

A COMPARATIVE STUDY OF ENGINEERING CHANGE MANAGEMENT IN THREE SWEDISH ENGINEERING COMPANIES

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ABSTRACT

This paper analyses the engineering change (EC) process in three different engineering companies in Sweden. In the paper, the influence of various company specific factors, such as change leadtime, for the design of the EC process are analysed. The current use of computer support is surveyed and the possibility to apply a modern product data management (PDM) system to support the process is analysed. The paper also presents different strategies for improving the engineering change management process as well as of the product data management systems in order to achieve an optimal process.

KEYWORDS: product data management, PDM, engineering change management, workflow management, process management

1 INTRODUCTION

The hard competition on the marketplace demands that the companies can develop and manufacture complex products with a higher performance and quality to a lower price than before to stay competitive. The product life-cycles have decreased during the last period, which emphasizes the ability to develop the products in a shorter time in order to maximize the market window. The old sequential way of performing product development (PD) and produce large series of expensive products is more and more turning into production of customer variants with a fast adoption to changing customer needs, requiring that the EC process can be performed quickly.

An increasing product complexity utilizing multiple technologies along with the shorter time for the PD process makes it necessary to have more people with different competences involved in each PD project, forming a concurrent engineering team.

The trend for the industry is quite clear with more digital product and production verification using virtual reality and digital mock-up technology. This will inevitably lead to an increased amount of digital files, which in turn demands a secure product data management, that can keep track on all virtual and physical products and their corresponding documentation. This impacts on the data management within the EC process, since an increasing amount of documents have to be managed and changed.

The ideal when designing a product is to get the design right the first time, eliminating the needs to make changes. However, changes due to wrong decisions and changes in customer requirements are unavoidable. If a undesired design decision has been made the product data has to be changed in a controlled fashion. The impact of the change has to be investigated and all documents related to the error have to be identified and changed. In the best case only some documents have to be changed, whereas the worst scenario is that the production has to be stopped and already delivered products have to be recalled with a substantial prestige loss for the company. When changing approved documents, many companies use a formalized engineering change management (ECM) process where the important issues when making a change are pointed out. The process should be designed

to solve the problem and prevent new errors. An EC process that is fast and reliable can even improve the customer relations.

The EC process requires extensive communication between different functions within a company. Depending on how far the product is in the life-cycle, more and more functions, ranging from design to after-sales, have been involved. In order to provide the best solution possible, all involved functions must be able to give their opinion on the change. This is often accomplished by a cross-functional engineering change committee, which decides upon the changes. The EC process does however not end with the committee decision. The information has to be processed several times through the company before the change can be fully introduced. Due to the intensive data management within the EC process, vendors of product data management (PDM) systems often provide an EC module (CIMdata, 1995). These modules are based on the assumption that the EC process can be generalized and implemented in a computer system. One of the purposes of this paper is therefore to determine whether the process can be generalized or not based on the conditions in different companies. By modelling the EC process in three engineering companies, specific company factors for the design of the EC process have been determined. Based on the models, suggestions of improvements of both processes and the PDM systems have been found in order to be able to provide a good interaction between the EC process and the PDM system.

The outline of the paper is as follows: section 2 gives an introduction to engineering change management. Section 3 describes the method used in the case studies at the companies presented in section 4, whereas the case studies are in section 5, section 6 and section 7. The studies are compared and analysed in section 8, and finally, the conclusions are presented in section 9.

2 ENGINEERING CHANGE MANAGEMENT

2.1 Why ECM?

In many companies the formal use of the engineering change process starts when a design project has reached its first baseline (e.g. "System Design Review"), after which all project documentation will be submitted for approval and locked for further work. The baseline is a check-point before starting new activities that may demand accurate information (e.g. detail design or production). In some industries (e.g. the defence industry) the customer is involved in the baseline approving the work done up to this point. All the documents are verified

against specifications and released. Once released, documents may only be changed by applying a formal EC process.

The reason for making changes can originate from different causes. The draft standard ISO11442-6 (1996) gives the following examples:

- change of a part depending on altered function or production requirements
- change in the application of a part
- introduction of a new part
- replacement of a part
- withdrawal of a part
- correction of errors on a document
- bringing an old document up-to-date

The examples above are very much focused on parts and documents. A view that is more focused on different stages in the product development (PD) process would describe the causes as:

- changes in the customer specification
- faults in the interpretation of customer demands into technical requirements
- difficulties in parts fabrication or assembly
- weaknesses in the product identified during prototype testing
- quality problems with some subsystem or component
- development for future product revisions

If the complete formal process would be used every time a released document changes it would have a very large impact on the progress of the PD process. In order to reduce the amount of changes companies often treat changes that do not affect the form, fit or function of a part with a simplified EC process. Another way to reduce the lead times for making changes is to classify changes in a more sophisticated way and treat them with different processes depending on the nature and the importance of the change (Balcerak and Dale, 1992).

The EC process is a core process of the larger configuration management (CM) process. Each change of the product or of its corresponding documents causes a change of the product configuration. This means that every time a new revision of a product document is created, it must be linked to the correct product individuals produced. When a malfunctioning product is reported to the company, the corresponding document revisions must be easily found. This is particular important in the defence industry and when many product variants are produced (Merlenbach, 1992). The implementation of an efficient as well as effective EC process is thus of general importance for a successful CM process.

2.2 Problems with the EC process

The EC process is associated with certain difficulties. The formal use of the process starts when documents have been released, which means that the documents have been distributed from engineering to other departments within the company. The reason to change the documents is often discovered at other departments than engineering. Many different departments are affected when documents are to be changed. In order to perform the change in the best way possible and fulfil the wishes of all parties, the EC process should be performed in a cross-functional environment (Diprima, 1982). This has often proven to be difficult, since functions typically have different goals. The goal of engineering is to perform a certain function in the best way possible, whereas the goal for manufacturing might be to assemble in short time and cutting material costs might be the main objective for purchasing and so on.

The EC process is often associated with long lead times, which is caused by a number of factors. First, the process requires extensive document management. Documents are checked-out from the archive, new documents are created in order to document the change and documents are sent for approval. This is time-consuming, especially if the archive and distribution is paper-based. The use of digital vaults and workflows in PDM systems offer a possibility for substantial rationalization on this point. Secondly, the process requires meetings with all affected persons in different departments, where alternative solutions are evaluated to satisfy everyone. This problem is mainly associated with larger changes. Smaller changes can often be performed within the design department.

The complexity of the change process leads to long learning time for new employees and consultants. It is not always easy to understand the reasons for the design of the process and why the information has to be processed in the specific way. This lack of knowledge and understanding often leads to frustration and employees tend to be unwilling to use the process. Instead, some changes are avoided or performed without using the formal process. This can lead to an incorrect or incomplete documentation and problems in the latter stages of the product development (e.g. manufacturing).

The nature of the ECM is also a source of irritation. When starting an EC process, it means that designers have to redesign something they have already done before. The designer might feel accused of having done something wrong or that he/she must do the work again because some other designer has made a design error on a connecting part. This gives the EC process a lower

status than the creative “first time” design and results in a negative attitude towards the EC process.

The process has no traditional computer support. The legacy systems at companies often only expedited the ECO:s (Engineering Change Orders), which in more advanced solutions were linked to the product structure or the affected documents. All functional departments have their own main computer system and the cross-functional nature of the EC process would require integration of many different systems. However, the commercial PDM systems now offer modules for the ECM. The systems also claim to enable integration of all systems within a company, thus making it possible to automate and improve efficiency of the ECM.

The research in the engineering research has been diversified into two main categories by Wright (1997). Firstly tools for analysis of ECM problems and secondly methods to reduce the impact on manufacturing and inventory control are studied. This study focuses on how both the process and the computer tool could be improved to get a good interaction between process and support tool.

3 METHOD

The EC process originates in the need to change information on different types of documents. The changes are done by people, who play a certain role in the process of changing information, by using different computer systems. A model in which the ECM is to be compared must thus manage the different entities *process*, *roles*, *information* and *computer systems*. It would also be an advantage if the information in these models could be linked to a holistic model of the complete EC process.

In order to be able to study and compare the EC process at the different companies a standardized modelling technique had to be used. The methodology is based upon the method presented by Vroom (1996), which suggests the creation of a metamodel based on the three dimensions *activity*, *information* and *subject*. Vroom's model has been extended to cover the aspects *process*, *system* (or *tool*), *information* and *roles*, which gives a more detailed view of the interactions between for example systems and roles which were all treated as subjects by Vroom. The analysis between the models for different companies is thus easier done when using more aspects.

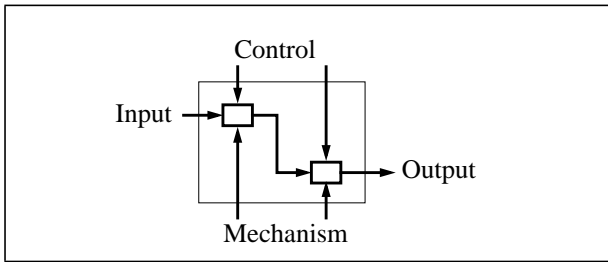


FIGURE 1: Conceptual IDEF0 model

The modelling was performed in four aspects: processes, roles, systems and information. The process is modelled with the IDEF0 methodology (Ross, 1977), also referred as the SADT methodology, and forms the main model in the study, see figure 1.

In order to do a more comprehensive study, the most important aspects were lifted out of the IDEF0 model and given own models. A computer tool may for instance be part of a larger computer system, where other tools are integrated. Conclusions regarding the use of computer support and possible information exchange between systems can be identified by using this model. The information model is also of a great interest because different companies have different views on how information should be classified and structured. For example, the minutes from change committee meetings can be regarded as project documentation at some companies and as change documentation at other companies. The role dimension will show which roles are involved in the ECM at the different companies. The interactions between the different aspects are modelled as relations.

The entities of the models and their corresponding relations are presented in figure 2. The different aspects play important roles within the EC process. The main objective of the EC process in engineering is to change the information content in documents. The documents are stored in different computer systems or in archives. The process dimension illustrates how the aspects interact (or should interact) with each other in different processes. By linking the different aspects, deficiencies between the process and access to systems or information can be discovered. For instance, the model quickly shows if a reviewer does not have access to an appropriate computer system, where the information (e.g. CAD file, text document) can be viewed without information loss.

The models tend to grow fast in complexity with a large amount of relationships, see figure 3. The relations can however be visualized in relationship matrices between the different entities, see figure 4.

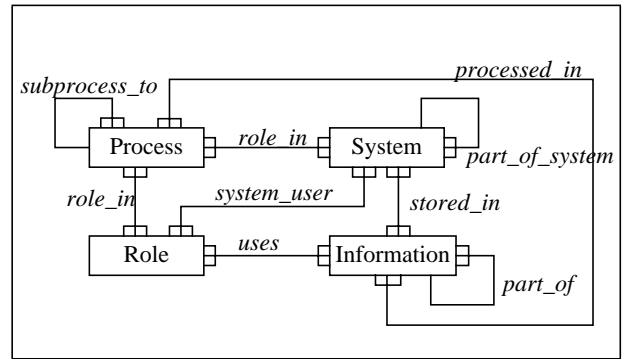


FIGURE 2: Entity-relationship diagram over the models

In summary the advantages of this approach are:

- good overview of the objects within an aspect
- the complete model gives a formalized picture of the entire process and therefore forms a good base for discussions and a future reference model
- the relations between objects can be represented in relationship matrices, which enables an easy interpretable representation of relations between objects
- existing computer tools can be used for the modelling as well as for the visualization (Metis (1996) and www).

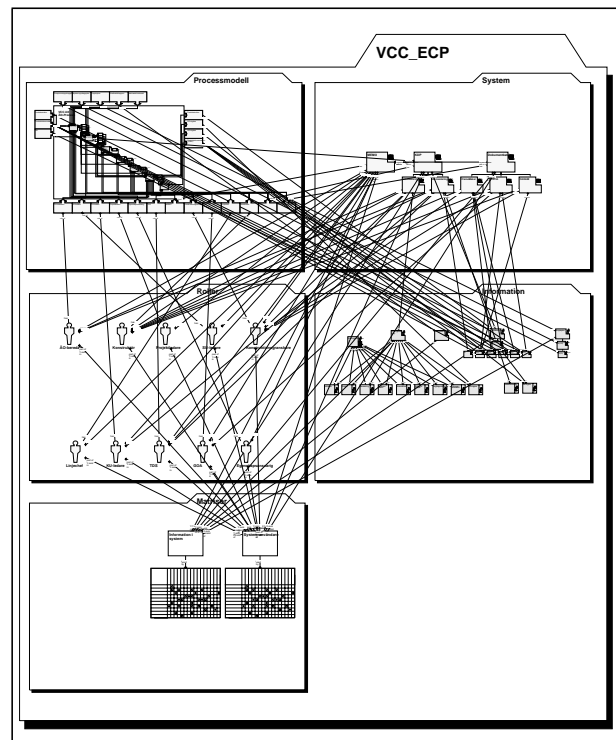


FIGURE 3: Complete model example

TABLE 1: Company profiles

	VCC	FFVA	CTE
Employees involved in PD [consultants]	1700 [300]	400 [few]	600 [<5%]
PD organization	Project	Functional	Project
Development time	18 months ^a	1 week - 15 years ^b	1-2 years
Complexity (no. of parts)	High	Low-high	Medium-high
Variants	Many	Few	Few
Series	>10000	<10	5-100
Reuse of information	High	Low	Low
Computer skill	High	Medium	Medium
End customer	Private people	Defence	Defence

- a. The development time for VCC regards new year models.
- b. The large span in the PD time and complexity for FFVA originates from the type of product that is to be produced. In the most simple case, the product may be a screw driver for a certain test purpose, and in the most complicated test equipment for military aircraft.

The single models will point out the differences between the companies documents, roles, processes and computer support, whereas the use of the resources can be analysed in the complete model. One shortcoming with this technique is that mainly document producing actions are captured, whereas the primary goals for an activity such as minimize cost or improve quality are omitted. The IDEF0 methodology gives weak support for the modelling of parallel subprocesses and for the informal communication within a subprocess. A simpler method for analyzing how a PD process can be improved is the use of design structure matrices (Eppinger *et al.*, 1990). This method also provides a better overview, since IDEF0 models tend to grow in complexity very fast. IDEF0 was however chosen, because the modelling of the different aspects was easier using this methodology and the complexity was not a large problem when using a computer tool for the modelling and presentation. The formalism of the IDEF0 methodology was also considered as a key issue for the analysis for a possible introduction of an EC process within a PDM system.

4 CASE STUDIES

The case studies that are performed in this study are discussed in more detail by Pikosz (1997). The case study has been performed in three companies:

- Volvo Car Corporation (VCC)
- CelsiusTech Electronics (CTE) a supplier to the defence industry
- FFV Aerotech (FFVA) a supplier of test equipment for military aircrafts

The companies were selected to have different profiles with respect to the factors listed in table 1. We consider the set and range of factors complete enough to draw some generally valid conclusions. It would have been desirable to have a company performing world-wide PD projects and one company that manufactures less complex products in the study.

The studies have been performed in accordance to the following process:

1. Introduction meeting, where process documentation was received
2. Study of documentation
3. Creation of a preliminary model based on the given information
4. Meeting at the companies to verify the model
5. Updating of the model

Final verification meeting with the company, where conclusions were discussed

5 CASE STUDY AT VOLVO CAR CORPORATION (VCC)

A global trend amongst large manufacturing companies wish to enable a better communication with its suppliers and also to transfer the design responsibility of parts and subsystems to suppliers. At VCC this sets challenging requirements on data sharing and security, since suppliers often deliver to several automotive manufacturers. A PDM system can provide access to selected parts of company data for suppliers. The supplier can see the progress on related parts at the manufacturer, and at the same time store his documents in the main system. This approach gives both the manufacturer and supplier a better holistic picture of the complete product development process and enables a closer cooperation with shorter lead-times for the PD process.

VCC has no direct requirement on PDM from its end customers. However, the adaption of cars to individual customers preferences requires that a large variety of variants is produced. This forces VCC to manage large quantities of documents corresponding to the variants. It is further very common that VCC communicates product data with its suppliers. This communication can range from sending product information for manufacturing at the suppliers to more complicated scenarios, where the supplier has full responsibility to develop and document a subsystem.

VCC has recently introduced a work methodology based on co-located cross-functional *module teams*. The teams are focused on subsystems (or modules) of the car and each team consists of representatives from design, production and purchasing. The teams are thus put together in a way that enables a maximum concurrency. Each team is provided with the state-of-the-art computer tools to solve their task, but the overall integration system is an in-house developed system that was designed to support a sequential work process. An investigation has now been started in order to identify a PDM tool that can support the concurrent work methodology and provide maximum support for communication of product data.

Product data management at VCC is today (1997) mainly supported by systems that originate from the late 1970's. A large problem at VCC is that consultants and new employees find the legacy systems difficult to use. The user interface is terminal-based and requires extensive training (one of the goals with the PDM system introduction is to offer the users an easy-to-use interface). In order to simplify the handling of transactions in the product structure and EC system a special role, EC coordinator, is currently necessary.

Every time a new year model project is started, engineering change orders are written for all subsystems that are to be changed. If new parts and documents are to be designed, new part id and document id's are assigned to the ECO. This use of the process implies that it should be well known to all PD team members. The process is however not particularly well understood amongst the PD team members, of whom many are external consultants.

The engineering change orders at VCC are problem oriented and not parts or documents oriented. This means that one ECO is written for each change request, rather than writing ECO:s on all articles affected by a change. A direct link from the ECO to the product structure exists in the legacy system. This gives the users fast information whether a part or subsystem is subject for a change, but there exist no links between the product structure to the system that manages the actual files. The ECO:s are focused on introduction in manufacturing and the time is stated in an early stage of the change process. This states a clear time target for all team members involved in the EC process. VCC also assigns priorities to ECO:s, enabling faster introduction of important changes (i.e. quality or manufacturability).

The ECO:s at VCC can be updated in several editions. The reason for this is the fact that many changed documents are iterated back to design from manufacturing due to errors like "inability to manufacture". A new edition of the ECO is then created and the documents can be modified without the release of a new ECO. The reason for this problem is a lack of communication between engineering and manufacturing. Manufacturing is not able to read the documents unless they are released from engineering, which is done when the ECO gets released. As a consequence of this late release of completely changed documents, feedback is given in a late stage. In order to prevent a new writing of ECO:s with special board and project meetings, a new edition of the same ECO is iterated and the documents are changed in accordance to the feedback from manufacturing.

The fact that VCC is a large company with a highly complex product is reflected in the fact that many different functions take part in the evaluation of change proposals as well as in the final release of the changed documentation. VCC has potential to improve the information sharing during the design and release phases. If for example manufacturing or purchasing could comment on a part during earlier phases of the design, the amount of iterations of the ECO:s would decrease. This could be supported by the viewing and workflow functionalities of the PDM systems. The progress of the design could be viewed by employees on other locations

than the engineering department and instant commenting can be done by red-lining and e-mail in the PDM system. Further on, the PDM system provide more easy-to-use interfaces, often web-browsers, which provide more information users with an interface they understand and are able to use without extensive training.

6 CASE STUDY AT FFV AEROTECH

FFVA is the main supplier of test equipment for aircraft within the Swedish defence. The many products developed at FFVA are classified as critical for flight safety, which is reflected in the EC process. The requirements on PDM at FFVA differs from most other companies. In order to develop their products, test equipment for aircrafts, FFVA relies on the documentation from the aircraft manufacturer. The test equipment is developed and manufactured in parallel with the aircraft, which can take up to 15 years, and documents are constantly transferred from the aircraft manufacturer to FFVA. This information must be connected to the correct version of the design information at FFVA, which makes the configuration management a key issue. In addition, the customer (FMV - Swedish Defence Materials Administration) demands extreme cautiousness with the PDM, due to flight safety regulations.

In this study, the focused changes were changes on delivered products. The reason for this is that change process in this phase is more complex and it is also well documented. Changes of in-work products are often treated informally, which gives a fast adoption to changes from the aeroplane manufacturer.

ECM at FFVA is to a large extent controlled by the customer. The main objective is to verify and document engineering changes before the introduction in the product, thus it is not a prime goal to get a fast change process. The biggest problem experienced at FFVA today is, as mentioned, the configuration management.

When a failure report is approved, a number of change alternatives are proposed. The proposals are examined and the best one is selected by an engineering change committee (ECC). The customer is often involved already at this stage, since the choice of solution may differ financially and the changes are paid for by the customer. When an emergency occurs, it can be solved by writing a special document that describes a preliminary measure until the change has been properly examined. When the selection phase is completed an ECO is written and the re-design process is started. When the documents have been changed, the new design is verified with respect to both functionality and manufacturability. The

documents are iterated until both tests turn out positive and the changed documents can be sent for approval. Depending on part type (HW, SW or maintenance documentation) different release processes are initiated. The hardware release is mainly focused on configuration but there might also be drawings with formal errors, which are corrected instantly. The software approval is carried out in two steps, firstly the code is reviewed and approved and secondly the program is tested in a prototype and released. Maintenance documents are also reviewed with respect to a technical standard (everything must be correct) and from a lingual standard, where a service technician is asked to perform service in accordance to the regulation. When the change is internally approved, the customer has to approve the introduction to produced and delivered products. This approval is based on the changed documentation and the additional documents and reports that have been produced during the EC process. The last step of the process is to distribute and archive the documentation.

The information handled in the EC process at FFVA differs with respect of two aspects. The first one is the special document for urgent measures on already delivered equipment. Secondly, the demands on the documentation set by the customer are high, which forces FFVA to produce an additional amount of product documents and reports. This large amount of additional documents can only be reduced by the customer.

Instead of having a designated EC coordinator, the ECO:s at FFVA are managed by a handling officer. The role of the officer can to large extent be compared to a designer but the handling officer is additionally responsible for all changes for an object (e.g. HW, SW or regulation) and is also responsible for deciding whether a failure report is correct.

The current computer tools are only used for the creation of data and to send e-mail amongst users. The archive is currently paper-based and all communication of archived documents is by sending paper copies through the internal post office.

The introduction of a PDM tool to support the EC process at FFVA would only provide isolated small improvements, like for example viewing of information, version management of own documents and archive storage. An automation of the complete process would be hard to perform in a PDM system, since different documents are treated differently. In order to obtain a process that can be fully supported in a PDM system, a business process reengineering (BPR) can be done (Davenport, 1993). Instead of focusing on process leadtime, which is often the case in BPR, the process can

be fit to the requirements of FFVA. Documents regarding aircraft are currently stored at three places: the aeroplane manufacturer, FMV and FFVA. Since the information already is shared, the companies should investigate the possibility of introducing a shared database instead of having three separate archives. The PD teams on FFVA and the aircraft manufacturer could better synchronise their activities and FMV would be helped by a better overall view of the progress for the complete aircraft system. Commercial PDM systems have the possibility to lock documents for different users, which enables the possibility to keep information secret until it is released to the other parties.

7 CASE STUDY AT CELSIUSTECH ELECTRONICS

CTE has about 900 employees. The products are mainly delivered to national defences. The products are often highly complex containing mechanical and electronic hardware as well as software. The design is mostly made to customer orders. The formal use of the EC process at CTE starts when a project has reached the first allocated baseline and the documentation has been approved and frozen.

The main focus when designing the current process at CTE has been to enable a fast and quality focused process that can be supported in a PDM system. The process starts by the evaluation of a failure report and investigation of possible solutions. The suggestions are evaluated by an EC committee, which decides on the proposed measures and writes ECO:s for all affected parts. This is followed by the redesign process, where the change is planned and executed, followed by a review and approval and finally the changed documents are distributed and archived.

The amount of documents created and managed in the ECM have been reduced by the replacement of three different failure reports by one. There are currently only three document types that are specific to the ECM. The information is though still paper based for the change documentation, but the reduction of ECM documents makes it easier to implement the documents in a computer environment.

CTE have no designated role for the management of ECO:s. The normal procedure is that the ECO is signed by the project manager, design manager or product manager depending on level and type of the change. If the change for example contradicts a company policy, it must be signed by the product manager. The EC committee is a flexible group, which is specially composed for each change proposal. This gives the company the possibility to always gather the most experienced people for each

change, thus giving the opportunity of making the correct decision.

The computer support for the ECM is today poor. However, CTE has investigated the possibility to introduce a PDM system to support the process. A closer study has shown that there exists a fundamental difference since CTE links the ECO:s to the product structure. Most PDM systems have a problem oriented approach linking one ECO to a problem, regardless the number of parts to be changed. CTE, as most companies in Sweden, have a part oriented system linking one ECO to each part that is to be changed. This is further discussed in section 8.

The main objective with the computer support of ECM in a PDM system is for CTE to enable a faster change process. CTE also experience a poor support for information sharing. The EC committee meetings could for example be supported by the viewing functionality of the PDM system to enable participants to view the information before the meeting. Moreover, the PDM system can be used to support check-in and check-out of documents and to support versioning of documents. In order to provide a fully automated process, only digital documents should be used in the process. Since most documents are created in computer tools, this should not cause any problems. Today's paper based ECM related documents could be directly implemented in the PDM environment. This would enable an intuitive link between changes and product structures providing all team members with fast and accurate information about changes in the product structure.

8 ANALYSIS OF THE CASE STUDIES

In this section a comparison between the different case studies with respect to the different aspects will be made.

8.1 Processes

The ECM at VCC is seen as a key process and it is used every time a document changes. When designing a new year model of a car, it is seen as a change of the old product structure. Thus, ECO:s are created for all planned changes of the product structure and all designed subsystems and parts have to go through the EC process, which is therefore more frequently used at VCC. Each ECO is connected to an introduction date for manufacturing, which gives a goal to work against. The information sharing is supported in the way that other designers can access the digital files after the first baseline, where the status is lifted from private to preliminary. The documents are, however, not made accessible to

other functions within the company. The ECO is released together with the other product documentation in order to provide a possibility to iterate the ECO due to late response on changed documents from functions that can not be co-located with the PD project. The reason for this is that VCC is a large organization and all design work cannot be performed at the same location, and in addition, some of the manufacturing and design is performed by suppliers. This diversity can not be supported by co-localization, thus computer support is needed.

The process at FFVA is focused on the quality rather than speed of the change. The reason for this is that the product is identified as critical for a system functionality and a system malfunction could result in an aircraft crash. It is possible to perform changes slowly at FFVA since they have no serial production, thus changes will not cause any severe production stops. In order to verify each change, the new solution is tested with respect to functionality and manufacturability. In special cases, when a fast measure is necessary, the longer change times are by-passed by a service report giving the possibility to implement a temporary measure.

The ECM at CTE is built up of fewer subprocesses than in the other two companies. The process is designed to be fast and able to implement in a PDM system. One step left from the past is the review of document layout, which can be omitted now when computer tools provide templates to control the formal layout. This responsibility can be assigned to the designer or to the technical reviewer.

A large potential for parallelization of the EC process is to let the reviewer take a more active part in the design process by locating him/her together with the PD team. By enabling a continuous dialogue between the designers and reviewer, the signing of documents becomes a formality since the reviewer has taken active part in the development and is well informed on all aspects. The review can also be done by another designer. This is done at VCC, where each designer can select the most suitable designer as reviewer. If the designer is certain that the design is correct, he/she can choose to review and sign it himself.

The difference in the processes indicates that a general solution for the ECM is not possible if an optimal process is the prime objective. The processes have a similar layout at the top level, but the impact of the company factors is visible already on the second level which differs strongly amongst the companies. On a task level, however, the performed operations are similar. A computer tool for the support of EC processes could therefore be built up by tasks, that are easily combined

into a company specific model. The system should further on enable a simple information sharing amongst users throughout the whole company, which seems to be a major problem at most companies.

8.2 Information

The information processed in the EC process is to large extent the same in each company. The process starts with a failure report which results in the creation of an ECO. One difference is that ECO:s at VCC can be updated in several editions. The reason for this is the fact that many changed documents are iterated back to design from manufacturing due to errors like for example inability to manufacture. The ECO is then given a new edition and the documents can be modified without the release of a new ECO.

The most common way to connect ECO:s to the product structure applied in the Swedish industry is to connect one ECO to each part or one ECO to every document. The PDM systems however tend to focus on connecting one ECO to one problem, thus connecting several parts (or documents) to one ECO. Both approaches have their advantages. By connecting an ECO to a problem, the status of the ECM can easily be monitored. The links between different parts are viewed, which makes it easier to calculate the impact when changing and the collected ECO also gives the team members a common goal to focus on. The main advantage when connecting ECO:s to parts is that all parts can be released independently. This is important for parts that are used in several PD projects, where more people than the own PD team uses the information. One ECO must not slow down the whole company.

The information management at FFVA includes management of other companies documents. There are mainly two reasons for that: FFVA produces advanced maintenance equipment based on the documents from another company and all documents are to be transferred to the customer after delivery. The customer sees the product as critical for air safety and the customer therefore requires extensive information from the change process. When the data is transferred, the maintenance must be able to recreate the parts and also keep track on why and how they were changed.

CTE delivers products to the national defence, but since the product is not regarded as safety critical as the product produced at FFVA, the customer does not require the same amount of documentation, e.g. minutes of meetings can be regarded as project documentation and not as change documentation as in the case of FFVA.

	Information																	
	Product documentation			Instructions				Reports				Complementary documents						
User	Product structure (RF)	Drawings	Specification	TONF	Systems development handbook	KOPRA	Standards	Project instructions	TOS	ECP	Failure report	Problem report	Request for guidance change	ECO report ATIS	DDAS report	ECO	Service report	Final report
	Project leader	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Designer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Supervisor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Customer	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Production	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Team leader	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Manager	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Drawing archive	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TO-editor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Central archive	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
System coordinator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ATIS-coordinator	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

FIGURE 4: Relationship matrix between users and information from the case study at FFVA

The possibility to a fast access to information is not well developed. Many roles in the EC process are depending upon information in different stages of the EC process. This is illustrated in figure 4.

Depending on stage in the process, the roles are affected by the information in different ways. Most employees want to keep updated on what happens with their design and related parts, which results in a large subscription of documents leading to an information overflow. This information push can be replaced by an information pull mechanism managed by a PDM system and/or a intranet viewer. The risk is here that users do not keep up to date with the documents, but this can be solved by automatic e-mailing of notifiers when a document changes status and an electronic billboard.

All companies identify both the product documentation and the product structure as subjects to a change. This indicates that all companies are well aware that most changes in the product documentation also causes a change in the product configuration.

8.3 Roles

The design engineer plays a central role in the ECM at all of the companies. The decision to perform a change is mostly authorised by the project leader with the support of an EC board. The EC board is a flexible team with various compositions within all companies. The most common composition is to have all project team members and some experts from manufacturing and other functions

including customers and suppliers to make the best decision possible.

VCC have a designated role to manage the administration of ECO and product structures in their legacy system. He/she helps the designer to create an ECO and he is also an important link when the ECO and all documentation is to be released. The introduction of the EC coordinator role is a result of the fact that consultants and less experienced staff have had difficulties when using the system. When the legacy system is replaced by a more easy-to-use process support tool, the role will probably change to manage processes and configurations within the system.

Both FFVA and CTE have a designated role to ensure the layout quality of certain documents, which originates from the nature of defence industry where all documents have to be correct for a long time span. The importance of this role has however decreased since modern computer tools (e.g. word processors, CAD systems) provide templates for a correct layout and the responsibility can be given to the designers.

8.4 Computer support

The potential computer support for ECM at the three companies is today (1997) not fully used. The most advanced support is provided at VCC, where the ECO:s are integrated in the configuration management tool. This system is however old and difficult to use for some employees. Moreover, the actual documents are managed by a second system and requires manual work to view the information. The long work with different systems has given users at VCC good computer skills, which in turn will simplify the introduction of a PDM system to support the ECM. The data from the legacy systems provides with both meta-data and digital documents (files) provides a good base for future work.

CTE is now implementing a system with digital archives containing product structures and document archive meta-data accessible through the company intranet. FFVA is currently introducing a prototype for a new CM system that will be purchased and introduced in a near future. Both of these works are going to support the ECM by providing the employees with more easy-accessible information, and on a longer scale, these systems will provide a good base for future process support in PDM systems.

9 CONCLUSIONS

This study shows that the EC process at companies is affected by company specific factors. If the company produces a safety-critical product, the process is much more focused on quality than on speed or low costs by extensive verification of functionality and manufacturability. The customer may also require the creation of specific documentation, to participate in EC committees and to approve the introduction of the change in manufacturing. The customers in the automotive industry require a large variety of product variants and fast response to failure reports. It is therefore very important for car manufacturers to listen to the customers voice and be able to quickly respond to the changing customer needs. When manufacturing large series it is very important to have an efficient EC process and also to be able to identify an introduction time. If the process is not fast, a large quantity of defect products will be produced. The introduction date gives a quantified goal for the designers and also a planning tool. The amount of consultants in connection with non-user-friendly computer tools and geographically distributed teams emphasizes the need of an EC coordinator.

The information processed in the EC process is to large extent the same in all studied companies. The name of the documents can differ between companies, but the information is generally the same. The only major difference is that FFVA must produce reports due to customer requirements, which is not done in the other companies.

The computer support for the ECM is today rather low in the studied companies. The reason for this is probably the width of the area, with many different departments with different computer tools that have to be integrated. A large number of data has been stored in old legacy systems, who can not longer support the changing work methodology. There are however activities in all companies that will form a base for future PDM support for the ECM. The fact that the ECM at companies is in much dependent of company factors makes it is difficult to provide a standardized workflow in a PDM system to fit the optimal EC process at all companies. Two strategies can be identified to support the EC process. The company can choose to customize the PDM system, which is associated with a customizing cost, or to introduce the standard process, which will give an increased efficiency, but perhaps not an optimal process.

ACKNOWLEDGMENTS

We would like to acknowledge Bertil Turesson and Mats Öberg at Volvo Car Cooperation, Sören Janeheden at FFV Aerotech and Hans Kling and Mats Sandell at CelsiusTech Electronics for their help and support.

This work was financially supported by the Swedish National Board for Industrial and Technical Development. This support is gratefully acknowledged.

REFERENCES

- Balcerak, K. J. and Dale, B. G.: Engineering Change Administration: The Key Issues. *Computer-Integrated Manufacturing Systems*, 5(2): 125-132, 1992.
- CIMdata, *Product Data Management: The Definition*, CIMdata, Ann Arbor, MI, USA, 1995.
- Davenport, T. H. *Process Innovation - Reengineering Work through Information Technology*, Harvard Business School Press, Boston, MA, USA, 1993.
- Diprima, M. R. Engineering change control and implementations, *Production and Inventory Management*, 23(1): 81-87, 1982.
- Eppinger, S. D., Whitney, D. E., Smith, R. P., Gebala, D. A. Organizing tasks in complex design projects, *Proceedings of ASME Design Theory and Methodology*, Article no. 95-1-13, 1990.
- ISO, *ISO11442-6, Technical product information - Handling of computer-based information. Part 6: Rules for revision*, Draft standard, ISO/TC10/SC1/WG6 N41, 1996.
- Merlenbach, C., The importance of configuration management: an overview with test program sets, *Proceedings of American Helicopter Society 48th Annual Forum*, Washington, D.C., 1992.
- Metis, *Metis Users Guide 1.9*, NCR Metis A/S, Horten, Norway, 1996.
- Pikosz, P. Ändringshantering i tre svenska verkstadsföretag (Engineering Change Management in Three Swedish Engineering Companies), Report PDM2000 project, *Machine and Vehicle Design, Chalmers University of Technology*, Göteborg, Sweden, 1997. (In Swedish)
- Pikosz P. and Malmqvist J. Possibilities and Limitations when Introducing PDM Systems to Support the Product Development Process, *Proceedings NordDesign'96*, pp 165-175, Espoo, Finland, 1996. (http://www.mvd.chalmers.se/publications/pub_list.html)

Ross, D.T. Structured Analysis (SA): A Language for Communicating Ideas, *IEEE Transactions on Software Engineering*, **SE-3** (1): 16-34, 1977.

Vroom, R. W. Information generated and/or used during product and process development. *Proceedings 2nd WDK Workshop on Product Structuring*, pp 131-140, Delft, The Netherlands, 1996.

Wright, I.C. A review of research in the engineering change management: implications for product design, *Design Studies*, **18**(1): 33-42, 1997.