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IMPACTS OF DESIGN PROCESS CHARACTERISTICS ON THE SELECTION OF PLM ARCHITECTURES

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Keywords: design process characteristics, product lifecycle management (PLM), PLM architecture

1. Introduction

As a consequence of the increasing stress of competition in manufacturing industry (especially in automotive industry) the Original Equipment Manufacturers (OEM) have been forced to address not only mass markets but also niche markets. As a result, products are now offered in a wide range of variants. For example a Mercedes-Benz car can theoretically have up to 10^{27} variants [Zagel 2006], where, at the same time, the product development phase is continuously forced to be shortened.

To meet these challenges, the automotive OEM have implemented Product Data Management (PDM) systems into their product development departments. The conceptual extension of PDM, the so-called Product Lifecycle Management (PLM), extends the approach of PDM while it aims to support the management of information and data along the whole product lifecycle. In the following discussion, the term PDM is used for the IT-system and the term PLM is used for the overall concept.

The selection and implementation of a PLM solution is an enormous challenge for the whole company. Unlike the usual basic PDM systems, PLM solutions cannot be purchased as a complete software package. PLM solutions can even consist of different software and hardware components – even from different vendors or system companies. Therefore, the selection and implementation of a PLM solution is very different from the implementation of a "normal" software product.

For a successful implementation of PLM mainly three dimensions have to be taken into account: technology, processes and human factors [Eigner 2007]. The priority of these dimensions can differ depending on the point of view, but all dimensions can be at least considered as equal or as increasing priority form technology over processes to the involvement of people [Rangan et al. 2005].

In this paper first results form ongoing research activities together with industrial partners are presented. The main focus will be on the process dimension. Especially the relation of characteristics of design processes and the determination of PLM architectures will be discussed. Thus the research questions for this paper are:

- What are the basic characteristics of a design process with regards to PLM architectures?
- What implications do these characteristics have on PLM?
- Which methods could support the selection of PLM architectures considering these characteristics?

Chapter 2 gives a short description of the methodology followed by this paper. Next, in Chapter 3, an overview of today's situation in automotive PLM is given. This includes a description of paradigms that have major impact on a PLM strategy. Moreover, chapter 4 introduces the so-called "design process characteristics" and their implications. Different processes inside a company and their link to PLM architectures are described in chapter 5. Based on process information and especially on design process characteristics a methodology for the selection of PLM architectures is explained in chapter 6. Chapter 7 concludes and shows aspects for future work in this research field.

2. Methodology

This paper is based on PLM implementation experiences made at a leading automotive manufacturer. Initial process analysis has shown great impact of key characteristics of the design process (such as the type of product, its complexity and variance, and type of design) on the selection and layout of appropriate PLM architectures.

Based on an overview of the current situation of PLM in automotive industry, this paper intends therefore to investigate the design process in detail in order to identify the characteristics that determine the PLM concept. Each characteristic's impact on PLM will be analyzed in detail.

This analysis emphasizes the importance to follow an "IT-follows-process" approach in the development of PLM concepts. As a next step, the findings will therefore be incorporated into a generalized implementation concept for PLM - the PPA approach.

3. Automotive PLM Today

Today the product development process in automotive industry is supported by a large number of IT-systems, which are represented by a so-called *IT landscape*. This IT landscape has developed stepwise over years and is very heterogeneous today. Each IT-system of this heterogeneous landscape proposes to deliver an optimal support for a specific phase of the product development process and thus creates a so-called local optimum. Therefore, several independent but interdependent systems were implemented or even have been developed by the OEM themselves.

The historical progress to the IT-landscape of today is shown in Figure 1.

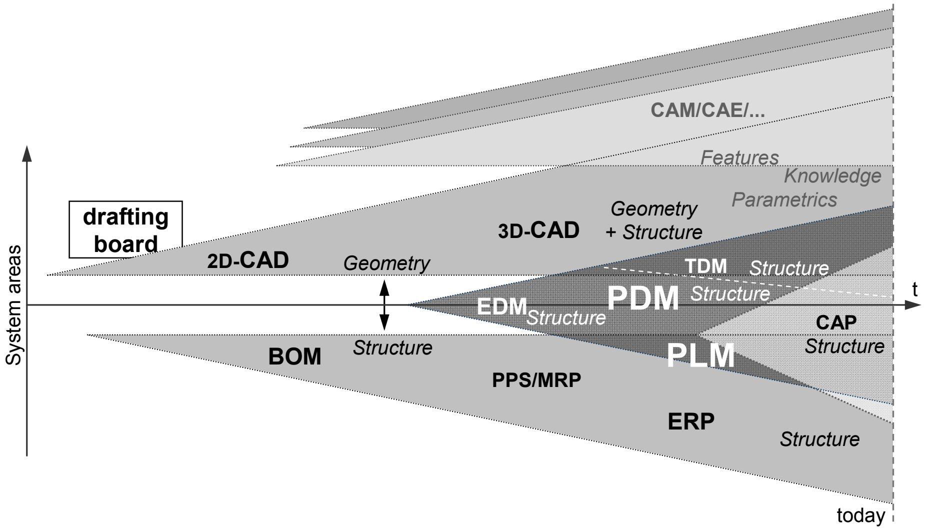


Figure 1. Evolution of today's IT-landscape [Vielhaber 2005]

Computer Aided Design (CAD) systems have historically been the origin and core of design-supporting IT-systems. By the increasing demand of more extensive CAD functionalities, for example Digital Mock-Up (DMU) presentations of a specific car configuration, and rising product complexity by a huge number of variants and versions, the need for PDM systems has grown. Over time PDM systems have become the new core and backbone of engineering IT.

PDM systems have been brought to their limit by an increasing level of digitalization in the product creation process and by the level of complexity of the application systems, e.g. authoring systems like

CAD. That’s the reason why a long-time strategy for PLM is needed, especially in automotive industries.

In the following sections several paradigms are discussed that are widespread in industry and have a major impact on such a PLM strategy.

A continuous way from the as-is to the to-be situation

PDM systems have become the heart of automotive product development and for this reason their operative status has to be guaranteed. Therefore, new approaches in PDM are more evolutionary than revolutionary.

Over the past years the growth of IT landscape has reached an internal and external complexity that is very difficult to handle. Internal data models, system interfaces and specialized functions are the main factors for this complexity. For that, new approaches tend to stick close to previous solutions.

System vs. process orientation

In contrast to the Japanese philosophy of product development, German development processes are often closely linked to and heavily influenced by the IT systems applied. First the systems are used and optimized, then interfaces between systems are more or less defined and finally processes are defined and adapted to system constraints.

Moreover, the organizational structure of a company is often directly matched to system-landscape; for example, in most automotive companies IT departments are split into CAD, CAE (computer aided engineering) and PDM departments. The overall processes are split and separated according to these departments – an overall process responsibility is often non-existent.

All requirements, even if these are process requirements, are dedicated to an assumed-to-be responsible system. The reason being that it is often easier to actualize a complex system requirement than to institute a process change. In many cases, overlaps and conflicts of system functionalities are unavoidable consequences.

Strategy dominance of vendors

The way of thinking in system limits, as explained above, also influences enhancement strategies for PLM. Either an OEM might develop its strategy together with a PDM vendor, or an OEM might even completely adapt to a PLM strategy, which was developed and offered by a PDM vendor. Even more problems might come up, if one IT landscape consists of systems from different vendors.

Decisions based on buzzwords

PLM solutions and concepts have reached a very high level of complexity, so that strategy and system decisions require an enormous amount of technical know-how, which might not be passed on to the higher management levels, where the IT-strategies normally are developed or at least decided upon. Moreover, it is not easy to bring complex and abstract PLM circumstances to a level that is generally understandable, which is why decisions regarding PLM concepts and systems often are based on marketing statements or buzzwords intelligible to all. SOA (Service oriented Architecture), for example, is often used by PLM vendor marketing departments to show that their product is on the cutting-edge. From the technical point of view it might be right or wrong, but anyway, SOA is a trend, a buzzword.

4. Design Process Characteristics and Their Impacts

The description of today’s PLM situation shows that an effective and efficient implementation method is not yet being followed. Process and methodical impacts are not considered systematically.

In the following section, the design process, as the key process in automotive engineering, is analyzed and the key characteristics that have major influence on the selection and layout of a PLM solution will be described.

The concrete layout of the design process and the optimal IT support for its methods depend on various factors, which will be referred to as design process characteristics (DPC) in the following section. Major examples for such characteristics are:

- the number of engineering domains (such as mechanics, electronics, or software) involved in the engineering design process, and the degree of cross-linking between these domains,
- the variance of products to be designed,
- the frequency and complexity of product changes during and after engineering design phase,
- the trait of the product and its geometry.

Each of these DPCs will now be discussed regarding their impact on a best-supporting PLM solution.

Single-domain vs. domain-spanning process

It makes a significant difference for a PLM solution how many different engineering domains are involved in the engineering design process and to which extent these domains are interlinked.

On one hand, a purely mechanical product for example, is designed with support of a CAD system and may use highly sophisticated and specialized CAD methods. These methods are best supported by a single CAD-near PDM system, a supposedly as highly integrated system as provided by the same IT system supplier as the CAD system itself. Whereas, on the other hand, a complex mechatronic product such as a car is developed across multiple domains, each applying domain-specific engineering methods and best-in-class IT systems. Therefore, the PLM integration aspect of interlinking and coordinating the different domains may predominate the single-system-view that is often favored on the management level. A central integration component is added to this strong domain-specific PLM components. In addition, the level of integration between the domain processes determines the character of the integration component.

Figure 2a summarizes the aspects described and correlates the architecture distribution level and the domain integration level. It should be noted that architectural solutions appropriate for higher integration levels might also be able to support integration levels further left on the x-axis; the solutions however may be overdone.

Product variance

As depicted by [Zagel 2006], product variance in automotive engineering is extremely high. As described in [Bergsjö et al. 2007], configuration management is, therefore, one of the key processes. Managing configuration - also across domains - is a key challenge for any PLM solution in automotive engineering. Simplier products featuring no or very few variants put less emphasis on the configuration aspects of PLM.

Looking at the architectural aspects of PLM, highly variant products need a strong and domain-spanning configuration component. Lower variance may also be supported by simplier domain-specific configuration modules. Figure 2b correlates the basic PLM architecture alternatives already depicted above with the level of product variance.

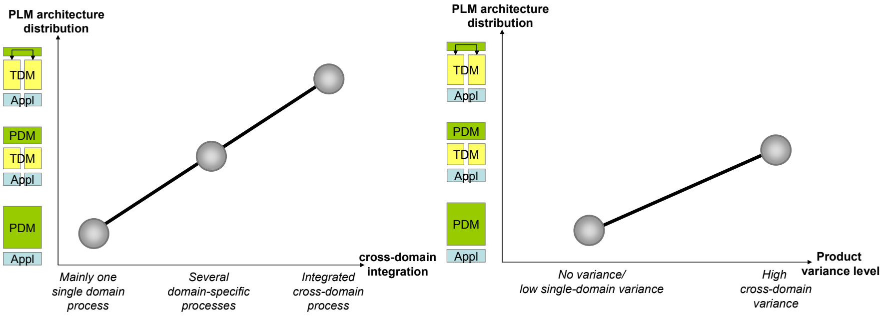


Figure 2. Implications of the design process characteristics "cross-domain integration"(a) and "product variance" (b) on PLM

Frequency and complexity of change

As described in [Bergsjö et al. 2007], change management is a second important key process within automotive engineering. Automotive processes feature a high quantity and complexity of changes, both throughout the initial design process phase and afterwards. Furthermore, each engineering domain involved featured different change frequencies and cycles, and it is a key challenge to keep versions of all domains coordinated and synchronized in real-time.

From a PLM architecture perspective, a strong domain-spanning change management mechanism is required to support the requirements of automotive engineering. Single-domain products may also be supported by simpler domain-specific change management modules.

Figure 3a correlates appropriate PLM architectures with the complexity of engineering changes within the design process.

Trait of product and product geometry

The trait of the product and its geometry heavily determines the design methods applied and their implementation using a CAD system. Similar conclusions can be drawn in other domains than CAD-supported mechanical design (Figure 3b).

Even within automotive engineering, a variety of different demands are posed by, e.g., powertrain solid modeling and body-in-white surface design, potentially resulting in different methods or even CAD tools even within the mechanical design domain. Furthermore, as already stated in [Vielhaber 2005], assembly-orientation of the design process calls for high-level domain-specific data management support. (Geometrically) complex products therefore call for application-near team data management solutions as a basis for higher-level PLM integration. For less complex products a simpler out-of-the-box PDM solution may deliver sufficient process support.

Each DPCs discussed above show significant implications on an optimal PLM support - optimal regarding each single DPC, respectively. Looking at just these four examples it becomes more obvious that the support of the conglomerate of all relevant DPCs is a complex challenge requireing a lot of consideration and process overview. A system-oriented implementation approach for PLM, which builds on the successive fulfillment of system requirements by customizing any out-of-the-box system, will soon be overstrained by the complexity, diversity, and even contradiction of claims to be considered and leads in the end to a sub-optimal solution for all stakeholders.

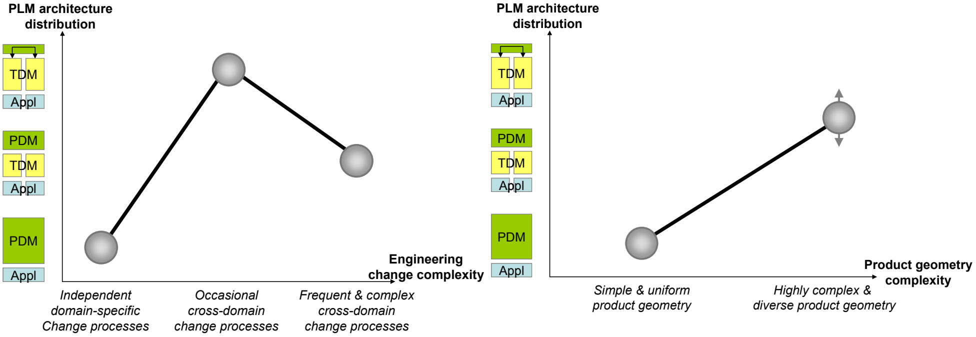


Figure 3. Implications of the design process characteristics "engineering change complexity" (a) and "product geometry complexity"(b) on PLM

Therefore, the next chapters will break with the paradigm of system orientation and introduce an integrated, process-oriented approach towards a PLM solution best supporting the entirety of requirements from the design process.

5. Process View

However, before presenting the approach the understanding of the term "process" as used in this paper and its relation to "PLM architectures" will have to be clarified.

5.1 Process - Definition and multi-level model

In literature, a lot of different definitions for the word "process" can be found. The differences in the definitions are very often caused by the origin of the process itself and the view on the process, for example economic or IT view [Brahm et al. 2003].

The basic definition defines a process as a description of a course or a development, whose aim is to achieve a goal or target [Hollingsworth 1995]. A process can be structured by a process box which has input and output figures. This generic process model can be used in different process levels. The typical classifications of hierarchical levels inside a company are: visionary level, strategic level and operative level [Scheer & Jost 2002]. For the PLM topic it is necessary to extend this approach (Figure 4a).

On the first level, called strategic level, visionary and strategic processes are located. These processes describe general business aspects and have effects on the whole company. The management level reflects processes which transfer aspects of the strategy down to real (operative) business aims.

All operative activities inside a company are represented on the business process level. Business processes consist of value-adding and supporting processes. For PLM the most interesting level is the workflow level. On this level information from the business process level and system level is linked. Thereby an integrated view on the processes including technical, such as design methods, and IT aspects, such as PLM functionalities, is enabled. On the last two levels, the system level and the data level, more technical information and data are represented.

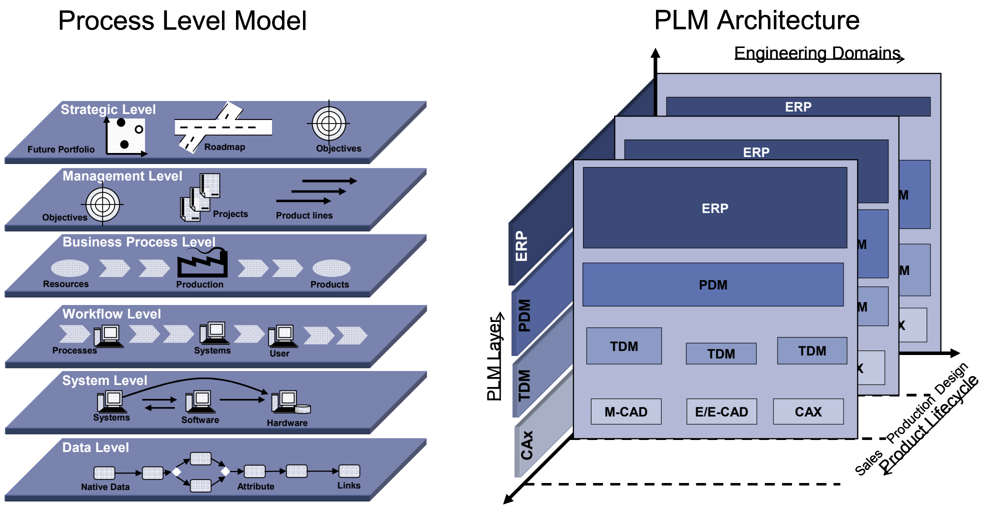
In literature a large amount of methods and tools for process modeling can be found. In industrial projects it is common to use business process model languages for modeling workflow processes, and, more important, because the tool seems to be the content of a singular process elements. A process element should include information about the process element name, person in charge, data format, data flow, IT systems and optimal extended process information. This way, a process model contains all relevant information for the following steps of analysis of the PLM architectures.

5.2 PLM Architectures

PLM architectures represent the individual IT landscape of *one specific company*. Very often the complexity of the organizational structure and the complexity of design (business) processes are reflected in the complexity of a company's IT and PLM landscape.

PLM architectures are built up of three dimensions (Figure 4b).

PLM layers: In automotive PLM mainly the following layers are distinguished: On the first layer are the authoring systems (CAx). Typically these are the systems where most of the relevant product data and information is created. The next layer covers all domain-specific data management systems, the so-called team data management (TDM) systems. These are often closely linked to authoring systems and support their advanced domain-specific functionalities. Moreover, TDM systems contain data or information which is only relavant for a defined team. The next layer, PDM, often is seen as the engineering backbone inside a company. PDM, as it is seen in this paper, interconnects the TDM modules and also builds the link with further company-wide systems, here the enterprise resource planning system (ERP). In a PDM system all product data is stored which needs to be distributed throughout the company. Typically, the product structure is located in the PDM layer. The last layer described here are the ERP systems which build the connection from engineering departments to the production and sales departments of a company. For this reason, in ERP there is more than geometrical data.


Process Level Model

PLM Architecture

Figure 4. Process Level Model (a) and PLM Architecture Dimensions (b)

Engineering Domains: The architecture of IT systems inside a company is very often structured in the same way as the organizational structure. As the organization of a company the architecture is therefore divided into several domains. Domains are organizational or thematic (business) units, like sub-departments inside the product design department. Examples for domains in automotive industries are mechanical (M), electrical (E/E), and software (SW) design. Normally TDM systems are structured in the same way as the domain-specific authoring systems. Exceptions might be possible, for example a common TDM system for mechatronic product development.

Product Life Cycle: The Product Life Cycle (PLC) can be seen as a time line in this context. Along the PLC the significance of specific layers and domains can vary. In the later phases of the product lifecycle the significance of geometrical data might be less important than in the early phases, whereas customer and service information gets more important.

A PLM architecture represents the situation of *one* company and for this very reason architecture has to be developed for each company individually. To reach an integration of PLM as deep as possible this development should start with the processes of a company. In the following chapter a pragmatic method is introduced which supports this idea of a process-oriented approach.

6. PPA Approach

The following paragraph presents an approach for a process-oriented development of PLM architectures (PPA). This approach was developed at the Institute for Virtual Product Engineering at the University of Kaiserslautern (Germany), evaluated in several industrial projects and is still under research. This will be explained in the last chapter [Bitzer et al. 2007].

The PPA approach is structured in four phases: "process analysis", "process requirement priorization", "architecture analysis" and "vendor analysis". Figure 5 shows the process model of the approach and its phases. "Strategic specifications" at the beginning of phase 1 and 3, represent critical input (e.g. "business strategy rules" or "pain points of the company") that might have a huge impact on the output of this particular phase. Each phase is closely linked with its subsequent operation by a loop. So, it is possible to react to changing surrounding conditions, like changing "strategic specifications" and to jump back again to the start of the previous phase.

Phase 1 – Process analysis

During the "process analysis" phase PLM-relevant processes are identified and investigated. A process is classified as *PLM-relevant* if it includes or affects at least one typical PLM function – like "configuration management", "release management" or "views management". Moreover, a process can be characterized by its process characteristics – e.g. "cross-domain complexity" or "product trait". Both factors are relevant for the following analysis and are covered by DPC.

When a relevant process is identified, it has to be "translated" into a process model language. In a first step, the as-is situation needs to be recorded and documented. Based on these process models process requirements are detected and written down in a requirement catalogue.

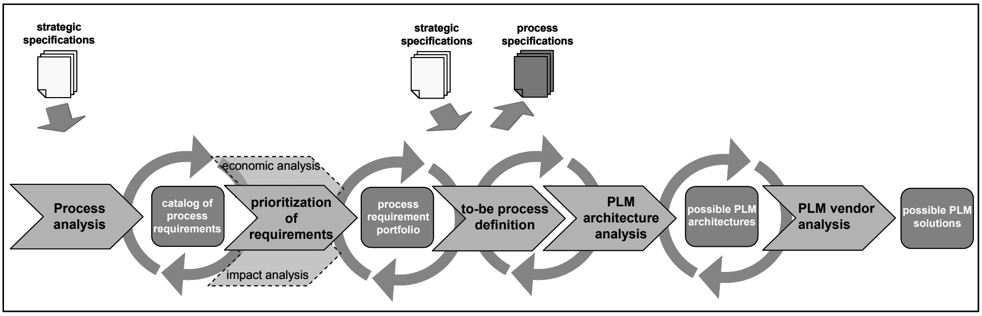


Figure 5. PPA approach model

Phase 2 – Priorization of process requirements

Depending on the complexity of the analyzed processes in phase 1 the number of requirements can be very high. Therefore, it is necessary to prioritize the requirements. Two criteria dimensions have been identified to support this process: economic and impact analysis. The economic quality of a requirement describes the monetary costs that are necessary to acualize the special requirement needed by a PLM IT tool. The impact quality is an indicator to express the interconnection between the requirements themselves. By this method, the requirements that have the most positive, active impact on others can be located, and they might be used to support the PLM implementation process in a very effective and efficient way. Based on the results of the economic and the impact analysis, the process requirement portfolio is build up as the output of this phase

Phase 3 – Architecture analysis

The PPA approach continues with the analysis of possible PLM architectures. Starting point for this analysis is the requirement portfolio. Based on this portfolio all relevant "to-be processes" can be developed. As an output of this sub-phase all optimized processes are documented. Moreover, pragmatic "process specifications" can be formulated which help the user in charge to work with these new processes. An example for such a specification could be the data format in which a 3D model has to be archived – e.g. "save as JTopen".

To transfer all information of the previous phases into an architecture, the so-called "PLM matrix" method is used (Figure 6). The PLM matrix is a pragmatic method to map relevant information on a hierarchical architecture (model) to find out possible PLM solutions.

In a first step all relevant process requirements are enlisted line-by-line in the matrix. Typical PLM relevant functionalities are set column by column and clamp the matrix. To complete the PLM Matrix typical PLM layers are enlisted above the line of functionality. PLM relevant functionalities are, for example, "product structure configuration", "change management" or "release management". In industrial praxis PLM layers typically are: (CAx), (TDM), (PDM) and (ERP).

The next step in this phase is to fill in the PLM Matrix and to use this method to transfer the information to concrete PLM architectures. First, line-by-line, all requirements are assigned to the functions that should be realized in the upcoming PLM landscape. Moreover, each function is mapped to one PLM layer where the function should be located in future. The mapping process is a process that should be done based on discussions in a group, e.g. the complete PLM project team – including PLM experts, both internal and external if possible.

The described approach is based on subjective evaluations. That means that different people filling out the matrix may come to different results. One way to overcome this potential disadvantage of subjective methods is to work in heterogeneous teams. A huge advantage of subjective methods is to get results without a definite basis of decision-making. Moreover, it is possible to get results in a very short time.

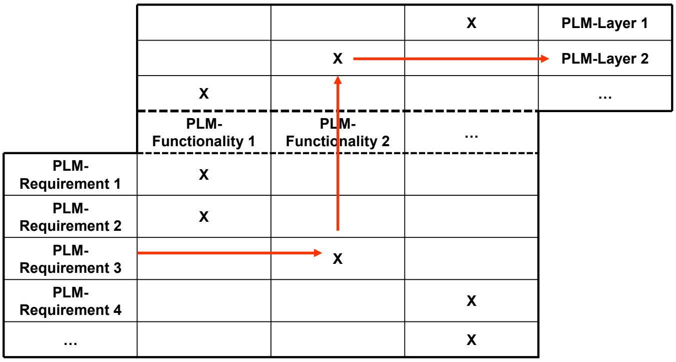


Figure 6. PLM Matrix

Phase 4 – vendor analysis

Based on the process-oriented architectures developed in the previous phase, the vendor analysis investigates available PLM tools and systems from relevant vendors that fit into the drawn PLM architecture.

7. Conclusions

In this paper, the correlation between design process characteristics and the selection of PLM architectures has been discussed. The analysis of today's design processes shows that in reality IT-systems have an enormous influence on the design process itself. In contrast to this, this paper presents a process-oriented approach developed on the example of a leading automotive manufacturer. This approach helps to analyze processes - especially design processes - and helps to develop suitable PLM architectures – based on the results of this analysis. By defining the PLM landscape in this way, design processes can be supported very effectively through tailor-made IT system solutions.

Future work will focus mainly on two aspects: First, the influence of design process characteristics on PLM will be further investigated as a sound basis for a scalable PLM architecture definition concept. Other process areas than design will have to be included into that investigation. A second point is the further formalization of the PPA approach as well as its validation in practical industrial PLM projects.

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