Integration between MES and Product Lifecycle Management

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Abstract

Today, within the global Product Lifecycle Management (PLM) approach, success of design, industrialization and production activities depends on the ability to improve interaction between information systems that handle such activities. Enterprises deploy mainly PLM system, Enterprise Resource Planning system (ERP) and Manufacturing Execution System (MES) in order to manage sufficient product-related information and provide better customer-products. This paper proposes a methodological approach to integrate product data generated during product design, industrialization and production. This involves the PLM and MES integration. Thus, the proposed approach aims to overcome the problem of data heterogeneity by proposing a mediation system resolving syntactic and semantic conflicts.

Keyword words: PLM, MES, integration, mediation system, web service architecture.

1. Introduction

In an extended enterprise context, the ERP had emerged as the enterprise management system and as the heart of the enterprise information system [1]. This system focus on managing customer orders processes by orchestrating all company's activities (commercial, financial, purchasing, logistics, production, etc.) [2]. However, over the last decade, the emergence of the PLM concept associated to the development of PLM support applications have generated multiple evolutions in the enterprises information systems. To meet the specific needs of each enterprise's activities, the integration of information systems required for these activities has been gradually realized. For instance, the development of information systems for controlling production (MES) [3] led to the standardization by the ISA 95 - IEC 62264 standard of MES functions and data structure exchanged between ERP and MES. This standard aims to enhance the integration of MES and ERP whose vendors are generally different [4]. As we mentioned earlier, at that time, the PLM system is not yet mature. Thus, the IEC 62264 was focused on a vertical collaboration from ERP to production. Based on this standard, the product-related data are needed for production management such as Bill Of Materials (BOM). For production planning and scheduling, product-related data are recorded in the ERP system. Moreover, the product-related data for production such as work instructions and for production operators are recorded in the MES. Nowadays, the deployment of PLM solutions challenges these choices and leads companies to redefine the borders of existing information systems (ERP and MES). However, the duration and deploying cost of these systems lead enterprises to limit changes to existing systems when deploying a PLM system. Thus, according to the enterprise strategy and the history of its information system (chronology of deployment of various information systems), the same information can be stored in more than one information systems. As revealed by the study "Integrating the PLM Ecosystem" conducted by Aberdeen Group in April 2008 [5] based on a survey of 260 companies, the "manufacturing processes" of a product is stored 15% in PLM, 36% in the ERP, 23% in the MES and finally even more surprising 26% in another system or not! These different solutions for product-related data storage reveal the absence of serious data management and monitoring of processes that generate such data. Therefore, there is a challenge of absence of a continuous product-related data flow from design to production. This situation limits the visibility of product data over the production. This limitation is due to the delayed data update and to the communication of partial data to production. In order to tackle these challenges, it seems important to study the interaction between PLM and production management. The first part aims to clarify the issue addressed in this paper. The main characteristic of this issue is to address a problem of three nested information systems. In the next section, an analysis of different life cycles (product object / instance, manufacturing system, purchase order) including the production step, which is the intersection of these life cycles, lead to classify these life cycles activities into four categories. A comparison with the current activities coverage's by the existing information systems (PLM, ERP and MES) leads firstly to confirm the current trend of PLM solutions evolution to the industrialization step but also to define borders among these three systems. A study of interactions among the activities of various life cycles led to propose integration architecture of the three information systems. Following this analysis, the fourth part focuses on the integration between PLM and MES. Finally, we describe the proposed mediation system and web service architecture.

2. Interactions among lifecycles

Nowadays, the concept of digital manufacturing offers, from design to industrialization, several computer tools based on digital 3D models for simulation (simulation of machining, analysis of ergonomics, shop floor simulation, etc..) such as the solutions proposed by DELMIA and based on CATIA (Dassault Systems). This tendency has already been started by some PLM suppliers such as PTC that includes the MPM module (Manufacturing Process Management) to include, within the PLM solution, the industrialization stage [6]. Thus, the data handled by the PLM solution will be required for production management, such as Bill of Materials (BOM) for Materials Requirements Planning (MRP), and other data required directly in the shop floor for the product manufacturing such as digital manufacturing process, controls programs or operator work instructions. Therefore, from the need for conventional integration of two information systems, PLM-ERP on one side and ERP-MES on another side, problem that appears is the integration of these three information systems. The integration of these three systems is variable depending on the selected solutions and blurred because of the same functions which existed in two or three of these systems. Finally, this integration depends also on the product type that can be customized and manufactured to customer's request or, conversely, be manufactured from stock. Thus, these research works aimed to propose architecture for integrating these three systems. The first step of these works consists on a life cycle analysis by focusing only on the exchanged data without taking into account the product and its impact on the frequency and timing of data exchanges. The second study based on a classification of products in five categories leads, firstly, to evaluate the frequency of data exchanges and thus classify the exchanges needed to be automated according to the product, and secondly to identify two data exchange scenarios

The research on the interactions among PLM, production management and production is based on a detailed study of different life cycles. Thus, two different concepts of product are distinguished: the product object and the product instance. The product object is a virtual product or digital product, while the product instance is the physical product delivered to customer [7]. Therefore, we distinguished one life cycle related to each product type [8] [9]. Two other life cycles related to product manufacturing are studied: manufacturing system life cycle and purchase order life cycle.

2.1. Product instance lifecycle

The product instance lifecycle consists of three stages: manufacture stage, the use / maintenance stage and the disposal / recycle stage. In the case of producing multiple product instances, the life cycles of different product instances are shifted in time because at the instant **t** when the instance **b** is in manufacturing, the instance **a** is in use. Usually, the period of product use varies depending on the robustness of the product, consumer behavior and conditions of use.

2.2. Product object lifecycle

The product object lifecycle consists of four steps : design, industrialization, marketing and mutation/disposal [9]. Product object design is performed by designers using several tools such as CAD tool (Computer Aided Design). The data and processes generated, during this stage, are increasingly supported by PLM solutions. At the end of this step, several data and documents will be generated such as BOM, CAD model and product configurations. The second stage of the object lifecycle is the industrialization. During this stage, manufacturing engineers perform the manufacturing process, the MBOM (Manufacturing BOM), work instructions for each operation and machine setup for each of the machine and shop floor programs for machines and robots, etc. The third step is making the product on the market. The duration of this stage is the period where the product is offered in the catalog and the customer can buy it. The final step is the mutation/disposal of the product. During this stage, it can be decided either to enhance the product to better meet market demands, or simply to abandon the product.

2.3. Manufacturing system lifecycle

We consider that a manufacturing system is itself a product that has the distinction of being manufactured in a single copy. For this product category, its life-cycle includes only four stages: design, manufacturing, use / maintenance, and finally mutation/disposal. At the stage of the product object industrialization whose instances are created by using the manufacturing system, the product manufacturing process and the manufacturing system architecture are extremely linked.

2.4. Purchase order lifecycle

Nowadays, companies are looking to minimize their inventories and to produce in approaching the concept of "Just-in-time". In this context, customer orders management is an essential element for production. Therefore, taking into account the purchase order lifecycle is essential in the study of the production. It consists of three main stages: reception, preparation and delivery.

The figure 1 shows the intersection between the four lifecycles.

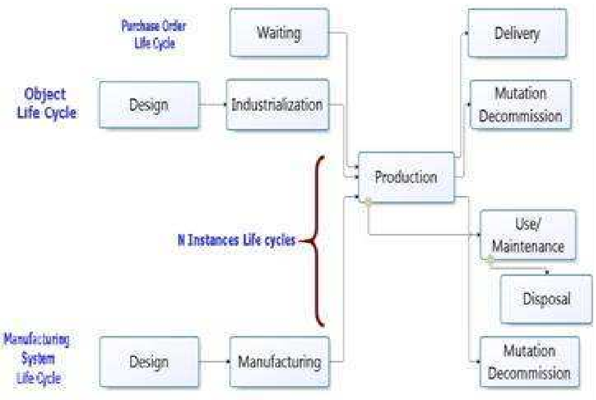

Figure 1. Lifecycles intersections

To synthesize, the analysis of the previous lifecycles reveals that the production activity is a meeting point of these lifecycles. The production can be defined like the instantiation of product object by using the manufacturing system in order to meet customer orders.

Indeed, after the identification of the activities of each life cycle, a classification of activities is carried out according to two criteria: Activity Type and Activity Output. Thus, we distinguished four categories of activities. This activities classification is shown in Figure 2.

	Certain	Incertain
Data	Pu : Waiting, Preparation	PO : Design, Industrialization, Marketing, Mutation, Decommission MS : Design, Mutation
Physical Effect	PI : Manufacturing, MS : Use, Manufacturing Pu : Delivery	PI : Use, Maintenance, Disposal MS : Decommission

PI : Product Instance Life Cycle   MS : Manufacturing System Life Cycle
PO : Product Object Life Cycle   Pu : Purchase Order Life Cycle

Figure 2. Activities classification

The first criterion is the activity type: certain or uncertain. An activity is certain when its duration and output are known a priori in the case of uncertainty absence. For instance, the production time of all operations are known a priori without machinery failure, lack of personnel, etc. In the case of an uncertain activity, output and / or duration are not known a priori. This is particularly the case of product object design activities whose result is never known and whose duration is very difficult to assess a priori. The product use activity is also uncertain because it depends on user behavior. The second criterion is the activity output: data or physical effect. For example, the object design activity generates only a virtual data. In the other hand, the manufacturing activity generates physical products. From these two criteria, it is possible to define four categories of activities: Data-Certain, Data-Uncertain, Physical effect-Certain and Physical effect-Uncertain.

2.5. Current and proposed activities coverage's

After activity classification, we identified the actual coverage of these activities by current PLM, ERP and MES solutions. In fact, the PLM system used in companies covers only the product design and industrialization. The comparison of current coverage and proposed coverage reveals a wide gap between the activities covered by current solutions (PLM, ERP, and

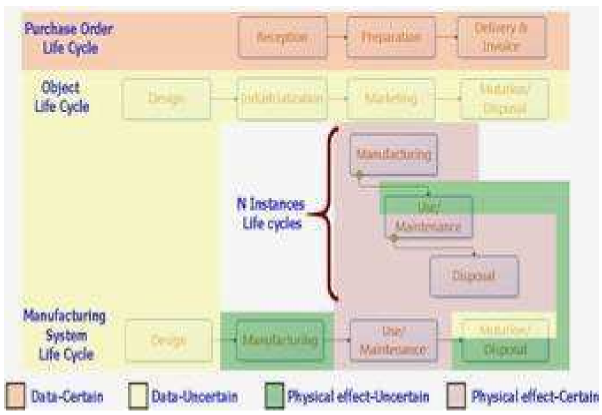

Figure 4. Current activities coverages

The current coverage reveals that the coverage of activities, via PLM, ERP and MES, is limited. The activities not covered by these solutions are handled manually or using tools developed specifically which can involve the limitation of information system flexibility. The PLM systems suppliers tend to provide a tool that manages all processes and product-related data at all life cycle stages. Because of the similarity of the nature of design and industrialization activities, there is a tendency today to manage these two stages by the PLM system. This tool is based on the development of digital tools for design and is adequate to support the whole digital manufacturing from data generated during design and industrialization which are generally digital such as CAD drawings, CAD / CAM, PLC program. For instance, the solution MPMLink proposed by PTC. By focusing on the management of the industrialization stage, this solution can generate more industrialization data. This solution is available as a module that adds to the core of PLM solution WindChill [6]. However, in most current solutions on the market, a part of the industrialization stage, the whole of marketing stage and disposal stage are no longer managed by PLM systems. In order to address this gap between current and required coverage, we proposed a solution that allocates the data-certain activities to ERP, data-uncertain activities to PLM, physical effect-certain activities to MES and physical effect-uncertain activities to other tools. This proposal will define information systems functional perimeters and will promote exchanges. These exchanges will be analyzed in the next section allows us to determine the technical data to be exchanged.

2.6. Interactions among activities

At this stage, we conducted a study of interactions among activities. In this context, we identified several cases of data exchange. Figure 4 shows all of these interactions. In this figure, solid lines represent permanent links in the case of producing all product types. The dots represent activities links depending on product types.

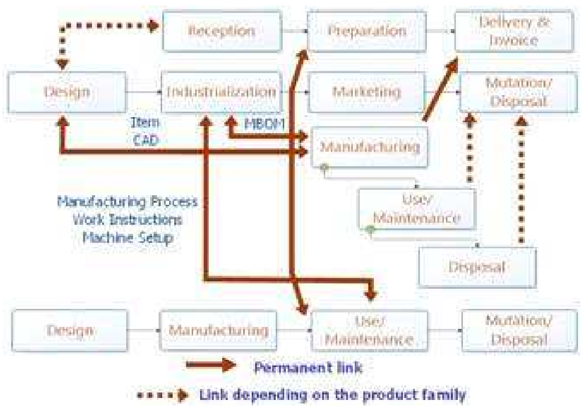

Figure 5. Interactions among activities

3. Systems integration

3.1. Architecture based on PLM, ERP and MES

In modern manufacturing companies, PLM, ERP and MES are typically deployed to manage manufacturing operations. Regarding ERP, almost all companies working in discrete manufacturing and continuous/batch manufacturing use this system.
The continuous/batch manufacturing (food, pharmaceutical, chemical, etc.) are characterized by:

- The traceability constraint normalized by strict standards.
- A high automated system that facilitates data acquisition on the production system status.
- Simple implementation of performance analysis function.
- A single production system widely used to produce many products by changing the recipe. Thus, the emergence of a need to manage production changes and parameters transmission (quality, volume, etc.).

Hence, the importance of MES systems solutions use. Such solutions include the production tracking, performance analysis and production control systems for batch / continuous manufacturing.
Part of the history of PLM systems strongly associated with CAD tools, these systems are still little used in this type of industry for which there is no CAD models for recipes. However, the recipes complexity, its numbers and the high variants number are leading PLM vendors to cover the continuous/batch manufacturing especially for change management processes.

In fact, the ERP-MES architecture is a classic architecture used in continuous/batch manufacturing. This architecture is based on IEC 62264 standard to exchange information between enterprise systems and control system without unnecessary time delays in order to optimize the production [10]. This standard provides the potential to simplify the deployment of ERP-MES integration. Data exchanged between ERP and MES can be structured in UML models. This work is the basis for the development of standard interfaces between ERP and MES [4]. For instance, Business to Manufacturing Markup Language (B2MML) is a set of XML schemas, corresponding to the IEC 62264 object models, intended to be used for data exchange between ERP and MES [10]. On the basis of the discussion above, it can be concluded that the problem of ERP-MES architecture is the absence of product data management systems. This architecture is illustrated in the figure 6.

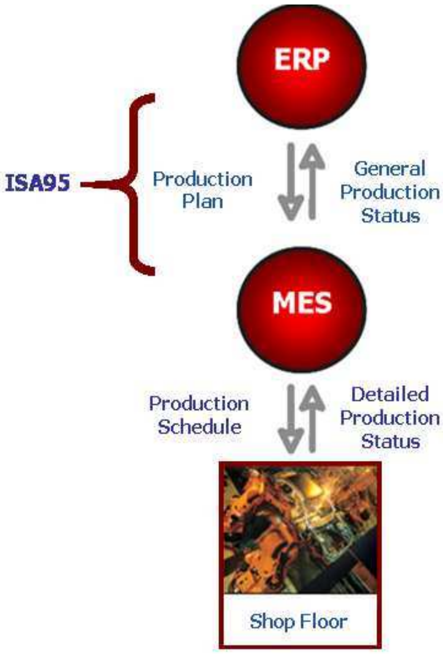

Figure 6. ERP-MES Architecture

On the other hand, the characteristics of discrete manufacturing (Automobile, Aerospace, Electronics, etc.) are:

- The use of the PDM systems that naturally evolved to PLM systems.
- Significant evolution of PLM systems allowing mechanical assemblies of various parts modelled via CAD tools.
- Varies automation according to companies' capability (from not to fully automated).
- A problem of acquiring production system status information
- Little tracking constraints.
- The use of ERP systems including the production management module. This module is usually sufficient to control the production but without any real control of performed manufacturing operations.

To synthesize, all these characteristics enable low penetration of MES solutions in discrete manufacturing. However, multiple product versions, more flexible production systems and the need for realistic performance indicators lead to the development of MES solutions for discrete manufacturing.

The classic architecture used in discrete manufacturing is the PLM-ERP architecture. In fact, several enterprises typically integrate PLM and ERP to ensure the consistency and use of product/shop floor related information throughout the enterprise and to use common product-related data and processes [11]. The PLM-ERP architecture is illustrated in the figure 7.

On the basis of the discussion above, it can be concluded that companies need to deploy PLM, ERP and MES in the same time. These deployments are usually successive over time and led to different changes. Therefore, the new architecture composed of PLM, ERP and MES leads companies to redefine boundaries of each system because the product-related information may need to flow across these boundaries several times. In fact, ERP system, as the only system communicating with MES, is unable to store and transmit all product-related data received from PLM for the MES. This inability is due to its data structure not expected to support detailed product data. Therefore PLM-MES integration becomes more and more required in these kinds of architectures. The general framework of data exchange among PLM, ERP and MES systems is shown in Figure 8 [12].

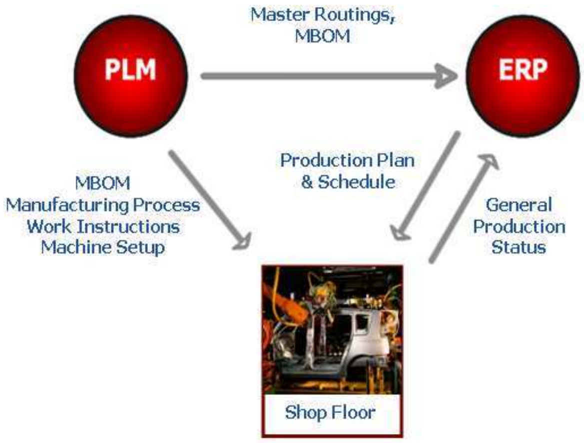

Figure 7. PLM-ERP Architecture

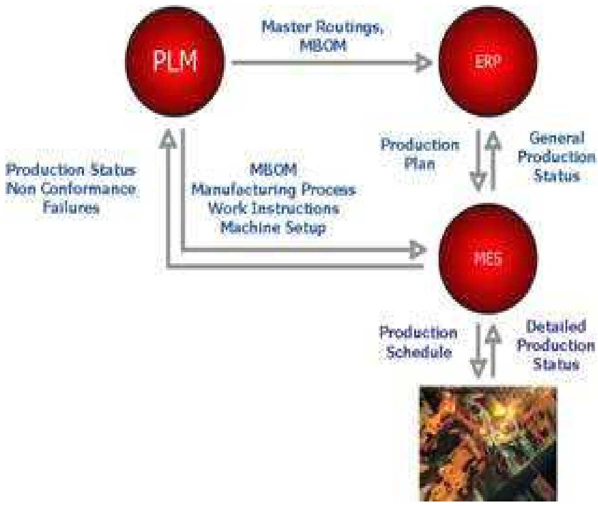

Figure 8. Data exchange among PLM, ERP and MES

3.2. PLM-MES integration

As we mentioned, this research work focuses mainly on the PLM-MES integration. In this context, we identified the data to be exchanged between PLM and MES. By focusing on the product manufacturing, there are five data categories that have been identified [12]: Items data: CAD model, plans, BOM, manufacturing process, work instructions and machine setup. These data have to be communicated to the MES from PLM. In another side, the MES should be able to communicate, to the PLM, reports if a problem related to these data was detected.

In our proposal, data related to the manufacturing system (machines, labour, materials, etc.) should be stored and managed into PLM system. In the other hand, the MES main role system transforms the digital product into a physical product. Nevertheless, it plays the opposite role of feed backing the production status information to PLM and ERP to enable the generation of performance indicators in order to improve future versions of the product information [13].

In fact, five interaction scenarios based on the product type have been proposed. The interaction frequency among PLM, ERP and MES varies depending on the degree of product customization. In fact, manufactured products can be classified into five major categories: contract product such as bridges, engineer-to-order such as aircraft and yachts, configure-to-order such as laptops, assemble-to-order such as cars and assemble-to-stock such as cell phones. Due to the differences of the five interactions, we propose to define the characteristic of each one:

- Contract product: the production of this product leads to develop specific information system managing its development steps. However in the case of using PLM, ERP and MES, the interactions among these systems require multiple data exchanges between PLM and ERP in order to take into account each customer need within design works.
- Engineer-to-order: this is a high customized product. The production of this product is characterized by a high frequency of product data modification, a low volume of production and a high variance of product. The use of PLM system is very important in the design and industrialization steps; consequently, PLM-MES interaction is essential to ensure the passage of production information to MES.
- Configure-to-order: The interaction among PLM, ERP and MES in the case of producing this product led to use the ERP system to perform several calculations based on configuration rules defined within product design step. Thus, the product customizing is realized only after product production.
- Assemble-to-order: the enterprise produces the same product for long periods of time. In that case, the frequency of product data modification is low. The interaction among PLM, ERP and MES is characterized by an important data exchange between ERP and MES enabling product production depending on the order to assemble.
- Assemble-to-stock: Same as assemble-to-order products, the frequency of product data modification is low. The PLM-MES interaction is rare.

4. Mediation system and web service architecture

4.1. Mediation system based on ontologies

At this stage of our research, the main objective is to design a mediation system based on ontologies. This system tends to resolve syntactic and semantic data conflicts. To achieve this goal, we chose the multiple ontologies approach for integration. In this approach, each information source has its own local ontology. The PLM ontology was derived from the Core Product Model (CPM) [14] and TOrento Virtual Enterprise ontology model (TOVE) [15]. The MES ontology was derived from ADAptive holonic COntrol aRchitecture for distributed manufacturing systems model (ADACOR) [16] and The Almost Perfect Approach to Scheduling (TAPAS) [17]. The PLM ontology and MES ontology are inter-linked using formalized mappings, defining corresponding concepts of the source ontologies [18]. For this perspective, we developed a mapping based on semantic dictionary. This semantic dictionary enables to inter-link the concepts of both ontologies (PLM ontology and MES ontology) with a super-concept. Each super-concept is linked to a set of concepts. The link between super concepts and the concepts has been manually integrated into the dictionary because the number of exchanged data between PLM and MES is limited. The enriching and updating of the semantic dictionary are made by a domain expert.

4.2. Web services architecture

The proposed architecture uses data exchange based on Internet technologies to help companies, especially expanded companies, to take advantage of opportunities generated by the Web Services. The concept of "web service" means an application (program or software system) which is designed to support interoperable machine-to-machine interactions over a network, according to the definition of W3C. A web service is available on Internet by a service provider and accessible by clients through standard Internet protocols [19] [20]. Web services are independent from programming languages (Java, J #, C + +, Perl, C #, etc.), Object Model (COM, EJB, etc.) as well as platforms for implementation (J2EE, NET, etc.) [21] [22]. The PLM-MES integration platform ensures interoperability between MES and PLM. The mediation is ensured by a mediation system based on ontologies. Finally, the data exchange is realized using web services. Actually, we developed a web service for each data exchanged between PLM and MES: web service for BOM, web service for manufacturing process, web service for work instruction, web service for production plan, web service for machine setup, web service for production report, etc. The architecture of web services is shown in Figure 9.

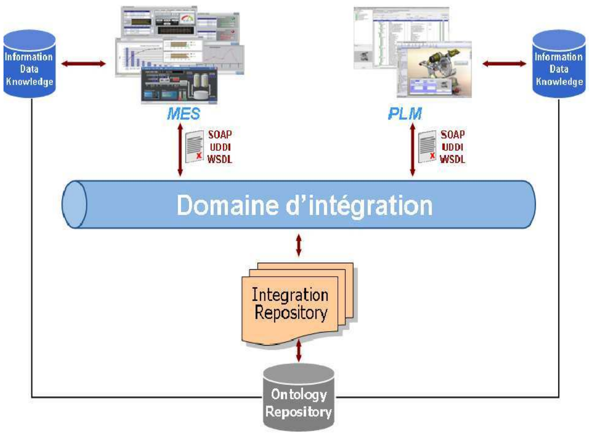

Figure 9. Web services Architecture

5. Conclusion

The need for a more effective solution supporting interactions among design, industrialization and production teams 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, ERP and MES. In this paper, by analyzing the problem mainly on the data exchange between the PLM and MES systems, the technological and non-technological difficulties in the exchange, we suggested an ideal distribution of role of each system (PLM, ERP, and MES) and some data exchange models based on a life cycle analysis and depending on product type. These models enable also the PLM-MES integration. This integration is important to manage data consistency and to avoid passing data in paper format which generate a lot of typing errors [23]. It shows some possibility for enterprises to realize the information integration of the PLM and MES systems to support the collaborative product development.

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