must be exchanged without unnecessary time delays, all in order to optimize the production. The faster the business system can be aware of what happens in the plant, the faster it can react. The faster the ERP can communicate its directives to the control system, the faster the MES can respond [16]. ISA S95 is the international standard for integration of enterprise and control systems. It consists of models and terminology. These can be used to determine which information, has to be exchanged between systems for sales, finance and logistics and systems for production, maintenance and quality. This information is structured in UML models which are the basis for the development of standard interfaces between ERP and MES systems [17]. For instance, Business to Manufacturing Markup Language (B2MML) is a set of XML schemas, corresponding to the S95 object models, intended to be used for data exchange between ERP and MES [16].

To support the integration of information flow between PLM and ERP, several researchers have proposed different methodologies. PLM does not include many ERP properties. These systems supplement each other. However, the exact role of each system must always be decided on a case-by-case basis [18]. The integration met more than one data exchange problems between the two systems such as the difficulty to synchronize between the EBOM and MBOM. Integrating PLM and ERP with solving all these problems offers instant access to current product data and engineering.

The need that appears today is to integrate PLM and MES. There are few researches that treat this integration. Nevertheless, many manufacturers require this interaction between PLM and production management. Today, the current IS integrations are shown in Fig. 3.

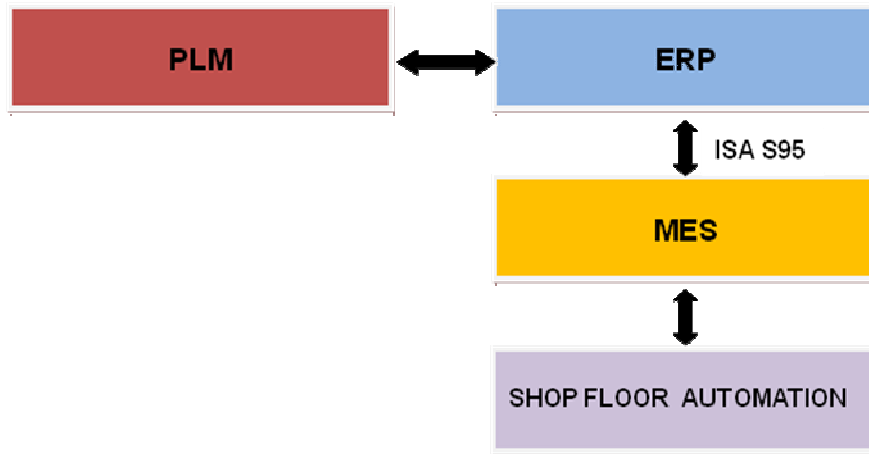


Fig. 3. The current IS integrations

2.3 Needs of integration

The important number of needs leads the academic and industrial to develop the integration between PLM and production management. These needs become more and more important. We can, for instance, identify:

- There are vast amounts of engineering information that are not effectively conveyed to production management. The same is true of production data availability for engineering to evaluate a design's effectiveness for manufacturing [5]. This causes negative impacts including costs of engineering changes that occur due to problems found in production [7].
- Each product lifecycle stage should send the product-related information in the following stages.
- The need to improve the consideration of production constraints in the engineering works. For instance, we should avoid the gaps between the results of simulations and what actually occurs on the factory floor [19].
- It is important to manage the life cycle of the production system as the product.

3 Research questions

The PLM and MES exist in a stand-alone environment increases the probability of a disconnect between both systems [5]. Systems that do not encourage collaboration between engineering and production actually hinder continuous improvement efforts [27]. Moreover, this disconnects causes many problems for manufacturers producing highly complex products that demand unfailing quality, such as aircraft or pharmaceuticals [5]. To study the extension of PLM to production management, research questions are :

- First of all, how to ensure the transfer of product data from engineering to production and particularly after product modifications. This transfer encompasses the management of execution date changes and ensures that from this date the production data are updated.
- Secondly, how to enrich the model of product data with data received from production for use in design during the modification of the product or even of new product, this mean that if PLM needs data from use and recycle to improve the product design it also needs data from the production.
- Finally, the question is how PLM can manage the production system-related information as those of the product.

4 Methodology and data

In order to realize objectives, we should follow a methodological approach:

- **Study of PLM**

During the first stage of our methodology, it seems important to study structure, characteristics and particularities of PLM system. In addition, we should study and analyze product-related information with its structure, processes and organization. In order to realize these tasks, we will use Windchill and @udros applications.

- **Study of MES**

The study of MES system can be divided into two major kinds. The first is the study of different MES functions in order to transform it into processes to achieve ultimately the integration to a process level. The second way is to study the ISA S95 standard to analyze the integration of ERP and MES. Global Screen Intra (GSI) is the MES application used in this stage.

- **Realization of PLM/MES integration**

The PLM/MES integration begins by sending information from PLM to MES and finish by analyzing and exploitation of this information. In fact, the impact of this integration on the product data structure is not very important. Currently, MES system has much product-related information such as product design and work instructions. This is a result of information passage in a random or non-formal way.

- **Realization of MES/PLM integration**

The MES/PLM integration seems to be more complex than PLM/MES integration. For PLM, the most important task after receiving information from MES is that it should manages the impact of this information on its data structure and performs the necessary changes in order to exploit the production data to improve the engineering works.

5 Expected results and contribution to theory and practice

5.1 Integration necessity

We can study the need to integrate PLM and production management in two ways. We can study the necessity of integration for production depending on enterprise typology. Two cases are identified:

- One product is produced on one production site. In this case, the PLM manages the production system data from the production lines until machine programs. Therefore, the integration is necessary when the modification of product or the modification of production will occur.
- One product is produced on several production sites. In this case, the PLM manages some production system data so it is limited to the production lines. Therefore, the integration is necessary only when the modification of product will occur.

We can also study the necessity of integration for engineering depending on product version:

- The enterprise develops a new product and builds a new production system. The PLM and ERP are already deployed. The remaining task is to develop production system including MES system with taking into account PLM and production management constraints.
- The enterprise modifies an existing product manufacturing with the existing production system. In this case, PLM, MES and ERP are already deployed. Therefore the production information concerning the previous product version is needed to improve quality and production system performance.

When we talk about integration, the first point on which we agree is that there is much to be gained in extending PLM to production management [5]. In fact, this integration will improve both production and engineering in order to generate advantages [26]. For instance, we identify:

- The procedural enforcement to the as-designed and as-planned records produces a high quality and traceability of the complete life cycle process and minimizes mistakes. The integration of data collection ensures the creation of as-built record.
- Communicating manufacturing data to engineering reduces data entry and hastens problem resolution [5]. This allows sharing common definitions of product and production equipment designs and processes [7].
- MES information is critical in adjusting Bill of Processes (BofPs). These information should then be fed back to engineering to improve their knowledge of the actual BofPs needed to produce desired results [5].
- Whether a request for an Engineering Change Order (ECO) originates in engineering or on the shop floor, integrating PLM and MES ensures that the information becomes part of the build record.
- Reduce product develop times while allowing manufacturing to integrate changes to the production process.
- Ramping up production of new products faster.

5.2 Integration between two levels

Indeed, extending PLM to production management means integration between engineering information and production/control information. Engineering information is the high-level information. Production and control information are the low-level information. Therefore, the integration between PLM and MES allows PLM to have a real time visibility to low-level production information activities. Production information provided by MES, are the lowest level of information, produced in the enterprise thanks to its capacity to provide the sufficiency and dynamic real-time shop floor data.

5.3 Information exchanged between PLM and MES

The most important advantage of integration is to allow MES enforcing as-designed and as-planned records in order to avoid mistakes and gaps. MES is also critical to PLM when it monitors and reports what actually occurred on the physical factory floor. The engineering data in PLM include the product information provided by CAD tools, such as the attributes of the parts, product drawing, structure relationship, EBOM and so on; and the manufacturing process information provided by Digital Manufacturing (DM) tools, such as manufacturing proceeding, 3D models, MBOM, work instructions, man-hour, materials and so on; and PLC code, Human Machine Interface (HMI) code and things alike. All of these data build the as-designed and as-planned records that represent the basic data for PLM in enterprises. Therefore, these data records will be put into the MES system in order to manufacture the product. As-built record is the creation of a virtual counterpart to the physical product [19]. It is divided in two important parts: specific parts that product has to be built and information about the processes that created product, as well as the monitoring and quality control information as the product went through the manufacturing process. As-built record contains manufacturing data collection captured by MES. That information represents parts, equipments, labor and production status, such as updated work instructions, generic issues, non conformance issues, component tolerance, product and process information and so on. MES will transfer as-built record back to PLM. The latter will manages and maintains all these information. So this described information is the main contents of the data exchange between the two systems.

To synthesize, we conclude that this data exchange is between the high-level information or engineering information, provided by PLM, and the low-level information or production information, provided by the MES. The advantage of this exchange is to allow closing the loop from as-built records to as-designed/as-planned records. It is necessary to take into account data exchange with ERP system. The bi-directional relations among PLM, MES and ERP reflect the innate control and feedback nature between each two of them. In order to have best integration results, we should define data exchange between PLM, MES and ERP. The first analysis of functional integration between PLM, MES and ERP is shown in Figure 4.

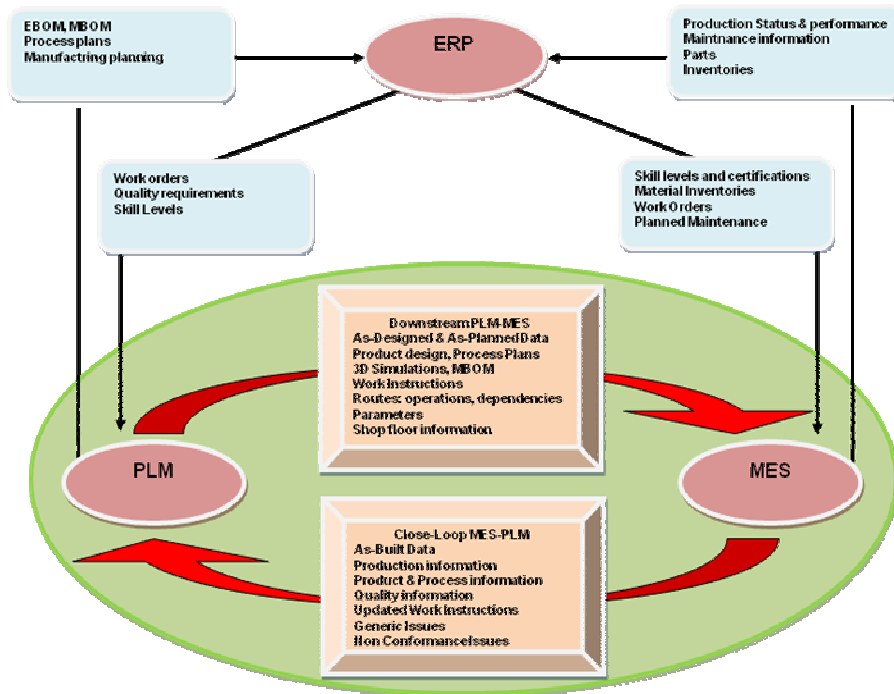


Fig. 4. Functional integration between PLM, MES and ERP [20]

The next step is the formalisation of the exchanged information to build meta-models with UML to model these exchanges in a formal manner.

5.4 Integration of processes

A process is a specific ordering of work activities across time and place, with a beginning, an end, and clearly defined inputs and outputs: a structure for action [21]. The product data is generated throughout business processes [3]. The integration of processes is an approach that is often based on the use of the concept of Business Process Management (BPM) and/or Business Process Integration (BPI), which respectively allow to define and integrate process by implementing an orchestration engine (BPM or BPI engine) or a workflow engine (Workflow Management System-WFMS) [22]. Through the product lifecycle, we identify seven business processes: process of expression of the need, preliminary design process, development process, production process, process of use, maintenance process, process of recycle or process of disposal. The objective in the current stage is to realize PLM and production management integration at process level so we establish integration between all business processes that applied on product and its parts during product lifecycle. However the most difficult task is to generate processes from MES

functions in order to integrate it with the other processes such industrialization process and use process. We will start by identify all the business processes, generate MES processes and realize business process integration.

5.5 PLM-MES interoperability

After identifying the data exchanged between the two systems, we identify several rules to perform successful PLM-MES interoperability. For instance, we identify:

- It is necessary to decide what kind of information will be updated in each system
- It is important to define the ownership of the information in various life-cycle phases
- The information should always be updated in one place so other systems can read information directly from the first system databases and it is possible that required information can be replicated on the databases of other system [18].

Indeed, the most difficulty of the IS interoperability is that it never designed to work together [24]. The level of integration can vary considerably. Information can be moved between IS in several different ways, from the manual transfer and copying of files, sophisticated database, [18], middleware integration to SOA or EAI. The commonest ways to integrate systems are:

- Transfer file integration: text file, XML files, etc.
- Database integration
- Middleware integration
- Enterprise Application Integration (EAI)
- Service Oriented Architecture (SOA)
- Model-Driven Architecture (MDA)

Acquiring needed information, for an IS, can be done in two main methods:

- Information transfer involves copying the information prior to moving it. It takes place in a batch-mode; a copy of a required file or a technical data package is sent over the network either by the sender or upon request from a receiver [23].
- Shared information involves the use of one common database: allowing access to a single database, if necessary at the same time [18]. It takes place in near real-time and it appears as a snapshot of single data source [23].

In practice, it is often easier to transfer information than to share it, because sharing information requires an exact knowledge of the basic mechanisms of the software in use and sometimes involves application specific tailoring [18].

Our expected interoperability strategy is based on SOA technique. SOA establishes a software architectural concept that defines the use of services to support the requirements of software users, making them available as independent services accessible in a standardized way [25]. SOA is based fundamentally on three roles: service provider, service requestor and service broker; and three basic operations: publish, find and bind [22]. We chose this technique because SOA offers mechanisms of flexibility and interoperability that allow different technologies to be dynamically integrated, independently of the system's platform in use [25]. Regarding to the

difference between MES and PLM environments and the use of several PLM applications, SOA can be the solution to realize this integration. One other main key of adapting SOA in our case is its capability to promote reusability and it has reduced the time to put available and get access to new system's functionalities, allowing enterprises to dynamically publish, discover and aggregate a range of Web services through the Internet [25].

5.6 Future Works

In the near future, we will accomplish processes integration that allows to build hybrid integration between engineering and production management in two views: process view and IS applications view. We will study the product information exchange, of the norm ISA S95, between ERP and MES. Finally, several collaborations with manufacturers will be established to compare needs, works and objectives. Therefore, testing the integration solutions in an industrial case is an aim of these collaborations.

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