Transiting Between Product Development and Production: How IT in Product Development and Manufacturing Integrate

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Abstract. One crucial moment in product development is when all specifications of a product are ready, and the start of production is imminent. Companies very often have a milestone gate at this point where the development project is signed off and approved making sure that everything is ready and handing it over to the production department. This is a crucial moment involving checking a lot of information that has originated from different departments in the company. It can result in errors since the checking often is done manually and based on that staff check and report the results to a central function managing the transition. The situation is worsened by interoperability problems between different IT systems and databases used for different purposes in the company. In this paper it is examined how an automotive company currently is conducting the handover, gathering and checking all specifications before start of production. Risks of mistakes and unnecessary time loss are identified. In the paper it is discussed how the integration can be improved and the amount of manual work reduced. Results indicate that there is a potential for both saving time and reducing risk of error by automating parts of the handing over and integrating the IT systems and databases.

Keywords: Interoperability · Production · Stage-gate

1 Introduction

There are many different functions in a company that needs to work in close cooperation in product development projects. This is traditionally described as "concurrent engineering", See for example [1], meaning that the product and the production process are defined in parallel rather than in sequence to reduce the risk of having to re-work the design after completion to solve all producibility problems. With increasing complexity of products, this is becoming more important than ever. Defining a new product does not only involve the engineering and manufacturing departments but indeed most of the functions in the company. Not least the increased demands on the sustainability of products require that the supply chains are well understood already in the development phases. One example of a company function is the market and financial functions of the company that needs to be involved early in the development project to ensure the

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profitability of the intended product. After completing the product development project, the new product is going to be produced. During the development phase, the various functions likely worked in several and in many cases incompatible systems. To enable the production of the product, much product data and information needs to be defined. This is commonly done in the Enterprise Resource Planning system (ERP) or similar. The product structure of articles is often referred to as the manufacturing bill of materials (MBOM). Prior to the start of production, it needs to be defined to know which and how many of each article the product consists of. The expected sales volumes need to be entered so that the correct amount of material can be bought at the right point in time. Production also requires material handling in the company as well as external logistics services.

The purpose of this paper is to answer the question of how to the transition be-tween the development and the production phases can be done with as little time loss and risk of errors as possible. Currently, it is commonly done at a specific point in time when all the information produced in the development project is gathered. There is a great deal of manual information transfer introducing risks of errors. It is also stressful for staff to gather all information putting a lot of demands on the project managers. With an increased degree of integration between the IT systems used in the development phase with the ones used in production, the situation can perhaps be alleviated. In this paper, this has been investigated by examining how it is carried out in an industrial company in the automotive sub-supplier industry. It was found that the process is carried out according to a checklist requiring manual inputs from many different functions in the company. In the paper alternative ways of making the transition through the integration of IT systems are discussed.

2 Method

The current paper was written as a part of a larger research project. The paper is based on two sets of interviews. First, eleven 20 min long interviews that concerned the state of practice in digitalization in the studied company were conducted. These were recorded and transcribed. They were analyzed by writing a summery, yielding an understanding of the company state of practice and the level of digitalization. The first round of interviews was followed up with additional informal interviews with two company representatives with insight in the IT environment of the company. The result of the two interview rounds is accounted for in Sect. 4 of this paper.

It was understood that the transition between the development and the production phase is an area of concern for the company. The company also provided corporate documents describing the product development process and supportive documents pertaining to the transitioning between the product development and the production phases. The study resulted in an understanding of the company operations so that it could be investigated what future alternatives for information transfer could be possible for the company and assess their applicability in the organization.

3 Literature

Product Lifecycle Management (PLM) is the business activity of managing, in the most effective way, a company's products all across the lifecycle [2]. PLM is both the set of software to create and keep track of all the product data and a philosophy to include the complete life cycle when creating new products in a single environment. This environment can be described as containing software and databases needed to design and manufacture products. The IT environment can be referred to as the PLM system. It involves the traditional PDM (Product Data Management) for keeping track of the product documentation and defining the processes as well as the software needed to define the product throughout the life cycle. One of the key PLM ideas is to integrate the functionality as much as possible, perhaps into a single system. Understandably, including everything will result in a very large system, and to date, no such systems are commercially available. Perhaps future PLM systems will cater for all needs of a smaller company, to begin with. However, systems containing part of the functionality are still referred to as PLM systems.

The integration of different IT systems in the product realization process can be achieved by building single integrated environments for all the required functionalities. Examples of integrating the core systems of development and production are emerging. For instance, a novel system architecture is proposed by Madenas [3] for integrating PLM systems with cross supply chain maintenance information to ensure that previous failures will not reoccur with new product parts.

According to Avvaru et al. [4] the core systems are PLM, Manufacturing Execution Systems (MES), and ERP. The authors describe the integration of the functionality in a framework for interoperability and apply it to a one-of-a-kind product. This is a starting point for optimization of the processes, highlighting the most pressing interoperability needs. In another application by Prashanth and Venkataram [5], an ontology is proposed for cross communication between PLM and ERP. The paper identifies the interoperability needs and proposes an integration module based on their ontology. It uses a middleware Enterprise System integration (ESI). The connection between the ESI and the ERP is managed by a manual or custom process. Their application is limited to BOMs and Meta Data with a degree of manual or custom service ESI for transferring from ESI to ERP. The PLM system used is Windchill ®.

One problem with the integration is the different needs in the design and manufacturing phases. In the design phase, the system must be flexible and handle frequent changes. Further, the product structure that is defined is the engineering (EBOM). It is not the same as in manufacturing (MBOM). The latter has been put together from a functional perspective whereas the former keeps track of the manufacturing process, such as which of the parts are bought and which are manufactured in-house and at which facilities. It also keeps track of the assembly sequence. After the engineering phase is completed, the MBOM and a much other information need to be defined. It is a transition between the phases. Arthur [6] describe the phase transition between design and production in the case of naval architecture and shipbuilding. The paper describes a transition between design and manufacturing and explains that the PLM system widely has facilitated the process.

A PLM system can be used separately but with integrated data. Such integration can be achieved by making several systems using the same model or using a reference model which was the case in [7] for innovation management. The authors created an enhanced data model in conjunction with a reference process model to make strategic information flow more efficient between marketing and customer service teams.

Cloud PLM systems are other examples of integration that use integrated data in separate systems. Broadening the scope of the PLM systems require connected servers. This is challenging for companies why cloud solution has been identified as a way forward. In the possibilities of cloud solutions in aerospace are discussed. The paper concludes that the major challenges are performance, trust, and data security. The study was concentrated to an application in India. Model-Based Definition (MBD) means producing and documenting the product data in models. The same models are (as much as possible) used throughout the lifecycle. This makes it possible to define the information needed for the production in the same models. This is demonstrated by Rinos et al. [8] in a case where they show that at least the manufacturing information can be incorporated into a model. Thus, they eliminate the need for 2D drawing, widely simplifying the transition to production.

The integration of different IT systems in the product realization process can be achieved by a central knowledge base system (KBS) as a database connecting separate IT systems. To realize an integrated PLM system, the domain-specific products (ERP, CAx, etc.) need to be developed on a functional level, assuming they provide defined services that can be used by other services. However, most PLM implementations are carried out like a traditional IT project in product architecture form. To overcome this PLM systems integration hindrance, researchers propose a taxonomy of terminologies to help the semantics from different domains match and in this way remove the integration barriers [9]. Similar approach attempts to use existing PLM systems as a knowledge management tool to solve the semantic interoperability problem of heterogeneous data are described by Raza et al. [10]. The authors discuss that ontology developments will represent and capture the data and help the production process in manufacturing.

The integration of different IT systems in the product realization process can be achieved by extending the PLM footprint to all phases of the lifecycle. By relying on a system engineering process framework for contextualization of PLM standards, Moones et al. propose an extended interoperability approach for dynamic manufacturing networks [11]. This approach defines system boundaries that can be preserved between the business, applicative, and ICT layers in their manufacturing models. Moreover, the PLM concept has been extended to ePLM [12] by an electronic product code for tracing and tracking of the physical product after it is delivered to the user.

The literature survey has showed three different ways of integrating the IT environment.

1. The systems are integrated into a single environment
2. The systems are still separate, but the data is integrated via for example KBS and ontology.
3. The models are extended to incorporate all necessary information for the start of manufacturing.

What will lead to the best environment likely depend on the type of organization and the product. In this paper, it is reasoned on how this would apply at an automotive car accessory supplier.

4 Case

The case company manufacture and sell mainly automotive accessories for primarily private use. It includes transport solutions for private cars allowing transportation of equipment that is too large for transport inside the car such as skies, bicycles, and kayaks. The company sells its products world-wide, directly to consumers or as original equipment (OM) to car manufacturers. The products are considered high end and the company put much effort into design and testing for the best consumer experience. The company has been on the market for many years and has an annual turnover of about 0,8 billion Euros and a number of employees worldwide of roughly 3000 in 2020. The company has an in-house production and is especially prominent in sheet metal forming and thermoplastic injection molding. All product development is carried out in-house.

4.1 Organization

The development of a new product is initiated from the top management level. A product manager is appointed to oversee that the envisioned product is created. The product manager is responsible for specifying the product and ordering the organization to develop it. The project starts with appointing a project manager. It is the role of the project manager to plan and execute the project and to see that the different roles work together and that the project is conducted according to a time plan agreed with the product manager. The project manager plans the project in agreement with the different functions in the company. Making the time plan require frequent contacts with the various functions to establish the plan and oversee it being kept. Resources in the company are allocated for the project. This includes several people with different roles. Examples of roles are: production planning, purchasing, quality, mechanical design, finance, storage, customer service, and sales forecast responsible. These corresponds to the various functions that are needed to conduct the project. The project is conducted in five different stages according to an elaborate instruction: A- Market research, B- Concept, C - Design, D- production engineering and finally E - production. Each of the phases are followed by a project review. These are called gates A-E. It has been set-up much according to the well-known stage-gate model proposed by Cooper [13]. The project instruction specify what information must be available and what documents to prepare at each gate review so a decision can be taken to continue or terminate the project. If any information is lacking, then the project is not transferred to the next phase. After the production has ramped up (gate E) the project is closed, and the production is handed over to the production department.

4.2 IT Environment

During the first stages of the project A-C, a standardized catalogue structure is created on a server. The project is not yet defined in the ERP system of the company. CAD models, drawings and the engineering BOM structure are handled in a PLM system including work processes and versioning for the engineering part of the work. Other functions are working in their own systems. When transiting between phases C and D, preparations for pre-series production is made. This requires that the project results are transferred to ERP so that pre-series production can be carried out. Now, it must for example be possible to order components from suppliers and keep track of how many units have been produced and how many bought units to order. This require that the information that previously was in the engineering PLM system and on the catalogue structure on the server needs to be defined in ERP. One examples of information that needs to be entered in ERP is the final MBOM structure. All functions engaged in the product are expected to transfer project documentation into the ERP system. This includes for example that the product as well as the process has been approved. The process approval to ensure part quality is in automotive industry commonly known as PPAP (Production Part Approval Process). The process FMEA needs to be approved as well as the all testing needs to have been completed with approved results. There are several other documents such as the final financial calculations and the sales volume predictions that needs to be defined in the ERP systems. There is a requirement to check that the information entered in ERP is correct. Several people from different functions are responsible for making these checks. There are some tools that have been developed specifically for this purpose such as a viewer to check the structure created in ERP so that it can be compared to the product structures in PLM. However, much of the information is taken manually from the "development" server and is manually inserted in the ERP system as needed. This includes for example the predicted volumes, the list of suppliers and the agreements

Table 1. Items to be checked and entered in ERP.

Production Engineering	**Purchase**
Update MBOM	Define suppliers for puchased products
Create semi finished components	Calculate cost for purchased product and components
Define storage in production	Enter purchased items in ERP
Enter manufactiring lead times in ERP	Enter cost for purchased items
Verify product cost calculation	Connect agrements with suppliers
Create first manufacturing order	**Quality**
Verify manufacturing cost	Inspect first serial batch
Verify manufacturing lead times	Make sample orders at supplier
Customer service	**Production planning**
Assign customers item number to the product	Register sample orders for new manufacured items
Forecast	Create manual manufacturing order
Enter sales forcast	Relese first serial production order
Mechanical Design	
Check structures	
Finance	**Warehouse**
Specify logistics prize	Create packaging
Calculate product costs	Assign packaging to product item
Calculate std costs for prod facility	Send info logitics suppliers
Calculate distributed costs on sales facilities	Update sales and logistigs on manufacturing warehouse
Update status to production	

with the different suppliers. In the Table 1, the major items that are checked and placed in ERP are shown. Table 1 also shows which function in the company that is responsible for its completion.

The people responsible for entering the information report that they have completed it in an excel document on the server. However, this way of working is perceived as time consuming and ridged and is gradually falling into disuse. Instead, the company is working to replace it with another procedure. They are currently in the planning stages of this new procedure.

5 Discussion and Conclusion

The problem has been understood via corporate documents and interviews with the company. The transition between the different phases is a commonly occurring problem at many companies. All companies where product development and manufacturing undergo the phase transition need to handle this problem. It is currently accepted by companies that there are points in time, the so-called gates when the specified documents are put on the table and evaluated. However, there is a clear development towards making this transient more smooth and less prone to errors. Instead of relying on the project manager to drive all functions towards the gate, the functions could work toward a common database making it possible to follow the progress in real time towards completing the phase. One example of this is that, instead of at a point in time transferring the product structures into from PLM to ERP they could gradually be build up in the ERP system.

Three major ways have been suggested. One is that the PLM system is extended to include all life-cycle phases which indeed it one in the key ideas with PLM. All the applications would work towards a common database from which various views can be derived. The second line of development is that the various functions continue using "their" software that is specialized for each task. Then, an integration using for example ontologies needs to be made. The third way is defining the production phase in the same models used in the development phase. By doing so, the information would be gathered in a limited space, readily transferable to production.

For the organization studied the path forward is a gradual integration of the systems and to some extent a more homogeneous information model for integrating between the BOM:s in PLM and ERP. The option of a large PLM system encompassing both product development and production is not feasible due to the size of the company. Rather than storing the information on servers in many different and incompatible formats there should be a common database also allowing different views to be derived. For this the API:s of the different systems need to be used to allow each of the applications to operate on this common database.

6 Future Work

Finding and elaborating critical parts of the integration for the studied organization to gradually prepare the start of production is identified as the next step in this research. A test implementation on a limited product development to production case is planned at the case company.

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