

# PRODUCT LIFECYCLE MANAGEMENT FOR CROSS-X ENGINEERING DESIGN

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## ABSTRACT

This paper deal with the urgent problem to create integrated PLM solutions in today's European automotive industry. Two European automotive companies have been used as case companies in order to carry out these studies. Configuration management and engineering change management are two information management processes that span throughout the extended company, through engineering domains and through the product lifecycle. This makes them ideal as study objects to create new methods, and to enable PLM for cross-x engineering design. Several guidelines regarding IT system architectures for cross-x PLM are presented, e.g.: modularity, central coordination, standard communication, minimum process redundancy, and general modelling constructs.

*Keywords: cross-x engineering, PLM, configuration management, engineering change management*

## 1 INTRODUCTION

In line with the demand for shorter time to market, automobile manufacturers are forced to cut lead-times, while product complexity continually increases. This trend is driving new concepts and strategies for product and process development. Concurrent engineering approaches have led to a situation where projects today are realized in a heavily interlinked, cross-domain, cross-business unit and cross-enterprise engineering environment – automotive engineering design is more and more cross-x; see Figure 1. Whereas the historically dominating mechanical design took place in the bottom-left-back box only, the challenge now is to manage the complete multi-dimensional landscape shown in the figure. With engineering IT having developed into being the predominant enabler for efficient engineering processes', this cross-x process landscape is now a precondition for efficient automotive engineering. Efficient cross-x engineering requires an efficient cross-x engineering information management system support – it calls for cross-x product lifecycle management (PLM).

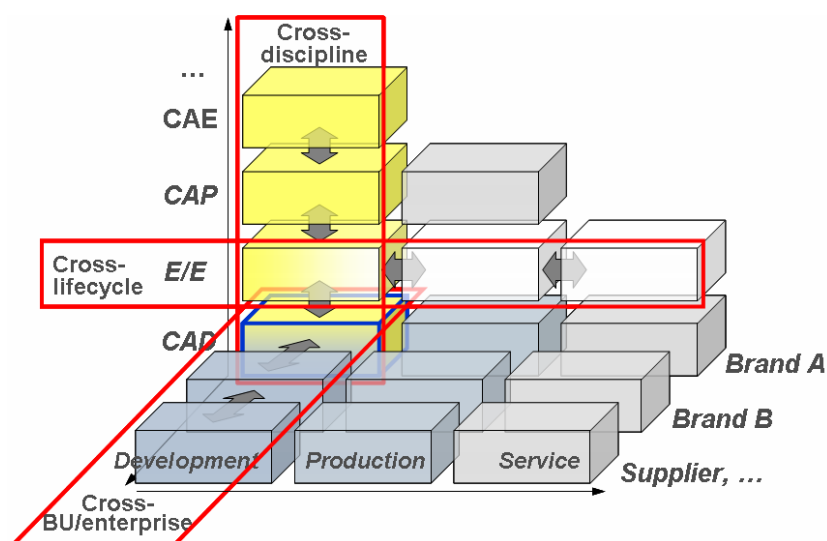


Figure 1. Cross-x engineering design dimensions.

Two cross-x engineering processes, configuration management (CM) and engineering change management (ECM), are investigated in this paper. The paper discussion is based on case studies performed in two leading automobile companies. Material has been compiled from previously written articles from the both companies, e.g. [1-4]. A workshop with 10 participants was held April, 2007 in Göteborg with representatives of both companies. In this paper, problems in product development related to gaps between engineering disciplines, development phases and enterprises are identified and elaborated. While cross-x engineering features at least the three dimensions shown in Figure 1, this paper will focus on general concepts based on the example of the cross-discipline dimension. The objective is to derive guidelines and principles for future solution concepts, and to present different options for such concepts (Chapter 5). Two case companies presented in Chapter 2. In order to study the cross-x possibilities two significant process areas for information management in automotive engineering – CM (Chapter 3) and ECM (Chapter 4) are discussed. An outlook (Chapter 6) is given on the future for an efficient solution realization in PLM systems.

## **1.1 Trends in automotive engineering**

Let us start with discussing current trends in automotive engineering in general and the trends of PLM in automotive engineering in particular. The aim is to identify research need related to PLM systems' abilities to support mechatronic engineering with standard PLM and product data management (PDM) functionality, and to investigate the lack of lifecycle and business integration approaches, involving the complete lifecycle of products as well as suppliers and partners within the extended enterprise.

### *1.1.1 Further growing complexity*

The product development process in the automotive industry is complex. Not only is this true for the products themselves, i.e., automobiles, trucks etc., which are continually growing in complexity to meet market demands. The product complexity is also recognizable for the customer; see Figure 2. Carmakers are confronted with a need to integrate a soaring number of electrical, electronic, and software components in what used to be a chiefly mechanical system landscape: “new cars are becoming computers on wheels”[5]. An explosion in the number of variants per model due to the trend toward mass customization, which strives to tailor-make cars to specification, continues to put pressure on the industry. Moreover, there are a multitude of organizational aspects that significantly impact product development. For example, experts across a variety of domains, both within a wide range of intra-company departments and from external organizations, are typically involved in the development of a single passenger car model. Thus the effective and efficient exchange of information between people and systems involved in the overall process is paramount. And the requirements and needs of the individuals managing this complexity need to be transparent in order to prevent a loss of information, duplicated tasks, and redundant data.

In state-of-practice product development, process activities are geared to run largely in parallel to reap the benefits from concurrent engineering [6]. The call for shortened development times makes it imperative that tasks are structured efficiently and that workflow is coordinated effectively. This therefore drives a continuing process of change, which affects the process landscape. In addition, the endeavour to cost- and time-optimize the iteration loops occurring during product development is pushing the general vogue towards front-loaded development, i.e., shifting of development tasks to the early phases of the product development process.

Apart from these cross-discipline aspects, collaboration in flexible and fast-changing cross-business unit and cross-enterprise engineering networks is becoming standard for future engineering. Large parts of the engineering work are outsourced to suppliers, putting the focus on inter-company communication and exchange.

### *1.1.2 Engineering IT approaches to manage complexity*

To cope with these challenges, the use of engineering IT tools for computer-aided anything (CAx) is spreading throughout the product development process, continuously increasing in functionality and covering areas formerly executed without dedicated IT tool support. Yet taking advantage of these enabling tools has led to rocketing heterogeneity of IT systems in the automotive industry; the system landscape now often resembles a jumble of stepping stones leading through the development path.



*Figure 2. Rapidly increasing complexity reflected in handbook thickness, where the manuals are separated by 15 years.*

The attempt is that the IT systems and tools provide optimum support in the areas they are tailor-made for, though due to the high degree of specialisation they tend to represent only partial solutions for engineering. In fact, many of these tools are proprietary in nature or, if bought off-the-shelf, have been customized to a large extent, thus generally necessitating a great deal of effort for maintenance and extension. What is more, data exchange between these isolated islands of IT systems is difficult to achieve. The obvious remedy to this problem is a move to integrated cross-x system concepts. In any such concept, PLM plays the key role on the way to a sustainable solution.

## **1.2 PLM as an enabler for cross-x engineering design**

The lifecycle perspective of PLM calls for integration of the whole product lifecycle. Collaborative Product Definition management (cPDM) [7] includes the extended enterprise in large collaboration projects. Lindquist et al. conclude that current support in PDM/PLM systems is focused on CAD, and that support in other areas is weak [8]. PLM as a basic concept requires management of the complete information relating to the product development process. When it comes to managing data, the aspect of data integrity is important; this is dealt with by ensuring information retrieval, provenance and protection [9].

Service-oriented architecture (SOA) [10] is an approach to design a PLM system that is not dependent on the server and client in a multi-tier environment. SOA makes it possible to integrate systems that are heterogeneous, and can since be a possible means of bridge PLM software gaps.

PDM/PLM systems traditionally have focused on hardware (mechanics, electronics). Their extension and usefulness for CM of mechatronic systems (functions, software and hardware), including interface to domain-specific tools such as Matlab/Simulink and software development environments, have been shown to be feasible given that the tools have open application programming interfaces (API) and provide means to customize the information models [11]. An integrated PLM solution that is able to trace all types of requirements and solutions will not only ensure that every requirement is presented and verified, but also facilitate change management and CM processes. In related research, the DIECoM project focused on CM of distributed systems [12]. In a study of introducing CM in automotive electronic and electrical (EE) development, it is concluded that there are no first-time right solutions, but rather a continuous zigzagging in order to find solutions that work [13]. Especially in the EE development, where the amount of functions and requirements has increased heavily, support for efficient ways of managing information is needed.

This paper targets the gap in research by connecting the state-of-art with the state-of-practice in the European premium segment of automotive engineering. This is done by focusing on cross-x engineering processes, and how these can be managed and made more efficient by the use of PLM. As pointed out by e.g. [4, 14], efficient information management both on a micro-level, i.e. on the level of engineering data modelling, and on a macroscopic level, i.e. on the level of system architectures, is one key challenge in industry and a basis for further improving the engineering processes.

## 2 PRESENTATION OF TWO AUTOMOTIVE COMPANIES

The companies are presented in this chapter regarding their cross-discipline PLM legacy.

### 2.1 Cross-discipline PDM at the Swedish Company

Traditionally the Swedish company has its roots in mechanical development, which has given the company a certain mechanical legacy reflected in its IT system support. The product development process is focused on development of specification documents spanning from high-level features to low-level requirements. The routines for management of complex relations such as connections to functional and system level requirements, are well established, especially when EE development is considered. The skills in managing requirements has had the result that the Swedish company has a lead regarding EE development, making the company the centre for global EE development within the group of other automotive brands that it belongs to. The IT systems have not been able to fully support and incorporate these relations into the PDM system. This has meant that components are managed in the PDM system while requirements are managed as documents in a document management system. There are overlaps between documents, since most references are copied between documents rather than linked. Document versions are difficult for ordinary designers to manage, and require specialist roles that cut and paste requirements between specifications. The heterogeneous landscape tied together by the PDM/Bill-of-Material (BOM) system is shown in Figure 3.

Within the group that the company belongs to there is a defragmentation strategy at a global level [15] and hence a striving towards more integrated solutions. The legacy PDM/BOM system, in use, is not intended to manage CAD data but rather focused on delivering BOM's for downstream systems. This has made the cross-lifecycle integration a relatively smoothly running process. Lately, several new systems have been introduced and placed "on top" of the legacy PDM system, which has made it easier to work cross-disciplines with requirements and CAD management. Integration projects of streamlining with the global development have been the source of several projects with different business drivers, e.g. for management of test protocols and requirements.

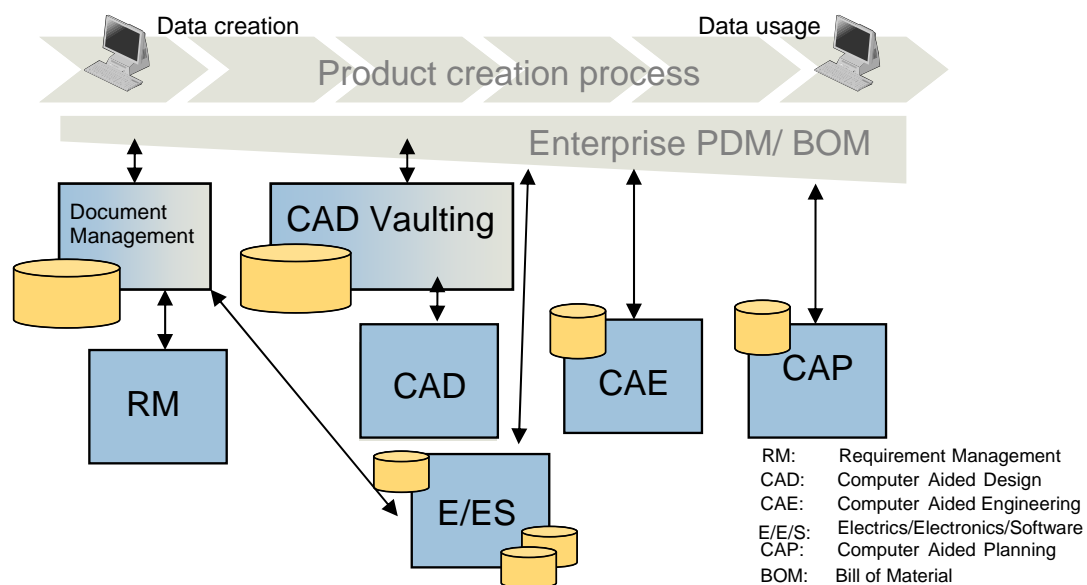


Figure 3. PDM/BOM system working as a cross-lifecycle integrator

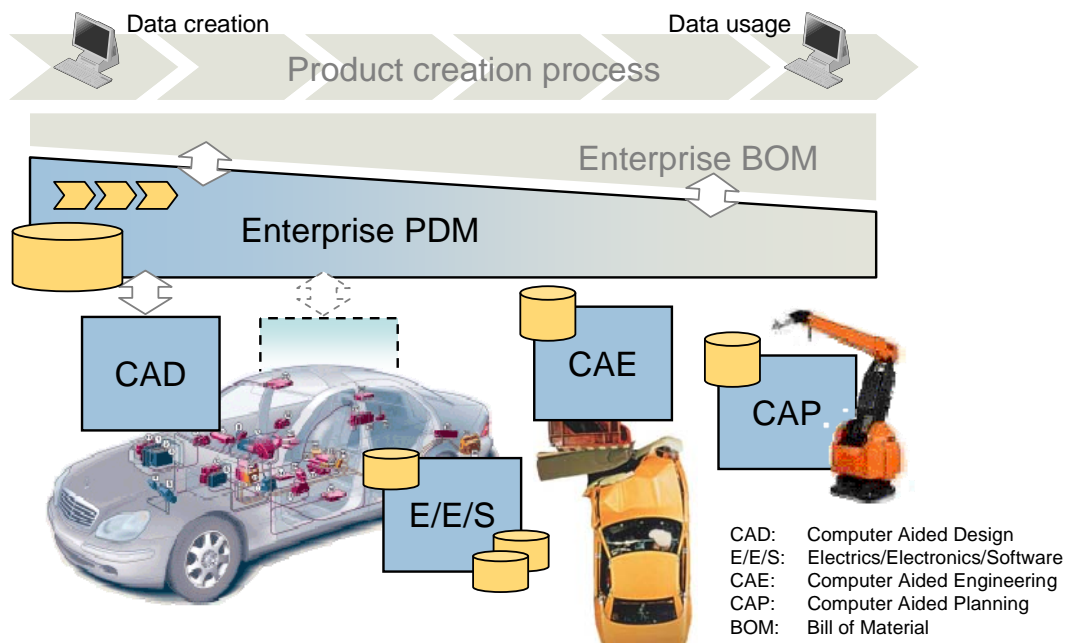


Figure 4. German company's PDM legacy

## 2.2 Cross-discipline PDM at the German Company

Similar to the Swedish automotive company, the current German company's PDM system landscape has derived from purely mechanical roots. The core development system is still the mechanical CAD system, the main product data management system is designed to best support CAD data management, and the development process and organization have long been oriented toward development of the mechanical product "car".

The CAD-oriented Enterprise PDM system was originally designed to support the earlier phases of the product development process, whereas the later phases are supported by an Enterprise BOM system, which also serves as the interfaces to the downstream systems that support the customer-oriented production process. Newer developments, however, show that data created in earlier phases are required also in very late phases, and vice versa. For example, with the replacement of drawings and other paper-based information by pure 3D master information, at least derived formats of CAD design data have to be made available to production and even service domains.

Besides the mechanical IT systems' world, several parallel IT islands have arisen with data partially managed in dedicated local product data management systems (LPDM). Creation and management of electronics and software information, a multitude of simulation and calculation applications, and digital production planning are just some examples; see Figure 4.

Early approaches to cope with this development were to successively integrate these data management islands into the CAD-oriented Enterprise PDM system. This, however, caused problems due to the different or even incompatible demands of the respective disciplines, and the thereby exploding complexity of the Enterprise PDM system. Therefore, newer approaches tend towards a more service oriented solution, as discussed in Chapter 5.

The examples of these two companies show that there are many things happening in the PLM industry, and that the companies have interests in introducing new IT systems existing on the market. Emerging standards have tried to link all these new concepts together (e.g., PLM Services [18]), but both of the studied companies are still struggling with how to manage the heterogeneous data created in LPDM's. There is no accepted standard way to exchange data between all LPDM's, and the concepts for how to do it, the processes that need the information, and the APIs supplied make the approaches different, even though the problem is somewhat generic. Both companies struggle with the integration towards downstream systems that are dependent on the legacy PDM systems.

### 3 CONFIGURATION MANAGEMENT

In order to study the cross-x possibilities management functionality spanning over several disciplines one of the significant processes identified has been configuration management (CM). CM, i.e. the management of both variants and versions of product information poses special challenges in a cross-x engineering environment. It is a complex process even in a single-domain environment since there is a large number of both people and components that has to be managed. The design cycle of an automobile is three to five years. In mechanical engineering, for instance, over this period of time, parts typically go through a process of several iterations until they reach a sufficient maturity for being released. In each prototype built, different versions of the same part may be used. Designers have to be able to manage all different kinds of such configurations to create and validate their designs. With thousands of parts comprising a car, it is obvious how sophisticated the configuration mechanisms must be in order to cope with these needs.

In a multi-domain environment, differences in the product development process between different engineering disciplines are problematic – for example in software and electronics development, different lifecycles, prototyping mechanisms, configuration logics, and data schemes are used than in mechanical development. The total lifecycle for an information appliance is generally less than a year [5]. Bringing this closer together with the mechanical design domain, in order to, e. g., ensure having a correct combination of software version, control unit version, and mechanical part version, both domains' configuration mechanisms have to be enabled to communicate with each other.

In addition to the described methodological differences, different domains are generally supported by different IT systems (e.g., LPDM systems), and the configuration mechanisms of different IT systems are generally not compatible with each other. There is currently no standard available which is powerful enough to allow a neutral description of automotive engineering configurations.

In order to support the described diversity, different options for CM have been evaluated. Figure 5 gives a summary of identified approaches. They differ in two dimensions: regarding how much data redundancy they require between the respective domains, and how much process redundancy they require. Data redundancy means that product data and structures have to be replicated between the respective domains. Process redundancy means that process logic from one domain's LPDM system has to be replicated, i.e. re-programmed or customized, in the other domain's LPDM system.

Option 1 shows the standard way such issues were addressed in the past in the studied companies. CM as a function, which was first established in e.g., a BOM system, was step-by-step re-implemented in other systems, e.g. the CAD LPDM system, to be used there as well. As a result, both product structure and configuration mechanisms were implemented redundantly in the same way in different systems. A sub-version of this approach is shown with option 5. Here, just a sub-functionality is re-implemented in the second system. It is not the complete configuration mechanism from the BOM system that is re-built in the CAD LPDM system, but rather a simplified mechanism on replications of discrete configured structures. With the general need of designers to more or less fully request the complete original BOM's configuration functionality to support the design process, this option tends to develop more and more in the direction of the described option 1. The realization of these options leads to re-implementation and thereby customization of one (data management) system's functionality into another system. It requires very complex interfaces and strong efforts to keep the redundant information in sync.

In order to overcome these issues, options 2-4 have been evaluated by the German company. Options 3 and 4 build on the principle of dividing the product structure and managing only defined parts of it in the different LPDM systems. It is however shown by Vielhaber et al [4], that the product structure as the central information carrier of the product development process has to be mastered by one key system. This must be made available, potentially in a different view, to all other structure-related LPDM systems.



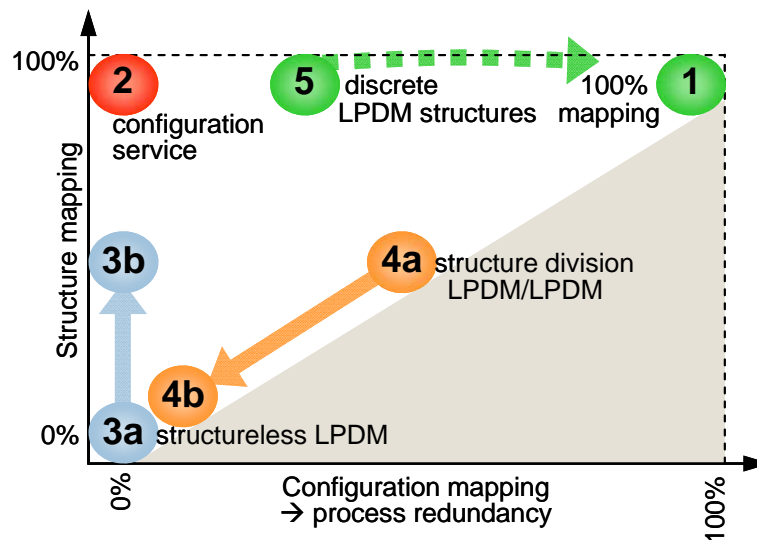


Figure 5: Five optional cross-x CM approaches.

Option 2 is being investigated further by the German company as a strategic domain-spanning CM approach. Here, the product structure is managed by a dedicated BOM LPDM system, and replicated to e.g. the CAD LPDM system. The BOM LPDM system provides CM services which can be called by the CAD LPDM system. Thereby the CAD users are enabled to use the comprehensive configuration functionality to support their design process without duplication of process functionality.

CM is one of the most important building blocks of automotive PLM solutions. New concepts for integration have to be developed in order to transfer the existing single-domain methods to a multi-domain environment. Different approaches for such concepts have been presented, and preferences have been pointed out. Initial investigations have shown that the main approaches suggested for CM are generalizable to support other cross-x methods as well – e.g. multi-domain access right management, or domain-spanning engineering change management.

#### 4 ENGINEERING CHANGE MANAGEMENT

A second key process area investigated in this paper is engineering change management (ECM). A better way to represent the products cross-domains would make it possible to enable relationships not limited to geometries, but also to include electronic functions realized by software. It is not a major problem if a PLM system would require some time to create new product information, as long as the information is easy to update. Changes in mechanical parts are relatively few since they are very costly (hard tooling etc.), and it would therefore not matter much if the change process requires some time. However, when it comes to changes in software there could be hundreds of changes to software during a product's lifecycle, which could lead to a lot of administrative work put on the designers.

The key concept when implementing cross-x ECM is to link all the affected data by an engineering change order. Problems with ECM are related to the lack of proper IT support in current IT systems. This leads to communication problems between different domains, as many functions can be involved in a change [16]. In a mechatronic product, both the EE domain and the mechanical engineering domain must be involved, as well as downstream domains such as manufacturing and aftermarket domains. When domain-specific IT systems are introduced, e.g. in the EE domain, these systems will only be able to manage changes in their respective domains, and changes that would affect neighboring disciplines have to be managed in another disciplinary system. Two major problems have been identified; process redundancy and data integrity. Process redundancy is coupled with systems that need to perform the same type of actions in separated disciplinary systems, while data integrity is connected to that information has to be duplicated in order to serve each disciplinary system. There are several options available that offers different possibilities for process redundancy and data integrity (Figure 6).

The first option is ECM in a heterogeneous IT-environment. The lack of an overall backbone PLM system makes it impossible to ensure a correct management of changes in a cross-x environment. Engineering changes that only affect one single discipline are dependent on the functionality of the discipline-specific IT system. The ECM would have to be performed manually, and when information is copied without tractability data integrity is difficult to assure which is shown as option 5.

The second option considers ECM in an integrated IT environment. This would offer the best possibilities but requires a fully integrated system. Data integrity is kept at zero, since data are only represented once across the company. However this approach is not likely to offer sufficient support for the specific engineering disciplines, since all needs are unlikely to be fulfilled with one Integrated IT system. Process redundancy is hence going to grow as new features are added to better support the design work. In a future it will also be virtually impossible to integrate all suppliers in the extended enterprise in such a data model; at some point it will be necessary to have separate systems.

The third ECM possibility involves the addition of an integration layer on top of the current LPDM's. Using an integrating layer that tracks what is happening in the discipline-specific databases will make it possible to find a compromise between the need for integration and the need for disciplinary tools. The problem is to manage and decide what information is needed for other disciplines, as well as how to ensure integrity if data are mirrored in an integration layer. This option would in most cases lead to medium process redundancy and medium information redundancy, since information and processes partly needs to be duplicated to assure availability to other disciplines.

The final option considered is to offer ECM as a service. This is an attractive approach since it is less dependent on the legacy systems. Process redundancy is kept at zero, since all applications have the opportunity to use the same service across the company. Data integrity is also kept high since data is not duplicated but extracted from the LPDM's. Problems with the service approach is to make it work with all the systems used at the company, this is however something that can be implemented over time as more services are added to the service layer. Gains are reflected to the maintenance and flexibility offered by the service architecture. When the service is not hard coded into specific software, e.g. the CAD system, this can be replaced without effect of the ECM service (Fig 7).

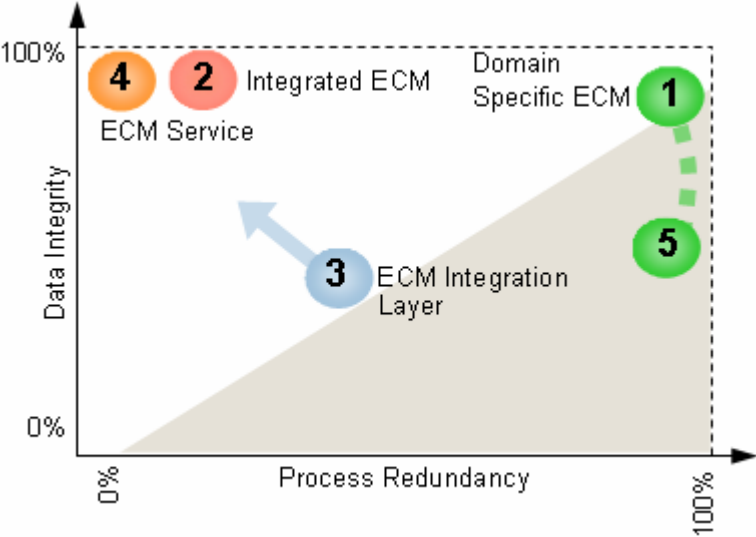


Figure 6: Mapping of ECM concepts to data integrity and process redundancy



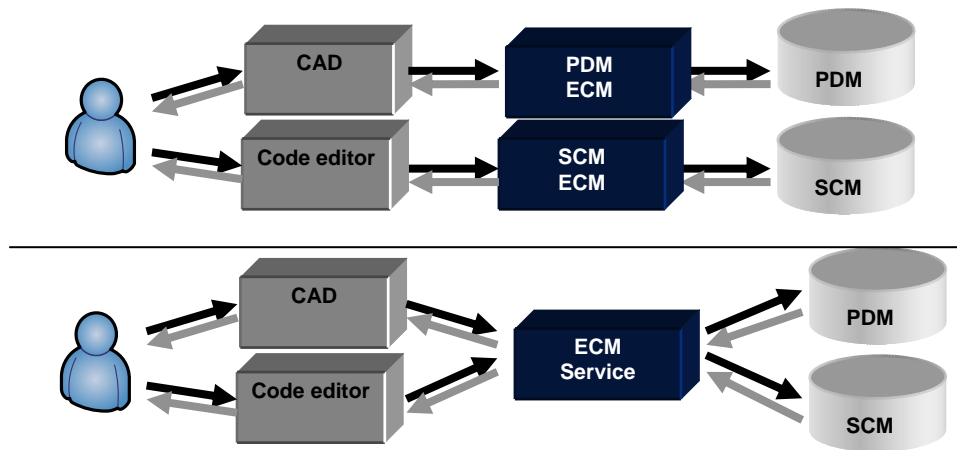


Figure 7: Process Redundancy in a (top) and ECM as a service (bottom)

## 5 ANALYSIS

The feasibility of the options discussed in Chapter 4 is heavily interlinked with the architectural layout of the supporting data management environment. In a first step, Chapter 5.1 will summarize essential principles that can serve as guidelines for the layout of future cross-x PLM environments. In a second step, Chapter 5.2 will propose and discuss alternative architecture approaches.

### 5.1 Guidelines and principles

#### **Modularity**

Future PLM layouts will have to support distributed, fast-changing processes, applications, and local data storages. This can efficiently be achieved by a modular approach replacing the monolithic legacy systems with highly independent, but strongly interlinked, domain-specific subsystems. Engineering applications have to be supported by domain-specific and application-near, LPDM databases. There must be means to flexibly add or replace such components.

#### **Central coordination**

In order to link the domain-specific modules together, a strong central coordination unit is required. On the IT side, this can be realized by some kind of integration layer. This layer will support the modules and their communication with central functions such as access management and a minimal, potentially standardized, domain-spanning data object and product structuring model [4]. Besides the technical view, it is of utmost importance to manage this coordination also on a domain-spanning organizational level.

#### **Standard communication**

In future PLM layouts, data flow will include all domains of the company. It will be difficult to manage a multitude of bilateral and proprietary interfaces. Instead, a strong standard for both communication and information structure is required that could tie the systems together with services. This communication standard is preferably based on a standard data model such as ISO 10303.

#### **Minimum process redundancy**

In a distributed modular PLM environment, methods and process step responsibilities should be clearly assigned to ensure data integrity. In a loose integration concept, strict rules have to be applied in order to avoid the same data being stored in different LPDM's. Cross-x PLM services will reduce the need for replication of functionality across different engineering tools.

#### **General modelling constructs**

In order to keep track of the information within distributed databases metadata to express conditions of use, cross-x would facilitate communication. Internally this added metadata would not affect the LPDM system but would be used to express cross-x relations and e.g. facilitate CM and ECM.

## 5.2 PLM IT Architecture

Current PLM systems are far from delivering an environment able to cope with the challenges presented above. The problems are at least twofold.

On the micro-level, the representation of the core product information is generally not sufficient. A rich cross-domain information model is required that sufficiently represents products, their structural information, their part information, and their assembly information. A universal modelling approach for product information based on so-called engineering objects (EO) was presented [4]. Based on such an approach, PLM system components will be enabled to fully support cross-x engineering processes. On the macro-level, the overall PLM architecture layout will also have to be enabled to support cross-x engineering processes. In the following, three different approaches will be presented and evaluated.

The integrated approach presented in Figure 8 can be seen as the ultimate type of integration. A compatible set of engineering tools is adapted to the processes and managed in one single database. However, the realities of automotive engineering have made this architecture an undesirable utopia that can not cope with the discipline specific needs. No single supplier today can deliver tools that are compatible and that work integrated cross-x. Not even in the R&D area itself has this been attained where tools and systems supporting different development disciplines cannot, without major customization efforts, be integrated while supporting the users. It is even harder to find integrated solutions that consider the product lifecycle.

In today's state of practice there exist several LPDM's; the tools give strong support for the specific domain, but cross-x information exchange is difficult and reliant on the APIs. The most common way to perform this is manually by a switching system and copying the data from one LPDM to another. The information needed in one system is therefore duplicated as a means to keep exchange of information between databases and engineering tools. Data integrity is difficult to assure since data are often duplicated and changed independently in databases. A set of rules has to be defined and it must be decided how and when information can be updated. If this is not done in real time, a problem of multiple existing concurrent versions arises.

With a service-oriented approach, as illustrated in figure 9, an integration layer contains the services, the rules ensuring data integrity will be possible to manage. The service layer will contain services that are needed to perform management functionalities cross-x. The rule basis for the service layer and how to manage the data integrity could be solved by accessing, collecting and checking the data from the correct database upon request. The domain-specific engineering tools will work as usual towards their appropriate database, offering full support for the design process. The PLM system as well as the user tools would access the services used for e.g. complete traceability and configurations when these functions are needed. The services could also be accessed by disciplinary tools and systems for non-domain-specific management functionalities, such as requirement traceability, DMU, simulations etc.

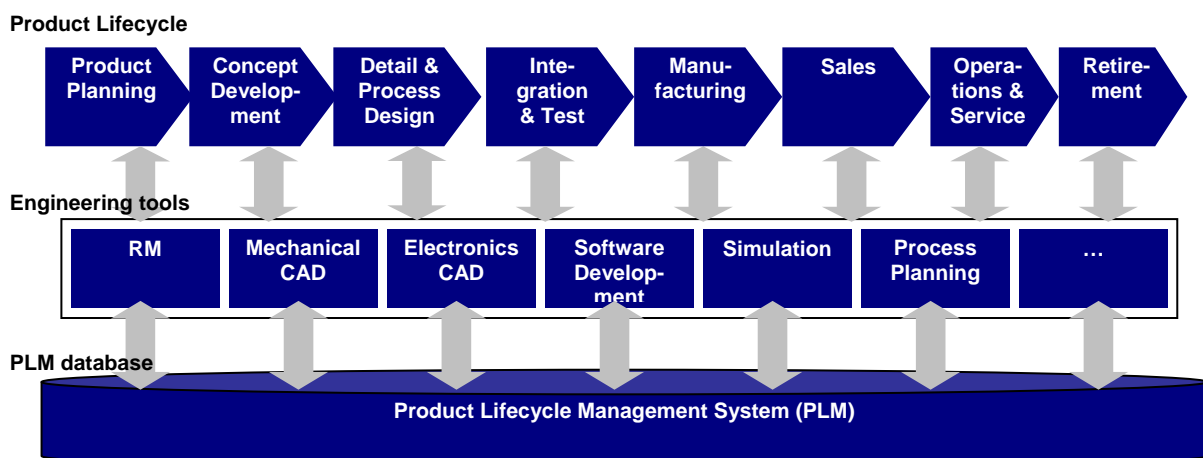


Figure 8: Utopia – all information is stored and managed in one single PLM database.

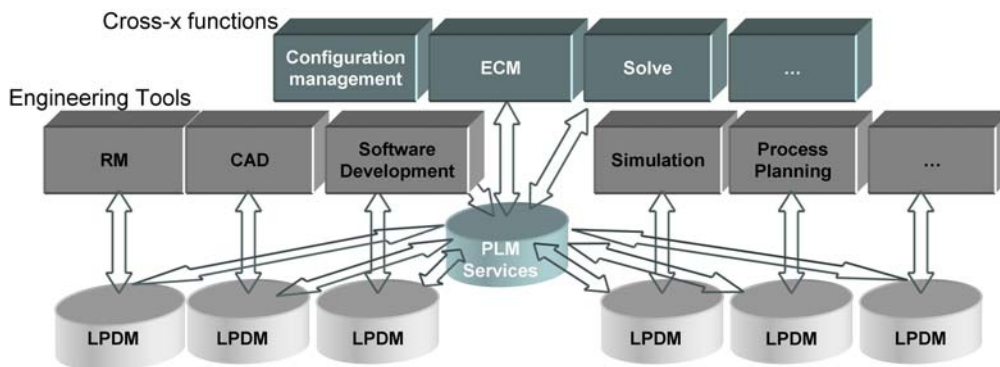


Figure 9: Service-oriented approach with cross-x PLM functions.

## 6 OUTLOOK

ECM and CM are two processes that are dependent on the availability of information from several LPDM's. ECM will ensure the quality of both information and the solutions if they are performed in such a way that related parts and information are checked for still being accurate after a performed change. Today the processes are quite slow, indicating that the amount of prudence is high since mistakes are easily made. A future where the data integrity is ensured could speed up the ECM process, something that has been shown to be essential especially in the EE domain where changes are performed continuously throughout the product lifecycle. The reality in the automotive industry, and especially in the premium segment, is the need to offer a variety of options to the customer. This has made it important to work with more advanced CM. When not only mechanical parts are to be configured on the basis "include"/"do not include" (if, and, else) but also configurable software is to be managed, the complexity increases dramatically. A future with configurable and replaceable software components is going to make it necessary to manage the individual produced car, since a future where all cars are unique and are differently configured will have complications in the aftermarket phase. With millions of configurations possible, it still must be feasible to test them all; in reality this could only be performed by simulations, which means that CM functionality has to be connected to the simulation software. In reality there exist a lot more integration aspects that may be manageable with a SOA approach.

There are differences between the two studied companies. The German company, for its part, has been using commercial PDM systems for some time and is in the process of replacing an old commercial PDM system. The Swedish company, on the other hand, has kept its legacy system for a longer period of time and is now in the process of introducing a commercial PDM system for the first time. The switch from a legacy system is regarded as more difficult since it is one of a kind where many interfaces to downstream systems have been developed over time, and where documentation is sparse.

As PLM is not a core business of automotive OEMs, this should be a basis for more cooperation and standardization efforts. This is already occurring in the German automotive industry as well as internationally in e.g. ISO/STEP [17]. Acting together, has shown that it is possible for the automotive industry to ensure that PLM suppliers support standardized integration concepts.

## 7 CONCLUSIONS

Car manufacturers in the premium segment struggle with relatively similar problems. It has been shown that engineering processes are more and more cross-x. CM is an important aspect in order to supply mass-customized products. Engineering change management is important due to the added complexity of managing more information (cross-disciplines) over a longer period of time (cross-lifecycle). PLM for cross-x engineering design is not yet a reality, but the companies have strategies moving in that direction. This research has identified important aspects of ECM and CM that can be further developed in future studies, and where integration through services is a promising concept. Moving towards an integrated cross-x PLM system, five major points have to be considered; namely: modularity, central coordination, standard communication, minimum process redundancy, and general modelling constructs.

It is believed that cross-x PLM will make it possible to work efficiently in each engineering domain while still being able to treat heterogeneous information in a way that ensures data integrity. The cross-x PLM will improve efficiency, since rules are built into the systems rather than the processes; costs, since configuration enables increased scalability; and quality, since relations are better managed.

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