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## An analysis of the interaction among design, industrialization and production

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Anis BEN KHEDHER <sup>1</sup>, Sébastien HENRY <sup>2</sup>,  
Abdelaziz BOURAS <sup>1</sup>

<sup>1</sup> [University of Lyon, Lumière Lyon2, IUT Lumière]  
[LIESP Laboratory, Bron, 69676, France]  
[Fax: +33 (0)4 78 00 63 28, Tel: +33 (0)4 78 77 26 27]  
[{anis.ben-khedher, abdelaziz.bouras}@univ-lyon2.fr]

<sup>2</sup> [University of Lyon, Claude Bernard Lyon1, IUT B]  
[LIESP Laboratory, Villeurbanne, 69622, France]  
[Fax: +33 (0)4 72 65 53 73, Tel: +33 (0)4 72 65 54 53]  
[sebastien.henry@univ-lyon1.fr]

**Abstract:** Today, within the global Product Lifecycle Management (PLM) approach, success of design, industrialization and production activities depends on the ability to coordinate and improve the interaction among information systems that handle such activities. Enterprises deploy mainly the PLM system, the Enterprise Resource Planning system (ERP) and the Manufacturing Execution System (MES) in order to manage sufficient product related information and provide better customer-products. In this paper, we propose a preliminary analyse of the interaction problem among engineering and production management by focusing on the industrialization step. A main focus on the information systems involved in the product development and manufacturing followed in this analysis. The use of the ISA 95 standard specifications to analyze the realization of a possible interaction is also presented. The recognition of the limitations of each solution is also part of these analyses.

**Keyword :** Design, Industrialization, Production, PLM system, ERP, MES, Information Systems interaction.

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### 1 Introduction

Modern manufacturing enterprises are facing several challenges such as shorten innovation lead-times, reduction of time to market, reduction of costs, mass customization demands, more complex products, improving product quality, inventories subject to rapid depreciation and rapid fulfilment needs [1]. These new business drivers encourage these enterprises to deploy information systems able to tackle the different challenges and allow them to have visibility of product information over the whole product lifecycle. The emergence of the PLM concept with the deployment of PLM systems has generated and generates yet important evolutions of the information system of the enterprises. In fact, before the emergence of the PLM systems, the Enterprise Resource Planning System (ERP) has been the heart of the information system of the

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enterprises. This system focuses on process management of customer orders and the orchestration of all business activities (commercial, financial, procurement, logistics, production, etc.). To meet the specific needs of each activities of the enterprise, integrating business information systems for these activities has gradually been realized. For instance, for the production activity, the development of Manufacturing Execution Systems (MES) has led by the ISA95 standard to define MES functions and the data exchanged structure between ERP and MES. This standard aims to facilitate the integration of MES and ERP systems whose software vendors are generally different. In the absence at this time of PLM system, the ISA95 standard has been focused on a vertical axis from ERP to the production. Based on this standard, the product data needed for production management (e.g. Manufacturing Bill of Material (MBOM) for production activities scheduling) are recorded in the ERP. And the product data needed for production (e.g. manufacturing process and work instructions for production operators) are recorded in the MES.

Today, the deployment of a PLM system must lead enterprises to redefine the limits of existing systems (ERP and MES). However, the duration and the cost of deploying these systems lead enterprises when deploying a PLM system to limit changes of existing systems (ERP, MES). Today according to the enterprise and the chronology of deployment of the different systems, the same information can be stored in a system or another. As revealed by the study "Integrating the PLM Ecosystem" conducted by Aberdeen Group in April 2008 based on a survey of 260 enterprises, the manufacturing process of a product is registered to 15% in the PLM, 36% in ERP, 23% in the MES and finally even more surprising 26% in another system or nowhere [2]. These different solutions for product data recording would not be a problem if they do not hiding the lack of data management and also the lack of supporting of the processes that generate such data. The propagation of product data from design to production is not ensured. The product modifications will be passed partially or late on production. In this situation, the study of interactions between the PLM, production management and production is essential. Thus, the second part suggests the macro processes that lead to the product manufacturing. In order to identify the difficulties to ensure propagation of product data from design to production, this second part presents a state of the art with an academic point of view but also the industrial solutions available to address this problem. The industrialization step in the product lifecycle is bridge between design and production. In the third part, the detailed presentation of this essential step demonstrates the lack of support systems for industrialization. The fourth part studies the problem of data management within the industrialization step and proposes a division of roles between PLM and ERP systems. However, the proposed architecture is a solution to ensure only propagation of data from design to production. To address the problem of data feed back from production to design, the fifth part proposes a framework with the MES system.

## **2 State-of-the-art review**

Nowadays, manufacturing enterprises are facing ever increasing challenges of geographically dispersed design teams to management of all manufacturing systems dispersed all over the world [1]. With the aim to address all these challenges, the enterprises support the need to connect product design and industrialization to production

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during the Beginning Of Life (BOL). This connection is realized by the interaction among the information systems deployed within each BOL step. In an extended enterprise context, the greater data sharing and the visibility among design, industrialization and production allow the reduction of cycle times, improve quality and efficiency and support strategic planning efforts [3]. We start by define these steps and the data generated and used within each step.

### *2.1 Design*

In fact, requirements and design teams start the product development by performing the engineering specifications and conceptual designs. The data generated by designer build the As-designed record. This record encompasses the product information provided using CAD tools such as the parts attributes, product drawing, structure relationship, Electronic Bill Of Material (EBOM) and so on. We proposed to call the system, supporting all the design activities, the PLM system. The PLM system supports the management of product information. It integrates a set of meta-models (product data, process and organization). Each class instanced is involved in the product development [4].

### *2.2 Industrialization*

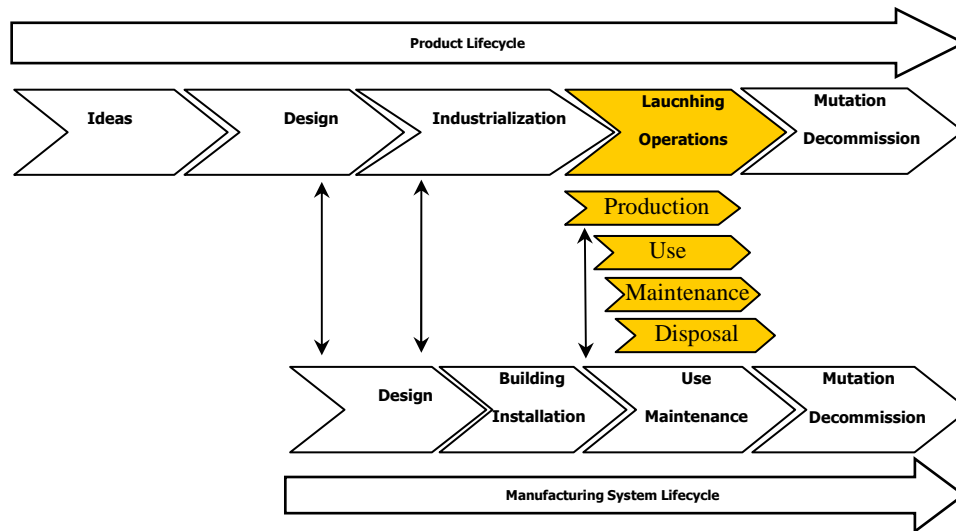
The industrialization is the second step of the BOL. The main activity within this step is to define how to manufacture the product in small time with ensuring better product quality. This activity is performed depending on designer's specifications and requirements. The data generated by the manufacturing engineers build the As-planned record. This record includes work instructions, machine setup, Manufacturing BOM (MBOM), Programmable Logic Controller (PLC) code and so on [5] [6]. The information generated is communicated to the production management.

### *2.3 Production*

The production team performs the production planning and execution. In order to control production operations, the production team is distributed into three control levels. The first is the strategic level using ERP system. The second level is the production execution where the MES is used. Finally, the shop floor that represents the operative level. The information granularity and execution time is different between these different levels. After executing production operations, the production data generated forms the As-built record. The As-built record contains the manufacturing data collection. It is the creation of a virtual counterpart to the physical product [7] [8]. It is divided into two important parts: product related information and information about processes that created product, as well as the monitoring and quality control information as the product went through the manufacturing process. That information inform the high level steps about parts, equipments, labor and production status such as updated work instructions, generic issues, non conformance issues, component tolerance and so on. The feedback of production status from shop floor is important to improve future product design and information, maintain manufacturing process, facilitate recall in case of problems and ensure production traceability.

In fact, the product lifecycle intersects the life cycle of the manufacturing system at the production step. The life cycle of the manufacturing system has no an industrialization step due to the construction of a single manufacturing system. The manufacturing system development starts after the beginning of product design [9]. The Figure 1 shows the intersection between the product lifecycle and the manufacturing system lifecycle.

**Figure 1** The intersection between the product lifecycle and the manufacturing system lifecycle.



The need for a more effective methodology supporting information system interaction is clearly stated by academics and industrial practitioners worldwide. For this purpose, we focus several researchers which have engaged in research and development of industrial information technologies to pursue the most competitive business advantages in product lifecycle [1]. A recent academic state-of-the-art review related to PLM reveals that several works has been conducted in this context. Some researchers focus to how PLM and Supply Chain Management (SCM) systems can be integrated together and play their role during the development and maintenance of an International Thermonuclear Experimental Reactor (ITER) remote handling system [10]. Other efforts include the collaboration between process planning and manufacturing within the product lifecycle management by integrating Computer Aided Process Planning (CAPP) and Computer Aided Manufacturing (CAM). This work tends to promote the exchange between the product design and the shop floor while knowing that CAM tool generates Numeric code (NC) for machines [1]. Other researchers propose an approach for integrating NC planning into PLM by developing a PLM NC reference framework [11].

The recent PLM solutions produced by vendors show that an important development and costs have been deployed to interact PLM system with production management. PTC is the pioneer in this type of development as it has developed the Windchill MPMLink. This tool tends to optimize the Manufacturing Process Management (MPM) [12]. On the other hand, Siemens tends to establish several permanent links among design, industrialization, and production planning and production execution by integrating systems assuring these activities and tasks: PLM, MPM, ERP, and MES [6]. A complete

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solution of extending PLM to the shop floor is also proposed by Intercim. This solution tends to allow data contained in PLM applications communicated to the shop floor followed by the feed back of production status from production information systems [3].

These solutions and several others vendors tests have been theoretically proposed. The data contained in each existing solution often does not encompass the complete lifecycle of the product. Unfortunately, in terms of interaction among design, industrialization and production, there is more complete solution applied in manufacturing industry. Such solution should capture all relevant data that affects a product throughout its life, from concept through retirement and manage the communication of that information to facilitate product and process improvement [3]. Within design and industrialization, there are vast amounts of intellectual property that are not effectively conveyed to the shop floor, if at all [3]. The existing lack between product design and production could be solved by the focus on the industrialization step. In fact, the industrialization is the linker between design and production. Based on these analyses, we consider that an important number of needs still existing in the context of interaction from design to production. As such, the PLM integrates people, processes, business systems and information together [7]. Besides, it manages processes in order to ensure the transfer of updated design and industrialization information to production. However, the lacks that significantly exist is to manage the industrialization processes because conventional information systems didn't provide an application solution dedicated only for these activities. There is a need also 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 shop floor [8]. The table 1 illustrates the data generated within each BOL step.

### **3 The industrialization process**

Within the industrialization step, the manufacturing engineers define how a product is to be produced. They receive digital product definition from designers, consider the capabilities and capacities of internal plants and external suppliers, and deliver the set of manufacturing plans required to produce the product [12]. They use designer's specifications such as items, EBOM, CAD models and so on. The manufacturing engineers require also several manufacturing system information such as machines parameters, operator's qualifications and so on. Therefore, the industrialization process is performed within the interrelation between product lifecycle and the manufacturing system lifecycle. Usually, they use several application tools for Digital Manufacturing (DM) such as CAPP and CAM. A serious development and optimization of the industrialization process fills important information and process gaps that exist between engineering and production. In Figure 2, we show different steps of the industrialization process.

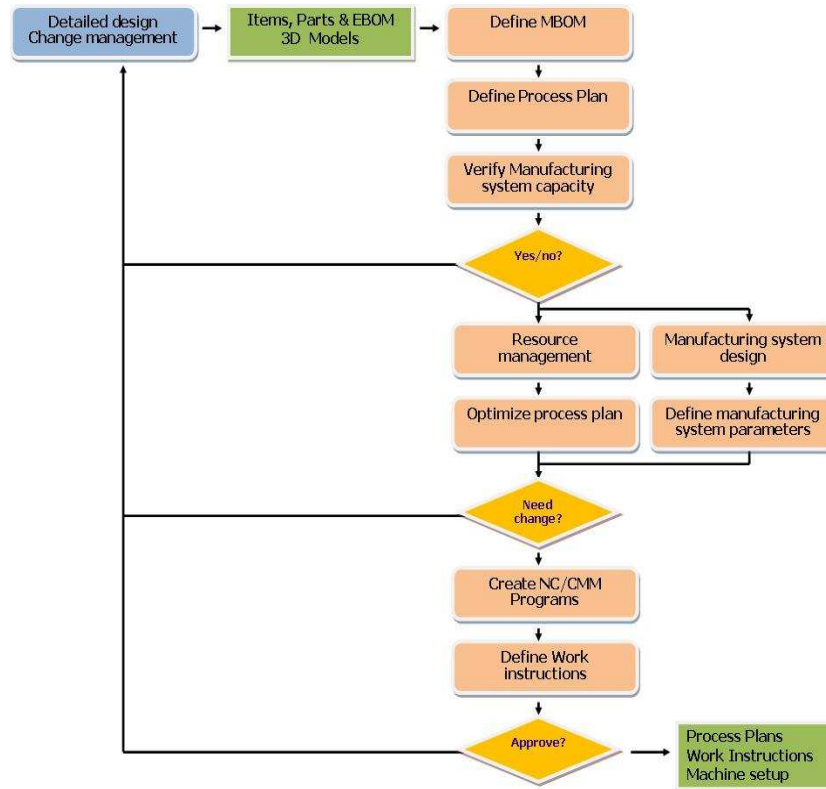
**Table 1** Data generated within each BOL step

Steps of the BOL	Design	Industrialization	Production
Process and data	Product design As designed: EBOM, 3D models, Items.	Manufacturing Process & manufacturing system design  As planned: MBOM, manufacturing process and work instructions.	Manufacturing operations (assembly, painting, etc.): physical product, As built
Process Management	PLM	-	ERP/MES
Data Management	PLM	-	ERP/MES
Tools	CAD, CAE	CAPP, CAM, DM	Machines, operators, Shop Floor automation

Indeed, the industrialization activities are similar to the design activities. Therefore, several vendors try to integrate industrialization activities to the PLM system. This solution assumes that PLM system encompasses all product information management from product design to manufacturing process management and NC codes. However, the limitation of this solution appears if the enterprise produces the same product using different manufacturing systems. Therefore, the enterprise deploys different machines and lines, uses different raw materials and has different production operators. The difference among the enterprise's manufacturing systems induces the development of a manufacturing process according to each manufacturing system parameters.

In the other hand, the ISA95 standard proposes to encompass several industrialization activities within the ERP and MES activities. ISA95 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 [13]. For instance, Business to Manufacturing Markup Language (B2MML) is a set of XML schemas, corresponding to the ISA95 object models, intended to be used for data exchange between ERP and MES [14]. In fact, this standard didn't take into account an independent system dedicated to the product information management. Therefore, according to the standard specifications, several engineering activities are supported by Research & Development (R&D), ERP and MES. For instance, the R&D and ERP support the realization of BOM, Bill of resources and product production rules. In the other hand, the MES performs the product definition management by extending information received from R&D and ERP into site-specific definitions using local material, equipment and personnel [15].

**Figure 2** The Industrialization process



To synthesize, the complete solution that encompasses the industrialization process does not exist. Vendors and researchers tend to establish the entire coverage of this step by developing an application module that could be integrated into the PLM solution. The increasingly development of PLM solutions encourages this type of solution developments. For instance, PTC has developed Windchill MPMLink module. This module tends to design manufacturing processes according to the designer's specifications to finally generate NC code [12]. The use of the ISA95 specifications still exists due to the large contribution of its specifications in exchange between enterprise information systems. The table 2 shows the coverage of the industrialization process according to each solution.

#### 4 The industrialization management

During the industrialization step, the manufacturing engineers define how the product is to be produced. This process depends on the information systems and tools deployed in the enterprise. In fact, our analyses are based on a recent report achieved in 2008 serving as a roadmap for enterprises in order to identify best approaches to integrate enterprise's applications. This report shows that 42% of MBOM information is stored into PLM



system, 42% into ERP system and 16% into the MES. Moreover, the ERP system stores 50% of the manufacturing processes while the PLM system 17% and MES 7% [2]. These statistics shows that the enterprises practices depend on the order to deploy information systems deployment over time. The first deployed systems often exceed the borders of its functions. This is followed by the inclusion of several other information systems functions. These practices induce special constraints because the choices made during the previous application systems deployments may not be questioned.

**Table 2** Industrialization process management

	Design	Industrialization	Production
Process and data	Product design As designed: EBOM, 3D models, Items.	Manufacturing Process & manufacturing system design  As planned: work instructions, machine setup, and MBOM, NC codes.	Manufacturing operations (assembly, painting, etc.): physical product, As built
Process Management	PLM + industrialization added modules	?	ISA95
Data Management			
Tools	CAD, CAE	CAPP, CAM	Machines, operators, Shop Floor automation

For instance, we have interested on the MBOM design. Usually, enterprises use PLM system or ERP system to handle the MBOM. The MBOM is developed by resequencing the EBOM in the context of the assembly process. It contains the product knowledge how to build and how to manufacture a product. Usually, the EBOM is generated using the PLM system. The manufacturing engineers use the EBOM and perform several changes such as the removal of sub assemblies that don't exist in the physical world, adding non-engineering items and so on.

Due to the difference of MBOM management from one enterprise to another, we distinguish two main practices:

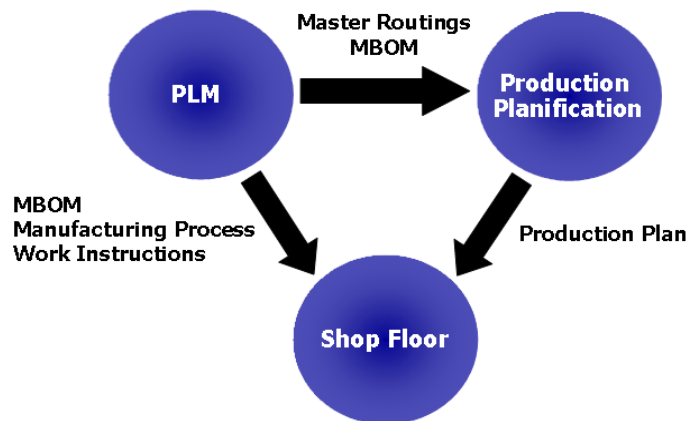
- The MBOM is handled in the ERP system. The manufacturing engineers communicate with designers to get the EBOM and then perform the MBOM depending to the EBOM structure. Therefore, an interaction between ERP and PLM system should be realized. The first limitation of this solution is that the ERP system is not dedicated for MBOM design. Therefore, it is a difficult task to ensure the correspondence between the EBOM and the MBOM. The manufacturing engineers have to update the MBOM in the ERP database after each EBOM modification performed in PLM system.
- The MBOM is handled in the PLM system. During process engineering there is a need to use, analyze and sometimes adapt engineering data. This could be done in the most efficient way within one system where all product data is available. The PLM system contains tools to create quickly based on certain rules a MBOM derived from EBOM and when changes occur even compare

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both structure again, to adapt to these changes. Furthermore, having a single environment for product definition and manufacturing improves the total product understanding. The limitation of this solution is that the MBOM generated in PLM system, should be communicated to the ERP system in order to calculate needs and make the purchase of raw materials. In this case, the item cost is the main product information added via the ERP system.

Based on the second practice, it seems that the main need today is the communication of updated data from engineering to production management in order to ensure continuous improvement efforts. This collaboration architecture is illustrated in figure 3.

**Figure 3** Data exchange among PLM system, ERP and shop floor



Despite the contribution of this architecture, there are some limitations. First, production needs data from the PLM system and ERP system. This diversity of data sources causes a problem of multiple Human Machine Interfaces (HMI) for the production operators. Therefore, the coordination of data received from the two systems is required. The production operators should perform production operations while applying production plan received from ERP system and work instructions received from PLM system. Second, the information granularity and execution time are different between PLM, ERP and the shop floor. The need becomes important to deploy a system such as the MES which is able to exploit the shop floor data and communicate sufficient and up-to-date data to PLM and ERP.

## **5 Architecture using the MES**

### *5.1 Utility of the MES*

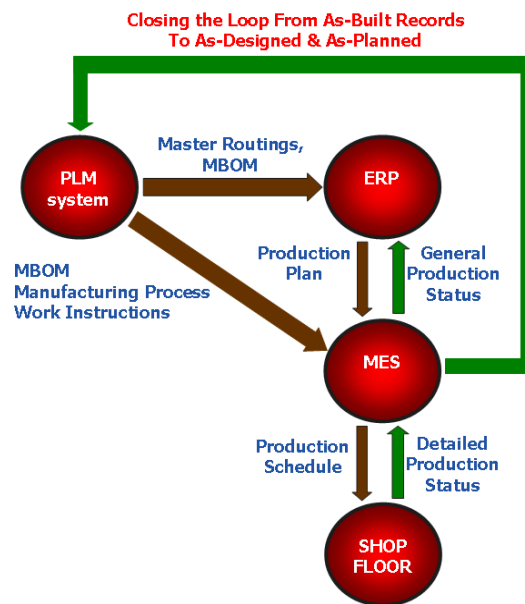
The information flow from PLM system to the shop floor is crucial in order to perform the production using updated designs and manufacturing processes. However, it is impossible to establish an information flow from the shop floor to PLM or ERP. These systems are not dedicated to gather and handle dynamic real-time shop floor data. In fact, the shop floor data is captured by the MES. The origins of the MES concept are to be found in the data collection systems of the early 1980s [16]. It 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 CNC machine tools and PLCs on the lower level and the ERP system on the higher side [17]. When real-time events occur in the shop floor, MES can promptly make response to them, restrict and process them with current accurate data [18].

## 5.2 Data exchange architecture

To synthesize, sufficient and up-to-date engineering data should be communicated to production. In return, design and industrialization need production status information to improve product designs and manufacturing process, facilitate recall in case of problems and ensure production traceability. This data feedback becomes important in order to allow each lifecycle step to make decisions while having visibility to others lifecycle steps. Indeed, this data exchange is between high-level information provided by engineering and low-level information provided by production management. This exchange leads to a closed loop among design, industrialization and production [19]. The closed loop architecture is illustrated in Figure 4.

**Figure 4** The closed loop architecture



## 5.3 Problems in practice

### 5.3.1 The data content of the MES

Several practical problems appear when PLM system and ERP acquire data from the MES. In order to overcome these problems, we start to analyze problem's origins. In fact, the data acquired from the MES is divided into two kinds [20]:

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- Product related information: product reference, lot number, manufacturing process reference, BOM reference, production time and so on.
- Manufacturing system information: operator identification, machine number, line number, raw material reference and so on.

In order to ensure better exploitation of these data, we consider that there is a need to extract product related information from data provided by the MES. This data extraction is needed due to the incapability of PLM system to handle the manufacturing system information. In the other hand, the manufacturing system information is important for ERP system in order to plan the maintenance operations, to have visibility of raw material consumption and operator's performances.

To synthesize, the interaction solution among PLM system, ERP and MES should take into account the classification of the data communicated from the MES into these two kinds. Therefore, each system handles the data that it concerns.

#### *5.3.2 Data consistency*

The delay in updating the product information at the production level is frequently detected. For instance, the manufacturing engineers update the MBOM and transmit it to the production managers and the production operators. Therefore, in the shop floor, the production operators have to verify the data consistency of the production plan received from the production managers and the MBOM or manufacturing process received from the designers or the manufacturing engineers.

#### *5.3.3 Loss of data accuracy*

The transfer of MBOM, manufacturing process and work instructions from the manufacturing engineers to the production operators via the manufacturing engineers causes losses in the accuracy of these data. In fact, the production managers use the ERP system that its data structure is not adapted to support detailed MBOM, work instructions, etc.

#### *5.3.4 The product data model*

For the enterprise, the use of information systems provided by several vendors' causes the incompatibility of the different product data. For instance, to communicate with an MES, the PLM system should be able to handle the MES product data model. This capacity of PLM system to support the MES product data model can be performed by integrating the two systems. Enterprises may use the Standard for the Exchange of Product Model Data (STEP). This standard is an international standard supporting the information exchange between engineering applications [7].

As we mentioned, the ISA95 has defined a product data model that only taking into account the production point of view. The question that occurs is how the integration between PLM system and MES could be realized using the ISA95 models.

### *5.3.5 Case of several manufacturing systems*

In an extended manufacturing enterprise, the same product could be manufactured using several manufacturing systems. Therefore, the interaction between PLM system and MES may depend on this feature. We distinguish two main interaction cases:

- In the first case, the enterprise has different manufacturing systems located in several countries which involve the product manufacturing according to different manufacturing processes. For example, in Asia, the low cost of labor promote handmade. However, in other countries the same product is manufactured by machines. As such, the design and industrialization teams cannot communicate with each manufacturing system with taking into account its specificities. Therefore, the design and industrialization information shouldn't exceed common plans and work instructions. The local manufacturing engineers should manage the manufacturing operations depending to their resources constraints [20].
- In the second case, the enterprise deploys only one manufacturing system. Therefore, the design and industrialization information include all the manufacturing system information and specificities.

## **Conclusion**

The need for a more effective solution supporting the interaction among design, industrialization and production teams, within a global PLM, is clearly stated by academics and practitioners worldwide. This interaction involves the data exchange among several information systems, mainly used by a huge number of enterprises all over the world, i.e. PLM system, ERP and MES. The main purpose of this paper is to contribute in the analyzing of extending the collaboration between engineering teams and production management teams with taking into account the difference of information granularity and execution time among information systems used by each team. We have identified the data exchange among BOL teams and information systems. Besides we have analyzed several particularities related to the industrialization step that we consider like the linker between design and production. In order to best focus on these particularities, we have analyzed two main solutions for supporting industrialization activities i.e. the PLM system coverage of all engineering activities and the industrialization activities coverage using the ISA95 specifications. Analyze of the limitation of each solution was a part also of realized analyzes.

There is certainly an ideal distribution of role of each system (PLM, ERP, and MES). From production point of view, ERP and MES would focus on the production management without product and manufacturing system data management contrary to ISA 95 specifications. Therefore, the PLM system would focus on product design, industrialization step and the manufacturing system design. This ideal solution may be feasible for the big enterprises (aviation, automobile, pharmaceutical, etc.) but it will certainly not be feasible for Small and Medium Enterprises (SMEs). Indeed, full integration of industrialization step within their PLM system would be too costly. Therefore, the SMEs lose probably their flexibility and responsiveness. According to the

ideal solution point of view and the criteria that remain to be defined, the objective is to minimize the integration of industrialization step within the PLM system with no guarantee of data propagation from design to production while developing warning mechanisms in order to ensure data consistency from design to production.

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