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Ilse Becker

A Flow Model for Contract Car Manufacturing Project

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Ilse Becker, Tampere University of Technology

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ABSTRACT

This study is about contract car manufacturing (CCM) projects in a case company. The aim is to find out if it is possible to create a flow model that will fit to these projects in general and that could support the flowing execution of the project. The target is expressed in the hypothesis of this study: It is possible to create a common flow model for a CCM project and that can be applied to different project cases in the same context.

The research is based on three literature domains, Design Science, Project Management, and Systems Thinking. They all are present in complex engineering projects execution but have seldom been considered together in previous research.

The model creation is based on the analysis of four CCM projects that have been worked out during the past years in the case company. The main analysis is based on one project and the other three projects are thereafter compared to the results of the analysis. In the analysis of these projects the focus has been on the project flow with the aim of finding out what kind of obstacles there are that prevent the project from proceeding according to the planned schedule.

The project analysis is based on four research questions. The first one aims to name the sub-project areas, which build up the CCM project content. It will serve as a framework in developing the flow model. The sub-projects form the needed transformation process where the new car model can be manufactured in serial production. The three other research questions want to find out what kind of obstacles there are that prevent the project from flowing and what kind of action support the flow mode during the project execution. The issues that keep the project from flowing are connected to the important interdependencies. They are often on the external stakeholder's responsibility and are not as easy to control as the ones that are in own hands. This study analyses the interdependencies between project deliverables and points out the most important ones that have the largest amount of interdependencies with other deliverables. The most important ones have two features, they have a large amount of interdependencies and they need an output from external stakeholder. When the project management is well aware of the schedule risks and is proactively prepared to them this can support the project flow. The activities that produce the risky deliverables should be described and planned in detail so that it is possible to control the proceeding step by step if the risk actualises.

The analysis of the four case projects showed that a general flow model for CCM projects is plausible and can be implemented in all projects. Furthermore, this modelling principle can be adapted to other kinds of projects as well. The deliverables only need to be formed accordingly.

PREFACE

This research work got started in the beginning of year 2000 when I was working at Valmet Automotive, a Finnish contract car manufacturing company. Before that I had worked at IT service providers in several system design projects with industrial companies in Finland and Scandinavia. I started my postgraduate studies in knowledge management and had a few years break in the middle when I was working abroad. After moving back home I had a new start in the studies where my supervisor and thesis topic changed to design and engineering sciences.

During my studies I have got support from several directions and people. I want to thank Dr. Tuija Kuusisto who was my first supervising professor in knowledge management domain and who inspired me into this research path.

From my research restart in 2009 I am grateful to professor Asko Riitahuhta. He encouraged me to the research in simultaneous engineering and helped to get a new start in my studies. I am thankful to all research group members of Riitahuhta Research Group (RRG) and especially to professor Tero Juuti and Dr. Timo Lehtonen who have helped me enormously through ambivalences. A special thanks goes to my fellow researcher MSc Nillo Halonen who was a great support many times when my confidence to this thesis was lost. I am also grateful to professor Asko Ellman who became my supervisor after Asko Riitahuhta's retirement. Professor Ellman aided me greatly in getting this work finalized.

I am also thankful to my employer of that time Valmet Automotive who gave me the opportunity to do this research.

My last but not least thanks go to my loyal husband who never lost his confidence in my efforts and always supported me to get this thesis finalized although it took more years than planned.

I dedicate my work to our great sons Otto, Matias and Kalle with whom I have had many interesting discussions.

Laitila, December 2015

Ilse Becker

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

BIW	Body in white
BOM	Bill of Material
CCM	Contract Car Manufacturing or Contract Car Manufacturer
CE	Concurrent Engineering
CM	Change Management
CMA	Contract Manufacturing Agreement
DiMo	Disposition Modeling
DR	Design Rationale
EBOM	Engineering bill of material
ECO	Engineering Change Order
EDI	Electronic Data Interchange
EOP	End of production
ET	Executive team
FMEA	Failure mode and effects analysis (risk analysis)
FTOK	First time ok
GA	General assembly
ISO	International Standardization Organization
LCM	Lifecycle management
LOI	Letter of intent
MES	Manufacturing Execution System
MBOM	Manufacturing bill of material
MIT	Massachusetts Institute of Technology
MS	Microsoft
NDA	Non-disclosure agreement
OFTP	Odette File Transfer Protocol
OTC	Order to cash
OTD	Order to delivery
PD	Product Development
PDM	Product data management
PM	Project management
PO	Purchase order
PPAP	Production part approval process
PPM	Parts per million
PSG	Project steering group
QG	Quality Gate
RRG	Riitahuhta Research Group

SCM	Supply chain management
SEPRO	Simultaneous Engineering of Process
SOP	Start of Production
SoS	System of Systems
SQ	Supplier quality
SSM	Soft Systems Methodology
TS	Technical System
TTS	Theory of Technical Systems
TUT	Tampere University of Technology
VB	Visual Basic
VDA	Verband der Automobilindustrie

1 Introduction

1.1 Motivation

This research is about contract car manufacturing (CCM) projects in a case company. The focus is on such projects where the OEM (Original Equipment Manufacturer) partnership as well as the car model is new for the company. The target in those projects is to design and build up the transformation system, which shall produce and deliver cars to the client. Hubka et al. (1988) have defined these kinds of systems as technical transformation systems.

In CCM projects the target is to design and build up manufacturing lines and the processes that back for the production, such as logistics and IT infrastructure. They are large and complex engineering projects and have many variables, uncertainties, and imprecisions. The design and build up of factory facilities and processes can also be understood as a phenomenon of product design and development (Hubka et al. 1988). In this context the "product" is the factory with its steering processes. Engineering projects in automotive industry are usually managed with a stage gate model (Cooper 1994), where activities and their deliverables at each gate are specified and controlled during the project execution at gate reviews. The stage gate model has been used many years but sometimes in the latest projects its usability has been questioned because fulfilling the gate specific requirements has been extremely difficult. This can be connected to the uncertainties and risks that the project has as well as to the tight timetable that allow no stumbling in the project execution. Although the model is very popular in automotive industry some new tools might help the management and execution in todays tight project schedules. This study aims to develop a flow model that supports the CCM project execution.

External stakeholders play an important role in the project execution. International Standardization Organization (ISO) 15288 "Systems and Software Engineering" defines a stakeholder as "individual or organization having a right, share, claim or interest in a system or in its possession of characteristics that meet their needs and expectations". The most essential stakeholder in a CCM project is the OEM who is responsible for the design of the car model. The OEM and the contract manufacturer have to find solutions to integrate their processes and the supporting IT systems. Furthermore other stakeholders like part suppliers have to be integrated into the processes. The manageability is challenging because so many separate companies have to cooperate and the time schedule has been getting tighter and tighter during the recent years. The competition in the car market is high and car companies bring new models to the market every year. When the spectrum of models is wide it is difficult to make capacity forecasts especially for new car models and that may cause fast needs for additional manufacturing capacity. This has also sometimes been the reason why the OEM seeks for a contract manufacturer to produce the model. When the need for additional manufacturing capacity is sudden there is usually pressure for a fast production start as well. The time to market seems to be crucial when the car model has to be brought to the showrooms as soon as possible and before the competitors. A rapid capital turnover is an important target for the OEM as well as for the

CCM, too. Furthermore, a fast project throughput is one critical feature in the competition for the contract as well. These car models have generally been niche quality cars and producing quality cars with haste is not easy to combine.

In order to meet the challenges of today's CCM projects new ideas to their execution need to be invented. Is the stage gate model still relevant in managing the projects? Should there be some other tools to support the project management? How to gain a flow modus into the project so that rework and waste is avoided?

It is challenging to manage many separate companies and external partners. This is especially the situation when the time schedule is strict. There are ranges of uncertainties in the project, which require evaluation beforehand. Especially when the partners have not a common cooperation history it takes time to become familiar with all the conventions of the parties. The risks and uncertainties are connected to the integration of those parties. A major uncertainty is the product development status if the car is still in the development phase. The on-going engineering changes in the product cause challenges to the simultaneous design of production line facilities. In that case there are two parallel projects that have to be coordinated and the amount of uncertainty is even higher. Part suppliers are another essential stakeholder group in a CCM project and the selection of them is connected as well to the Product Development (PD) status as to the agreement with the new manufacturing plant. Furthermore, the part suppliers have to integrate themselves to the procedures of the PD, too. Their part design and statuses have to be synchronized to the engineering changes as well.

Research regarding Design Science is generally focused on product design. That is one reason why this research got started. Hubka et al. (1988) name several classification systems for a technical system. One of them is complexity and he ranks building up a plant to the fourth, and highest, degree of complexity class. System thinking defines complexity as a relative term (Gharajedaghi 2011) that depends on the number and nature of interactions among the involved variables. According to Gharajedaghi when nonlinear closed loops are formed by interdependent variables and furthermore, if their response is delayed then the system becomes complex. With independent variables and open loops the system is not complex. A simplified example of a complex and not complex system is presented in Figure 1. In the above presentation of the Figure the partners influence to the project outcome separately which is a theoretical situation. In practice all the actors, the client (OEM, Original Equipment Manufacturer), CCM, Part Suppliers, and Engineering Partners are all working concurrently. In reality the activities are such as in the lower picture where almost every actor has some influence on each other.

What would be the best way to manage and control this networking project environment where issues can pop up unexpectedly and they have to be handled as soon as possible? This study tries to find answers to that question.

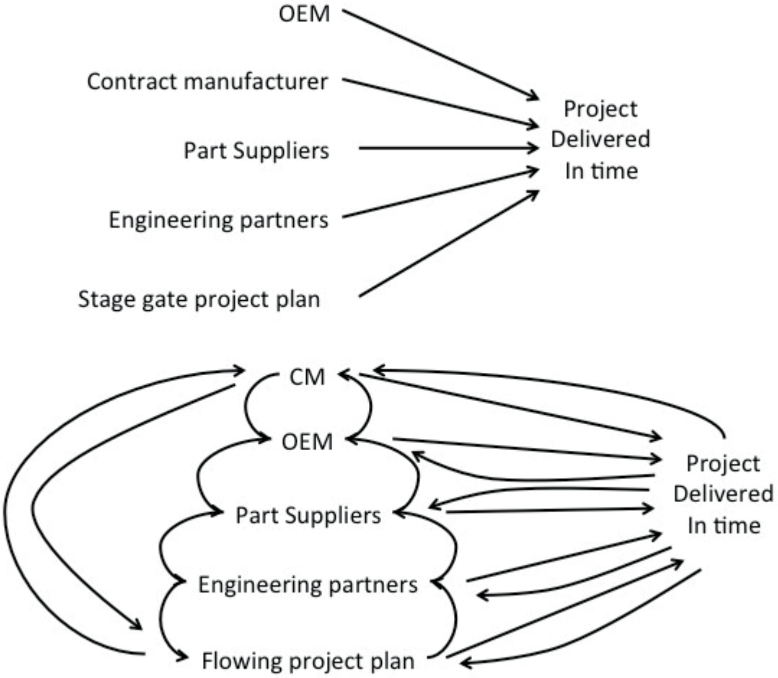


Figure 1. Simplified presentation of a system with independent variables, open loop and laundry list thinking (above) and interdependent variables, more realistic interactive operational model (below). (Gharajedaghi 2011)

1.2 Objective of the research

The case company Valmet Automotive is a contract car manufacturer in Finland. It has been manufacturing cars to several customers for over 40 years. An OEM who has made a manufacturing agreement with the case company has mostly done the design of those vehicles. The objective of this research is to investigate and analyse those projects in order to find the possible similarities in order to create a model for the project execution and management.

The research data extends back to twenty recent years in the case company and in four CCM projects during that time. The common challenges lately in them have been:

- Fast time to market at least in the recent years
- Management of the co-operation with the client and various stakeholders
- Management of the sub-project’s interdependencies

The company has always divided the CCM project into several sub-projects. This has made the management of the project easier but on the other hand coordination is needed between the sub-projects. The sub-projects are typically created according to the production processes as well as their backing procedures, like e.g. body, paint, and assembly shop as well as ordering and logistics processes.

McGrath (1996) has investigated the influence of development time into the product life cycle and units sold. The results in Figure 2 show that with reduced development time the company gets more units sold than with a longer development time. This is also the way in which the companies act today. They try to reduce the development time in order to get the products to the market as soon as possible in order to make more revenue. This has been experienced also at the contract manufacturer in its CCM projects.

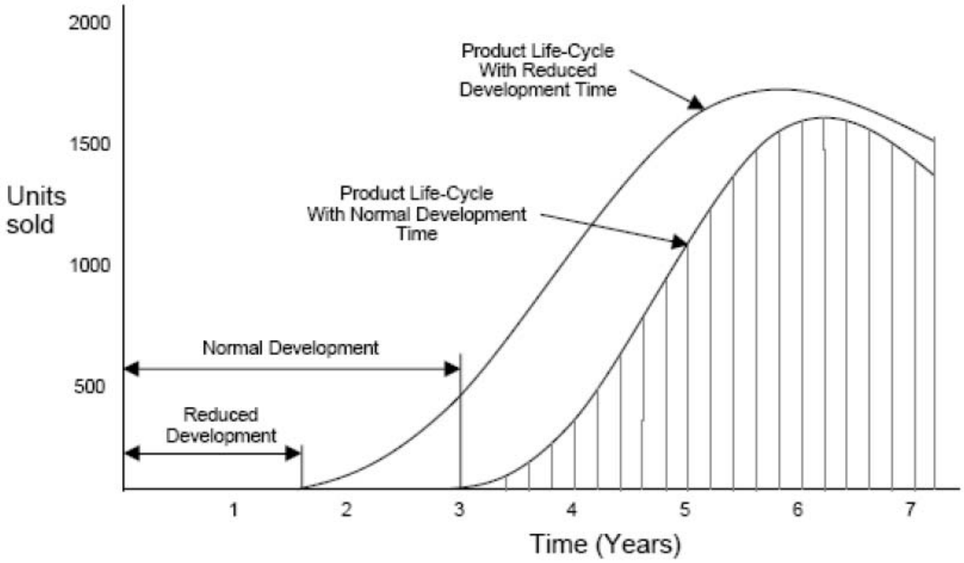


Figure 2. Product lifecycle and units sold curve for normal and faster time to market. (McGrath 1996)

All the projects in this study have been with different clients. The agreements (Contract Manufacturing Agreement, CMA) have been case specific and some project features of each of them will be described in Table 5, Table 6, and Table 7, which are presented in section 3.3 Presentation of contract car manufacturing projects. The CMA forms always the basic framework for a CCM project. The differences between the projects are e.g. degree of product development maturity at the project start, time period and production volumes of the contract, how and by whom the parts shall be supplied as well as the level of sub-assemblies in the final product. The engineering changes to the product have always been a challenge in a CCM project. The developing organization has its specific process and IT system for managing those changes. That process and the information flow in it has to be captured and implemented right in the beginning of the project to avoid flaws in manufacturing engineering designs. To take over that process in the very beginning of the project cannot be taken for granted. That is one area where simultaneous engineering (SE) in between design and manufacturing engineers can help to keep the engineers on track. In literature also the term concurrent engineering (CE) is used for the same function. The difference between the two terms has been explained that concurrent engineering is most often used in the American language area, while simultaneous engineering is more common in Europe (Gierhardt 2001). Both terms describe the parallel development work with all the partners who are integrated in the product design and engineering process (Krause et al. 2007, Becker et al. 2011). The case company has been using the term SE because that functionality was first implemented in a CCM project with a German customer who already had named the functionality with that term.

The benefit of SE is that the manufacturing engineering has the possibility to influence the product features during the development phase and influence the design to be more suitable to manufacture and assemble (Design for Manufacturing and Assembly, DFMA). If the product is already being manufactured in another factory, synchronizing the engineering change procedures is not so cumbersome but anyway still challenging, because the changes are frequent for a new car model and will speed down first after a few years have gone by. The official change procedure is relatively burdensome and it starts after the design freeze –phase in the product development. Before that the changes can be made more smoothly with development teams cooperation that evaluate the dependencies and influences on the costs. Figure 3 shows that in the beginning the influence of the stakeholders, risks, and uncertainties is larger than later on and respectively the cost of the changes rises when the time goes by.

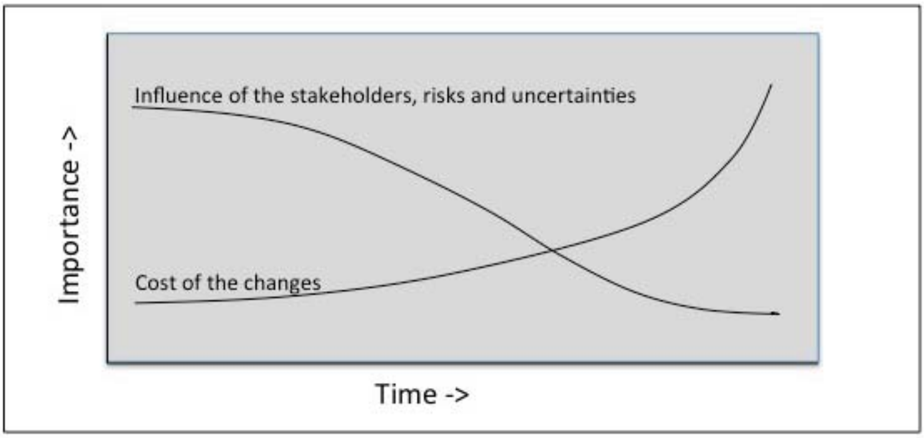


Figure 3. Changes, stakeholders, risks, and uncertainties during the lifecycle (PMI 2008, ref. Ilveskoski 2014)

1.3 Research questions and thesis contribution

The author has been participating in several CCM projects in different roles during twenty years time frame in the case company. The idea of developing a flow model for the project management and execution grew up in discussions with some of the colleagues during this time. A model might help to get the project organized at the beginning as well as managing it during the execution. The project schedule is nowadays been planned very tight and it does not allow any spanners in the works. It is impossible to avoid them totally because of all the uncertainties and risks that will always be part of the project. With help of a flow model creation this research wants to prepare a tool for CCM project management and execution.

The hypothesis of this study claim that it is possible to create a general flow model for a CCM project and that can be applied to different project cases in the same context.

The main problem in the model creation is how to do it so that it can be applied to different projects in the same context. Although the project target is always the same: Creation of a transformation process that will produce cars, the projects are always unique and their management has much to do with participating organizations and their culture. For example Lilja (2013) has investigated these features in IT projects. This study will not go deeper in the organization culture of the project partners. It will concentrate on the deliverables that come from external stakeholders and that have connections with many other deliverables. By defining those deliverables in the flow model the project management can proactively be prepared to the obstacles that would prevent the project from flowing.

This study approaches the model creation problem with following research questions which have been experienced problematic in many previous CCM projects and that is why they can support the model creation for a CCM project:

1. What are the essential sub-project areas in CCM projects?

2. What are the most important interdependencies between the different sub-project areas?

3. What are the obstacles in a CCM project execution and what prevents it from flowing?

4. How to support the project flow?

The scientific contribution of this research is:

- A new approach to the management of complex engineering projects by presenting a flow model where the interdependencies between project deliverables and their influence to project proceeding is shown
- Connection of three research areas Design Science (DS), Project Management (PM), and Systems Thinking (ST) together in modelling the flow of the case company's projects
- Hubka (1988, 1996) as well as other researchers in Design Science have concentrated in their studies on product design and development. This thesis adds the design of a factory to the Design Science domain
- Combination of two tools, DSM (Design Structure Matrix) and DiMo (Disposition Modelling), which aided in the analysis of interdependencies and obstacles for the project flow. These tools showed which deliverables should be dismantled into activities in order to be prepared for obstacles and to perform the needed tasks to prevent them from happening

- Basis for future research where the flow model principle can be investigated in different kind of project systems

1.4 Research approach and methods

The nature of this study is qualitative case study. Yin (2009) has categorized four different types of case studies. They are presented in Figure 4. According to Yin the case study can be a holistic single case study or a holistic multiple case study as in the upper part of the Figure 4. The other two possibilities are a single or multiple case studies with embedded units as in the lower part of the Figure. When Yin's definition is adapted to this study it can be categorized to the group of single case study with embedded units as in the lower left corner of the Figure. The single case in this study is the CCM Company and the embedded units of analysis are the four different CCM projects that are presented here.

The approach to the data is conceptual-analytical targeting to build up a project model that can be applied to all CCM projects. Olkkonen (1993) categorizes conceptual approach to one of the five approaches in Finnish methodological discussion. New concept systems are needed in order to illustrate or recognize new phenomena, organizing data, as a base for design systems, etc. The concept system can be a novel or a developed version of an existing concept system. In this case study the concept will be a flow model for CCM projects in the case company. The model is developed from a CCM project schedule in the company.

The background literature and theories for this study lie on three research domains: Design Science, Project Management Research, and Systems Thinking. Several researchers have contributed in each of them but not much literature can be found that combines all the three research areas. Figure 5 shows the domain connections in this thesis. Design Science and Project Management research contain the base literature for a CCM project as a transformation system. The literature presentation in Design Science starts with the Theory of Technical Systems followed by New Product Development (NPD), Dispositions and Domains, Design for Manufacturing and Assembly (DFMA), Modularity, and *Monozukuri* and Flow. In the Project Management research literature presentations are conducted in Classifications of Projects, Uncertainties and risks, Scheduling, Stakeholders, and Stage Gate model. Systems Thinking will close the literature presentation. This domain is divided into two approaches; hard and soft systems thinking both of which can support modeling in the system analysis.

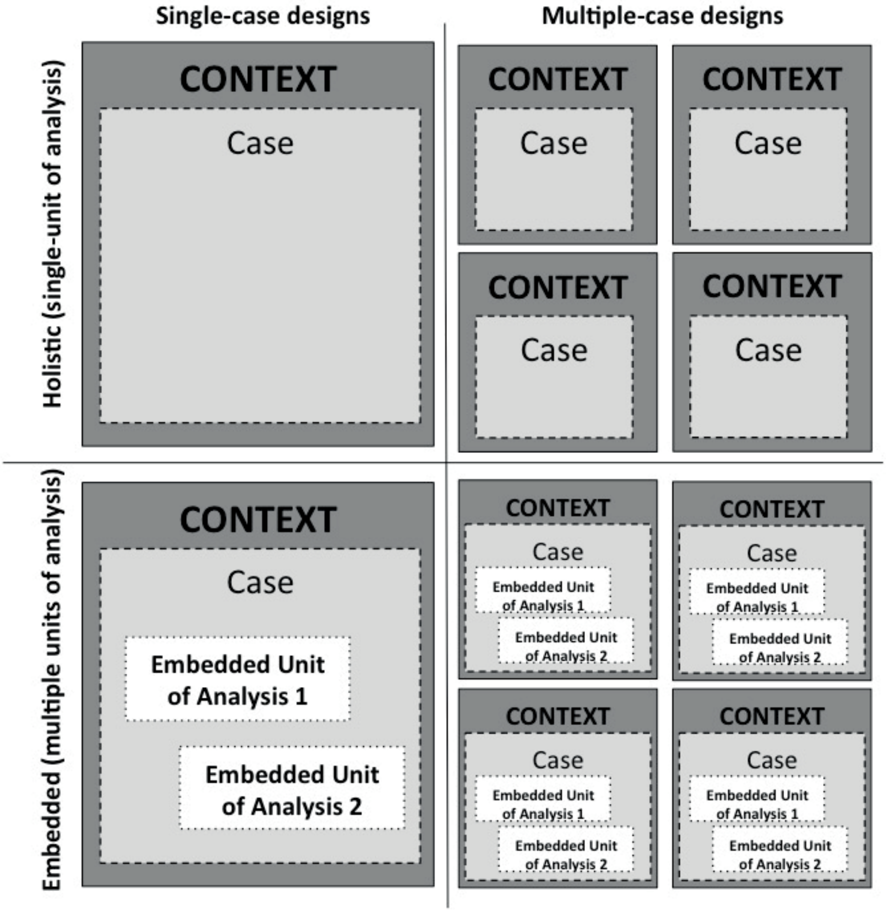


Figure 4. Basic Types of Designs for Case Studies (Yin 2009)

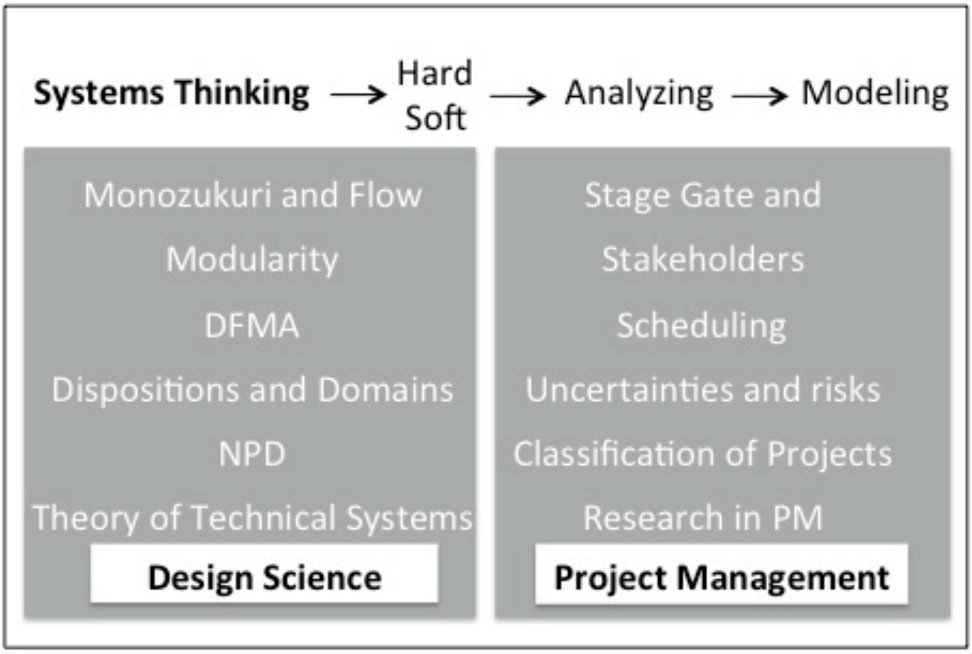


Figure 5. Summary of the theories and the research background in this study.

Hubka et al. (1996) define that Design Science itself is a system, where engineering knowledge is becoming organized in order to create another system, which can be either the technical system alone or it can be included in a transformation system. In Figure 6 a presentation of this principle can be seen. One part of the technical system is the transformation process, which gets inputs from human system (HuS), technical system (TeS), information system (InS), and management system (MaS). With help of these inputs the process produces the operand in the desired state. This principle picture can be applied to the CCM project in this case study as well as to the technical system that is the outcome of this CCM project. Furthermore the transformation system where the car model is being designed and developed is a technical system as well. This research concentrates on the CCM project as a transformation system.

There are two main kinds of Systems Thinking approaches in the literature: hard system thinking and soft system thinking (SST) domains. System Engineering e.g. is categorized into the hard system-thinking domain. According to Jackson (2000) Checkland has been the inventor of SST. When looking at a CCM project as a system the engineering design of the production lines can be considered into the hard system thinking context whereas the networking actions among the different project team members at the contract manufacturer and stakeholders are more on the soft side.

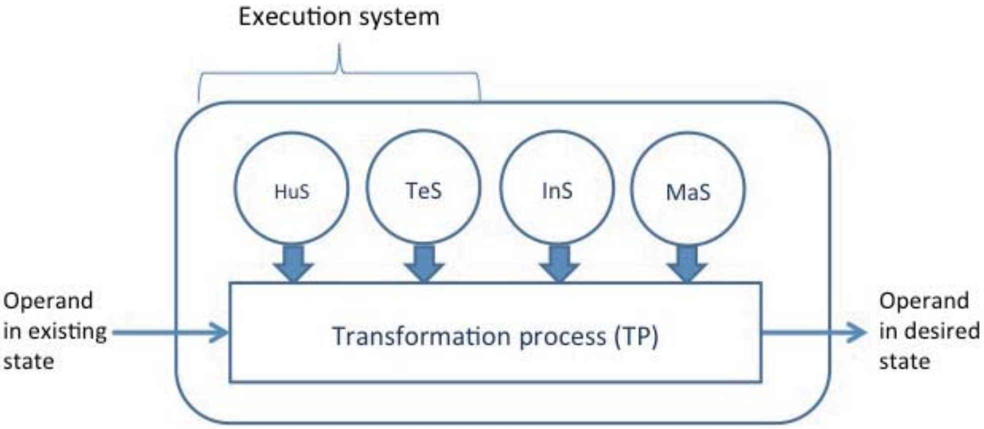


Figure 6. Model of a technical transformation system adopted from Hubka et al. (1988)

Figure 7 shows the research strategy and procedures of this case study where the target is to create a general model for CCM projects. The starting point of this research is on the literature review of the three domain areas that were presented in Figure 5. The CCM project analysis will be based on the reviewed theories. The basic evaluation is done with project A, which is the first embedded unit of analysis (Yin 2009). Result of that analysis will answer to the first research question to find out what are the essential sub-projects in a CCM project. The sub-projects are presented as groups in a "big picture" of the CCM project using Systems Thinking methodology. This grouping will then be utilized in the next step where a Design Structure Matrix (DSM, Steward, 1981) is created of the project A schedule and its deliverables. Thereafter the deliverables and their interdependencies between different sub-projects are analysed and the project duration is evaluated. The result of these two analysis will give answers to the research questions two, three, and four. All analysing until now is done with the project A, which is the first embedded unit of analysis (Yin 2009). Thereafter the features of the other three embedded units, which are the projects B, C, and D, are compared to the results of the project A. The conclusions will be thrown based on this comparison and hypothesis will be proofed. The final step in this procedure flow is the modifications to the theory base.

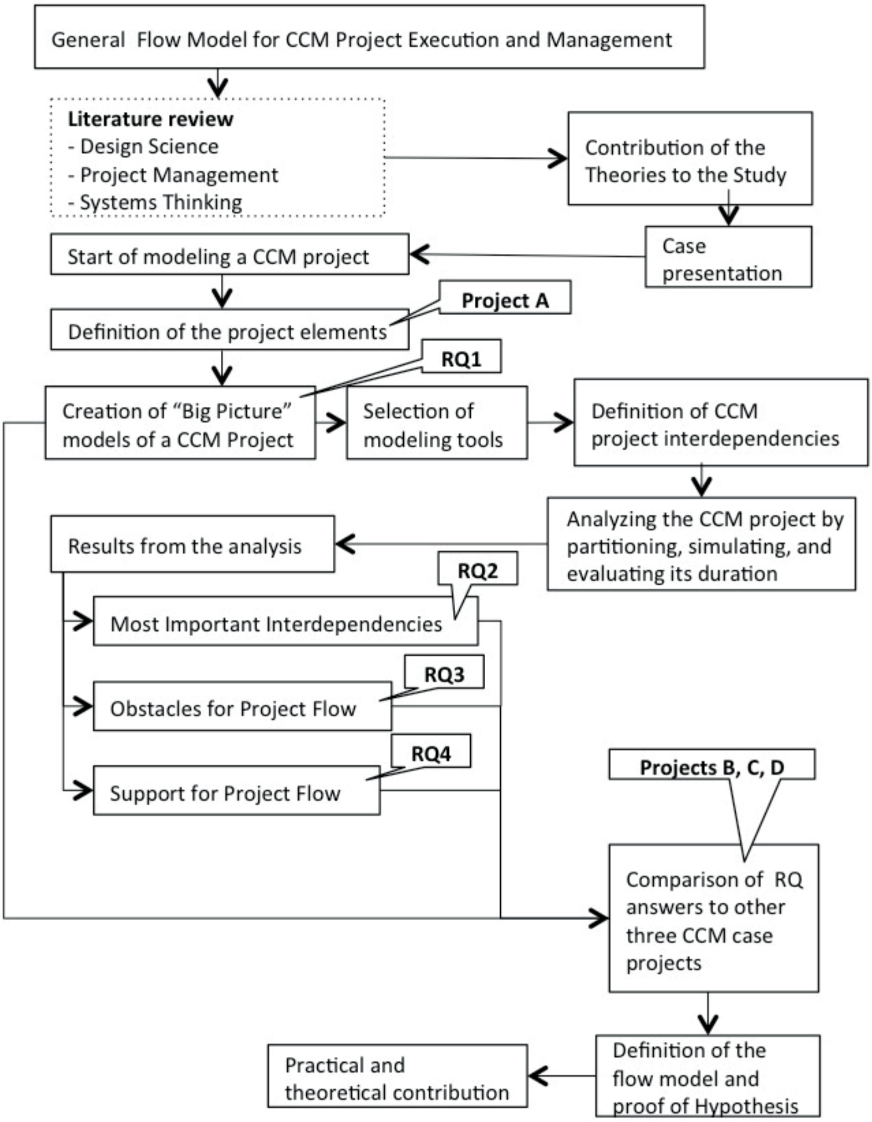


Figure 7. Research strategy in this case study

1.5 Outline of the thesis

The three background theories for this study are presented in Chapter 2, Literature review. The first domain area is Design Science and its sub-domains starting with a presentation of the Theory of Technical Systems. The next Section will present the research in NPD followed by Dispositions and domains in design. Thereafter the Design Rationale (DR) of a CCM project will be introduced. Next presentation is DFMA together with simultaneous engineering (SE) function. Simultaneous or concurrent engineering has been utilized in the projects at the CCM in cooperation with product development in order to get the design of the car as manufacturing friendly as possible. One Section in this context introduces the ICT (Information and Communication Technology) as an absolute precondition for the cooperation between development and manufacturing teams. The next Section presents modularity in product design and the final part of DS domain introduces the Japanese manufacturing culture, *monozukuri* that is focused on flowing production model where waste is decreased in to minimum.

The second research domain is Project Management. It starts with a survey of theory in Project Management. That is followed by project type classifications and definitions of complex mega-projects. Furthermore the investigations in uncertainties and risks of megaprojects are presented. Thereafter the different approaches to project time schedule as well as stakeholders influence on project execution are presented. The stage-gate model being commonly used in product design projects is also introduced here.

The third research domain is Systems Thinking, which in this study connects Design Science and Project Management domains together. This introduction starts with the history and development of Systems Thinking. The next Section divides the domain into hard and soft Systems Thinking. After that Soft Systems Methodology is presented in more details. Also two hard system methodologies are presented thereafter, dynamic system modeling and Design Structure Matrix. The last part of ST introduces combinations of projects and systems and describes the CCM project as a system.

In Chapter 3, Presentation of contract car manufacturing projects and the case company, presentation of a typical CCM project as well as an overview of the case company will be shown. The presentation starts with introducing contract car manufacturing functionality in Europe. The presentation of the case company and features of four different CCM projects will follow that. Furthermore, typical project targets and practices like FMEA (Failure Mode and Effects Analysis), RASI (Responsible, Approval, Support, Information), and Quality Gates will be presented.

In Chapter 4 the flow model will be developed starting with formulation of CCM project's big picture. In the picture the project process and with system modules will be presented. Presentation of the analysis tools that are used in this development will follow thereafter. The next Section introduces the tool usage procedures in detail and the principles of the analysing. All the three tools used were based on DSM. Two of them were developed in MIT (Massachusetts Institute of Technology) and they helped in partitioning and simulating the matrix. The third tool is called DiMo and that was developed in TUT (Tampere University of Technology). The final Section of this Chapter will present the results of the analysis.

Chapter 5 will present the findings of this thesis and conclusions are driven in Chapter 6.

2 Literature review

2.1 Design Science

Hubka and Eder (1996) define that the purpose of Design Science is to create a consistent and complete knowledge view about engineering design. Hubka and Eder (1988) divide Design Science in two dimensions prescriptive and descriptive (Figure 8). Furthermore he takes two aspects in those dimensions, the Technical System (TS) and the Design Process itself. In his book "Theory of Technical Systems" (TTS) he presents several statements from which he derives these two dimensions. The descriptive statements of Technical Systems are presented in that book and the prescriptive statements contain the branch-specific design knowledge of how to realize TS. The descriptive statements of the design process are as well introduced in the book and the prescriptive statements about the design processes show the ways in which the design process can be successfully performed in a socio-technical environment. The fifth element in the dimensional Figure 8 are the CAD Expert Systems which include all the equipment, applications, and devices that are essential in the designer's work.

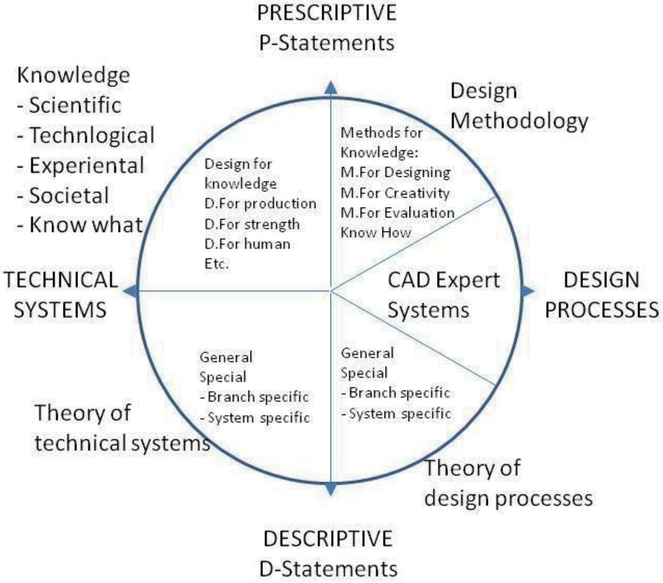


Figure 8. Two dimensions of Design Science (Hubka et al. 1988, p.232).

Blessing et al. (2009) define design by referring to those activities that generate and develop product documentation needed to realize the product. The need may be economic e.g. a manufacturing system for mass production. H.A. Simon (1996) notes that design is concerned with how things ought to be whereas natural sciences are concerned with how things are. The roots of design science are in the German-speaking world and in machine design. Lehtonen (2007) claims that it can be implemented also in other design areas e.g. electronics. Fujimoto et al. (2011) has analyzed the design processes of complex products in mechanics, electronics and software development. They note that the design in mechanics is based on structural philosophy as against electronics and software design is based on functional philosophy and that is why there are difficulties in the integration of those design processes.

Blessing et al. (1992, 1995, and 2009) present the model framework of Design Research Methodology (DRM), Figure 9. This methodology has four stages; Research Clarification (RC), Descriptive Study I (DS I), Prescriptive Study (PS), and Descriptive Study II (DS II). They state that a thorough task clarification at the start of a research project will improve the design process.

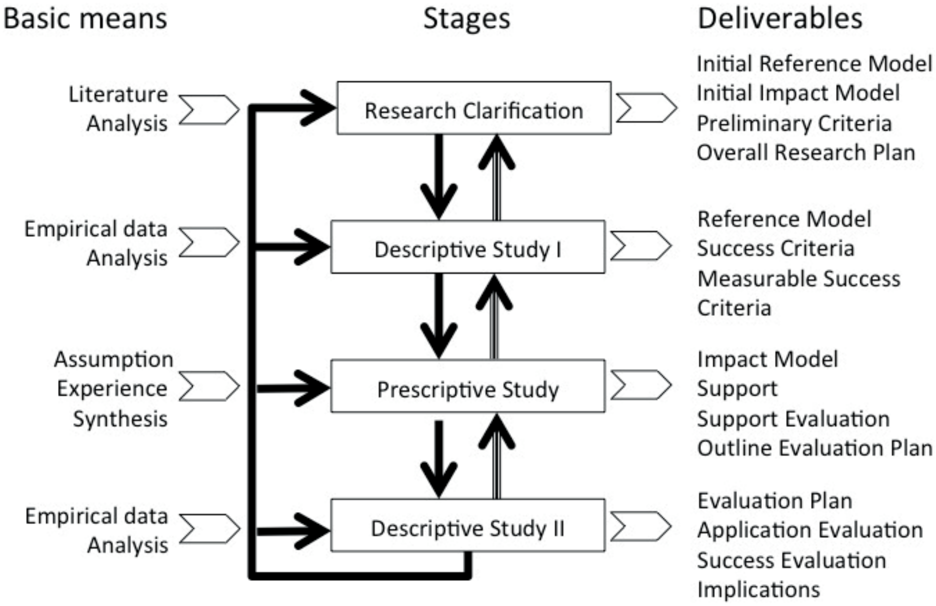


Figure 9. DRM Framework (Blessing et al., 2009)

The researchers shall not concentrate on their first idea but to apply a systematic research approach where in the second stage (DS I) the goal is to understand the design requirements in their whole with the help of literature reviews and to make a detailed description of the design tasks. In the PS stage the researchers use their increased understanding to correct the initial description of the desired and improved situation. In DS II stage the researchers investigate the impact of the support to realise the desired situation.

Gharajedaghi (2011) approaches the designing of Systems Thinking point of view. According to him the core of the design process is the iterative process of holistic thinking. To design is to create structure, functions, and processes in a given context. The context is actually defined by the end user although the designer needs to capture that in his design by taking the initiative. The point is that design cannot deal with context, function, structure, and process independent from one another. That is why iterative processes are needed to keep the relationship among them interactive and meaningful. Gharajedaghi (2011) states that three iteration loops are needed before the design is complete. Those loops are presented in the Figure 10. In the first iteration the designers will concentrate on developing the desired specifications of the system starting on the function and what output the system should have on a larger system of which it is a part. This approach means understanding the whole context as well as the behavior of the stakeholders. Defining who they are and what are their specific interests. What they want to control and where they influence. As a result of this first iteration loop the interdependencies and conflicts among the specifications should be found. In the second iteration loop the designers may let their imagination take over to create mental presentations of possible structures and processes that would produce the desired outputs. In the third iteration loop the designers make a symbolic model of their design to communicate with the design itself as well as with the stakeholders to achieve consensus that satisfies all parties. The next iteration is the final one and it will convert this initial rough design into the next generation of the system. In between each iteration loop the designers have to pause and synthesize the information into a whole where they use their increased understanding of the system.

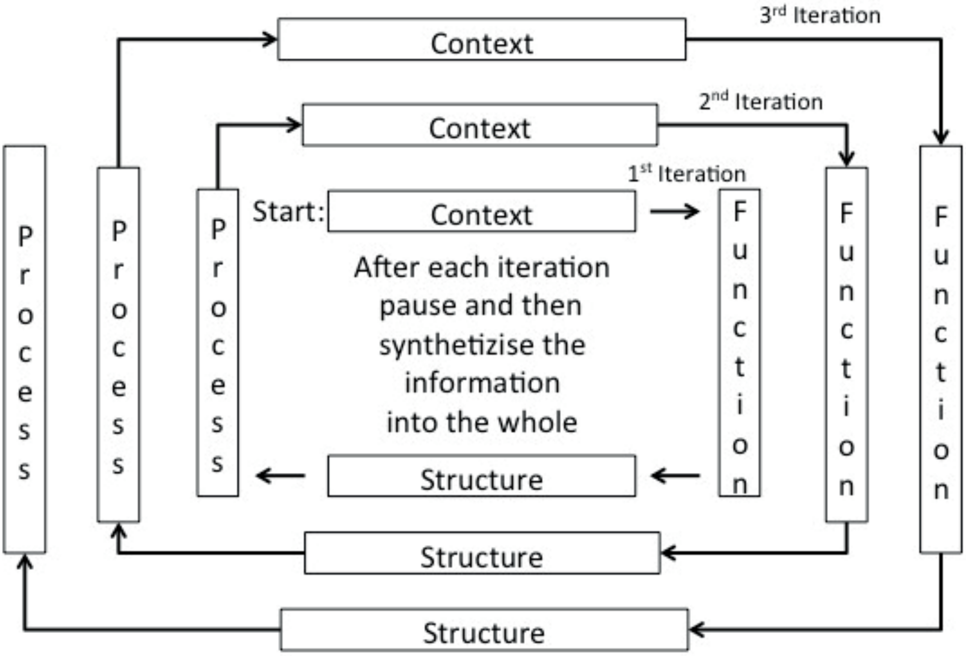


Figure 10. The holistic view of analysis to get the design completed (Gharajedaghi 2011).

In the first iteration the designers will concentrate on developing the desired specifications of the system starting on the function and what output the system should have on a larger system of which it is a part. This approach means understanding the whole context as well as the behaviour of the stakeholders. Defining who they are and what are their specific interests. What they want to control and where they influence. As a result of this first iteration loop the interdependencies and conflicts among the specifications should be found. In the second iteration loop the designers may let their imagination take over to create mental presentations of possible structures and processes that would produce the desired outputs. In the third iteration loop the designers make a symbolic model of their design to communicate with the design itself as well as with the stakeholders to achieve consensus that satisfies all parties. The next iteration is the final one and it will convert this initial rough design into the next generation of the system. In between each iteration loop the designers have to pause and synthesize the information into a whole.

Furthermore, Gharajedaghi (2011) states that in order to create a viable design the designer has to understand its dynamic behaviour and to be able to do that operational thinking is needed in the process. Therefore design thinking needs support from other areas of thinking (Figure 11), holistic, operational, and sociocultural thinking. The same elements have actually been included also in Hubka et al.'s (1988) theory presentations.

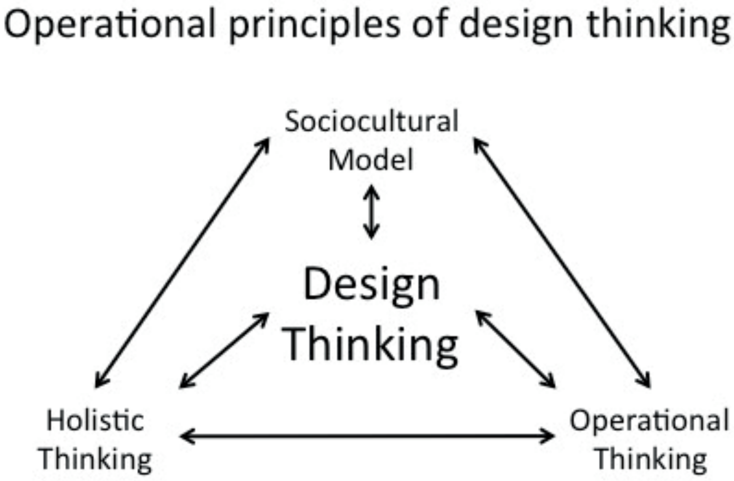


Figure 11. Foundations of design theory. (Gharajedaghi, 2011).

Several researchers claim that design science is too much focused on new product development (NPD). Koskela (2000) claims that the existing design science has contributed little to advances of design practice, like e.g. the rise of concurrent engineering (Cross 1993). Also Oja (2010) states that the Theory of Technical Systems has not given attention to the industrial approach like process development or multi-disciplinary products. He notes that the theory does not classify transformation processes differently according to how many disciplines are involved. Shakeri (1998) found out in his research for multi-disciplinary design problems that the most common methodologies use sequential design to overcome the complexities of the design and that information sharing between different disciplines is often limited. Hence conflicts between disciplines are discovered late resulting in expensive solutions.

2.1.1 Design process and Theory of Technical Systems

Hubka et al. (1988) defines a technical system as a collection of engineering activities working together in the engineering design process, where they generate, process and transmit information about products. Suh (1990) notes that in the design process structural parameter groups and functional parameter groups are connected in order to fulfil the customer needs. Hubka et al. and Suh take more static viewpoint to the design process than et al. (2011) who describes it as a dynamic flow of knowledge and information that create the target product.

Design theory encompasses also the design of a plant (Hubka et al. 1988) like mentioned already earlier in this study. The literature in plant design is not so numerous as in product design. Project management research has investigated complex design projects like nuclear power building (Ruuska et al. 2011). They as well as ship building projects are examples of complex design projects that are commonly also System of Systems Engineering projects (SoSE). Several researchers have defined System of Systems (SoS). They are large-scale simultaneous and distributed systems that consist of complex systems (Jamshidi 2005, Carlock et al. 2001). Also in the war and defence context SoS is a common phenomenon: “In relation to joint war-fighting, System of Systems is in relation to joint war-fighting, System of Systems is concerned with interoperability and synergism of Command, Control, Computers, Communications, and Information (C41) and Intelligence, Surveillance, and Reconnaissance (ISR) Systems (Manthorpe 1996).

In a CCM project there are two simultaneous and distributed transformation systems, which are the design of the car and the design of the plant. Furthermore there is also the construction project for the plant that includes all the steering and supporting processes and ICT to be able to run the production. Management of engineering changes during the design processes is challenging to all accomplices involved in the project in order to avoid false designs.

2.1.2 New product development

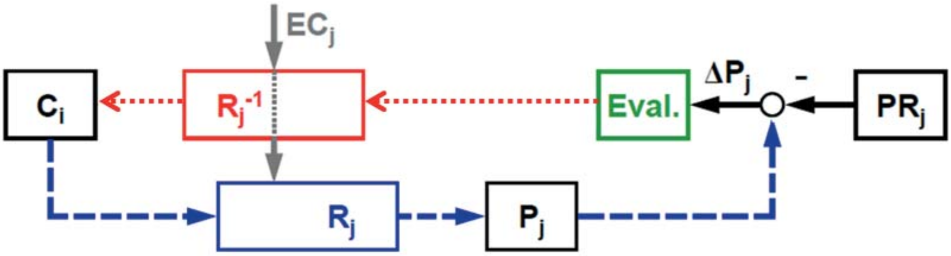
Many viewpoints to new product development (NPD) can be found in the literature. Ulrich et al. (2008) describe generic product development process with six phases: Planning, Concept Development, System-Level Design, Detail Design, Testing and Refinement and Production Ramp-Up. The traditional customers follow more or less these phases and review the proceedings of the development project between each phase. Ulrich recognizes also companies that are not even able to describe their processes, which can be the situation in a start-up company because their procedures still evolve. But also the traditional customers have their company specific operations model derived from the common process, which need to be internalized before the CCM project can start. According to Ulrich et al. important reasons for a well-defined NPD process are:

- Quality assurance, which can be controlled at certain checkpoints of the project
- Coordination; the development teams will know their responsibilities better to exchange material and information
- Planning where milestones are set at the end of each phase. That will connect the schedule to the whole project.

- Management; by comparing the actual events to the established process, the manager can identify possible problem areas.
- Improvement is easier when the process is documented.

Hubka et al. (1988) have expanded the product concept and introduces a technical system (TS) model where certain well-defined effects (coming from the human, other TS, and the active environment) exist. They form the inputs to the TS under consideration. The TS has three structures according to Hubka et al., function, organ, and component. The components form the organ and the organs altogether build up the functionality of the TS. Hubka et al. describe the TS degree of maturity and divides it into four development phases where the first one is clarifying the assigned problem, second one is conceptual designing, third one is layout planning, and fourth one is detailing. Hubka et al. recommend completing the design in the actual phase.

Weber & Deubel (2003) have researched the modelling of a product and the product development processes (Figure 12). The starting point in their research is a hierarchical tree structure of the parts and sub-assemblies and the characteristics of them. In many cases there are dependencies between different characteristics. In addition to the characteristics, the wanted properties of the product have a central role in the modelling of the product development process. Between the characteristics of the product and the desired properties there is a relation that can be approached from two directions, analysis and synthesis. Analysis is marked with a dash line in the Figure 12 and there the issues that describe the properties are estimated from known/given characteristics of the product. Synthesis is marked with a dot line in the Figure 12 and there the characteristics of the product are determined from given product property requirements. The starting point in Property-Driven Development depends on the case e.g. whether the attempt is to develop a totally new product or shall the old product design only be improved. In the design cycle proposed by Weber & Deubel (2003), the guiding element is the difference between the requirement properties and the gained product properties. According to their analogies this difference is called deviation between as-is and the required properties.



Analogies:

Required properties, Soll-properties (PR$_j$)	Reference value
As-is-properties, Ist-properties (P$_j$)	Output & feedback value
Deviations between as-is- and required properties (ΔP$_j$)	Current “error”
Characteristics (C$_i$)	Input values
External conditions (EC$_j$)	Disturbances (!!)
Synthesis methods/tools (R$_j^{-1}$)	“Actuators”
Analysis methods/tools (R$_j$)	“Sensors”
Overall evaluation of current deviations (“Eval.”)	“Control unit”

Figure 12. Cycles of analysis and synthesis in Property-Driven Development (Weber & Deubel 2003).

2.1.3 Dispositions and domains in design

The Danish researchers have investigated the survey area of dispositions and theory of domain. According to Lehtonen (2007) Andreasen has brought Hubka et al.’s (1988) theoretical views closer to practice. The four domains that affect in the dispositional mechanism are the structures of process, functions, organs and parts. When the causality relation is vertical, it is affecting inside one domain and when the relation is horizontal the causality affect happens between the domains. The latter one affects in the situation where the design takes into account e.g. the manufacturing feasibilities (Design for Manufacturing, DfM) and this is called dispositional mechanism. It is the mechanism where a product achieves its concrete form based on the design (Olesen 1992). Product quality is a strong influencing factor in that mechanism where Mørup (1993) defines it with two q’s; the big Q describes the quality expectations of the customer and the small q presents the internal quality.

2.1.4 Design Rationale

The design process includes exploring design spaces, simulating and verifying design choices and possibly redesigning and repeating the circle. The body of all this information is called Design Rationale (DR) (Chandrasekaran et al. 1993). The authors approach the DR from a functional representation (FR) point of view, which starts from top-down, and where the elements of the system are described first. After that the behaviour of each element function shall follow. Each sub-project team have to do their decomposition. This contrasts to the bottom-up approach that is normally used in many descriptions as well as in the case company's project designs until now. Shipman et al. (1997) note that there are three different perspectives to DR, which they call argumentation, communication, and documentation. These perspectives differ from each other but not totally. They have some overlapping features as well. The argumentation perspective means the reasoning of an individual designer and the discussion among participants in a design project. Whereas the communication perspective means recording naturally occurring communication, e.g. design discourse, among the members of a project team and it tends to overlap the content of both argumentation and documentation. The documentation in turn is collecting and documenting the decisions behind the design. This helps also the stakeholders and other persons outside the project to understand what is done inside it. According to Shipman et al. (1997) structuring of the documentation can be done first afterwards when all the consequences can be seen and analysed. The documentation perspective is one of this study's viewpoints as well, where the captured element functions in the four CCM case projects are forming a general project design structure in contract car manufacturing.

2.1.5 Simultaneous Engineering in Design for Manufacturing and Assembly

Simultaneous engineering (SE) in product and manufacturing design often support also the design for manufacturing and assembly (DFMA). Both approaches have been used in the CCM projects and they can have remarkable influence to the product design if that is still under development.

The terms Simultaneous Engineering (SE) or Concurrent Engineering (CE) are widely discussed in the literature of product development and industrial processes. Gierhardt (2001) studied the terminology thoroughly in his thesis on global product development projects. According to him both terms are used as synonyms while concurrent engineering is more spread out in the American language area and simultaneous engineering more in the European language area. Bullinger et al. (2000) use *concurrent simultaneous engineering* as a strategy and methodology for modern product development (Bullinger et al. 2000). The essential issue in this thinking is to create parallel process steps between different design tasks in order to acquire the optimal design result. In the German design environment this means standardization on all three levels, process, organization and product as well as integration of information in the networking companies. Also Fujimoto et al. (2011) note the need for the information integration and corresponding IT systems. The target is to shorten the time-to-market of the product as well as to improve the product quality and reduce the development costs (Eversheim, 1995). This can be achieved with product and process design's time parallel integration. Eversheim (1995) and Bullinger et al. (2000) speak also for an interdependent and well-organized teamwork. According to them the organization form with simultaneous engineering teams is the most suitable way to work out product development in the industrial field and in a cooperative manner. When SE teams are organized and working well it brings regularity into changing information, helps to integrate the interdependent knowledge and brings flexibility and creativity to the development teams. The main target of SE work is the reduction in costs and development time as well as improvements in the product quality. Erixon (1998) has described the time reduction in his thesis, presentation in Figure 13. The overhead presentation in the Figure shows the stages in traditional product development where the next phase starts first after the previous has been finished. Whereas in the lower presentation the development phases can be overlapped in some amount in order to get time reduction in the whole process. This overlapping is possible because of the simultaneous engineering work in product and production system design.

The SE way of working can also be called integrated product development (IPD). Although Lindemann et al. (1998) see CE and SE as elements of IPD this study's aim is not to differentiate those concepts. The elements influencing in this parallel development process are presented in Figure 14 (Gierhardt 2001).

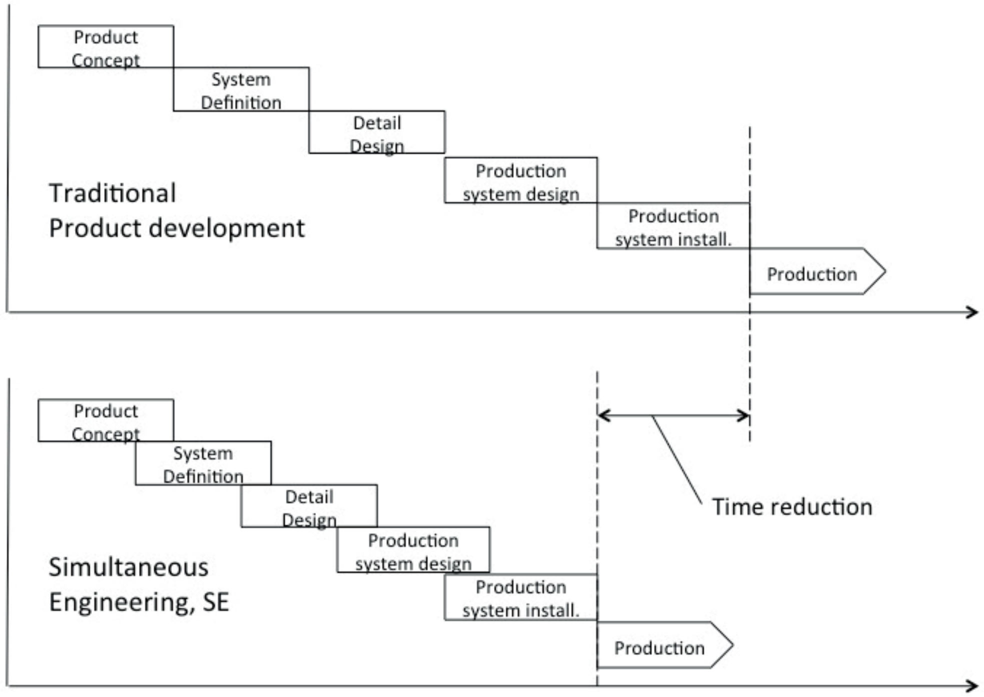


Figure 13. The principle of the SE work's influence to the product development process according to Erixon (1998).

The first example of DFMA and SE in the automotive manufacturing was probably the T-Ford. The first of them were manufactured at the Piquette plant in Detroit in 1908 and eleven cars were finished during the first month. Two years later the manufacturing was moved to the Highland Park plant in Michigan, which was built up to serve the needs of manufacturing and assembly and the assembly time was reduced from 12.5 hours to 93 minutes. (http://en.wikipedia.org/wiki/Ford_Model_T)

This can be considered as an early implementation of SE and DFMA although the terminology was not known at that time. Boothroyd et al. (2002) created and developed the DFMA concept in the early 70's. These methods are used to help the design in almost all the industrial fields with manual and robotic assembly, as well as with machining. One of the reasons that T-Ford as well as the VW Käfer later on had success was their capability to manufacture mass-production cars in a lean manner with good quality and a fair price. Japanese car companies became first later successful in this capability but today they are considered to be the most ahead in the design and manufacturing process integration. Especially Toyota has refined their processes to world-class examples in that area. Several research and books report about their success in lean design and manufacturing, the most famous writers of them are Fujimoto (2003), Liker (2004), and Morgan and Liker (2006). Toyota's set-based product development and their fastness in finishing the new car projects are well analysed in those books.

The SE way of working can also be called integrated product development (IPD). Although Lindemann et al. (1998) see CE and SE as elements of IPD this study's aim is not to differentiate those concepts. Gierhardt (2001) has studied the cooperation elements that influence in the parallel development process in global product projects. He found that the cooperation elements that characterize the global product development are (Figure 14) information flow in the network, a framework for problem solving, systematic application of the methodology, team work implemented in the organization, parallel work tasks, and knowledge usage and distribution. All those elements could be found in both ways of working, project or process oriented.

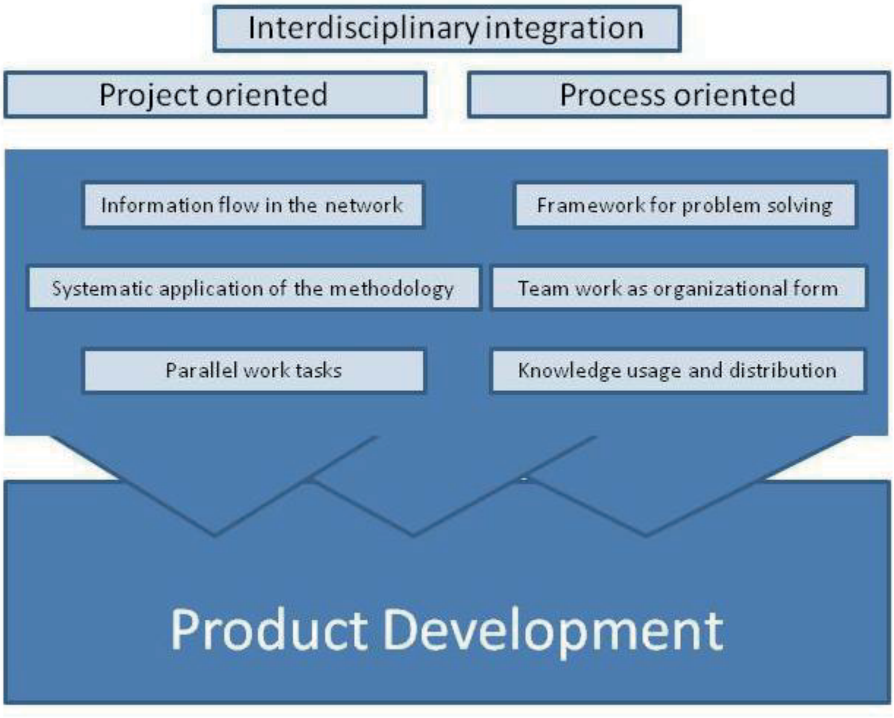


Figure 14. Presentation of the cooperation elements in the product development strategies (Gierhardt 2001).

Eskilander (2001) has presented the hierarchy of Design for Something concepts in his thesis (Figure 15). The design of a product can be focused on many different targets. The first level of the target domains is manufacturing, service, recycling, and anything. Furthermore manufacturing can be divided into fabrication and assembly (and anything) and assembly can still be divided into automatic and manual assembly. So there are a lot of possibilities to take into account in design and of course combinations of the different targets are also possible.

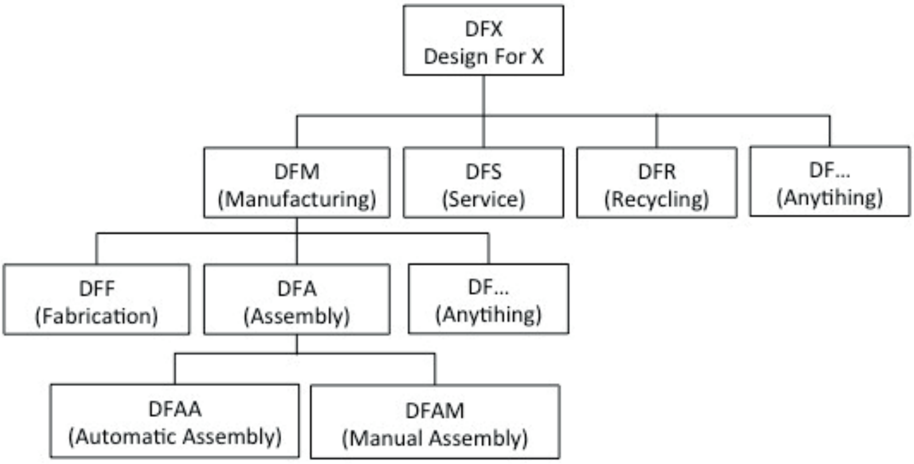


Figure 15. The hierarchy of DFX (Eskilander, 2001).

A sufficient design for manufacturing is reached when the designer's knowledge of car manufacturing in general is good. If he or she has also detailed knowledge of the actual manufacturing facilities the result will be even better. In Toyota and other cases mentioned above this knowledge was available because the development teams operated near the manufacturing facilities. But when it comes to manufacturing under contract in another company and novel cooperation, the knowledge has to evolve before the design can take the advantages of it. Even if the design engineers are familiar with car manufacturing in general and experienced in their own production facilities, the new manufacturing company will bring new features of the cooperation between design and manufacturing because of the different organizations and systems which have to be integrated.

Whitney (1988) has studied a lot vehicle door design and notes that design is a strategic activity. It influences the flexibility of sales strategies, the speed of field and the efficiency of manufacturing. It can be responsible for the company's future viability. In his study he focuses on the development of the process quality instead of product quality. He claims that converting a concept into a complex, high-technology product is an involved procedure consisting of many steps of refinement. The initial idea has to be modified including the increasingly subtle choices of materials, fasteners, coatings, adhesives, and electronic adjustments. He takes an example where the manufacturer's appliance depended on close tolerances for proper operation yet edicts from the styling department prevented designs from achieving the required tolerances: the designers wanted a particular shape and appearance and would not budge when they were apprised of the problems they caused to manufacturing. The conclusion of Whitney (2008) was that the problems arising during the project are usually very complicated and the ones who understand them do not have enough authority to solve them, and those with enough authority do not understand the problem. A tolerance problem similar to Whitney's (2008) findings has occurred also in one of the CCM projects studied here.

Adler (1995) has investigated the relationship between product design and manufacturing. He found out that coordination tasks and mechanisms typically change over the course of the product development project's lifecycle. Adler names this the design / manufacturing relationship (DMR). The DMR elements in CCM projects are the same but the project proceeding correlates strongly with the type of the car company and other stakeholders in the project. The characteristics for a CCM project and its targets as well as cooperation and responsibilities are defined in the contract manufacturing agreement (CMA). The most important targets in the projects have been time-to market as well as the production volumes. Both of them affect strongly on the project schedule.

It is most useful and economical to change the design in early phases where the product design has only 3D models. The earlier the change needs are found the better it is because there are not yet many documents that need to be changed. In the later phases and particularly after the design freeze changes need to be accepted through a rigorous process to make absolutely sure that everything will be taken into account that is connected to the change. That process takes time and costs a great deal because of the many stakeholders and functions involved. They have to evaluate the influence of the change in their own responsible area. In the terms of Koskela (2000) this belongs to the category of wasted time. Ulrich and Eppinger (2008) recommend that when disciplined teams are first time ready to "freeze the design" they should do that and leave incremental improvements for the next generation of the product.

According to Lindemann et al. (1998) the possibility to reduce the product development time is the most interesting element of the integrated product development strategy. Their research shows that the integrated product development methodology is an essential part when implementing integrated cooperation. Also Winner et al. (1988) name concurrent engineering as a systematic part of the integrated and parallel development of products and processes. Bender (2001) suggests an extensively goal oriented cooperation management for a product development project. This should be based on the perspective of work as well as organization psychology. He aims at optimizing the product development with the help of cooperation. The focus is in getting the company's internal cooperation implemented in the product development teams.

Loch et al. (1999) have studied the optimal levels of concurrency combined with communication, which is essential especially in the early development phase. They found out that when choosing communication and concurrency separately it prevents achieving the optimal time-to-market, resulting in a need of coordination. Terwiesch et al. (2002) have researched coordination and found out that previous studies have either described coordination as a complex social process, or have focused on the frequency, but not the content, of information exchanges. Coordination among tightly coupled (interdependent) and parallel tasks makes parallel teams to share preliminary information about the work in progress. That is why components must be specified while interacting systems are still under development. This kind of coordination often proceeds in an informal, *ad hoc* manner. It is hard to tell if the right information is shared at the right time. Terwiesch et al. (2002) and Loch et al. (1999) found out that organizational literature has primarily focused on to find appropriate organizational structures in order to respond to uncertainty and interdependencies. Most of the models have been static in nature and that is why they cannot fully capture the concept of concurrency, which is time dependent and helps in the project execution flow. The prior studies have also left the concept of preliminary information itself undefined, despite of numerous recommendations to do so (Clark and Fujimoto 1991).

Whitney (2008) has done investigations with door design because their structure is highly complex and they contain about everything that a car as a whole contains except powertrain elements. That is why they are a suitable example of automotive design. The customer feels their functionality when opening them; they have both interior and exterior elements. Many of the attributes conflict, e.g. better water leakage and wind noise behaviour will make it more difficult to close them. Better side intrusion protection will make them heavier as well as stronger motors for raising the glasses. Whitney (1988) compared the door architecture and manufacturing in six automotive case companies and found out, that the only common thing in those companies was that all of them removed the doors after the body was painted, assembled the components to the doors on a separate line, and reassembled the doors to the body at a later stage in the final assembly line. Whitney's (1988) findings reflect the many possibilities and needs for optimization that design has. Furthermore they noticed that Toyota had made remarkable efforts in designing and making its doors based on the same standards, which was not the case at the other five companies. The least opportunities for standardization in their research had one contract car manufacturing company who had to follow the procedures that the client had dictated with almost no possibility to affect the design, which had already been completed.

In an integrated product development process where the manufacturing company brings its ideas to the development teams the simultaneous engineering teams have to be built up with members from both organizations. The manufacturing team members need to work near their own production line but their know-how is needed also at the development team's site. When there is a geographical gap it is challenging to communicate the issues in spite of all sophisticated IT systems. Often there is still a need for a real face-to-face communication. In that case part of the gap can be filled with resident engineers from both sites working on each other's locations. In the design phase the focus is on the development site but when the pre-series production starts the focus will be at the manufacturing site. This is a question of resourcing, how many resident engineers there should be and what kind of experience and knowledge they need to have. According to Adler's studies (1995) the amount of cooperating engineering resources varies and depends on the actual project phase. That means that the engineering resources should be organized flexible and depending on the actual phase of the project.

Also Clark and Fujimoto (1991) and Paashuis et al. (1997) have found advantages that SE brings to product development like it enables an as early start of new product-related activities, it enables “first-time-right” design, i.e. reduces the need for re-design, and it can result in reduced costs, improve manufacturing and assembling features, reduce design and manufacturing lead-time.

2.1.6 Need for information and communication technology in simultaneous engineering

ICT plays and fundamental role in the cooperation between different parties in contract car manufacturing and product development. Partners, who cooperate the first time together, lack a common ICT infrastructure and systems. The PD data should be placed available for all the co-operators. But while this data is very sensitive the car companies need usually some time to solve the way to construct the process and infrastructure system. Lanz (2010) investigated in her thesis knowledge representation for assembly and manufacturing processes and found two major problems in that; the first one is the large amount of information without meaning inside the company systems and the second one is the incompleteness of product knowledge and information in the production company’s decision support system. Also Järvenpää (2012) found a lack of sufficient information models as well as tools for capturing and managing the information to support the adaptation planning.

To be able to work simultaneously with product development the first thing is to establish a “platform” for the cooperation (Lanz 2010). But a common IT system between the operating partners is not alone enough; the design processes which produce the data for the 3D models should also be described and adapted by all partners involved. It is important to agree the procedure for engineering changes and how the requests of them should be handled, what are the actions after a change order release, and what kind of ICT infrastructure and software is needed for that process. Also Prasad (1997) states that in this kind of cooperation many different ICT tools are needed and attention should be paid to process and organization level as well. Zwicker et al. (1999) see the ICT support on the foreground in the cooperation.

To be able to analyse the DfA in the earliest possible stage when there are no physical parts yet the manufacturing experts can have support of immersive virtual reality (VR) equipment. The system presents the car body in its real size and the assemblies can be visualized more realistic than with traditional CAD software. Furthermore if the product and manufacturing design teams have similar VR systems they can also discuss their findings through the communication line, which can be even more supportive.

Fujimoto et al. (2011) have started a novel research concerning the complexity in today’s artefacts. This goes for the products as well as for the production systems designed for that. The customer demands extend the amount of functions needed in the products and that leads to a large number of structural parts which design need to be synchronized with the functions. This phenomenon generates a strong need for supporting IT systems to manage the processes which are impossible to manage manually. So this increasing number of “computers” inside the car is another challenge to the engineering change management with its new software version updates management.

2.1.7 Modularity in product design

Hellström et al. (2010) define modularization as a method where the product is divided into functions or parts, modules, which then build up the product structure. The modules help to understand what each module consists of and makes it easier to gain a grip from a complex product. Hellström et al. (2010) claims that modularity reduces the lead-time of design e.g. in helping to reduce the rework because everybody is aware of the interfaces and dependencies between different design objects. Riitahuhta and Andreasen (1998) have developed a Dynamic Modularization process, where new merited modules can be brought into the system and the old ones can be left out. Their process is based on the definition of encapsulation and similarities as well as the description of interfaces and modular management system. The process also takes into account all the different stakeholder views in the development project.

Fixson (2002) has analysed modularity from three perspectives, system, hierarchy, and life cycle. He notes that like a system a product can also be described via its elements and the relations between them. When talking of technical viewpoint and functionality Fixson names this perspective hierarchy. The life cycle viewpoint lifts some aspects in the modularity to the foreground and puts some other aspects to the background. Furthermore Fixson claims that the different definitions of modularity in the literature are often overlapping and do actually not differ from each other very much. His modularity analysis focuses on cost evaluation in his theory generation, Figure 16.

Also Hsuan Mikkola (2003) builds up a theory of modularization in her research. The viewpoint is NPD where she divides her analyses on three levels, industry, supply chain, and product architecture and focuses on supply chain level.

Modularization is an essential precondition for a product configurator, which is a tool that helps to create configuration for a product (Pulkkinen 2007). Several researchers have defined configuration, e.g. Collins (2000, ref. Pulkkinen 2007)) defines it as the arrangement of parts of something. Webster (1989, ref. Pulkkinen 2007) adds the geometry to the definition. He says that this is the relative disposition of the parts or elements of a thing.

Lehtonen (2007) studied modularity in connection to products and business. He presents the configurable product paradigm (CPP) that is a corporate method of operation and an essential part of it is the defined order-delivery process. CPP concentrates on mass-production products. Pulkkinen (2007) demands that modularity could follow up the concept of DFX, design for X, where X may be assembly, manufacturing, purchase etc.

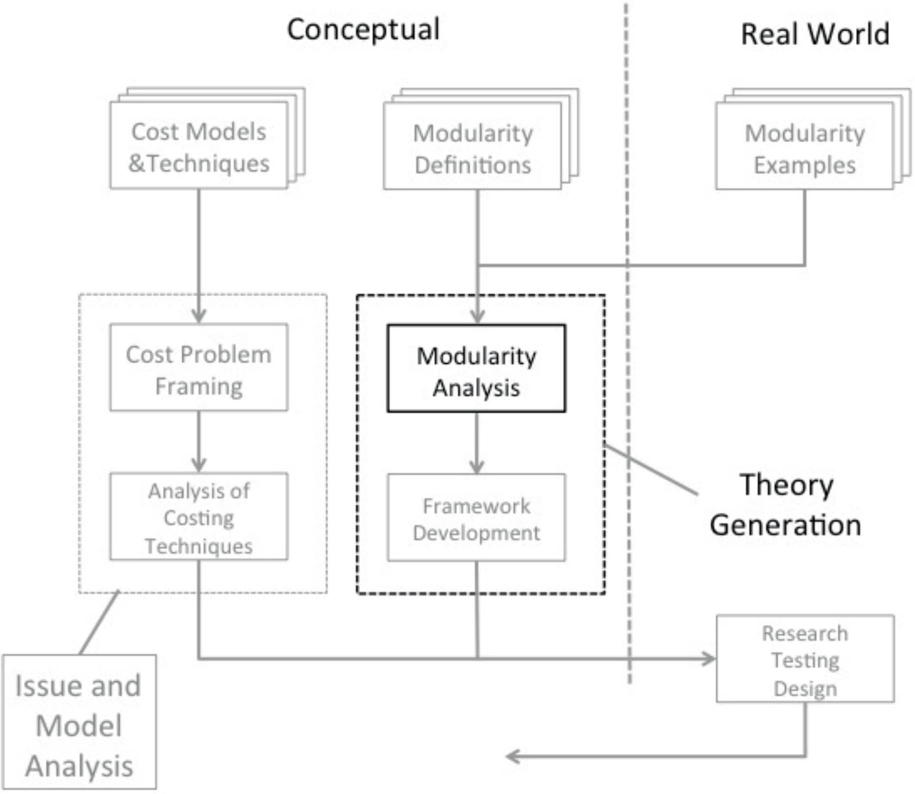


Figure 16. Relation of modularity analysis for theory generation (adapted from Fixson 2002)

The numerous approaches to modularity show that modularity is not only product related. The same ideas can be applied to any systems after analysing their elements and interdependencies. In this study's object, a CCM project, modularity means the project structure and elements in it, how it is divided in sub-projects, and what are the dependencies between them. They compose the module system in this case. Like in products the architecture of projects can be modular or integrative. Sosa et al. (2000) define modular systems as those whose interfaces are well specified and shared with only a few other systems. Integrative systems are those whose interfaces may be more complex and shared across the product. When looking at this study from Sosa's viewpoint the structure of a CCM project is integrative because it has interfaces all over the project with several stakeholders. But after the project has ended and the factory is up and running the structure of that outcome is modular because the interfaces have been defined exactly and they should also work exactly to be able to manufacture quality cars in serial production. So the CCM project architecture has modular features and the project can be divided into interdependent modules. The tasks and actions inside one module have dependencies to the tasks in other modules and that integration will be analysed in Section 4.5 Results from the tool analysis.

2.1.8 Monozukuri, knowledge, and flow in product design

One of the reasons why the Japanese car companies have achieved their excellence in car manufacturing is their capability to create information flow between the different functions, which are involved in the product development and production. They call this way of acting *monozukuri*. Fujimoto et al. (2011) translate that Japanese word to "manufacturing", which in their context means more than its English expression. Monozukuri-manufacturing signifies a broad network concept operating together in order to gain customer satisfaction through design, development, production, purchase, and sale of artefacts. An artefact means all design objects, which in this thesis context are the CCM project's targets, to build up a plant and launch the serial production there. In this research the original Japanese word will be used to avoid confusion with the traditional English word. Furthermore monozukuri is not only about creating an object but creating the design information for an object as well.

Information is an essential part of product development also in the western world. Gierhardt (2001) finds that product development is a cooperative process that creates, works out and forwards information. This information concerns products and artefacts as well as the process itself and the tools and methods used in it. In this context Miller (1993) refers to an "Intellectual Process" of solving the problems. When the product development process is proceeding, the information gets more and more extensive and detailed. When taking the information viewpoint to the simultaneous engineering function, process management and computer support are important for the implementation of that function (Miller 1993). Allen (1985) states that the concrete products are physically coded information, which reminds the monozukuri conception of Fujimoto et al. (2011). Hubka et al. (1988) take a similar viewpoint in his Theory of Technical Systems. Also Ehrlenspiel (1995) combines information with product development. He divides the information flow into three phases: producing it, handling it, and forwarding it. The system thinking view raises also information for an essential part of any system (Meadows 2008).

A construction project has many similarities to a CCM project, which builds the facilities for production process. Koskela (2000) has investigated the waste in construction project phases and defines as waste costs all those that do not add the value to the end product. In the design the waste costs can arise from the design or construction itself or from the design project management. All these waste costs are cumulated to the value of the project to the customer in the column that is most right in Figure 17. Waste costs can arise during design due to project management and the design itself. Furthermore waste cost can be generated during construction due to project management, due to design, and due to construction itself. All these waste costs may originate value loss to the customer due to project management, due to design, and due to construction.

Koskela (2000) has researched in his thesis transformation flow value (TFV) in construction industry's design. He provides three conceptual views on design; transformation concept, flow concept and value generation concept. In Table 1 these concepts are described in detail and adapted to this research. Koskela (2000) notes that only the transformation view has usually been taken into account in design. The other two views have been left for informal consideration of designers. Koskela (2000) challenges the design projects to integrate all viewpoints in project management.

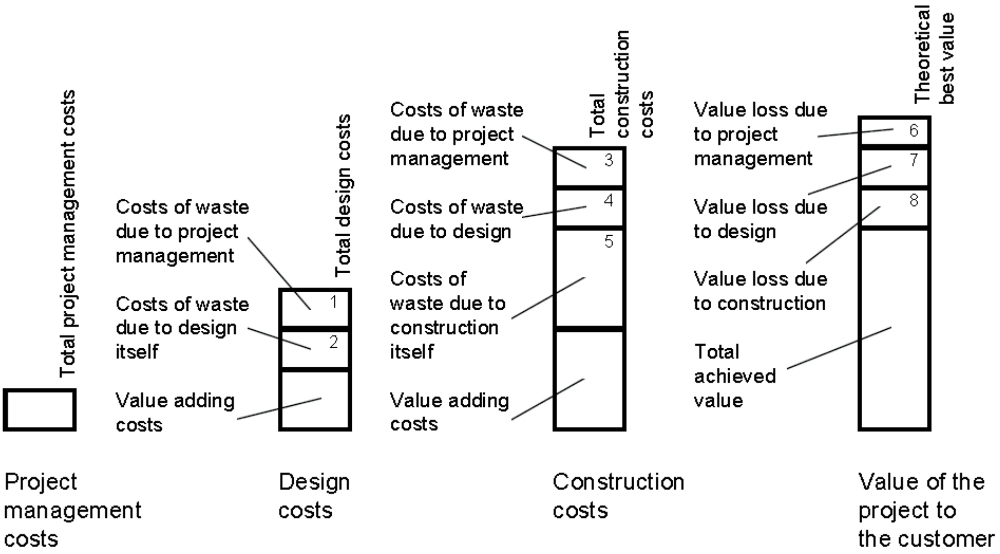


Figure 17. Schematic figure of waste and value loss in construction project phases; the column sizes do not indicate relative quantities of costs (Koskela 2000).

Table 1. Transformation flow value (TFV) concepts in a CCM project. (Adapted from Koskela 2000)

	Transformation concept	*Flow concept*	*Value generation concept*
Conceptualization of design	Transformation of requirements and other input information into project design	Information flow formed of four stages; Transformation, inspection, moving and waiting	Process where value for the customer is created through fulfilment of his requirements
Main principles	Definition of project's hierarchy and activities as well as their control	Elimination of unnecessary activities (waste) which leads to reduction of time and uncertainty	Elimination of value gap between achieved value and best possible value; careful detailed planning of how the customer requirements will be fulfilled
Methods and practices (examples)	Work breakdown structure, critical path method, definition of responsibilities in all participating organizations	Design structure matrix, simultaneous engineering, cooperation and partnering between organizations, tool integration	Clear and detailed targets for process quality, agreed way of reporting to customer the project proceedings
Practical contribution	Taking care of what has to be done	Taking care that unnecessary doings are minimized in the project	Taking care that customer requirements are filled as good as possible

Halonen (2012) introduces Disposition Modelling (DiMo) that combines DSM with graphical presentation to model and analyse dependencies, or dispositions between system elements in product development. The dependencies are an extremely important part of the flow concept and monozukuri.

Lehtonen et al. (2012) refer to cultural-historic activity theory based on research of Leontjev and Vygotsky (1981, 1978 ref. Lehtonen et al. 2012). The theory explains that a company has to have organizational capability in order to be able to operate in the monozukuri-way. This organizational capability depends on the possibilities of tacit and explicit knowledge to interact. Monozukuri is not a process that can be copied. That kind of capability is not achieved very fast. In Japanese companies it is the result of a long evolution (Fujimoto 2003).

Fujimoto (2003) describes the responsibilities of the organization e.g. that the responsibility to create design information is the responsibility of development department and transferring it to the object is the production department's responsibility. When speaking on the rough level about the responsibilities this is true but when there is a large and complex CCM project there are subcontractors, which make the responsibilities difficult to manage. Project execution in this context is a complex integrative knowledge field and the approach should be to model and develop a project specific convention in naming the responsibilities (Bredillet, 2010).

Fujimoto et al. (2011) have compared two different information transfer styles in transferring the design information to the medium that are batch transfer and sequential transfer. They have taken in their comparison three kinds of products, mechanical, electric and software products. They found out that the information transfer is significantly affected on the target product. Because large engineering projects are a combination of all three product types a great deal of attention should be devoted to their information flow and synchronizing their development processes. Fujimoto et al. (2011) note that the Japanese researchers, like Araki, Ueno (2005) and Fujitsu with Japan manufacturing society 2007, have recently started to make analyses of design and development logic in similar kind of projects.

Nonaka and Takeuchi (1995) have investigated Japanese companies in their ability to create new knowledge and use that to produce successful products. They categorize the knowledge in two types that are explicit and tacit. Explicit knowledge is attached in manuals and procedures while tacit knowledge is learned only by experience. They describe the development of explicit knowledge with a spiral in Figure 18. The tacit knowledge starts to gain explicit form when it is socialized. But to be able to spread that out to all organization levels it needs to be made explicit. According to Nonaka and Takeuchi (1995) the creation of explicit knowledge needs interacting between tacit and explicit knowledge.

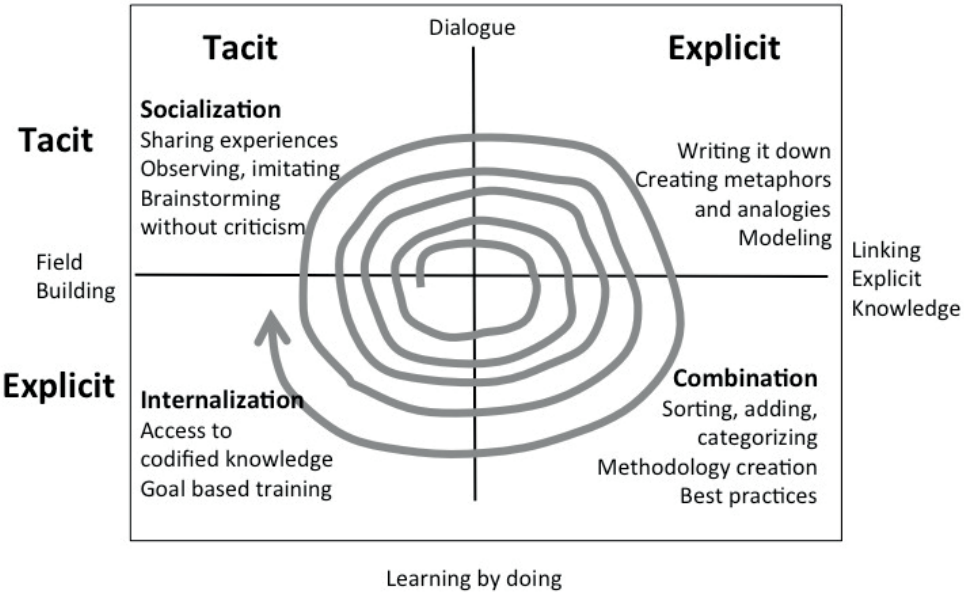


Figure 18. The spiral creation of explicit knowledge in working teams (Nonaka et al. 1995).

Lipman-Blumen et al. (2000) have researched working environments and found out that in some projects there seem to be groups where individuals voluntary dedicate themselves to the common challenges and targets in a manner, which make their working very effective. They name these groups hot where individuals from different teams and departments in the company form them and the organizing happens from their own initiation. Their collaboration and work results seem to be amazing. These groups are usually temporary and their motivation needs special management skills. Sometimes these groups can be found in projects especially in the early project phases but their efficiency often decreases towards the end of the project, especially in long lasting projects.

2.2 Project management research

2.2.1 Theory of project management research

According to Project Management Institute (PMI 2008) the project is a temporary endeavour which target is to create a unique product or service. The handbook is very much based on the instrumental perspective like many other books trying to give instructions for a successful project management. They are in the right place when one wants to present the framework, which is useful in conducting a project through its phases. But those books take not into account the knowledge and information flow that is not following the rules in the book.

Turner (2006) takes a more cognitive perspective when defining that a project is an endeavour in which human, material and financial resources are organized in a novel way in order to undertake a unique scope of work with given specifications and constraints of cost and time. The French researchers (Declerck, Debourse, & Declerck, 1997; Declerck, Debourse, & Navarre 1983, ref. Bredillet 2010) have taken a political perspective to the definition of project: They say that a project is a whole of actions which are limited in time and space and interacting in an environment which has certain political, social and economic features. The tendency is towards a goal defined in the project plan, which is redefined during the project to be equivalent with the reality. But the French school has not either investigated the knowledge flow which is an essential addition what the project management research needs to take into account. Because the nature of the flow is dynamic and it may evolve in other stages than the stage gate model specifies, some system modelling tools may help in controlling the project, like some system engineering researchers have pointed out (Checkland 2009, Sterman 2000, Nygård 2010).

According to Sutherland (1975) a theory constitutes "an ordered set of assertions about a generic behaviour or structure assumed to hold throughout a significantly broad range of specific instances". There have been many attempts to develop such theories of project management for project research e.g. Andersen (2006), Artto and Wikström (2005), Leybourne (2007) and Turner (2006). Bredillet (2010) in his study argues that the research field of project management is in its pre-paradigmatic phase meaning that there is no consensus on any particular theory although the research carried out so far can be considered as scientific in nature. Bredillet (2010) claims that if the actors of the community in this pre-paradigmatic phase could commit themselves to one of those conceptual frameworks and agree on methods and terminology then the phase of normal science could begin.

So far there is no theory of project management although Turner (2006) has made attempts to that in the Journal of Project Management's editorials, beginning with the title "Towards a theory of project management". In those articles Turner (2006) has looked at the nature of projects, the nature of project management as well as to the five functions of managing it which are 1) managing the scope, 2) managing project organization, 3) managing the quality, 4) managing the costs and 5) managing the time. The five functions are the same ones, which the Project Management Institute (PMI 2008) calls Body of Knowledge (BOK) areas. The other four BOK areas are 1) project contract management and procurement, 2) information and communication management, 3) resource management and 4) risk management. Sauer and Reich (2007) argue that Turner's (2006) approach to theory building is just one and that even if there was a fully developed theory of project management according to Turner's (2006) sketches it would leave some important key questions unanswered as well for researchers as for practitioners. Sauer et al. (2007) compare this issue to the general field of management research where a single theory cannot explain all the behaviours in complex organizational environment. They criticize Turner's (2006) theory base of taking mathematics as its model. In his theory definition certain consequences follow logically each other and if not, that should anyway have done so. Furthermore if the proceeding is not according to the logical follow up, then the project is not correctly managed. According to Sauer et al. (2007) the theory has its value as an inclusive, comprehensive statement of what should be true. They claim that a theory is needed which will help to understand the conditions and drivers that lead to both functional and dysfunctional behaviour so that different behaviours can be influenced by addressing the root causes. They admit that the problem with their perspective is that they tend to be very specific. Turner (2006) on the contrary tries to sketch a unified wide-ranging theory in the domain of project management. Also other researchers who discuss theories in project management refer to the theories of management science.

Bredillet (2010) has studied project management research and found out that it started as an offshoot of operations research but it has now grown and at least nine schools of research (Figure 19) can be identified in project management. The first school of them was the Optimization School that started already in 1950s, thereafter in 1960s came the Modelling School followed in 1970s by the Governance School. In 1980s the dominant school was Behavior School, in 1990s came the Success School followed still in the same decade by the Decision School and Process School. Contingency and Marketing School were launched in the 2000s. Bredillet (2010) claims that project management draws on and makes contributions to research increasingly in other fields of management. In his article he suggests a possible "meta" approach of the project management field to provide an integrative ontological and epistemological framework. He proposes to address project management as a complex integrative knowledge field, which can lead to "modeling-developing specific convention-to do ingeniously". He refers to many French researches that have studied the theory of convention in economic and social environments. Le Moigne (1990) e.g. has stated that acting in complex situations involves "modeling to understand". When it comes to complex and systemic environments then acting and learning cannot be separated and this means needs to have information and tacit as well as explicit knowledge and contextual understanding of the whole system. Bredillet (2010) writes about meta-modeling approach and with a project management perspective it is about to design a contextual structure where project staff and stakeholders can learn and integrate their perspectives. It also enables to create a specific convention (configuration of order) and some kind of stability to cope with uncertainty and ambiguity in a given projects complex situation. So Bredillet (2010) and Le Moigne (1990) share the viewpoint of this study that the best way to manage large engineering projects is by means of modeling the system with its elements and dependencies.

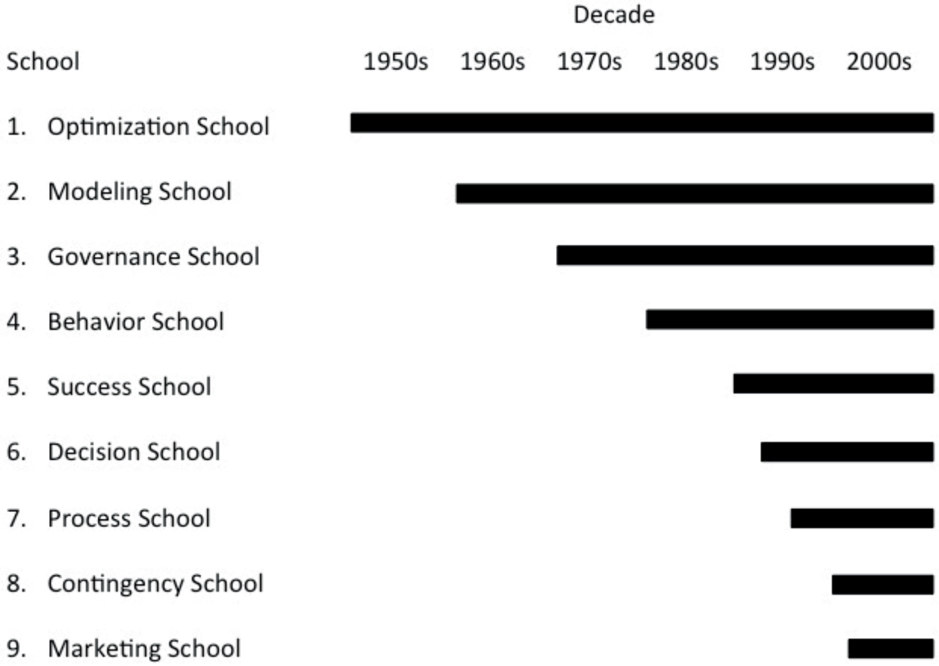
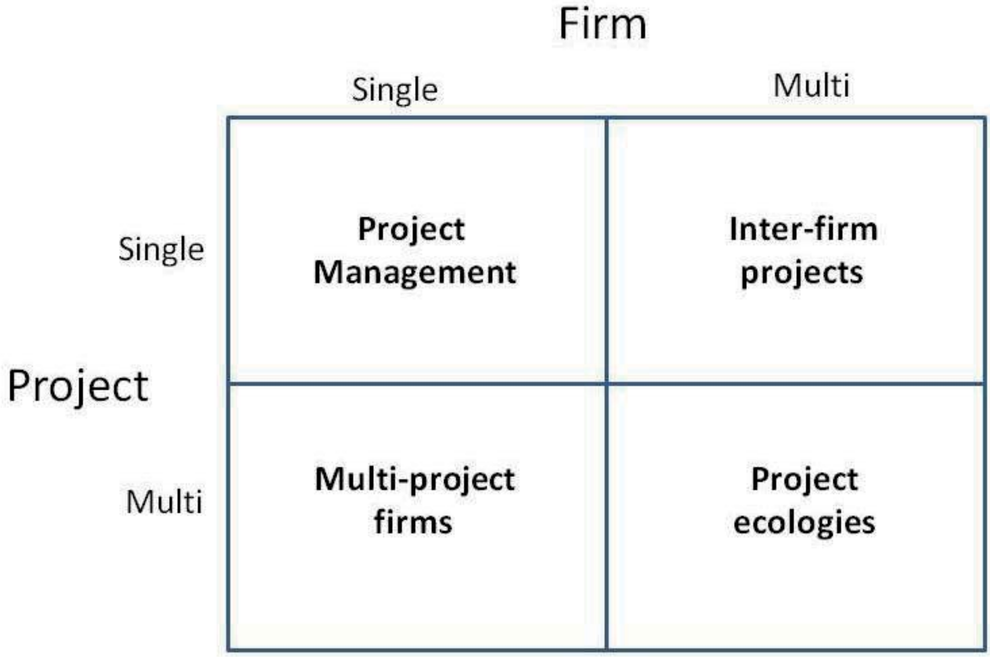


Figure 19. The nine schools of project management research according to Bredillet (2010)

2.2.2 Project classifications and complex mega-projects

Several researchers of project management have created classifications to the project types. Söderlund (2004) uses two variables, firms and projects, in a fourfold table (Figure 20).

Mega-projects are large-scale complex projects delivered through various partnerships and they are often affected both public and private stakeholders, Public-Private-Partnership projects (PPP), (van Marrewijk et al. 2008). The management of them can be very demanding because of their large and often international nature (Aramo-Immonen 2009). Flyvbjerg et al. (2003) call mega-projects “the new animal” and often public investment projects of infrastructure construction. One typical example of those projects is the channel tunnel in the British canal about which a lot of research has been done (Flyvbjerg et al. 2003). Those projects seem to be promoted by almost every European country as well as by a pair of neighbouring countries and they are often sponsored by the European Union that also may have influence in that “the new animal” was born. Ruuska et al. (2011) categorize the nuclear power plant projects as large multi-firm projects where there is a famous example, Olkiluoto 3, in Finland. Aramo-Immonen (2009) compares a fragmented, diversified mega-project organization to the definitions of the virtual organization. They are closely linked to the web-age and characterized by terms like flexibility, opportunism, improved utilization of resources and the collection of core competencies (Barnes and Hunt 2003).



		Firm	
		Single	Multi
Project	Single	Project Management	Inter-firm projects
	Multi	Multi-project firms	Project ecologies

Figure 20. The fourfold table of project classifications (Söderlund 2004)

According to Marrewijk et al. (2008) there are two main models of mega-projects that are turnkey and alliance model. Flyvbjerg et al. (2003) claim that the majority of megaprojects overrun on costs, fall behind of schedule and fail to deliver in the terms used to justify the need for the project; the channel tunnel again is one example of these. Flyvbjerg et al. (2003) suggest that a main cause of such overruns is a lack of realism in initial estimates. The length and cost of delays are underestimated; contingencies are set too low, changes in project specifications and designs are not sufficiently taken into account, changes in exchange rates between currencies and price changes are undervalued as well as many other cost influencing factors. Many major projects also contain a large element of technological innovation with associated high risk.

2.2.3 Uncertainties and risks in complex mega-projects

Flyvbjerg et al. (2003) claim that the uncertainties in mega-projects are not so well analysed in advance as they should be. They compare that to the private sector projects and claim that the analysing is done more precisely there. Unforeseen remains seeing if the channel tunnel would have met better its target figures, if the analysing of uncertainties had been done more carefully. The channel tunnel opened in 1994 with a construction cost of 4.7 billion pounds and with several near bankruptcies because of the construction cost overruns of 80 per cent, financing cost overruns of 140 per cent, and revenues being less than 50 per cent from budgeted. They claim that if the pre-examination of a project and its uncertainties would be done carefully, many mega-projects would not have been started at all.

Koskela (2000) has researched the design projects in construction business and categorizes their peculiarities in three groups; which affect on the transformation-flow-value generation (TFV concepts) in the project. According to him the peculiarities are one-of-a-kind projects, on-site production and temporary organizations. Same three groups can also be found in the CCM projects.

Ward et al. (2004) have studied risks and uncertainties in projects and combine them partly with the identity of project parties and their respective roles and relationships with one another. The relationships may be complex and they may involve formal contracts. According to Ward et al. (2004) the involvement of multiple parties in a project introduces uncertainty arising from ambiguity with respect to several issues like specification of responsibilities, perceptions of roles and responsibilities, communication across interfaces, the capability of parties, contractual conditions and their effects, and mechanisms for coordination and control.

Atkinson et al. (2006) have studied uncertainty management in projects and claim, that the common practice does not consider the range of sources of uncertainty in projects. Furthermore they claim that neither does it consider what a coordinated approach to proactive nor reactive uncertainty management can achieve. They name three key areas of uncertainty: 1) uncertainty associated with estimating, 2) uncertainty associated with project parties and 3) uncertainty associated with stages of the project life cycle.

2.2.4 Planning the project time schedule

The standard instructions for project management support in the formal project management books are defined for the circumstances when 'Everything Goes According to Plan' (Flyvbjerg et al. 2003). They claim that a more preferred approach should be MLD (Most Likely Development).

Marrewijk et al. (2008) have studied how project culture and project design can successfully support cooperation between partners in megaprojects. They claim that the integrative perspective used in the PMBOK Guide is too limited to fully understand the dynamics of project culture in megaprojects. Mega-projects are characterized by a culture that is ambiguous; it has fuzzy limits and different participants have also their own targets, which may conflict between objects, and actors who want to have the project realized (Engwall 1998). Rationality in megaprojects is always incomplete and imperfect in action and the decision makers rarely look at optimal solutions, as they never have sufficient information to be able to do so (March et al. 1958).

The mega-project should be defined also by performance specifications and not only with the conventional technical solution-driven specifications. The former design approach is functional and the latter one is structural. Deficiencies of the conventional approach are often under involvement of the general public and stakeholder groups concerned by outcomes and over involvement of business lobby groups, lack of identification of public interest objectives to be met by projects, and lack for clearly defined roles for involved parties. (Flyvbjerg et al. 2003)

Fujimoto et al. (2011) have analysed the architecture and design process for mechanical, electric and software systems. Their conclusion was that electric and software systems were control systems whereas mechanical systems are controlled systems. They found that the management of those processes must be different because of that. Furthermore they note that the design projects today are a combination of all three systems, which makes them extremely complex to manage.

Critical Path Method (CPM) is a schedule network analysis technique. The DuPont Corporation developed that in 1957. Critical path determines the shortest time to complete the project and it is the longest duration path through a network of tasks. Critical tasks are activities on the critical path. Goldratt (1997) has developed that method furthermore and named the result Critical Chain Project Management (CCPM), which is as well a schedule network analysis technique. The main improvement to the CPM is that also resources are taken into account. In his study Goldratt (1997) found out that when people give their estimated durations for the tasks they usually put some safety in there. That means that safety has been put also on the non-critical tasks. The suggestion is to cut the duration of the single tasks in e.g. half the time and put that time instead to the end of the project as a project buffer (Figure 21). Goldratt (1997) claims that you should not strive for accurate answers when the data is not accurate. In this way the project has some time margin left for surprises at the end of the project. In Figure 21 there is an example of the principle with four tasks. Above is the presentation with four project tasks with the estimated buffer duration inside each task. Lower is the presentation where the task durations are set to the most realistic ones and the buffer time is put at the ending.

Several researchers are interested in fuzzy project planning and scheduling. Bonnal et al. (2012) have investigated that research and note that fuzzy project scheduling approaches have been kept in the academic sphere. They present in their study a DSM-based resource-constrained fuzzy project-scheduling problem and a framework, which might help also practitioners in scheduling their projects. Bonnal et al. (2012) name some traditional models in project scheduling like simple Gantt charts activities without dependencies in between, CPM activity networks with durations and finish-start constraints, Precedence Diagramming Method activity networks with links like finish-start, start-start, finish-finish, start-finish and with possible lags added, resource constrained when required resources are taken into account, interdependencies between activities can be taken into account with DSM, PERT (Program Evaluation and Review Technique) is used in combination with CPM and represents the tasks that are needed in completing a project. Furthermore it allows considering the activity durations by means of pessimistic, optimistic, and realistic figures, LSM (Linear Scheduling Method) and RSM (Repetitive Scheduling Method) help in modeling the project scheduling, and GERT (Graphical Evaluation and Review Technique). Furthermore Bonnal et al. (2012) note that their fuzzy approach in project planning and scheduling take into account the set of activities, which belong to the possible activities foreseen to perform the project, the dependencies between the activities, which are constrains, links, and interdependencies that can more or less exist, and the required resources, which can be more or less necessary to perform an activity where the workloads may not be known precisely.

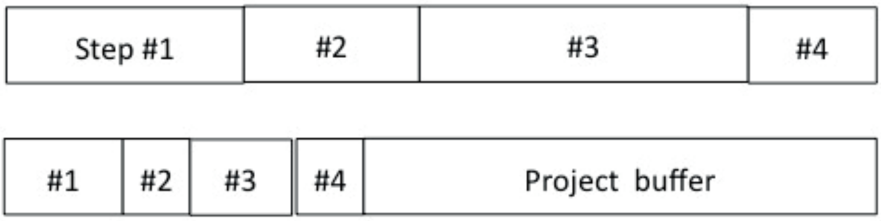


Figure 21. An illustration of project tasks with durations where the upper part is describing the four tasks with duration estimates from the task expert and the lower part describes the idea to put the safety into the end of the project (Goldratt 1997).

2.2.5 Stakeholders effects and integration in project management

Achterkamp et al. (2008) have done a meta-analysis of project management literature to find out how the stakeholder notion is used there. They studied 42 papers and found out that only a minority of the papers provide a clear definition of the stakeholders. They conclude that role based stakeholder identification is a promising approach to identify stakeholders in projects. They recommend that this area in project research should have contributing studies.

It is important to plan the stakeholders reporting in large engineering projects. Flyvbjerg et al. (2003) noticed also that investors and other stakeholders are usually inadequately informed and even misled regarding the risks involved in mega-projects. Wikström et al. have investigated business models for project networks and note that linking of all the stakeholders together in the model requires understanding of a larger context and that systems integration and engineering competence are needed to make this business model work.

System-thinking researchers state that stakeholders have significant influence to the projects and business processes (Gharajedaghi 2011). Customers, suppliers, and other shareholders are factors of this group. They have to be taken into account when modelling the system because it is essential when trying to understand an open and living system that is always bound to its context. The wide range of stakeholders shapes the environment, which is connected to the openness of the system. That is first of the five system thinking principles that need to be considered when creating the mental model of the system (Gharajedaghi 2011). The other four principles are purposefulness, multidimensionality, emergent property, and counterintuitive behaviour. The openness principle means that in modelling the system one needs to define the elements that can be controlled and that cannot be controlled. Furthermore the latter ones can most often be influenced like in today's projects many of the stakeholders. The stakeholders form a transactional environment and understanding their behaviour is significant for understanding the system's behaviour as well.

The second principle, purposefulness, means that to be able to influence the actors in the transactional environment it has to be understood why they do what they do. Gharajedaghi (2011) defines that understanding deals with the questions why, while information deals with the question what and knowledge with the question how. To understand the decisions made by the stakeholder one needs to know that in business world the point of view is most often rational and what is rational for the stakeholder is not necessarily rational to the contract manufacturer or the client. The decision can also be based on cultural or emotional choices, which is also important to understand. Organizations have their own specific culture that has grown up with the organization irrespective whether it is young or old.

The third principle, multidimensionality, means that when searching for solutions in conflicting tendencies the target should be in trying to find strong possibilities, like win-win solutions. This means that situations that were previously considered as conflicts can interact and create new ideas.

Gharajedaghi (2011) categorises emergent properties, the fourth principle, into type II properties, which are a product of the interactions and can be more successful than acting alone. Lipman-Blumen et al. (2000) named those groups hot, when working enthusiastically together towards common project goals. Gharajedaghi (2011) compares emergent properties to the type I properties which are the sum of the actions like e.g. weight of the parts.

The fifth principle, in Gharajedaghi's (2011) definitions for acting with stakeholders is counterintuitive behaviour. It means that actions that are meant to produce a desired outcome may generate opposite results. Like a set of variables that initially played a key role in producing an effect may be replaced by a different set of variables at a different time or with a different client.

2.2.6 Stage-Gate and Spiral Models in Product Design

Cooper (1994) defined the stage-gate model, which has been widely used in project management and product development especially in automotive industry. The model divides the project from five to ten gates. Each gate includes its own definitions of criteria that are needed in order to pass the gate. Figure 22 is presenting the stage-gate model principal by Cooper (1994). In the example there are five gates that operate like milestones. The gates are scheduled in the project timetable and in each gate definition there is a list of deliverables that have to be completed before the gate may be passed. In between the gates there are stages where certain scheduled tasks are performed in order to produce the deliverables. The example in the Figure 22 is a rough presentation of a product project from idea to market launch. In reality the author has experienced more detailed gates in a CCM project. An example of this can be found later in Table 11, which will be presented in section *3.5.3 Quality Gates.*

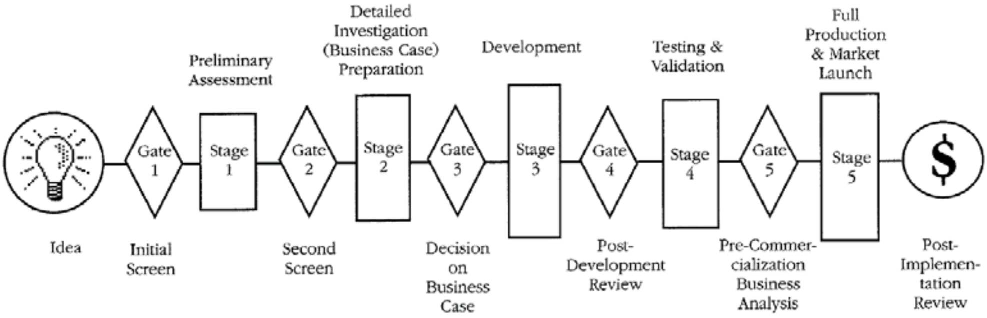


Figure 22. Typical stage-gate model from idea to launch

Thamhain (1996) suggests that the stage-gate model should be used especially when there is a SE function between the engineering departments to be able to handle the changes more efficiently. Although the model is popular in automotive industry, it has got a lot of criticism especially among the knowledge workers like software developers today (Gonzales-Rivas et al. 2011). The stage-gate-model is also called waterfall model (Figure 23). In the model the target is to get all requirements defined right in the beginning of the project. Because of their earliness they may contain some assumptions and guesses that become detailed first in the later project phases. If hard decisions are based on the soft requirements that may cause rework in the project. The knowledge workers say that stage-gate is the orthodox approach to new product development. Another approach to product development is spiral development. In Figure 23 can be seen how the spiral starts with a small set of tightly defined requirements and how they get completed in iterations. The stage-gate model on the contrary starts with a large set of loosely defined requirements and adds the details later.

Although the model is popular in automotive industry, it has got a lot of criticism especially among the knowledge workers like software developers (Gonzales-Rivas et al. 2011). Knowledge workers group call the stage-gate approach the orthodox approach to new product development. The most common techniques that differ a lot of stage-gate are e.g. spiral development, rapid prototyping, agile development, and SCRUM.

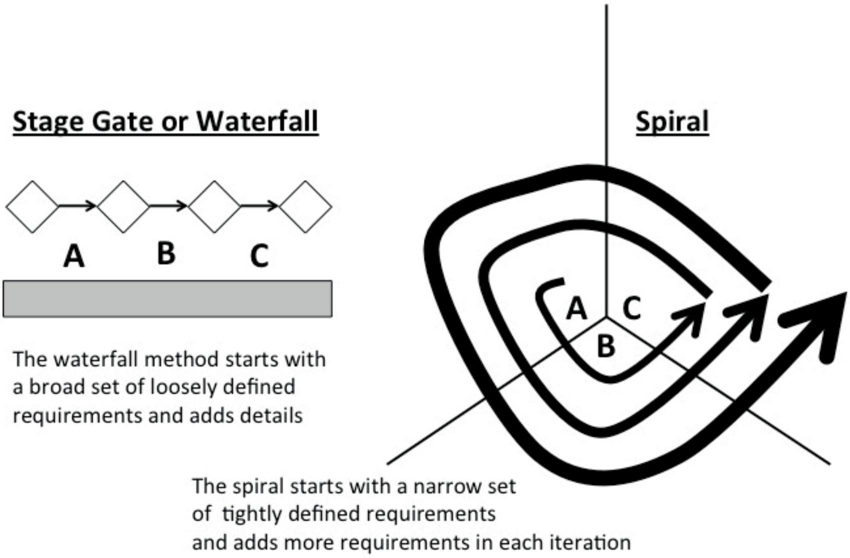


Figure 23. Approaches to development, stage-gate and spiral (Gonzales-Rivas et al. 2011)

In stage-gate approach there is a disciplined review at each gate where the project status and target achievement on that particular milestone are controlled. According to Gonzales-Rivas et al. (2011) passing the review gate becomes in this approach easily the focus of the development project in spite of searching for the optimum design solution together in the development team. The authors criticize also the traditional project management tools, like the common scheduling charts, PERT and Gantt, and their ability to improve the situation. They are task based and present the activities on high-level dependencies and do not expose the essential information dependencies between different activities. Gonzales - Rivas et al. (2011) recommend to handle the interdependencies is Dependency Structure Matrix (DSM), which will be discussed later in Section 2.3.3 The Design Structure Matrixof this study.

2.3 Systems Thinking

2.3.1 History and development of Systems Thinking

There are many kinds of domains in Systems Thinking research field. Jackson (2000) represents those domains and their development quite comprehensive. He notes that the history of this holistic thinking is quite long and one of the beginners in this research was Ludwig von Bertalanffy who worked on General System Theory (GST) (1950, 1968 ref. Jackson 2000). GST research started among a group of researchers in biology who studied the organism as a whole and they were called organismic biologists. Bertalanffy participated in organizing the Society for General Systems Research (SGSR, now ISSS – the International Society for the Systems Sciences) together with an economist (Boulding 1956), a physiologist named Gerard, and a mathematician named Rapoport. They wanted to improve the communication between specialists to solve problems of many disciplines together. But unfortunately GST had to pay for its generality with lack of content. (Checkland et al. 1994).

During the 1970s and 1980s traditional Systems Thinking became subject to increasing criticism and alternative systems approaches started to grow (Jackson 2000). For example "Hard" and "Soft" Systems Thinking (HST and SST) were two different approaches that developed during those years. E.g. Systems Engineering is an approach of the HST. This approach assumes that the system objectives can be defined precisely and that they can be reached by engineering using different well-tested techniques. (Checkland et al. 1994)

According to Jackson (2000) Checkland made the breakthrough from Systems Engineering and established Soft Systems Methodology (SSM) in the 1980s. In SSM approach the questions "What is the system?" and "What are its objects?" are considered to be too naïve in management situations where the clear definition of the objects was not possible. This happened in situations when the participants had conflicting viewpoints and interests. Systems Engineering approach did not take into account the complexities of human affairs. SSM thinks that systemicity lies in the process of inquiry rather than in the world that is assumed in HST. SSM approach generates continual learning about human situations and the intentions that arise in them. Figure 24 describes these two different disciplines in Systems Thinking. The "hard" observer sees there a system that consists of other systems (SoS). He thinks that those systems can be engineered to work together. Whereas the "soft" observer sees complex and unclear processes inside the system but thinks that he can organize exploration of it as a learning system.

Also Senge (1990) has studied learning organizations and names five disciplines that are important to them. According to him the fifth discipline is Systems Thinking and he connects it to the System Dynamics. The other four disciplines are "personal mastery", "mental models", "building shared visions", and "team learning". Senge (1990) notes that Systems Thinking is the basis that integrates the other four disciplines for organizational learning to take place. Senge (1990) does not separate HST and SST in Systems Thinking but he connects e.g. learning and mental models to his disciplines. Those two disciplines are actually the core ideas in SSM. Senge's ideas have developed from System Dynamics, which was originally invented by Jay Forrester in 1950s (Sterman 2000). The basic message in it is that the system can be designed after understanding its dynamic behaviour where the concept of feedback-loop dominance is a central factor.

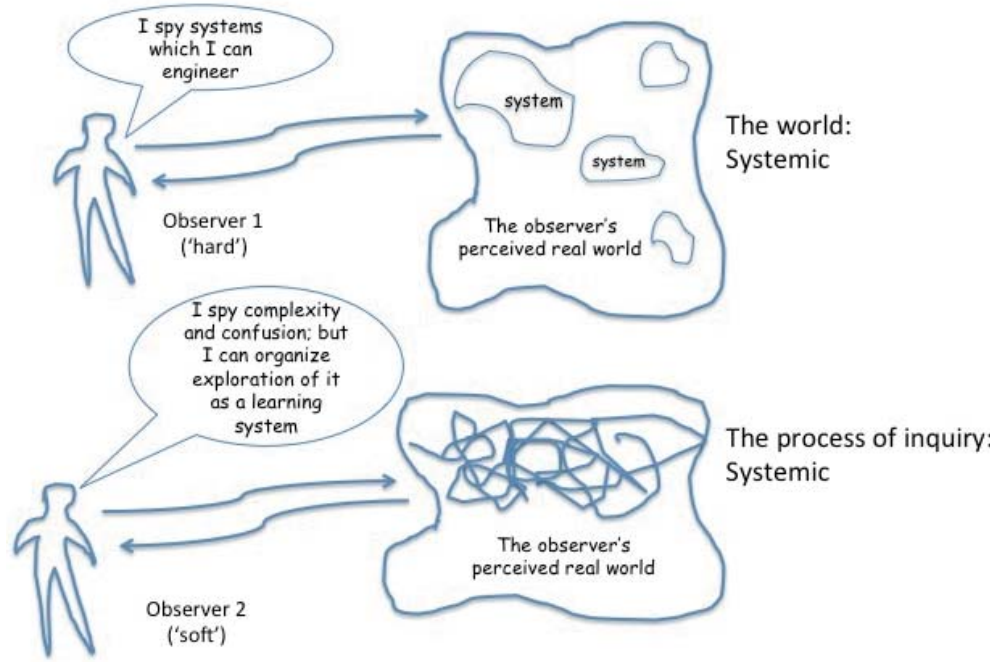


Figure 24. The hard and soft systems view (Adapted from Checkland, 2009).

Browning et al. (2006) have studied product development processes in automotive and aerospace industry. They treat processes as a kind of system that can be engineered. Browning et al. say that when a product system has to be created the process system has to be discovered and generated. Their system approach has similarities with Hubka et al.'s (1988) theories, which also consist of several systems like the technical system, transformation system, and execution system as well as transformation process (Figure 6). According to Browning et al. (2006) engineering projects consist of five systems. Product system (1) or object system or technical system is the result of the PD process, which is the Process system (2) or transformation system like Hubka et al. (1988) call it. Organization system (3) consists of the people assigned to do the work in producing the product system and Tool system (4) represents the technologies used by the people to get their work done. It is a significant portion of the tool system and important there is to have compatible systems provided at every location where the design work is done. In the theory presented by Hubka et al. (1988) the last two form the execution system. The Goal system (5) connects the four other systems together because all of them operate in the context of requirements and targets, which may be related, and e.g. making it easier to receive one target may make it difficult to receive another. According to Browning et al. (2006) these five systems can be found in every project, which the company may have at the same time (Figure 25).

Soft Systems Thinking (SSM) considers the existence of conflicting worldviews that characterizes all social interactions. In that approach the world is taken to be very complex but it is assumed that it can be organized as a learning system. In SSM the word system is not anymore applied to the world, it is applied to the process of our dealing with the world (Checkland 2009 and Checkland et al. 2010).

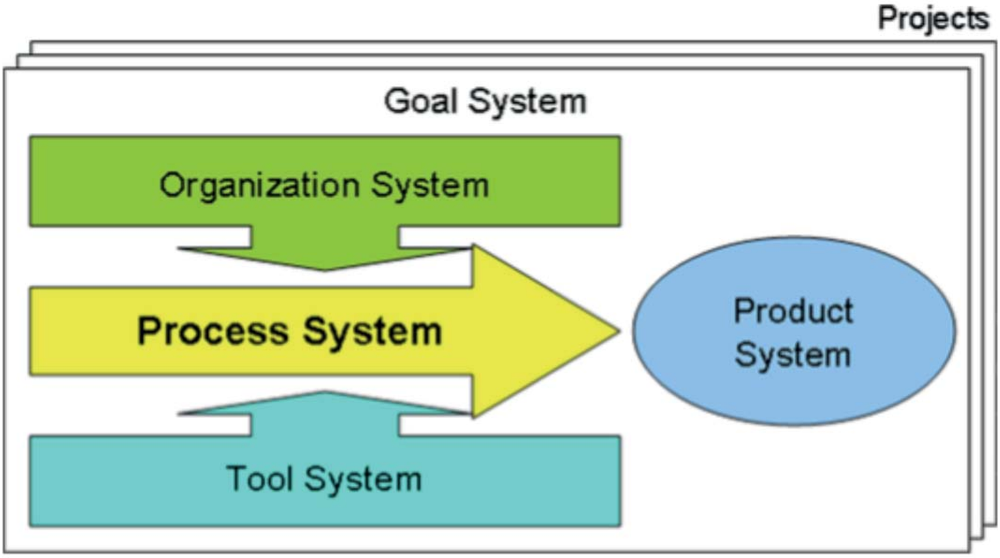


Figure 25. Five systems in an engineering project (adapted from Browning et al. 2006)

2.3.2 Soft Systems Methodology

In Checkland's (2009) SSM the word methodology is not a method but a set of principles of method which in any particular situation have to be reduced to a method which is suitable to that occasion. Action research is an outstanding part of SSM. The basic concept of action research lies on behavioural sciences and is applicable to an examination of human activity systems, which are carried out through the process of attempting to solve problems. The basic idea is that the researcher does not remain an observer outside the subject of investigation but becomes a participant in the human group and the process of change becomes the subject of research. The research target in action research is often to develop a methodology for tackling "soft" and ill-structured problems and using that experience as a source of insight into the special properties of social systems.

Checkland (2009) categorizes the problems in two groups, structured problems, and unstructured problems. The first ones are the typical ones that hard Systems Thinking and operational research are concerned with. The unstructured problems cannot be explicitly stated without this appearing to oversimplify the situation. Furthermore in a human activity system's history the agenda changes over time and sometimes the problems even go away. The unstructured problems are more conditions to be eased rather than problems to be solved.

The SSM principle is presented as a diagram in Figure 26. The diagram shall be read in chronological sequence from 1 to 7. According to Checkland (2009) this sequence does not necessarily be followed when implementing the methodology. Moreover Checkland (2009) recommends using the methodology as a framework into which purposeful activities can be placed during a system study. The stages 1 and 2 as well as 5-7 are real world activities and involving people to participate in the problem situations whereas 3 and 4 are Systems Thinking activities and do not necessarily involve people. Checkland (2009) names the stages 1 and 2 expression phases which attempt to build the richest possible picture of the situation where the problems arise. This can be done with investigation how the structure and the process relate to each other. The structures are typically slow-to-change elements whereas the process consists from elements that are continuously changing. Stage 3 includes the systems that are relevant to the situation where the problems may arise. This stage is named the root definition and expressed in Systems Thinking language whereas the stages 1 and 2 are presented in normal language. The model building happens in stage 4 and it is fed by the stages 4a and 4b, where 4a uses a general model of any human activity system which is that described in the root definition and helps to check that the models built are not fundamentally deficient. In stage 4b the model can be re-expressed in another systems approach "language" e.g. systems dynamics, if there is a need for that. In stage 5 the models are brought into the real world and compared with the observations made there. In stage 6 the results are discussed with people concerned with the problem situations and possible changes will be planned to the structures to manage the processes better in the future. In stage 7 the actions are taken to carry out those changes.

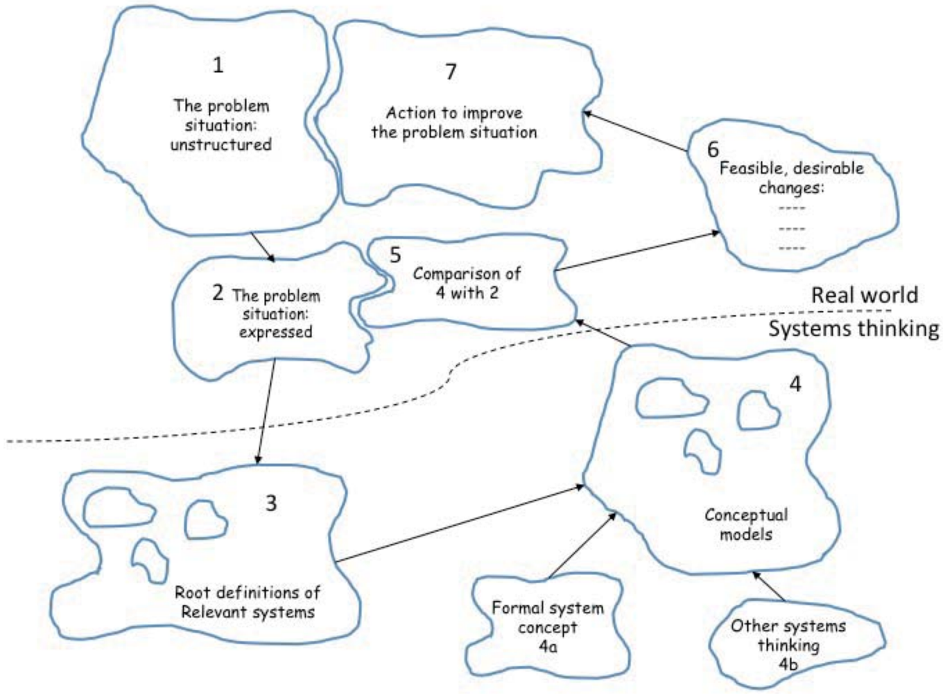


Figure 26. The Soft Systems Methodology in summary (adapted from Checkland 2009)

2.3.3 The Design Structure Matrix

One useful tool for analysing dependencies in complex systems is the Design Structure Matrix (DSM). It can be seen as an extension for the mess formulation where the elements define the system more detailed. Steward developed DSM originally and IEEE Transactions on Engineering Management published it in 1981. The publishing took over a decade because three journals had turned the same paper down before that (Steward, 2007). Steward's thesis on the DSM was published in 1973 and based on that he has published also a book in the same year as the first paper. Thereafter Steve Eppinger, Dan Whitney and others at MIT picked it up and that resulted in many DSM theses (Steward, 2007). Research and development of the tool can be found e.g. by Ulrich and Eppinger (2008), Yassine et al. (1999), Kusiak et al. (1993), Denker et al. (1999) and Krishnan and Whitney (1997) among all.

A DSM community has been established, which is an interdisciplinary and international group of researchers, practitioners and tool developers from many different disciplines (http://www.dsmweb.org/). Inside the community there is also a special interest group for industry, DSMiSIG, which is part of Design Society (https://www.designsociety.org/about-ds). The DSM community as well as literature uses also other terms like dependency structure matrix, dependency source matrix, dependency map, interaction matrix, incidence matrix, and precedence matrix. The numerous amounts of researchers in this context reflect the usability of the DSM tool. It has become a popular representation and analysis tool for system modelling, especially for purposes of decomposition and integration.

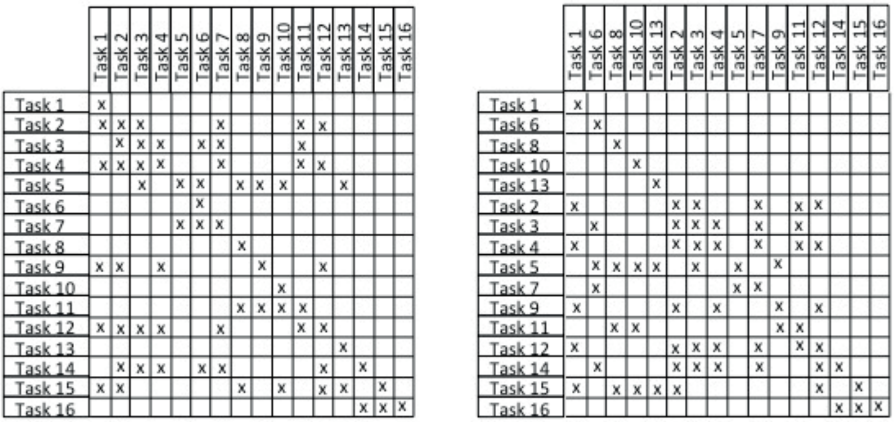
Gonzales-Rivas et al. (2011) recommend its usage in the information interdependencies representation. They claim that DSM is the most illustrative tool in showing the dependencies between different Information Elements, which they call infels. They claim that using a process flow diagram in presenting the dependencies the picture gets easily messy and when dealing only with inputs and outputs, and dependencies, the physical flow of the infels is not interesting. Also the inventor of DSM, Donald V. Steward, has endorsed this book by saying: "It's one thing to develop a concept. It's another to make it sing. This is a hymnal." (Gonzales-Rivas et al. 2011). The author of this study thinks that when applied in this research the infel presentation without the task flows is enough as long as the deliverables are completed in schedule. But if it is uncertain to get some deliverable completed in time and if it risks the project schedule then the tasks that produce that certain infel should be described with smallest detail tasks in order to resolve the obstacles for the project flow. The resolution level in this study's DSM will be the infel level.

Steward (1981) recommends using DSM in managing the design of complex systems because there are interdependencies involved and those interdependencies have to be determined. When starting to use the design structure system Steward (1981) advises first to list the variables which define the design of the product that in this case study is the CCM project. For each variable the other variables that must be known or assumed have to be listed next. The other variables are called predecessors. The variables are called elements or deliverables in this study and they are presented in the DSM (Appendix 2). When going across the rows the marking shows what deliverable precedes it and when going down columns the marking shows what follows it. In this study the dependencies are shown with binary markings. If a dependency exists there is a mark 1 in that cell and if not the cell is empty. When that is done the matrix displays the relationships between the elements in a compact, visual and analytical format. It is a square with identical row and column labels. The diagonal is presented with black background and the respective element number on it. The elements are listed in the matrix rows and the dependency on another element is marked in the corresponding column on that row.

Another possibility to show the dependencies is numbering them from 0 to 1 or 0 to 9 where the number presents the probability of iteration, amount of data flow, sensitivity of downstream activity etc. (Denker et al. 1999). This presentation will not be used in this study.

Whenever the elements are reordered the rows and columns are reordered accordingly. Steward (1981) presents that if the elements could be reordered so that the marks are either on or below the diagonal, then proceeding in this order, the variables could be determined one at the time. Unfortunately that is not possible in engineering design because there will always be circuits, which are shown by marks above the diagonal. The circuits show up if there are iteration loops where adjusting of two or more objects affect to each other.

The DSM tool can use a process called partitioning (Figure 27) where the elements are reordered so that the marks appear either below the diagonal or within square blocks on the diagonal. This kind of matrix is called block triangular. There the blocks are the smallest possible so that all the circuit elements can be found in the same block. The blocks represent the smallest set of elements that must be determined jointly. There are three types of task dependencies; sequential tasks, parallel tasks, and coupled tasks. Sequential tasks have to be performed in sequential order but they may still be overlapped between two sequential tasks, only that the latter one cannot be finished before the former one. Parallel tasks are independent from each other but dependent on a same task before they can start. Whereas coupled tasks are mutually dependent and need to be performed either simultaneously with continuous information exchange or in an iterative process.



	Task 1	Task 2	Task 3	Task 4	Task 5	Task 6	Task 7	Task 8	Task 9	Task 10	Task 11	Task 12	Task 13	Task 14	Task 15	Task 16
Task 1	x															
Task 2	x	x	x				x				x	x				
Task 3		x	x	x		x	x				x					
Task 4	x	x	x	x			x				x	x				
Task 5			x		x	x		x	x	x			x			
Task 6						x										
Task 7					x	x	x									
Task 8								x								
Task 9	x	x		x					x			x				
Task 10										x						
Task 11								x	x	x	x					
Task 12	x	x	x	x			x				x	x				
Task 13													x			
Task 14		x	x	x		x	x					x		x		
Task 15	x	x						x		x		x	x		x	
Task 16														x	x	x

	Task 1	Task 6	Task 8	Task 10	Task 13	Task 2	Task 3	Task 4	Task 5	Task 7	Task 9	Task 11	Task 12	Task 14	Task 15	Task 16
Task 1	x															
Task 6		x														
Task 8			x													
Task 10				x												
Task 13					x											
Task 2	x					x	x			x		x	x			
Task 3		x				x	x	x		x		x				
Task 4	x					x	x	x		x		x	x			
Task 5		x	x	x	x		x		x		x					
Task 7		x							x	x						
Task 9	x					x		x			x		x			
Task 11			x	x							x	x				
Task 12	x					x	x	x		x		x	x			
Task 14		x				x	x	x		x			x	x		
Task 15	x		x	x	x	x							x		x	
Task 16														x	x	x

Figure 27. Example of a DSM before and after the partitioning (adapted from Steward 1981)

DSM has been a subject of research especially at TUM (Technische Universität München) and MIT (Massachusetts Institute of Technology) as well as in Cambridge. It has been widely used in large industry projects such as automobiles and airplanes, where product development consists of many complex objects like doors in a car. Noor (2007) has done comprehensive studies in that development area where he used DSM and Datum Flow Chain (DFC) to document organizational, design and physical interfaces to improve closures design and manufacture. He found 82 product development tasks with 753 dependencies. The tasks revolved around design parameters, cross-functional design decisions such as assembly and locator schemes in manufacturing, sheet metal formality in stamping, physical testing of product performance, and measurement of assembly capability. The attributes that shaped the core of the design problem were wind noise, closing effort, water leaks, craftsmanship; margin and flushes, squeak and rattle; door chucking. Because of so many attributes and many teams involved there were several coupled development tasks and that made the reorganizing of the tasks very difficult but according to the researcher the matrix was still helpful in recognizing the dependencies.

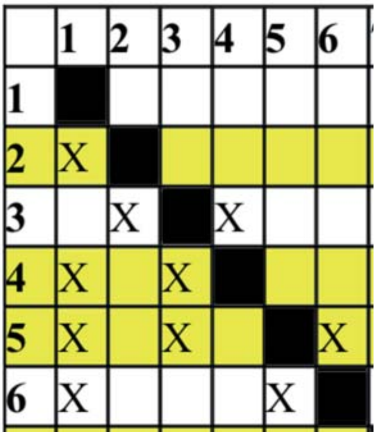
There are several other ways to handle the DSM matrix like tearing, banding, clustering, simulating.

Tearing is procedure where a set of markings above the diagonal is chosen and then removed from the matrix. Those removals are called “tears”. Before tearing assumptions have to be made for those element outputs and after that no other estimates need to be done. (Steward 1981, Yassine 2004).

In banding light and dark or coloured bands are added to the DSM in order to show independent elements. If two or more elements are not dependent of each other they belong to the same band. For example in Figure 28 the elements 4 and 5 don’t require information from each other and so they belong to the same band.

Yassine et al. (2001) have studied complex product development processes and note that the traditional project management tools do not help the project teams to gain deeper understanding of task interdependencies and iteration in the process and that the DSM methodology provides means to model and manipulate iterative tasks and multidirectional information flows. But DSM models do not include the duration of tasks or the impact of rework as well as no estimate for the project duration. For this reason simulation techniques for DSM models have been created in project management literature.

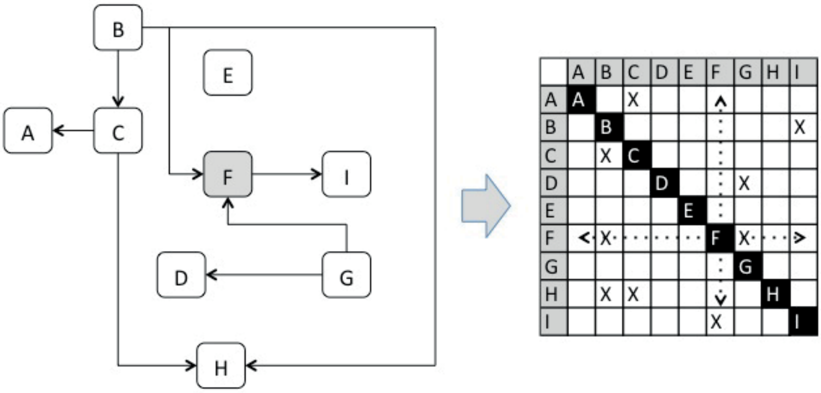
Figure 29 is presenting the principle of DSM dependencies in connection to a traditional flow chart. When analysing the matrix from the element F point of view the marks show that it depends on the elements B and G, furthermore element I depends on element F. The marks above the diagonal are an input from a latter element and not advisable. The more far it is above the diagonal the more risky it is to bring reworking later on. The flow chart is not showing the dependencies as clearly.



	1	2	3	4	5	6
1	■					
2	X	■				
3		X	■	X		
4	X		X	■		
5	X		X		■	X
6	X				X	■

Figure 28. Example of banding

Gonzales-Rivas et al. (2011) have studied the DSM analysis in knowledge work. They recommend also rearranging the matrix so that as few of the markings as possible end up in the areas, which they call bad and ugly (Figure 29 and Figure 30). The dependencies just below the 45-degree line are good because it represents an orderly sequence of steps. The dependencies slightly above or significantly below the diagonal predict trouble; the ones lightly above represent iteration circles within coupled tasks and can be very productive. The ones significantly below are not either good because they are often too early prepared values and are a subject of change when they go through the official process and the preparation work may be wasted.



	A	B	C	D	E	F	G	H	I
A	A		X			^			
B		B				:			X
C		X	C			:			
D				D		:	X		
E					E	:			
F	<	X	· · ·	· · ·	· ·	F	X	· · ·	>
G						:	G		
H		X	X			v		H	
I						X			I

Figure 29. A simplified DSM with its corresponding flow diagram (Gonzales-Rivas et al. 2011)

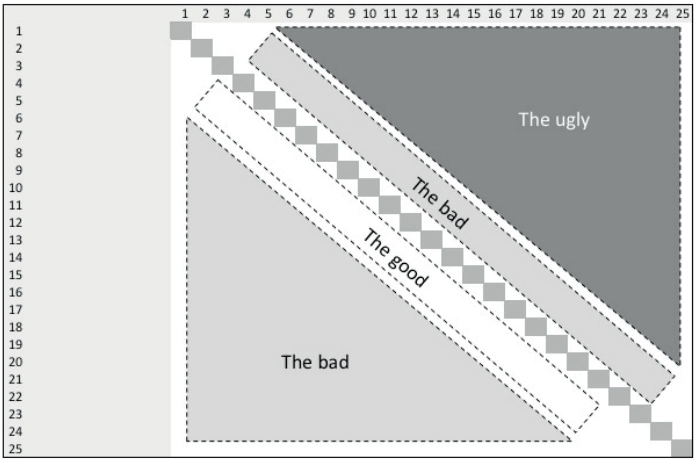
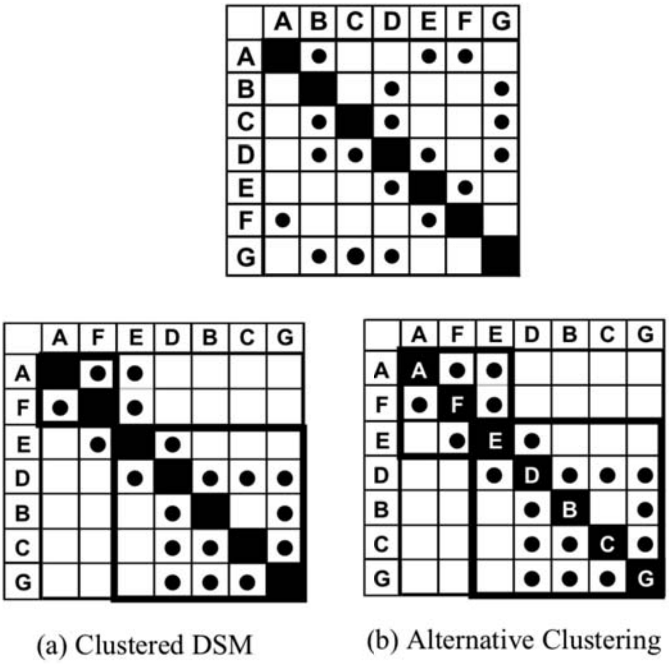


Figure 30. The dependencies depending on the position in the matrix (adapted from Gonzales-Rivas et al. 2011).

The analysis methods that were presented above are of time-based DSM's whereas static DSMs should be analyzed with clustering methods. In partitioning the main object was to move markings from the above of the diagonal to the below of the diagonal. In that approach it was supposed that the elements in the matrix were tasks to be executed. But when the elements are people who are responsible for these tasks or when they are sub-systems or components of a larger system then arranging the matrix does not help. The target is to find subsets or modules of the elements that are minimally or not at all interacting and the method is called clustering. Example of this method can be found in Figure 31. In clustering the marks above the diagonal do not have to be moved under it. They are as good as the marks below the diagonal. They represent interactions between the teams or interfaces between the modules. In the example the elements A, B, C, D, E, F and G present persons in an organization who work together and have to communicate with each other daily, weekly or once a month for example. In the clustered DSM left there are two blocks (AF and EDBCG) but three interactions are still outside of the blocks. Whereas in the clustered DSM on the right there are two overlapping teams and the person E participates in the meetings of both teams and works as a coordinator between them.

There are several ways and also computational clustering techniques that can be used in generating the blocks to the DSM according to Yassine (2004). They will not be presented in this research.



(a) Clustered DSM

(b) Alternative Clustering

Figure 31. Example of clustering (Adapted from Yassine 2004).

The handling depends on the DSM type. A structure for different kinds of DSM types is presented in Figure 32. The two categories in that taxonomy are static and time-based DSMs. The static category includes component-based and people-based DSM. The time-based category includes activity-based and parameter-based DSM. Component-based DSM can also be called architecture-based and it is useful for modelling system component relationships and facilitating architectural decomposition strategies. People-based DSM can be either team-based or organization-based and it is useful when designing integrated organization structures which are helpful for team interactions. Activity-based DSM is a schedule DSM and models the information flow among process activities. Parameter-based DSM is a low-level schedule and effective when integrating low-level design processes based on physical design parameter relationships.

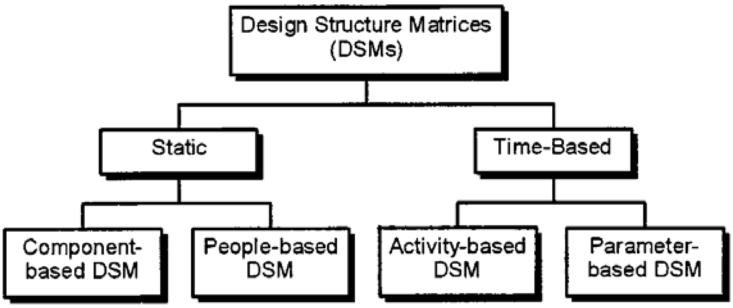


Figure 32. DSM taxonomy (Adapted from Dorf 1999)

Table 2 lists the different types of data that can be presented in a DSM. With a matrix it is possible to represent information relations among components of a product, among teams concurrently working on a project, among activities in a project, and among parameters.

Table 2. Summary of DSM type characteristics (Adapted from Dorf 1999, Browning 2001, Yassine 2004)

DSM Type	Representation	Applications	Analysis
Component-Based or Architecture DSM	Components in a product architecture and their relationships	System architecting, engineering, design, etc.	Clustering
Team-Based or Organization DSM	Individuals, groups, or teams in an organization and their relationships	Organization design, interface management, application of appropriate integrative mechanisms	Clustering
Activity-Based or Schedule DSM	Activities in a process and their inputs and outputs	Project scheduling, activity sequencing, cycle time reduction, risk reduction, etc.	Partitioning, Tearing, Banding, Simulation and Eigenvalue Analysis
Parameter-Based DSM	Parameters to determine a design and their relationships	Low-level process sequencing and integration	Partitioning, Tearing, Banding, Simulation and Eigenvalue Analysis

Yassine et al. (2001) have studied complex product development processes and note that the traditional project management tools do not help the project teams to gain deeper understanding of task interdependencies and iteration in the process and that the DSM methodology provides means to model and manipulate iterative tasks and multidirectional information flows. Whereas DSM models do not include the duration of tasks or the impact of rework as well as no estimate for the project duration. So both approaches have some good and some lacking features.

In combination with DSM a useful tool that can be applied is DiMo. This tool supports the flow model presentation of a project by making it more visual.

2.3.4 Considering projects as systems

Shenhar et al. (2005) have done several investigations in NASA's development projects. NASA says that it is a systems organization having documents and guidelines for system projects. They found out that when having a cross-cultural partner (i.e., Germany) and a new type of partner role it requires cultural integration for seamless coordination and communication. So the social system has to be taken into account as well. Seeing the project as a system project, rather than assembly, would enhance focus on integration and additional communication efforts, which means also needs for SSM usage. Shenhar et al.'s (2005) approach to project classification is presented in Figure 33. The diamond model defines four variables, which classify the project type and behaviour. The variables are technology, novelty, complexity, and pace. The explanations of the variables are presented in Table 3.

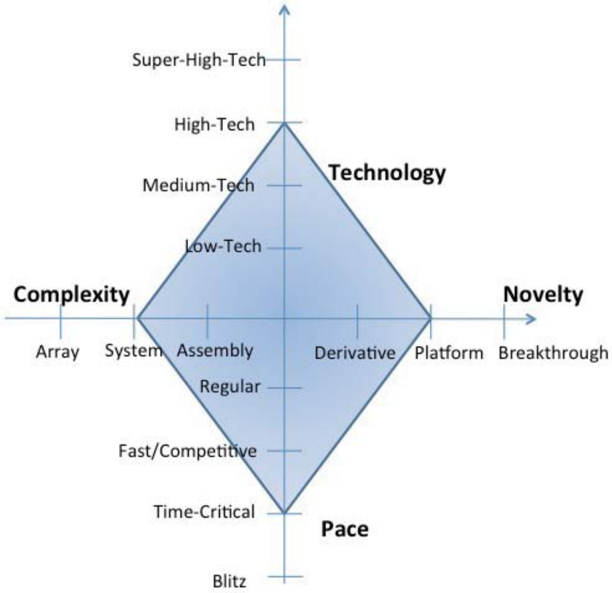


Figure 33. The diamond model in project classification (2005)

Table 3. The different variables and their values in Figure 33, adapted from Shenhar et al. (2005)

Novelty: How new is the product to the market: Derivative: Improvement of an existing product Platform: A new generation of existing product line Breakthrough: A new-to-the world product	*Complexity:* How complex is the product: Assembly: Subsystem, performing a single function System: Collection of subsystems, multiple functions Array: Widely dispersed collection of systems with a common mission
Technology: Extent of new technology to the company used by the project: Low-tech: No new technology is used Medium-tech: Some new technology High-tech: All or mostly new, but existing technologies Super high-tech: Necessary technologies do not exist at project initiation	*Pace*: Project urgency and available timeframe: Regular: Delays not critical Fast-competitive: Time to market is important for the business Time-critical: Completion time is crucial for success-window of opportunity Blitz: Crisis project – immediate solution is necessary

Complex projects have been an interesting object for many researchers. Hobday et al. (2005) name them with an acronym CoPS and they define them as complex high value products, systems, networks, capital goods, or constructs. Artto (2005) has investigated project management in such kind of projects and claims that when a multi-firm network is involved in a project then it can be treated as a project enterprise. According to Artto in those projects the body of knowledge lies in the procurement and supply chain management as well as in systems integration. Ahola (2009) has treated project networks in his study as a complex system of transactions between multiple organizational actors. He found out that ex post transaction costs reduced the efficiency of project implementation. To these transaction costs he included the costs of monitoring transactions, costs of planning transactions, and costs of adapting transactions.

System dynamics is a perspective and set of conceptual tools that enable us to understand the structure and dynamics of complex systems. System dynamics is also a modelling method that enables to build formal computer simulations of complex systems. According to Sterman (2000) simulation is needed to be able to deal with the dynamic behaviour of the system. He presents a highly simplified principle model of a system in Figure 34. When undiscovered rework is found after the task has been "finished" that is one of the main delay causer in the projects. In the example rework is caused either because of quality issues or customer demands that occur first after the work has already been done. Rework as well as waste cause delay in the throughput and make the system likely to oscillate (Meadows 2008). Also Koskela (2000) and Fujimoto et al. (2011) point out the waste as a target to be minimized in order to get the project and process systems to flow.

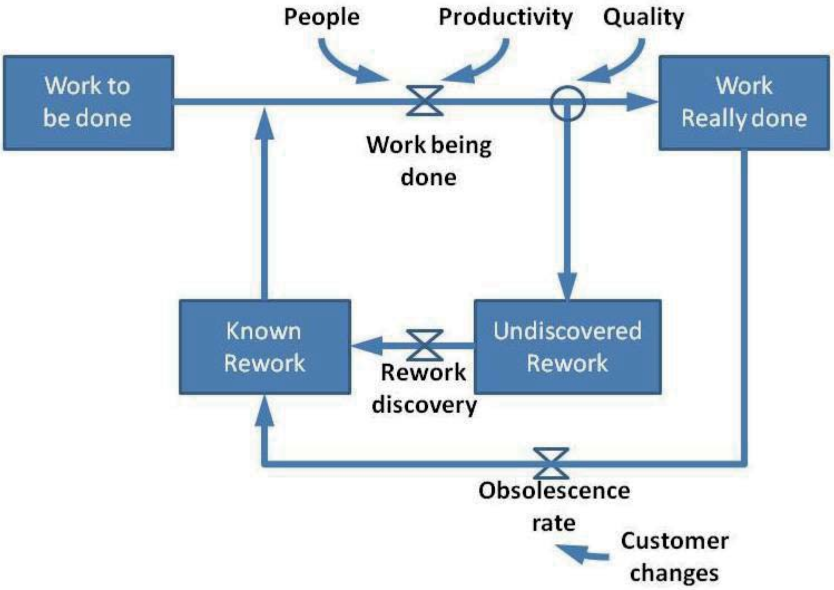


Figure 34. A highly simplified stock-flow system model of tasks in one project phase as well as the flow from one status to another. (Sterman 2000)

The behaviour of complex systems is more related to the way they are organized than the characteristics of their individual parts. This behaviour is caused by the emergent property of the system. An emergent property is the end result of a dynamic process that operates online. The critical properties of every throughput system are time, cost, flexibility, and quality. In order to improve the throughput of a system all the four variables have to be handled simultaneously and that can only be done with help of a dynamic model with those interdependent variables (Gharajedaghi 2011). Those four variables are widely recognized and discussed in project management literature. Goldratt (1997) has created the Theory of Constraints (TOC) on those variables and furthermore developed the critical chain method for project scheduling. He uses the chain as an analogy for the throughput where the strength of the chain represents the throughput of the process and the weight of the chain represents its cost.

Operational Systems Thinking states that one cannot control a complex social system but can redesign it. Meadows (2008) advise how to get handle on a complex system by first just watching how it behaves. Thereafter the history of it should be studied and the thinking should be directed to dynamic and not static analysis. The analysis should focus on two questions: “how did we get there” and “what is wrong”. In the end the analysis should search answers to the why question: “why the system behaves the way it does”. In Checkland's (2009) SSM the system exploration happens as a learning system. Gharajedaghi (2011) suggests that the mess should first be formulated and that can be done by first searching, then analyzing, and finally telling the story of the object system.

2.3.5 Mechatronic Systems

Comerford (1994) says that the world of engineering is like an archipelago where the inhabitants live on their own islands and have not much communication with the others. He compares this situation to the engineering design in e.g. electronics, mechanical, civil, and chemical field. The need for this was first recognized in Japan where Ko Kikuchi in Yaskawa Electric Co. introduced the term mechatronics in the seventies. Also Fujimoto et al. (2011) has noticed the differences between design of mechanics and electronics as well as software design. According to them the design of the former one is based on structural philosophy and the design of the latter ones are based on functional philosophy. Integration of different design process types is challenging. The CCM project can also be approached as a mechatronic system although Hubka does not use the term but he talks about complex Technical Systems and they consist of similar phenomenon (Hubka et al. 1988).

Tschirner et al. (2014) have studied product engineering in mechatronic systems and found out that the future paradigm in them is MBSE (Model-Based System Engineering). The core concept is a system model that allows a holistic perspective to the system in a domain-spanning way. Gharajedaghi (2011) and Checkland (2009) recommend a similar approach in their Systems Thinking models. Tschirner et al. (2014) claim that there still is much focus in the technical aspects of MBSE when defining the system model and that there should be more socio-technical aspects of product engineering. Different external stakeholders and their roles and responsibilities may bring surprises and uncertainties into the project and they may cause delay to the project schedule.

Figure 35 presents the concept of MBSE unity (Gausemeier et al. 2013). In the middle of the Figure there is the Systems Engineering function, which coordinates the development project management and the PD process with the object product system where the product is a car and the project is managing the engineering design of it. The project management is following the process model, which is the framework that guides the project execution. The product design of the system is following the engineering design guidelines for the car. System Engineering operates in between these two environments to make sure that the targets are reached.

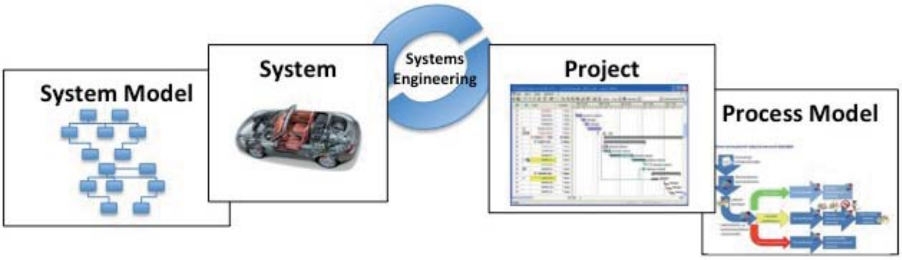


Figure 35. The MBSE concept adapted from Gausemeier et al. (2013).

2.4 Contribution of the literature to the study

The literature review in Design Science contributes to this study by connecting the CCM project and its design to this domain. Hubka et al. (1988) defined designing of a plant as a Technical System and its degree of difficulty to the fourth grade, which categorizes these projects to the complex ones. The CCM project is a combination of many Technical Systems and Transformation Processes. First the project itself is a Transformation Process that generates the Technical System of a plant as well as the Transformation Process that will control the manufacturing of the cars. Furthermore, the car is a Technical System as well and its design is another Transformation Process. Also the research in modularity and structural and functional design contribute to the CCM project design.

The literature review in Project Management research contributes to this study with its state-of-the-art academic knowledge. Where does Project Management stay today and what tools are used in controlling projects. The focus is on project classifications and presentations of complex mega-projects and their risks. The CCM project can be considered as a complex mega-project and this should be taken into account in its management. Furthermore, common tools in project scheduling and as well as models in project controlling are presented. One of the scheduling tools, MS Project, will be used in the analysis when trying to find out the project duration in connection to the RQ's 2, 3, and 4.

Systems Thinking in turn provide direct support for analysis in this study. With help of Gharajedaghi's (2011) and Checkland's (2009) methods the big picture of the CCM project is created that contributes to the first research question. The model itself is presented with a Design Structure Matrix where the sub-projects are divided into deliverables as matrix elements. The main advantage of DSM is in its outstanding ability when handling the interdependencies. In combination with DiMo the flow model can be presented even more visually and that is why DSM and DiMo will be the base approach for the flow model depiction in this study. Furthermore, they both contribute to the analysis, which aims to answer on the research questions 2, 3, and 4.

3 Presentation of contract car manufacturing projects and the case company

3.1 Contract car manufacturing in Europe

Contract car manufacturer (CCM) is a company that produces cars on behalf of the OEM’s. They are capable to fulfil almost all the tasks in automotive manufacturing that are needed so that the end customer can get his or her car. They are like small OEM’s and have large automated assembly lines, which need highly skilled workers to operate as well as appropriate engineering capabilities. They have to be able to work more or less international because of the many actors participating in the transformation system. There exists a high interdependency between the CCM and OEM as well as with the part suppliers.

In the 2000s the amount of contract car manufacturers in Europe has decreased to three enterprises, which are Valmet Automotive, Nedcar in Netherlands, and Magna Steyr in Austria. Magna Steyr’s company size and history is different. It has been developed during over 100 years to a large corporation with many factories and services broadened outside Europe. In addition to contract car manufacturing they offer also system supplier services. Nedcar and Valmet Automotive were established in the same year, 1968, and they are about the same size. Valmet Automotiver’s name was at first Saab Valmet and it was a joint venture of Swedish Saab Scania and Finnish Valmet. The company vision was to produce Saab cars for the Finnish market in that time. In 1992 the car company came to Valmet ownership alone and after that there have been a few other ownership arrangements after which the company is now owned by Pontos, Finnish Industry Investment, and company management. In 2010 Valmet expanded its business area by buying a German automotive company, Karmann with engineering and convertible vehicle roof manufacturing. Karmann was once also a contract car manufacturer but that part of its business did not belong to the deal with Valmet. With the new company ownership Valmet became more international and could grow its engineering competencies as well as offer new services to the OEM’s.

3.2 The case company and its history

During Valmet Automotive’s existence it has had several car companies as customer. There were usually two basic CCM project types in its business. The car model design and development was finished and the vehicle was already in production in the customer's own plant. Or the PD was still in progress and the CCM project started parallel with the PD. The latter situation had advantages and disadvantages. The CCM could participate in the design process and bring its own aspects to that. In that case the CCM placed simultaneous engineers to the developing site and established SE teams to coordinate the PD process and the production engineering process. This gave possibilities to affect the PD so that the manufacturing of the vehicle could be as lean as possible. The models are presented in Figure 36 and Table 4.

Figure 36. An overview of the car models and years of production start in the case company.

The Swedish Saab Scania was the first customer and cooperation with the company lasted over thirty years, which was the longest customer partnership. The first project with them was Saab 96 and it was targeted to the Finnish customers. The production started in 1969 and the manufactured amount was ca. 65 000 cars. In Figure 37 the first Saab 96 vehicle rolls out from the manufacturing line in the final assembly. The production of Saab 96 lasted ten years and ended in 1979. The Saab partnership at Valmet continued until the year 2003 and the whole production volume of different Saab models was over 500 000 vehicles. The first Saab 900 convertible model came out in 1986. They were built at Valmet for over ten years. The convertible had three different models during the production in Finland and they were all produced at Valmet. The total production volume of convertible Saabs in Finland was almost 200 000 vehicles.

Table 4. CCM project models in the case company with years of production start (SOP) and total amount of produced vehicles (Statistics of the case company).

Model	SOP	Total amount
Saab 96	1969	65 887
Saab 99 2/4 D	1970	149 003
Saab 99 3/5 D (new product)	1974	42046
Saab CD 1976 (new product)	1976	590
Saab 900 3/5 D (new product)	1978	142694
Chrysler/Talbot 1510	1979	10498
Talbot Horizon	1980	17932
Talbot Solara	1981	3549
Saab 900 4D (new product)	1982	58407
Saab 900 2D (new product)	1984	37797
Saab 90 (new product)	1984	25380
Saab 9000	1986	8267
Saab 900 Convertible (new product)	1986	48895
Opel Calibra 1991	1991	93978
Saab 900 Convertible II (new product)	1994	55047
EuroSamara	1996	14048
Porsche Boxster (986) 1997	1997	69213
Saab 9-3 Convertible (incl. Viggen) (new product)	1998	94096
Saab 9-3 Viggen (Conv., 3D, 5D) (new product)	1999	
Porsche Boxster S (986) (new product)	1999	40000
Saab 9-3 5D (sis. Viggen)	2002	7789
Porsche Boxster ja Porsche Boxster S (987) (new product)	2004	59264
Porsche Cayman S/Cayman (new product)	2005/2006	59413
THINK	2009	
Garia	2009	
Fisker Karma	2011	<2500
Mercedes-Benz A-Class	2013	

In 1990s Saab Scania was divided and the company for the passenger cars was named Saab Automobile. At the same time General Motors bought half of the company shares. This led to an CCM agreement of Opel Calibra production. Soon after this agreement Saab 900 model ended and it was replaced with a new model Saab 93. This vehicle was designed on the same chassis as Opel Vectra, which again had the same chassis as Opel Calibra. This could be utilized in the production line engineering, which was a good thing. The Opel manufacturing started in 1991 and ended in 1997 and the total amount of vehicles was over 94 000.

Figure 37. The first vehicle rolls out from the finishing line in the assembly plant of Valmet in 1969.

At the same time in 1996 started the production of Eurosamara. That was a vehicle from the Russian OEM Lada and the target audience was in Europe. Ca. 14 000 vehicles were produced in two years time. The manufacturing of this car model differed from the other examples here. The welding and painting were operated in the Valmet main factory but thereafter the bodies were transported for assembly to another Valmet site in the neighbourhood.

Porsche cooperation started in 1997 with Boxster generation 1. The Boxster production had started one year earlier in Zuffenhausen at Porsche plant and the demand was surprisingly huge and Porsche did not have enough capacity to fulfil it. Therefor they had to find a new manufacturing plant where the production could be started as soon as possible. Valmet was fortunate to get the agreement (Deckstein et al. 2002). The yearly production volume in the contract at the start was only 5000 vehicles but it increased very fast because of the huge demand and ca. 40 000 vehicles were produced until 1999. Thereafter Porsche designed the Cayman model and a new generation model of Boxster. Valmet simultaneous engineers participated in those PD projects in order to get the manufacturing viewpoint into the design. The vehicles of generation 2 were both manufactured at Valmet until 2011 and the total amount of produced Porsche cars was ca. 220 000. Figure 38 presents the first generation Boxster (986) and the brand new Cayman model (C7) that was manufactured only in Finland at Valmet.

Figure 38. Examples of Porsche models in the case company. First generation Boxster (986) on the left and Cayman (C7) on the right side.

In the year 2008 a new customer partnership started with Fisker Automotive, which was a start up company in the US. The car model was Fisker Karma and the designer of it was Henrik Fisker who also was one of the founding partners in the company. They had gathered development teams into their company organization from engineers that had previously worked at traditional OEM's mostly in US. The vehicle was a plug-in hybrid that had both electric motor and combustion engine and a space frame body structure of aluminium. That production started in 2011. The production was put on hold in august 2012 and never started again after that. The reasons for so short production time were financial difficulties. The amount of produced vehicles was about 2000.

The latest customer agreement in contract car manufacturing was conducted with Daimler AG in 2012 considering the new Mercedes Benz A class model that already was produced at the Daimler plant in Rastatt Germany as well as its sister model B class vehicle which was produced in Kecskemét Hungary. The manufacturing at Valmet started one year later after the project agreement and continuing today. The exact production volumes have not been published but the plan according to the mutual agreement is to produce over 100 000 vehicles between the years 2013 and 2016.

At the beginning of a CCM project there are two possibilities for the PD status. The vehicle may be ready designed and in that case usually also in production. The other case is that the vehicle design is not yet finished. The good thing in the latter case is that the design can still be influenced and that he manufacturing point of view can be taken into account. The challenging thing in that case is that the design freeze has not yet happened and the decisions in the manufacturing plant design have to be made under uncertain circumstances. Dvir et al. (2003) have investigated high-tech product development projects at NASA and found out that their design freeze point is typically scheduled in the second or even third quarter of the project execution time (Figure 39). Those projects are often characterized by a highly flexible style, high involvement of customers, and intensive communication among teams. They also found out that system integration problems occurred often in those projects and say that those projects should have been handled as systems which are made of many assemblies and sub-systems. The companies that work with high-tech product development know that even if they meet successfully the various sub-systems specification requirements that does not yet mean that the whole system will work successfully. In Figure 39 Dvir et al. (2003) categorize the project types according to their level of high technology where type A is the lowest one and type D the super high tech one. The presentation shows that in type A there is only one design cycle whereas in type D the amount of design cycles may be from three to five. Many design cycles increase the project risks by lengthening the project duration and increasing the amount of needed resources. When the PD had been finished before the initiation of the CCM projects the scheduling has not been so risky.

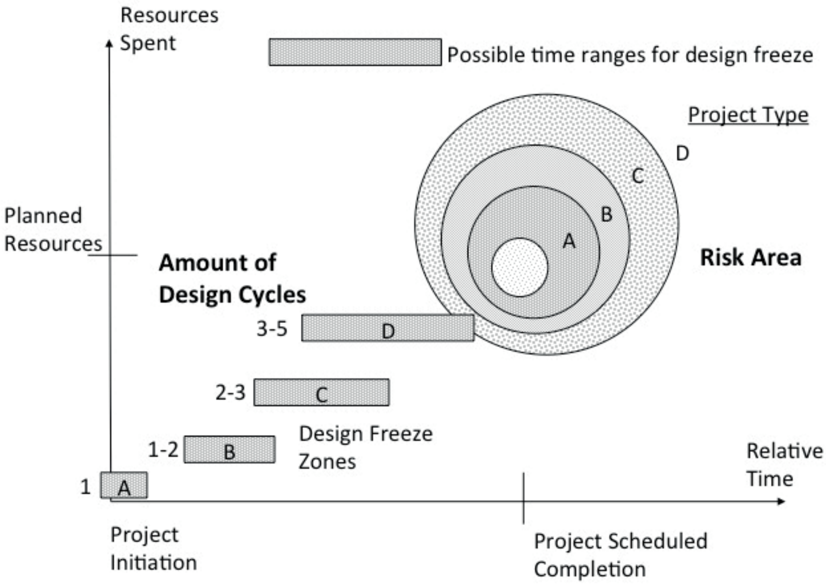


Figure 39. Design freeze regions for different levels of technological uncertainty (Adapted from Dvir et al. 2003)

Characteristic for the recent case projects has been a tight schedule and fast time-to-market period. At the same time the product complexity has been increasing. The complexity stems mainly from the growing amount of control units and electricity in the car. E.g. in Porsche Boxster's 1st generation the amount of control units was under five and in the 2nd generation that amount was over forty. The control units are embedded systems that guide different functions in the car. Their software updating happens either on the assembly line or already at the supplier before delivery. The management of software versions combined with the control units' revisions brings an extra challenge to manage. Furthermore they may have also influence in other control units and that has to be coordinated as well. In combination to the increasing product complexity the time-to-market schedule has been decreasing. Figure 40 shows the development of that phenomenon which has been investigated in automotive industry by Warwick University's WMG Center (Yazdani 1999). The car complexity has increased three folded in fifty years since 1950s and that development seems to go on. During the same years time-to-market interval has decreased accordingly.

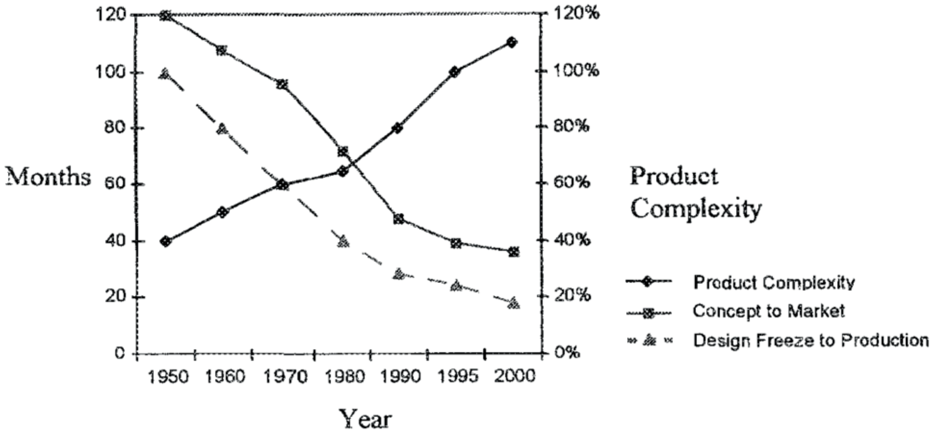


Figure 40. Time to market decreases while cars are increasingly complex. Adapted from (mi, 1999).

Furthermore, the PD Design Freeze point of time before production start has decreased from hundred months to less than twenty months that demands simultaneous engineering work between PD and manufacturing departments. Although the Figure 40 has been published before a few years the trend has still been observed in the company CCM projects. The result in Figure 39 (Dvir et al. 2003) backs to WMG's presentation in the case when the products are of high technological uncertainty in NPD. In that situation the design freeze-ending point tends to move towards project schedule completion point. This has been experienced in the case company projects as well. This is a challenging situation to the CCM project because the product design changes the whole time and the project has to keep on track with the design information which needs to be integrated to the transformation process to build up the manufacturing facilities. This monozukuri functioning (Fujimoto 2013) is extremely essential in the situation where the design freeze has not yet taken place. An extra challenge is provided by the separated organizations of product development and manufacturing company. Simultaneous Engineering is the functionality what the CCM utilizes in these cases. The SE teams focus on following product development evolvement and changes in the product design. They make even change proposals into the design if necessary. In the case company these teams are called SEPRO (Simultaneous Engineering for Process) teams. Their main focus is to operate as intermediates in between the PD and the manufacturing process design and engineering in order to get the product designed for manufacturing and assembly (DFMA). A principled presentation of the information and data flows between the manufacturing company teams and the product design teams is presented in Figure 41. In the middle of the Figure there are three processes that have to be integrated.

The SE process in the PD company has usually been on the OEM's site whereas the SE process in the manufacturing company has been at the CCM's site. Both of them are engineering processes and the first one is developing the product and the second one is designing the manufacturing layout with equipment and facilities. The PD process is the leading one and the SE manufacturing is actively following its proceedings and discussing the solutions with PD. If some solution is not optimal for the production then a change proposal will be created and the PD organization has its own processes to handle these proposals. The SE team in the manufacturing company makes sure that the solution fits in the production process. Sometimes the fitting can be made possible with a change in the assembly sequence. Because the geographical location for the PD and manufacturing site is different the discussions have been supported with video- and teleconferences besides email and other communication medias such as virtual reality. The case company has implemented equipment that uses immersive virtual reality in product design evaluation. The target was to get a common understanding for the designers and the manufacturing engineering of the solutions in both locations. An interview study was carried out among the SEPRO teams to figure out the usefulness of virtual reality (VR) in planning the manufacturing process. The teams considered that the VR system helped in achieving a better impression of the car in a situation when there was no physical body available yet. Although the models could have been studied with Catia 3D modeling tool as well the manufacturing engineers preferred still the VR system more because it made an impression of a real car better than the plain 3D models. This was surely because of the real size of the vehicle added with the immersive 3D impression. The reality was more observable than with Catia CAD presentations.

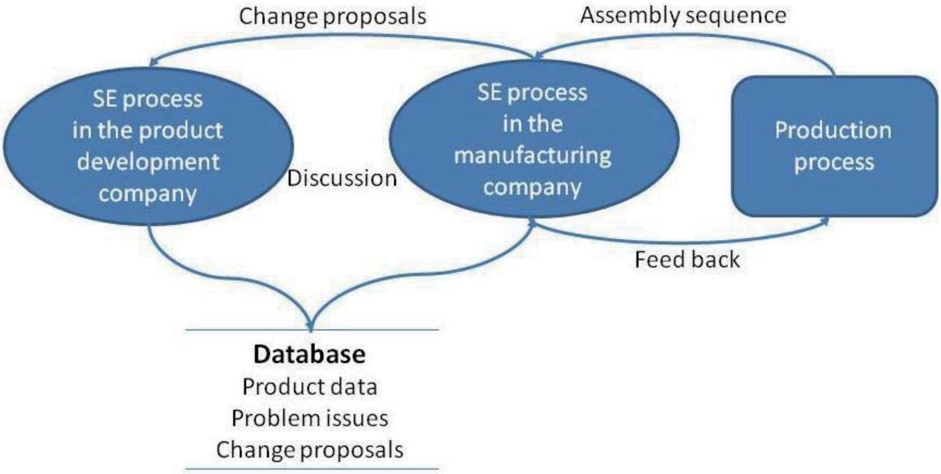


Figure 41. Monozukuri information flows and the simultaneous engineering function in the case company.

The pictures in Figure 42 and Figure 43 show a team session (Becker et al. 2011) in one CCM project. In the upper picture a session facilitator is showing the body in white for the assembly team and thereafter they start to plan the assembly sequence by inserting parts into the body. In the interview study another result showed that the manufacturing engineering teams preferred physical cars more than VR systems in their assembly sequence planning. But if that was not possible the VR provided a sufficient solution.

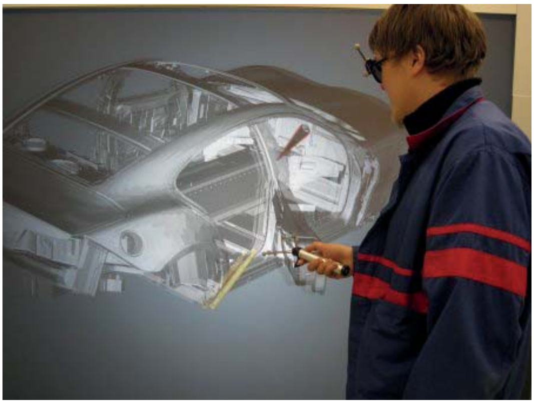


Figure 42. The facilitator in a Virtual Reality session operating the system in order to get the assembly sequence optimized.

Figure 43. SEPRO team in a Virtual Reality session planning the assembly sequence.

The development in body shop automation degree has been huge at the CCM in the past 30 years. When looking at Figure 44 it is possible to sense what influence the automation has to the process capability in producing quality. The first picture is from body shop in 1980’s from Saab 9000 manufacturing line. Two workers are welding manually the joints between the side panels and rear end at the same time. The second picture shows the new built body shop line with the large amount of robots for the MB A class vehicles in 2010’s and no manual welding.

Figure 44. In the upper picture welding of Saab 9000 CC (Combi Coupe) in 1980's and beneath almost finished preparations for a new car model production in 2010's.

3.3 Presentation of the contract car manufacturing projects

In this case study the CCM projects from over 20 years are considered. During that time period there have been several CCM projects of different car models and customers e.g. Saab, Opel, Eurosamara, Porsche, Fisker Karma, and Daimler. Most of those customers had a long history in automotive industry but one of them was a start up company in automotive. The four projects in this study are chosen from the above mentioned customer project list. They are named with characters A, B, C, and D in order not to reveal the companies. All four projects comprise construction of the body shop, paint shop, and final assembly as well as the logistics area. Furthermore, the operating processes and ICT systems with interfaces to external stakeholders are an important part of the CCM projects as well. They support the monozukuri function where design information is integrated with the manufacturing engineering teams. Although the four projects have similar structure on the main level they differ from each other in their behaviour. This has much to do with their organization culture and history. Project A was done with a large customer who had long history in designing and manufacturing cars. They have created their own processes and ways to work as well as their ICT systems their self. They also had experience of manufacturing their cars in other companies as well. Project B agreement was with a large established customer who also had a lot of manufacturing cooperation with separate companies and ICT system integration with them. Project C in turn was an independent company with very little experience of manufacturing cooperation in other companies. It had customized ICT systems, which worked well inside, but their interfaces to an external manufacturing partner were limited. Whereas the customer in project D was quite different. The company was a start-up with an organization collected from other established car companies. Because of its novelty the product development processes had not yet developed into stable form and the ICT systems were not all implemented in the very beginning. This was particularly challenging to monozukuri in integrating the design information with the manufacturing engineering. Additionally, the customer had no own manufacturing site and the product development had to cooperate a lot with the CCM engineers. In Table 5, Table 6, and Table 7 on the next pages the features of the four projects are presented in more details. These Tables focus on the deliverables that are dependent on external stakeholder support. This viewpoint was chosen because the external conditions are the ones that vary depending on the OEM and the agreement. The Table topics are divided according to their process genre.

In this study the analysis will be based on project A. The other three projects will thereafter be compared to the results of analysis in project A and conclusions will be drawn.

In Figure 45 there is an aerial view presentation with markings of the production departments and other main facilities. The Body Shop (2) describes the area where the model specific manufacturing lines are built. In Paint Shop (3) as well as Final Assembly and Quality the existing production lines and facilities are usually modified. Logistic area has to be sized and located according the production volumes and assembly sequence.

Figure 45. Aerial view of the case company with production department locations.

Table 5 describes the production process area and its deliverables that are influenced by an external stakeholder, which in here is the OEM. In the projects A, B, and C the design was frozen before the project start and the product specifications and the 3D models as well as EBOM were available and this was an advantage for considering the time schedule. Anyway the MBOM had still to be optimized from EBOM with the CCM's manufacturing process because it is connected to the assembly sequence and the sub-assemblies.

Table 5. Comparison of project features in four CCM projects on the production process area

Deliverable	**Project A**	**Project B**	**Project C**	**Project D**
Production process				
Product specifications	Available and ok, only minor imprecisions in the project beginning	Available and ok, only minor imprecisions in the project beginning	Available and ok, only minor imprecisions in the project beginning	Because of late design freeze the product was not exact specified in the project beginning
Product 3D data and drawings	Incompatible PDM systems, separate file transferring caused extra work for a few months in the beginning.	Only paper drawings	Only paper drawings	Efforts were made towards compatible PDM systems but the results were not satisfactory
EBOM	Available and worked ok. At the project beginning an excel-file at the CCM but a common IT solution was found after some months when project had started. It was not easy to find the right contact persons at the customer's site.	Available right away and because the customer took care for the requirement calculation the CCM had remote access to the data at the customer's site.	Available and worked ok. At the project beginning an excel-file at the CCCM was used but the customer was very supportive in the customization of the CCM's ERP system	Available only as an excel-file during the whole project at the client and the CCM. Management of the BOM caused a lot of extra work that could have been avoided with a proper IT solution
Process approval	The client let the CCM build up the process independently and wanted to have project progress reports only on the defined milestones. Process approval tests	The project time schedule was not too tight and because of that there was enough time to adjust the process for approval	The client participated very intensively to the build up of the process during the entire project phase to ensure the production process quality already in	The client let the CCM to work very independently with the production process design and build up. The client concentrated on product development

Deliverable	Project A	Project B	Project C	Project D
	were made in a late project phase and not approved which caused delays		advance	and part supplier relations.

In project D the product was not yet in the design freeze status at the project start and that brought some uncertainties into the manufacturing engineering work. The advantage in this project was that the manufacturing sequence in body shop could be designed more freely because of the still changeable design. In paint and assembly shop the existing production line had to be modified and there the degrees of freedom were not as many. On the other hand body shop engineering would have needed the initial data of EBOM and 3D models but unfortunately they were not all ready because of the late design freeze. So there are pros and cons in the delayed design freeze time schedule. Furthermore, when developing the MBOM from the EBOM also the effects on the logistic costs have to be taken into account. This means that the MBOM development needs to be optimized considering the manufacturing and logistics needs parallel.

The production process approval is a common interest for the OEM and CCM. This means that the process is capable to produce cars according to the CMA requirements. The target may be difficult to reach when the project schedule is tight and the production volume-increasing curve is steep. In low volume production it is possible to do some manual adjustment in the process but in high volume production everything has to go automatically. This was the situation in project A and the targeted volume-increasing curve had to be made less steep.

Table 6 presents the external stakeholder dependencies in OTC & SCM process area. Purchase orders (PO) for the car parts and sub-assemblies were on the OEM's responsibility in projects B, C, and D. In A they were on the CCM's responsibility. The agreements with the suppliers for the purchase orders are done during the product design process. Also the financial terms are agreed then. When a new manufacturing plant joins to the production plants the agreements have to be updated accordingly. In the projects B and C this updating was not so burdensome because the OEM supported in it. In A the updating was more laborious because the OEM did not support in the beginning. The OEM started to help later on when it was noticed that the PO establishment did not proceed. Because the OEM's are always the other contract partner in these agreements their support seems to be necessary in getting the agreements for new PO's created.

Table 6. Comparison of project features in four CCM projects on the OTC and SCM process area

Deliverable	Project A	Project B	Project C	Project D
OTC & SCM processes				
Purchase orders (PO)	The CCM tried to get the PO's and their agreements by contacting the suppliers directly. But the suppliers wanted to negotiate the terms for the new manufacturing site and support from the client was needed.	The client took care for the orders and their agreements.	The client took care for the orders and their agreements.	The client tried to get the PO's and agreements done in time but this was extremely laborious, because almost the whole supplier group was new and had to be established first.
Packages	The package design and development was on the CCM's responsibility, the client did not participate	The package design and development was done in cooperation with the client	The package design and development was on the CCM's responsibility and the client was very supportive in getting the approval of the supplier for them	There was very little package design because the client wanted to use disposable paperboard packages
Parts	The CCM owned the parts until the car was delivered. The CCM took also care of the MRP.	The client owned the parts during the whole production process. The client even did the MRP for the CCM	The client owned the parts during the whole production process. The CCM did the MRP itself.	The client owned the parts during the whole production process. The CCM did the MRP itself.
ECO process	The ECO process and IT system had to be learned at	The ECO process and IT system had to be learned and	The ECO process and IT system had to be learned and	There were a lot of changes during the project

Deliverable	Project A	Project B	Project C	Project D
	the client but because of their large organization the competence and knowledge of the procedures was scattered and the system integration was not easy to do	because the client had already many other manufacturing plants they had a concept of system integration and provided remote access to CCM into the needed systems	the client was very supportive in that process. An experienced engineer from the client site was located at the CCM and led the system integration	because of the incomplete product design and managing the changes was extremely laborious
Sales forecast	The client provided one. There were some minor technical problems with the data definitions at the beginning	The client took care	The client provided one but it was very difficult to get the right forecast because of minor experience in selling the new car model	It was very difficult to get one from the client and that was one reason, which caused problems to the part requirement forecasts, agreements, and PO's with the suppliers.
Car orders	Ok	Ok	Ok	Ok after clearing the difficulties in the order data definitions
Car deliveries	The client took the responsibility first in their import harbour	The client took the responsibility after the car was approved for delivery at the factory gate	The client took the responsibility after the car was approved for delivery at the factory gate	The client took the responsibility after the car was approved for delivery at the factory gate

Unlike in the other three projects the car model in project D was still in the concept phase and there were neither prototype cars nor any prototype parts when the project started. This meant that the EBOM and the 3D models as well as the product specifications were still in the design phase and design changes were going on. Because the product design was uncompleted also the supplier nomination was also started late in the project.

The transport distance to Finland is one challenge and it is connected to the carrier design where the target is to fit as many parts in the package as possible and not to damage the part quality. That is why the packages have to be designed carefully. In project B and C the OEM was supportive in the package design, in A the CCM took alone care of the design as well as the part ownership was also on its responsibility. This meant that the CCM got the part payments with the car invoicing. In the other three projects the OEM owned the parts during the whole production process and the CCM invoiced only the assembly work for the delivered cars. The OEM did material Requirement Planning (MRP) in B, in the other three projects the CCM did that part itself.

Monto (2013) has studied the impact of operational working capital management on the profitability. That capital consists of inventories, accounts payable and receivable. Their research was done in the value chain of automotive industry. The profitability is investigated in the value chain relatively taking into account all the actors in the chain. They found out that the most efficient way to increase the profitability of value chain is to manage all the components of working capital simultaneously and that a radical reduction in payment terms would increase profitability. Also other management accounting researchers have recognized the need for interorganizational accounting practices (Ramos 2004) as well as accounting systems for networks and chains (Håkansson and Lind 2004). They suggest that companies should take the profitability of the whole value chain into account because transaction costs are a remarkable expense in networking environments. The part logistics in automotive industry has been developed to an extremely lean process since already many years ago. The cost-efficiency in the material requirement calculations and their synchronization with the sales order manufacturing schedule affects the warehouse value which again can have a great influence to the company profit. The production start phase is especially risky for miscalculations if the production volume ramp-up does not go according to planned. That extra cost falls normally to the partner who owns the car parts during the manufacturing process and it can cause remarkable extra costs for the responsible company. Furthermore, the arrival of the car parts has to be synchronized with the manufacturing process pace in order to avoid extra costs. All the manufacturing departments need to have the same pace as well and if there are a lot of disturbances in one of the production lines it will affect on the whole system.

Although the product design in projects A, B, and C was ready there were still engineering changes going on during the CCM project execution. The experience in new car projects has shown that the amount of engineering changes is larger during the first few years of production. They cause changes also in BOM and that is why the project has to clarify the EC process at the OEM and adapt itself rapidly to that process to have the latest product data at hand. This adapting is quite difficult without ICT interfaces to the customer's respective data systems and that is why they have to be clarified very soon after the project start.

It is typical in the CCM production to have exact car orders defined for two weeks stock and after that time period a forecast that covers one year. The forecast is showing which options and car model versions are in the plan and that can be broken down into part requirements, which is important for the supplier planning. In projects B and C the OEMs found it difficult to make these forecasts because the car model was so new that there was no previous experience of the sales. The actual car orders have options and there are always case specific rules how to break them down into material requirements. These systems have usually been quite complex and that is why special attention should be promoted to this clarification.

In projects B, C, and D the OEM accepted the finished car at the CCM's gate but in project A this happened first in the arrival harbour after the see transport. The delivery acceptance is the point where the ownership of the car goes to the OEM and it means that the CCM can invoice the car.

Table 7 shows the stakeholder dependent features of ICT systems in the four projects. The PDM systems started to get general first in the millennium change in the contract manufacturing. Until that the drawings were presented in 2D format and often as paper versions like in projects B and C. The good thing was that there were no compatibility problems like in the projects A and D where the drawings were in the PDM system and in 3D format. The CCM has experienced many different PDM systems and there are always more or less integration issues even if the system comes from the same service provider. In all the projects there are several data interfaces that have to be established. The interfaces are connected to the product data, car orders, engineering changes, and car deliveries among others. The communication line has also been an issue and how to find an optimized solution for it. Especially when the 3D models are being transferred from one system to another the file sizes are so large that the line has to have enough capacity. In the earlier times when the file sizes were smaller because of no 3D models the line capacity was not an issue. The EDI connections are mainly used with part suppliers but also with the transport companies and possibly with the OEM, too. The big issue in these connections is the supplier connections and whether the suppliers already have EDI connections with the OEM. In projects A, B, and C those connections existed and the only thing was to build up the connections with the existing guidelines to the CCM's system. In project D there were many suppliers that had no EDI readiness and extra actions needed to be done in that situation. The CCM provided a supplier extranet for these cases. The supplier could get the plans for part deliveries from the extranet server. The material plans as well as call offs were sent through these connections to the suppliers who again sent their shipping messages as well as the transport companies their shipments to the CCM so that there was always information about the material arrival status.

Table 7. Comparison of project features in four CCM projects on the ICT systems area

Deliverable	Project A	Project B	Project C	Project D
ICT systems				
PDM	PDM system was needed. Incompatible systems between client and CCM caused some extra administration work	No need for a 3D data system. The geometry was presented on paper drawings	No need for a 3D data system. The geometry was presented on paper drawings	PDM system was needed and compatible systems were installed in the beginning. Problems with the system integration during the project because of different SW versions and parameters.
Data interfaces	Definition was done in cooperation with the IT departments with the process owners' support	Definition was done in cooperation with the IT departments	Definition was done in cooperation with the IT departments and the process owners' support	Definition was difficult because of minor competence in system integration at the client.
EDI	Clear guide lines existed and earlier implementations were helpful in this project	Clear guide lines to create the EDI connections existed	Clear guide lines existed but new message standards had to be implemented at the CCM	Guide lines had to be created from scratch

3.4 Typical industrial project targets

The project targets are named in the beginning of the project. These target labels are from the project A but they could as well be from any other three projects. The point is to show with which units and target areas the project success is measured. Some of the targets are agreed in the CMA that is the contract manufacturing agreement between the client and the CCM. The CCM has additional targets for its own purposes but they are not communicated to the client. Furthermore the CCM has defined more stringent target figures for itself in the mutual target meters than in the official CMA. In Table 8 the commonly used meters for the targets are presented. They are divided according to the same transformation process themes as in Figure 46 in Chapter 4. These themes are production processes in body shop, paint shop, and assembly shop as well as the OTC and SCM processes. Most of the meters are defined by the CCM. Reaching the supply chain targets needs often involvement of both counter partners, the CCM and the OEM, because the fundamental agreements are on the OEM’s responsibility.

Table 8. Typical targets for a CCM project in the case company. The target may either be agreed mutually in the CMA or an internal target at the contract car manufacturer (CCM).

Process	***Area***	***Target***	***Description***	***CMA/CCM***
Production	*Quality*	*Final audit*	Total amount of finished cars/day	*CMA*
			Failure index with variations	*CMA and CCM*
		FTOK	First Time OK; per cent target of each production department, what is its capability to manufacture daily target production without rework	*CCM*
		Aftermarket	Warranty; defined in the CMA what is the allowed amount of warranty rework in the delivered vehicles	*CMA*
SCM	*Part deliveries*	*Shortage of parts*	What is the allowed per cent of needed inbound parts that are missing in production	*CMA or CCM*
		Inventory	Value at the plant	*CMA or CCM*
			Turnover	*CMA or CCM*
	Delivery of parts	*Supplier quality*	PPM; Parts Per Million, how many defected parts are allowed in the total amount of million parts	*CMA or CCM*
		Inbound logistics	Part transport costs / car	*CMA or CCM*
			Part transport volume / car	*CMA or CCM*
			Package amount in inbound transport	*CMA or CCM*
			Package turnover in the transport process	*CMA or CCM*
OTC	*Production lead time*	*Throughput of the manufacturing process*	The amount of days that one car needs from the first manufacturing line station to the point, where it is delivered	*CMA or CCM*
		Stability of the production	Per cent figure of the amount of the car	*CCM*

Process	Area	Target	Description	CMA/CCM
		sequence	orders which keep their original position in the sequence	
		Delivery performance	What is the actual delivery date compared to the planned one; per cent target and the allowed variation	*CCM*
Financial intention	*Profitability in production*	*h/car*	How many working hours are spent to one car ready for delivery	*CCM*
		Amount of WC in production	How many white collar employees are working in production	*CCM*
		Process material	What is the cost of process material (e.g. liquids like chemicals, glue, tape etc.) per car	*CMA or CCM*
		Energy	What is the cost of energy per car	*CCM*
		Safety	What is the cost of safety per car	*CCM*
Financial intention	*Profitability in production*	*Up-time*	Daily up-time per cent in each manufacturing department; BS, PS, and GA	*CCM*
		Paid by spending curve	Plan vs. actual amount of project investments	*CCM*
	Project investments	*Amortized in vehicle price*	Plan vs. actual amount of investments embedded in the vehicle price	*CCM*
		White collars	Plan vs. actual amount of white collar employees	*CCM*
		Blue collars	Plan vs. actual amount of blue collar employees	*CCM*

3.5 Other practices in a contract car manufacturing project

The instruments that help the management of a project at the CCM are defined in the company's certified quality system (ISO/TS 16949 and ISO 9001). The project's quality assurance plan includes quality gates with reviews, project and process risk analysis (FMEA and P-FMEA) and control plans. They are introduced in the following Sections as well as RASI charts, which can support in the definition of responsible organizations and persons in specific project activities.

3.5.1 Failure Mode and Effects Analysis

The quality instructions require that the project and each sub-project have to create one risk analysis for the project (FMEA, Failure Mode and Effects Analysis) and one for the manufacturing process under creation (P-FMEA).

The aim is to capture all possible risks for the respective case in advance and to have action plan to avoid them or to their realization. There are instructions how to evaluate risks and the most remarkable risks need to get plans of corrective actions with timing. The verification of this behaviour is controlled in the quality gate reviews. If the risk in P-FMEA could not be eliminated with a corrective action proactively the manufacturing department got instructions how to handle the problem in production. These instructions were documented in the Control Plan. With this procedure the company wants to insure that the quality targets in production and product are met. In Appendix 3 there is an example of the form that has to be filled and updated regularly during the project execution. The columns that need to be filled are numbered in the form presentation in Appendix 3 and the corresponding explanations of them are introduced in Table 9.

Table 9. FMEA form field explanations

1	Process number	An identification number for the process
2	Process Function/Requirements	Name description of the function
3	Potential Failure Mode	Description of the possible failure
4	Potential Effect(s) of Failure	Description of the possible consequences
5	Severity of Effect (1-10)	Minimal severity 1, Maximal 10
6	Classification of the failure	Connected with assembly parts and car crash
7	Potential Cause(s)/Mechanism(s) of Failure	
8	Occurrence of failure	Likelihood to occur, low to very high 1-10
9	Current Process Controls – Prevention	Way to prevent the failure today
10	Current Process Controls –Detection	How failure is detected today
11	Likelihood and Opportunity of Detection	How possible is the detection of failure
12	RPN (Risk Priority Number)	Multiplication product = (5) * (8) * (11)
13	Recommended Action(s)	Action plan for elimination of the failure
14	Responsibility & Target Completion Date	Target date and responsible person for the action
15	Actions Taken & Effective Date	Verification of the taken action
16	Severity	New evaluation after the action taken
17	Occurrence	-“-
18	Detection	-“-
19	RPN	-“-

If the RPN is larger or equal to 100 an action plan is required. And if the RPN is still over 100 after the action plan evaluation then the responsible person had to organize actions in control plan. This serves as an instruction for the assembly.

3.5.2 Responsibility charts

The responsibilities in a CCM project and its different areas can be defined with a RASI chart. An example of RASI in SEPRO activities is presented in Table 10.

Table 10. Example of a RASI chart

RASI IN SEPRO ACTIVITIES

R=Responsibility, A=Approval, S=Support, I=Information

SE activities in Product Development	FA	VA
Proposals from the production and logistics point of view to get an optimized solution for the product design	A	R
To take VA proposals into consideration in the product design	R	S
VA specific production and quality definitions	A	R
Lessons learned to get the assembly time optimal	S	R
Lessons learned to get the purchase level optimal	S	R
Proposals to get investments and costs at VA optimized	A	R
Follow up of the pre-series vehicles	A	R
Creating P-FMEA’s and carrying out the actionplan in it	S	R
Evaluation of the product and process readiness in different level 2 deliverables milestones	A	R
SE Activities in Manufacturing		
Carrying out VA internal reviews in the factory planning	S	R
Creating VA specific production documents; working instructions, MBOM etc.	S	R
To plan and supply all VA specific equipment needed	S	R
SE Activities in Logistics		
Plan and design the packaging material to get the optimized solution	A	R
To supply the sample packages and review them	A	R
To supply the serial packages and review them	A	R
To plan an optimized process for a fluent mtr flow to achieve the MRD's	S	R
Logistic concept definition	R	S
Logistic concept implementation at VA	S	R
SE Activities in the production phases		
Controlling timetable with investments and equipment	A	R
Call off new parts at the supplier	S	R
Compare required parts with available parts	S	R
Create vehicle production program together	R	S
Make sure that the start of LV production is in schedule	R	S
Follow up timetable in vehicle production	A	R
Steering the material flow in the process	S	R
Teach the assembly stuff	S	R
Follow up the vehicles during the manufacturing	S	R
Create an issuelist of not fitting parts, functional and qualitative lacks,etc.	A	R
Implement actions for investigating: Measure parts, measure body, sample assemblies	I	R
Make corrective actions based on investigations above	S	R
Weekly meeting about the problem issues between vehicle development and manufacturing teams via internet or videokonference	R	S
Document the status of all built vehicles	A	R
Follow up quality targets	A	R
Audit the preseries vehicles	A	R
Administration of ramp up at VA	S	R

The target is to have a mutual agreement among the partners what is their role in every deliverable, who has the responsibility for the output and who should support in the accomplishment of it. Does somebody need to approve the result or should the partner only be informed about the deliverable.

The charts are used in those deliverables where the responsibilities are unclear. It clarifies e.g. if the specific deliverable shall be produced by the client or by the CCM. The chart presentation is e.g. especially recommended in that case where SEPRO teams are participating in the product development so that it shall be clear for everyone who is responsible for what and to assure that all tasks get accomplished in schedule.

The activities in the SEPRO function are divided in four groups that are product development, manufacturing planning, logistics, and production. In PD issues the CCM is e.g. responsible to make proposals from the manufacturing point of view so that an optimal product design solution will be found but the OEM has to approve this like every other issue that influences the product design.

Furthermore the CCM has to make proposals also in order to get the design optimal for transporting the parts from the supplier to the plant. The pre-series car manufacturing is on the CCM's responsibility but the OEM has to approve the finished vehicles. The CCM is obliged to evaluate the possible risks and uncertainties in its manufacturing process with respect to the product specifications and the OEM needs to support the CCM in its action plan in order to avoid the realization of the risks. In manufacturing issues the CCM is obliged to have internal reviews during the project execution and the OEM has to support in order to pass the review requirements. Furthermore the CCM is responsible to create the MBOM and the OEM shall support in that creation. In logistics area the CCM is responsible to design the transport packages for the parts but that has to be made in cooperation with the OEM because it means fairly large investment costs. The MRD's (Material Requirement Date) and their calculation is on the CCM's responsibility but the OEM has to support this procedure as well as forming the logistics concept. SE activities in different production phases are those that want to make sure that all the needed preparations are done to be able to start the serial production. Most of those activities are on the CCM's responsibility.

3.5.3 Quality Gates

The CCM project is divided into quality gates in the case company. The number of the gates depends on the project type. If the product is still under development there are more gates than in the case where the CCM project is about a product, which already is produced somewhere and its design is completed. The CCM's quality department defines the amount of gates accordingly. An example of the quality gates is in Table 11. This example is from a CCM project where the product is still under development. In that situation the prototype has to be manufactured also at the CCM (QG3) and there is a need for more number of pre-series than in a case, where the product has already been produced in another plant.

On the review date each sub-project has to present their status with respect to the planned target values. The status of each sub-project is described with traffic lights where red light means serious lacks in the targeted deliverables and the project should be stopped until the critical issues are resolved. By yellow there are open issues which are not critical and where the responsible project manager has to organize actions to get the issue sorted out. By green everything is going according to plan.

Table 11. Quality Gates in a CCM project.

Gate	Project Phase and Gate Name	Review Date	Status
QG1	Project planning	dd.mm.yyyy	🔴🟠🟢
QG2	Manufacturing Concept Planning	dd.mm.yyyy	🔴🟠🟢
QG3	Prototype Series Process Approval	dd.mm.yyyy	🔴🟠🟢
QG4	Serial Process Planning	dd.mm.yyyy	🔴🟠🟢
QG5	Preseries 1. Process Approval	dd.mm.yyyy	🔴🟠🟢
QG6	Preseries 2. Process Approval	dd.mm.yyyy	🔴🟠🟢
QG7	Preseries 3. Process Approval	dd.mm.yyyy	🔴🟠🟢
QG8	SOP Process Approval	dd.mm.yyyy	🔴🟠🟢
QG9	Project Approval	dd.mm.yyyy	🔴🟠🟢

3.6 Contribution of the case presentation

The first three sections in this chapter presented the CCM projects and customers of the case company. The aim was to describe the circumstances and environment where the case company operates and how it has developed during the company history. Thereafter four CCM project (A, B, C, and D) features were presented in more detail. These details focus on deliverables that come from external stakeholders, Tables 5, 6, and 7. In Table 5 the features of production process area are presented, Table 6 shows the features of OTC and SCM process area, and Table 7 is about ICT deliverable connected features. The four CCM projects that were presented in the Tables form the embedded units of this single case study.

The two next sections in this chapter presented the tools that are used in the case company when managing and controlling a CCM project. The aim was to show that no flow model has been used and therefore development of such can be useful for the project execution.

4 Modelling a contract car manufacturing project

In this Chapter the model creation starts with an introduction to CCM project elements in Section 4.1. The elements are adapted from the scheduled deliverables of project A. Thereafter a big picture of a CCM project is drawn with help of these elements in Section 4.2. Thereafter different analysis tools are considered and presented in Section 4.3. The next Section 4.4 will describe how the analysis of the case was done with the two selected tools. Section 4.5 concludes the results from the tool analysis and Section 4.6 presents contribution to the research questions.

4.1 Contract car manufacturing project elements

In a CCM project the target is to get everything done what is needed for the production of a new car model. In Hubka et al.'s (1988) words this means to create a transformation system that takes care of all the functionalities needed in automotive manufacturing. The CCM project model shall consist of the deliverables that are needed for this.

Before going deeper into the deliverables let's look first at a rough presentation of a contract manufacturing plant processes (Figure 46). This can be considered as an introduction to the model creation in this study. The three topics that build up the transformation system for CCM are the manufacturing processes (red arrow in the Figure), OTC and SCM processes (green arrow), and the ICT systems (lilac oval) that provide services and are embedded in the factory automation systems.

The manufacturing processes conclude at the contractor's site; body shop, paint shop, and assembly shop. The CCM does not possess an own press department, which is not taken into account here. The focus in designing these processes has been more structural than functional because the focus is on getting the production cells designed and installed for the new vehicle. The manufacturing process has similarities with mechatronic systems because there are embedded functional entities in the production automation facilities. Furthermore, designing the manufacturing lines with facilities reminds construction projects as well. Especially in body shop where the line has to be built up from the beginning whereas the lines in paint shop and assembly shop have often been only modified. Considering product development body shop project is similar to NPD projects whereas paint and assembly shop projects are more similar to incremental product development projects.

OTC (Order to Cash) and SCM (Supply Chain Management) processes take care of the information that the production process needs to know e.g. what kind of cars have to be produced and which parts are needed for that. The ICT takes care of the communication between these processes and the production process. The production status as well as the car orders status and parts and materials usage among all the other things that need to be taken care of are updated in the OTC & SCM process with the support of ICT systems. The systems have to be designed so that the part deliveries take place just in time and that the stock values are on optimal level. The nature of designing these processes is more functional than structural.

The ICT systems are embedded in both of the main processes. They carry all the data that is needed in the processes and the status changes are updated in those systems. The main

IT system areas are connected to product data (PDM, Product Data Management), car order data, material requirement and warehousing as well as logistics data (ERP, Enterprise Resource Planning), manufacturing data (MES, Manufacturing Execution System), quality data (Q Systems), and integration to outside partners like suppliers and the OEM (EDI, Electronic Data Interchange).

PDM system includes the EBOM (Engineering Bill Of Material) and the 3D model data. That data has to be integrated with MBOM and purchase orders which again are in the ERP system as well as the car orders and their status. ERP system in turn has to be integrated to the MES system that carries the data for the robots and manual assemblers as well as collects the needed data from the process. The ERP and MES systems tend to be composed to one single system when the car orders are concerned. These systems are all internal at the CCM and they need to have interfaces with the corresponding OEM systems. Furthermore the CCM manages data exchange with the suppliers as well as EDI with an extranet system. EDI is a standardized messaging system developed for data exchange between two parties. This practice has been used in the automotive industry over 30 years and there are two standards that are mostly used, OFTP (Odette File Transfer Protocol), and VDA (Verband der Automobilindustrie). The CCM has used Odette with Saab suppliers, and VDA with the German suppliers. Establishing the EDI connections is normally only hard work if the suppliers are already having the system. If not which can be the case with new suppliers in the automotive business then another possibility is to pass on the material call-offs with the extranet system. Designing the ICT systems is more functional than structural and the system development is similar to incremental system development because the existing systems have to be modified for the new vehicle production.

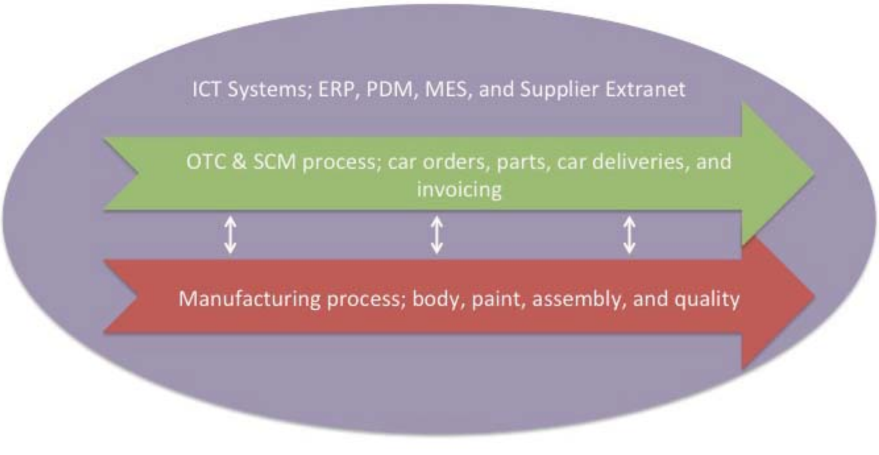


Figure 46. The factory transformation system that will be delivered by the CCM project.

4.2 Big picture of the problem

In this Section the problem will be approached with big picture drawn with two different methods to get grip on the issue. Gharajedaghi (2011) suggests that the mess should first be formulated and that can be done by first searching, then analysing, and finally telling the story of the object system. Checkland (2009) advises to start with defining the root of the problem first and proceeding thereafter according to the instructions described earlier in Figure 26. The target in the mess formulation is to map the dynamic behaviour and nature of the system. Checkland (2009) has the same targets but he advises more precisely that the elements shall be presented as activities in his conceptual model whereas Gharajedaghi gives no such advice.

4.2.1 Formulating the Mess

The mess formulation in this study means telling the story according to Gharajedaghi's (2011) methodology. In the search phase the four projects in this study were found and their features were analysed based on the project structure and time schedules. Figure 47 presents the result of this method, the story.

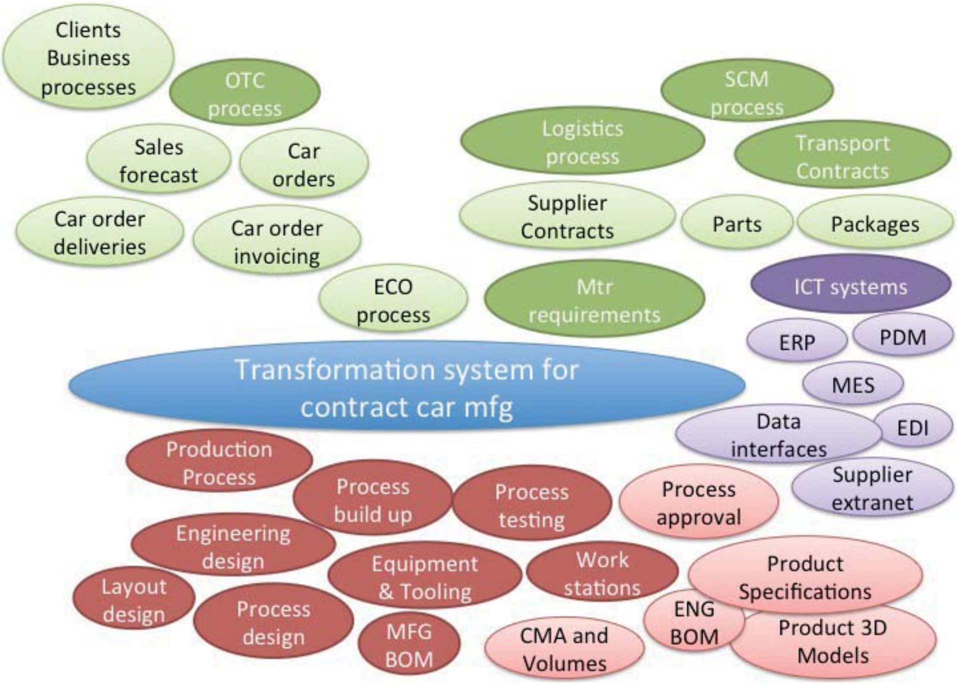


Figure 47. Presentation of a CCM project with its deliverables. The main deliverable is to create a transformation system for contract car manufacturing (adapted from Gharajedaghi 2011)

When looking at the mess in Figure 47 it can be noticed that there are same colours as in Figure 46. The colours describe the process in which the specific element belongs. The light coloured ellipses present such deliverables that need strong involvement from external stakeholders like client or suppliers to get the tasks finished. E.g. sales forecast and car orders as well as 3D models are deliverables from the client and when the definition is done the files will be transferred through a data interface to the CCM's system. To get the needed parts to the assembly plant hundreds of suppliers have to cooperate and commit themselves in the project targets. This is where the social communication skills play a role in order to get the suppliers committed to the same target schedule. Suppliers have usually many other clients as well and they may have limited resources to do the extra work that is needed in establishing connections to a new manufacturing plant. The mess describes the whole system roughly. When dealing with a system there are always uncertainties and imprecisions, which cause risks. There are more of them in the beginning of the project and they decrease towards the end of the project like already presented in Figure 3. It has been experienced that most uncertainties and risks are connected with negotiation issues like managing to get the supplier cooperation up and running or to reach the same level of understanding with the OEM.

If the risks go real they often cause delay to the project proceedings. To be prepared for these risks it is important to keep in mind the big picture and the dependencies between different deliverables in the project. Experience in the case company projects has shown that usually the company external actors like e.g. stakeholders, cause most of those uncertainties, which lead to delays in the project. It is sometimes difficult to find the way to deal with the external actors in order to get the needed deliverables from them. One simple reason can be to find the right counter partner if the stakeholder organization is very large which sometimes has been the case.

The elements in Figure 47 will be explained in the following sections.

4.2.1.1 Production process

Production process is the result or deliverable of the chain where the physical structure and layout of manufacturing departments, body, paint, and assembly shop, are designed and built up. Furthermore production process includes also the functional operations, like automation of robots and the manufacturing line. The design philosophy of the mechanical part of the process is structural whereas the philosophy in the automation design is functional and their integration is not always easy what also Fujimoto et al. discovered in their research (2011).

Process approval means the official approval of the resulted production process that has to have certain level of capabilities when producing the cars. The client verifies this level after sufficient *testing* with proper results. The process is a complex system and even if its subsystems meet their requirements the entire process may not do that.

Layout design starts already with preliminary product information but when proceeding to detailed *process design* precise *product specifications* with *3D models* and *EBOM* are needed. This can be very challenging like in the project D because of the late design freeze. During the design process the EBOM is modified to *MBOM* (Manufacturing Bill of Material), which as well determines the purchase level. That is the component level of the parts that the suppliers will deliver for the assembly. The purchase level and the size of the components have a big influence on the transport costs.

The different views into the BOM (Bill of Material) are presented in the Figure 48. The first phase of BOM is EBOM that the product design develops. EBOM is connected to the 3D models in the PDM system and it presents every single part that the basic product consists of. EBOM has to be developed to the BOM that consists of all the variable parts that different car configurations may have. The ERP system where this data lies contains also the rules for the possible configurations. MBOM is the definition for each manufacturing plant describing the sub-assemblies and parts in that plant from which the configured car will be built as well as the sequence of the assemblies. Different plants may use different sub-assembly level for same car model because of several reasons.

The 3D data models are needed for the *engineering design* where the *equipment and tooling* is designed as well as the *workstations*. The physical *build up of the process* will follow after that.

OTC and SCM processes

Order to Cash and *Supply Chain Management* are processes that provide the needed information for assemblers in production so that they know what kind of cars have been ordered and what parts have to be installed in those versions.

OTC process is dealing with the *sales forecasts and car orders* that are basis for the *material requirement* (MRP Material Requirement Planning) calculations. The other bases for those calculations are MBOM and inventory level. The inventory level will also have influence to the timing of an engineering change. If there is a high amount of stock available it may transfer the planned date more far in the future. SCM process takes care of the inbound and internal *logistics* and OTC process takes care of *car deliveries* in outbound *logistic*. In order to get the parts to the manufacturing plant agreements for the *purchase orders (PO)* have to be negotiated with the suppliers. Experiences in several CCM projects have shown that even if the car company already has agreement for the parts there are issues that have to be negotiated again. Such issues are e.g. terms of delivery and payment, which affect on the supplier's revenue. Furthermore the supplier has to accept the new package designs that differ from the previous ones. Part quality lies on the supplier's responsibility and defects may be caused during the transport. Also the *transport contracts* with logistic companies have to be signed in a new CCM project.

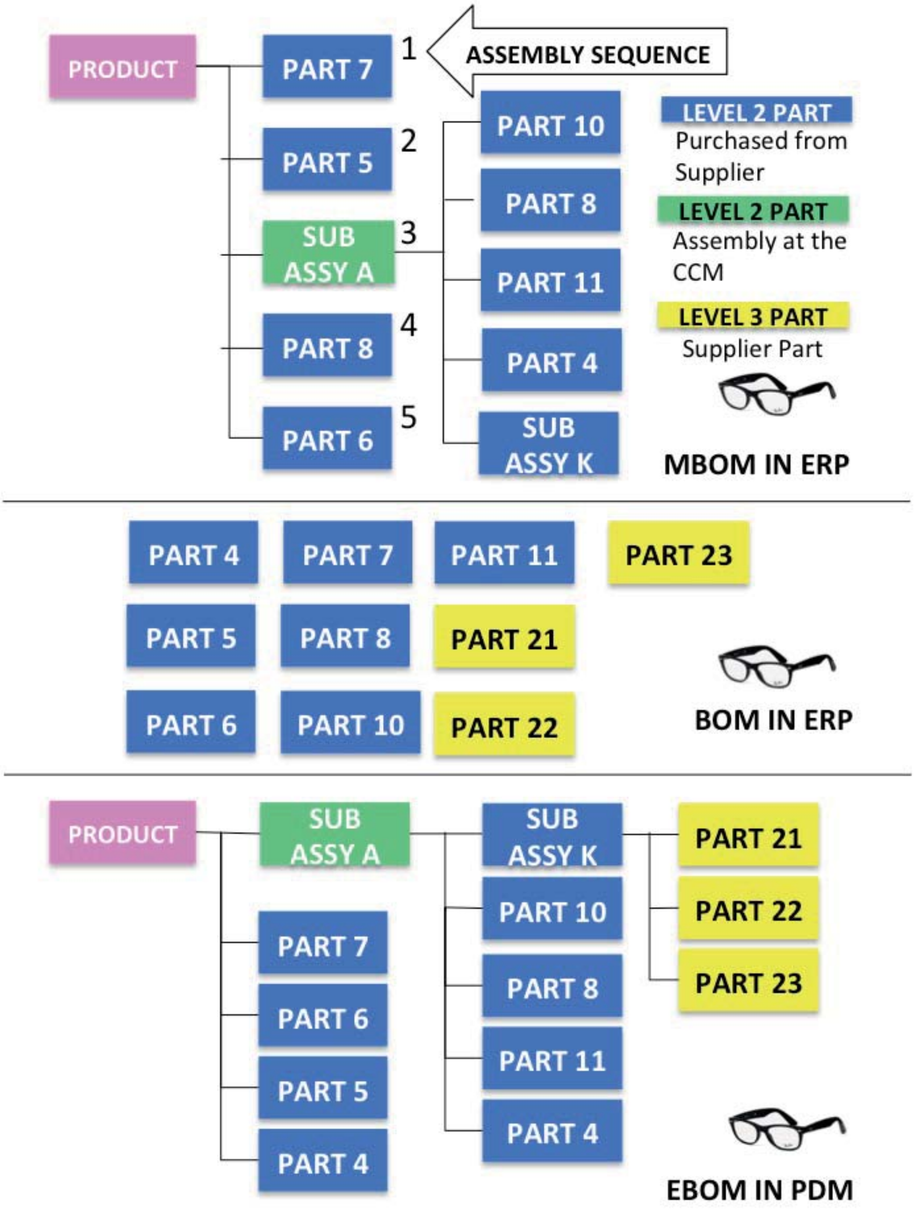


Figure 48. Different views to the Bill of Material (BOM).

4.2.1.3 ICT systems

The CCM has basically the ICT infrastructure with *ERP* and *PDM* and all the other *ICT systems* already available because they are essential for the manufacturing process. The present systems have always to be customized for a new CCM project. The *data interfaces* with the client have to be determined and the data that the client provides to the CCM has to be defined. Furthermore, the data that the CCM has to report to the client has to be defined as well. *EDI* (Electronic Data Interface) is a widely spread concept in automobile industry with standardized messages for part supply. Although standardization this has to be clarified in the project and implemented with each supplier separately. The German automotive industry uses VDA standards and the other largely used standard is OFTP.

4.2.2 Presentation of the conceptual model

The conceptual model is presented in Figure 49. The presentation is adapted from Checkland's (2009) Soft Systems Methodology (SSM). According to that the presentation starts by the root definition. In the case company's project system the root definition can be expressed as following:

The starting point for a CCM project is a signed CMA, which is the base for the project definition. A team of company sales department has negotiated the CMA and it has been experienced that there are always uncertainties, which are difficult to evaluate in the dealing phase. The project has to adapt itself to the situations, which emerge from the client's properties. The uncertainties in the project can easily risk the time schedule. Most of them are connected to activities that need contribution from stakeholders. This causes challenges for the project management in keeping to the schedule and to meet all the project targets.

The elements in the conceptual model include the main activities, which are needed to fulfill the intermediate project deliverables. Checkland (2009) recommends to use verbs in describing the activities and not to take too many of them into the model. The intermediate deliverables in this model are Order to Cash OTC) and Supply Chain Management (SCM) process, as well as the physical manufacturing process. The same deliverables have been presented in Section 4.2.1 where they were part of the mess (Gharajedaghi 2011). The CCM projects are large engineering projects and they are organized in sub-projects according to the process deliverables. The common final deliverable and target for the whole CCM project is to get the production started in time and not to risk the quality of the manufactured cars. That deliverable is called Start of Production (SOP). The process capability to produce cars with sufficient quality is verified and approved by the client. The activities in Figure 49 are following:

1. *Define the manufacturing and engineering bill of material (MBOM and EBOM).* The basis for the whole system as well as process planning is the EBOM of the car. It should be transferred to the CCM right in the beginning of the project. To be able to manage the BOM and changes in it the common process has to be defined clearly and commitment with the rules of managing it has to be agreed. The product development creates the EBOM and MBOM is an implication of that. MBOM defines the purchase level of the parts at the CCM. The manufacturing company uses the MBOM when it plans the assemblies. Also logistics need the MBOM when planning the transport packages and concept for different subassemblies and parts. The purchase level has always to be agreed between the client and the CCM because it affects strongly on the

material costs. This is one main uncertainty in the project because it involves so many external stakeholders like the client and the suppliers to agree.

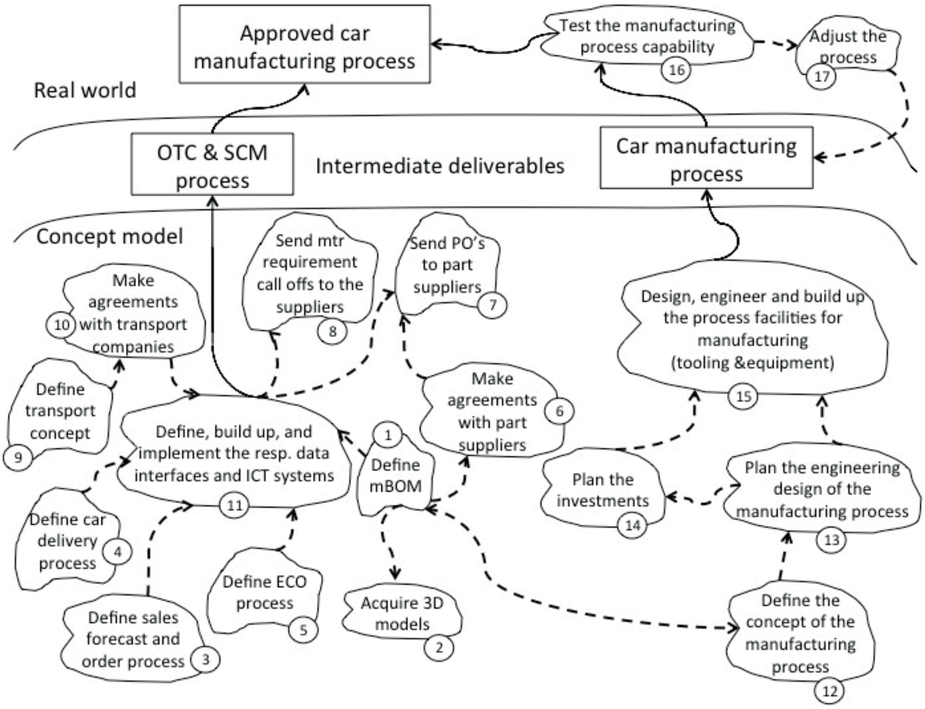


Figure 49. Conceptual model of a CCM (Contract Car Manufacturing) project modified according to Checkland's (2009) Soft System Methodology (SSM).

2. *Acquire the necessary 3D models*. The 3D models are as essential as the BOM in the production process planning as well as in the logistics. The manufacturing engineering needs the models to be able to design their tooling and equipment and logistics need them to design the transport packages. The 3D models are also needed in the VR system if there is no physical prototype of the car available yet. In that case the assembly sequence can be designed virtually with the 3D models. The other possibility to do that is a prototype car, which can be torn down to plan the sequence.
3. *Define the sales forecast and order process.* The sales forecast and order process is basic information for the material requirement planning to be able to calculate the material needs. The suppliers need that information to be able to plan their production volumes. Normally the required amounts are calculated on order basis for 3-4 months ahead and the rest of the calendar year is calculated on forecast basis. The production process needs the sales orders to be able to build the right properties in the vehicles and to steer the production.
4. *Define the car delivery process.* Definitions and agreements need to be done to where and by which means the vehicles shall be delivered. Also other terms of delivery and invoicing need to be agreed. This information serves as basis for the negotiations with

transport companies and outbound logistics planning. The process has also an important influence to the company finance while affecting the amount of working capital.

5. *Define the ECO process.* Engineering change order process is essential in the whole production process and already during the project phase. One single engineering change in one single part can have influence to other parts or subassemblies. The influence of this chain reaction has to be taken into account in timing the change actualization date. Furthermore the timing affects the stock levels, which again burdens the working capital.
6. *Make the agreements with the part suppliers.* One laborious activity is agreeing the terms of part supplying with the respective suppliers. There are normally some hundreds of them and they may be spread around the globe. Because there are certain quality requirements for their parts it is important that the packages are planned so that no complaints arise because of delivery damages. Also other details of the logistics process have to be agreed with each supplier. Although the client has contracts with the suppliers a new manufacturing location brings always some changes to that contract at least in terms and ways of delivery.
7. *Send purchase orders to the part suppliers.* After the agreements have been made the purchase orders define more precisely the estimated amounts and their schedule for part deliveries.
8. *Send material requirement call offs to the suppliers.* The exact delivery amounts and dates will be called off with EDI (Electric Data Interface).
9. *Define transport concept.* The transport concept for the parts (inbound) has to be defined together with the transport concept for the finished cars (outbound).
10. *Make the agreements with the transport companies.* In the case company transportation partners are needed as well on land as on see because of the geographical location. The production volume affects the amount of needed parts and that has to be planned carefully with the vessel capacity and time schedule.
11. *Define, build up, and implement the respective data interfaces and ICT systems.* The ICT system is an integral part of the process deliverables that the project has to produce. The amount of car properties, parts and subassemblies, engineering changes etcetera is not possible to handle manually or with some separate it tools like excel that sometimes has been the case because of delays in the system creation and modification.
12. *Define the concept of the manufacturing process.* This defining has to be done to all three manufacturing departments, body shop, paint shop, and general assembly. In body shop the designing means creating a new production line for the car and in paint shop and general assembly the design means modifications to the existing production line.
13. *Plan the engineering design of the manufacturing process.* Calculate the needed external resources for manufacturing engineering. Find the partners for that and make agreements with them.
14. *Plan the investments.* Plan and calculate the needed investments and go through the commercial negotiations with the offering companies to procure the equipment
15. *Design, engineer and build up the process facilities.* The process facilities are mainly the workstations in body, paint, and assembly shop. In body shop most of them are

new productions cells with robots. In paint and assembly shop they are the current workstations and modifications to them as well as new workstations if needed. Also the conveyors in the process have to be investigated and modified for the new product.
16. *Test the manufacturing process capability.* The process capability in producing the planned volume of cars has to be tested as well as the quality and safety requirements for the cars.
17. *Adjust the process.* In order to reach the targets in the manufacturing process it has to be adjusted often in several loops before the final approval can be achieved. The most laborious adjustments are related to the geometry of the body. That needs iteration loops in automation and fixture settings as well as the production cell robotics.

Furthermore, the activities 2-5 in Figure 49 need information input from the client. Otherwise these activities cannot be completed. This input may sometimes be delayed of several reasons. One reason has often been that the client does not have a formal process for transferring this kind of information. It is not everyday business for the client to start manufacturing cooperation with a new CCM.

4.3 Analysis tools

The basic tool used in the analysis was Design Structure Matrix. The elements in the matrix are based on the big pictures presented in Figure 47 and Figure 49. DSM is a supreme tool for analysing the element dependencies in a project. Ghoniem et al. (2004, 2005) have made a study where they compared the readability of graphs between node link and matrix based presentations. Their conclusion was that the matrix based was almost always more readable than the graphical presentation. Only when the amount of elements was not too large the graphical presentation was more readable in viewing the interdependencies. But also that feature was better in the matrix presentation when the amount of elements was large. In this study the number of the elements is 227 and that is considered as a large matrix (Ghoniem et al. 2005). The elements are the deliverables of a CCM project and its sub-projects, body shop, paint shop, assembly shop, as well as OTC and SCM processes. In this context the matrix could also be called Dependencies Structure Matrix. Different naming and context possibilities are presented on the DSM community web site (http://www.dsmweb.org/en/dsm.html). Furthermore the web site presents notable amount of scientific conference publications considering DSM.

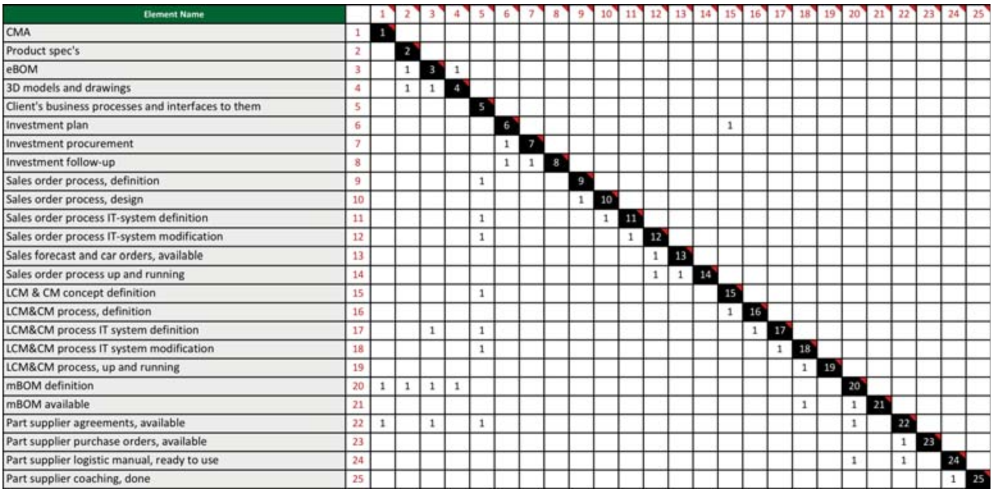
The whole DSM model of a CCM project with its 227 elements is presented in Appendix 2. Furthermore in Appendix 1 there is a list of the elements categorized according to their responsible sub-project area. A snapshot of the matrix with its 25 first elements is showed in Figure 50. The elements are comprised from the sub-projects' time schedules in project A. The sub-project areas are the three manufacturing departments, body, paint, and assembly shop and OTC & SCM as well as Quality sub-projects. Some of them are physical deliverables of the sub-project like the installed production cells in body shop or the modified skids in paint shop. Some of them are information elements, which Gonzales-Rivas et al. (2011) call infels. Examples of infels are CMA, product specifications, EBOM and MBOM. Some infels are deliverables of external partners like product specifications and EBOM from the customer. Some infels are internal deliverables at the CCM like MBOM but the creation of it needs EBOM as an output. A graphical presentation of the same matrix is made with the DiMo tool and shown in the Figure 51. With DiMo the project flow can be described in more visible way than with the matrix presentation. The project flow is actually a depiction of product process integration where the design information of the product (car model) is transferred to the production process under development.

The element presentation in the DSM comply the functional representation of Chandrasekaran et al. (1993) and their Design Rationale that was presented in Section 2.1.4. There the elements are defined from top down and the project functionality can be represented on different resolution levels. The one used in this study can be called the project management level. The sub-project managers used that level when they reported their project status in the regular meetings.

After the elements have been defined their interdependences are marked in the matrix. Reading across the row and placing a mark on all those element column cells of which output is needed before the respective row element can be completed was the way of proceeding when filling the matrix.

In Figure 50 example the first five element deliverables are infels and their input comes from the OEM. They in turn are output for many CCM internal elements like manufacturing concept planning. The next three ones are investment related at the CCM and they are managed by the CCM project management. The planning of the investment budget needs output from the processes concept planning. But this works also vice versa: the concept planning has to take into account the restrictions given in the investment budget. The next deliverables are connected to the sub-project OTC concerning sales orders for cars, life cycle and change management for parts, manufacturing BOM, and part suppliers. The DSM continues with more deliverables like material requirement calculations, inbound and outbound transports, factory internal material handling processes, purchase and sales invoicing processes and systems, production department process designs and construction, ICT systems, finally ending on the last deliverable that is SOP (Start of Production).

The handling and analysing of the dependencies in large matrixes is quite laborious. Different tools have been created to help the analysing. Both commercial as well as free software is available. The free software has mostly been developed in universities. This study will utilize the free tools because of limited financial resources. They were presented on the website www.dsmweb.org (2014, 2015) and the first tool that is used in this study is from this site. It has been developed in MIT by professor Eppinger's researchers. It consists of macros for partitioning, tearing and simulation of a DSM. It can handle a matrix with the maximum of 250 elements, which was adequate for the purposes of the present study. The tool is based on Microsoft (MS) Excel and Visual Basic (VB) software. The other tool that is used in this study has been developed by Riitahuhta Research Group (RRG) in the TUT (Tampere University of Technology). It is called DiMo. The software is built on a Java based object-oriented architecture. It is still under development but an early version is already available for the use of the TUT students. The basis in DiMo is also a DSM matrix with element dependencies. The idea is that the software should use the matrix in forming a graphical flow model of the elements and their dependencies. This feature is unfortunately not yet functioning properly and the graphic presentation had to be drawn manually. Otherwise DiMo turned out to be a positive surprise as a tool. The program worked perfectly and did not crash even once.



Element Name		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
CMA	1	1																								
Product spec's	2		2																							
eBOM	3		1	3	1																					
3D models and drawings	4		1	1	4																					
Client's business processes and interfaces to them	5					5																				
Investment plan	6						6									1										
Investment procurement	7						1	7																		
Investment follow-up	8						1	1	8																	
Sales order process, definition	9					1				9																
Sales order process, design	10									1	10															
Sales order process IT-system definition	11					1					1	11														
Sales order process IT-system modification	12					1						1	12													
Sales forecast and car orders, available	13												1	13												
Sales order process up and running	14												1	1	14											
LCM & CM concept definition	15					1										15										
LCM&CM process, definition	16															1	16									
LCM&CM process IT system definition	17			1		1											1	17								
LCM&CM process IT system modification	18					1												1	18							
LCM&CM process, up and running	19																		1	19						
mBOM definition	20	1	1	1	1																20					
mBOM available	21																		1		1	21				
Part supplier agreements, available	22	1		1		1															1		22			
Part supplier purchase orders, available	23																						1	23		
Part supplier logistic manual, ready to use	24																				1		1		24	
Part supplier coaching, done	25																								1	25

Figure 50. Snapshot of the DSM with 25 first element deliverables and their dependencies. The entire matrix is presented in the appendix 2.

Neither of the previous tools, DSM nor DiMo, had the scheduling feature, which is essential in project management. That is why the DiMo developing team had created an interface with MS Project. Unfortunately the MIT Excel tool had not that kind of interface to any scheduling software. MS Project was used in this study to analyse the total duration of a CCM project and therefore the interface was needed. The MIT Excel tool had a VB macro that simulated the project duration based on the given task durations, minimum, maximum, and probable. This method reminds Monte Carlo simulation and provided another way to analyse the project duration.

In this study, two features of the MIT tool, partitioning and simulating, were used. Furthermore, DiMo graphical presentation was used as well. From the graphical presentation the data was transferred into MS Project. The aim of these experiments was to find out how well these tools would suite the project duration evaluation and what their contribution would be in the CCM project modelling.

4.4 Analysing the case with two different tools

4.4.1 Partitioning

The first analysis was done with the MIT Excel tool and its partitioning macro. The target was to organize the elements in the matrix in such a sequence where the interdependencies fall to the lower section of the diagonal which means in practice that a depending element is placed beneath that element that it depends on. This is not always possible because sometimes there are iteration loops between depending elements like in adjustment of the production cells fin body shop.

After the partitioning the dependencies were analysed. In the first analysis the dependencies per element were calculated to find out which were the elements with most dependencies. Thereafter the dependency type was analysed and categorized in two groups, if an external or an internal actor generated the output.

4.4.2. Simulation

The MIT Excel included also a simulation macro. The macro promised to calculate the duration of the whole CCM project by simulating different occurrences (Browning et al. 2002, Yassine 2004). The basic idea was to characterize the process as being composed of activities that depend on each other for information and where changes in that information caused rework. The activities got different duration times by random drawing within the given values.

The duration estimates with minimum and maximum values were first given to each one of the DSM elements participating in the simulation. Thereafter probability and impact numbers between 0 and 1 are given to each dependency in the matrix. The probability number described the probability of a change in the input and the impact number described the impact of the possible change to the dependent element. The binary DSM had two additional sheets copied, one for the probabilities and one for the impacts. The number estimates replaced the dependency marks on those copied sheets.

The macro was run thousand times in this case and it raffled durations for the project elements within the given values in each run. Because of the large number for needed manual updates this macro was only tested in the body shop sub-project to get the rough understanding of the effects. The target in running the macro was to find out the project duration in alternating situations where one task can take e.g. 10, 15, or 20 days. Each task duration was evaluated based on the body shop time schedule and three values had to be given to them to be able to run the macro. This principle is similar to the PERT (Program Evaluation and Review Technique) methodology where expected duration for each project task is calculated based on the most optimistic duration time, pessimistic duration time, and normal duration time.

4.4.3 Disposition modeling

DiMo software was another tool to analyse the project duration. With DiMo this could be done with more precise input data than with the MIT simulation and therefore more precise project duration estimates were expected. That was because DiMo had the feature where the elements and their dependencies could be transferred in MS Project through an interface.

In DiMo the interdependencies were first updated manually with the graphical tool. The result can be seen in Figure 51. The updating was done so that the different sub-project elements were clustered together as much as possible. In the Figure 51 it can be seen that there are clusters of the manufacturing sub-projects body, paint, and assembly shop in the lower part of the picture and OTC & SCM sub-projects in the upper right part of the picture. The five elements in the upper middle of the picture and inside the circle are CMA, Client's business processes, Product specifications, 3D models, and EBOM. So product data is included in this group. They are the central elements which output is needed in many sub-projects. Although the dependency details are not easy to follow in the graphical presentation it still can show the big picture and sub-project clusters that are formed around the product data in the upper middle of the presentation.

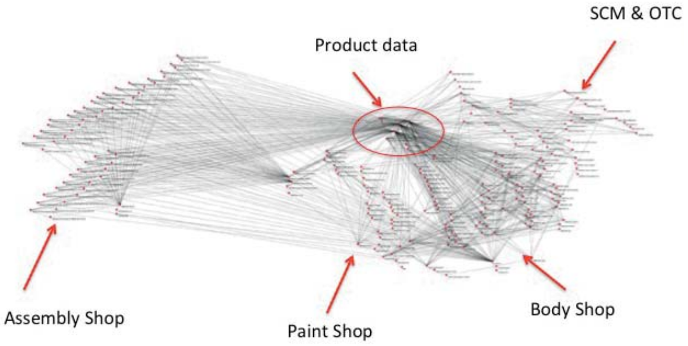


Figure 51. Graphical presentations of the interdependencies in a CCM project with DiMo

Thereafter the DiMo file was exported to MS Project, which included the elements and their predecessors. The iteration loops that are possible to define in DSM and were used for example in body shop production cell test runs could unfortunately not be transferred to MS Project because the software could not handle them. So these dependencies had to be left out and their effect to the project duration is not with in the calculations. A snapshot of the MS Project presentation is shown in Figure 52. The first five task lines are the five central elements in DiMo inside the circle. The column most right in Figure 52 shows the successors of the task. For example the elements 4, 14, 24, 27 and so on are dependent on eBOM and element 4 can be started 10 days before eBOM element is finished. The preceding element for eBOM is 2 (Product spec's) and their mutual overlapping time is 10 days.

Task Name	Duration	Start	Finish	Predecessors	Successors
▾ **PFM_MSPROJ_2014121...**	**0 da...**	**Fri 28/11...**	**Fri 28/11/...**		
.CMA	3 days	Fri 31/7/15...	Tue 4/8/15...		19,23,24FS,83,112,113,114,116,117,118,119,122,12...
.Product spec's	20 days	Fri 31/7/15...	Thu 27/8/15...		3FS-10 days,4FS-10 days,24FS,27FS,28FS,29FS,30FS...
.eBOM	20 days	Fri 14/8/15...	Thu 10/9/15...	2FS-10 days	4FS-10 days,14FS,24FS,27FS,28FS,29FS,30FS,31FS,3...
.3D models and drawings	30 days	Fri 28/8/15...	Thu 8/10/15...	2FS-10 days,3FS-10...	24FS,27FS,28FS,29FS,30FS,31FS,33FS,34FS,35FS,36...
.Client's business proces...	50 days	Fri 31/7/15...	Thu 8/10/15...		6FS-25 days,8FS-10 days,12FS-25 days,19FS,20FS,1...
.Sales order process, de...	40 days	Fri 4/9/15 8...	Fri 30/10/15...	5FS-25 days	123FS,136,7FS-20 days
.Sales order process, de...	30 days	Mon 5/10/1...	Fri 13/11/15...	6FS-20 days	8FS-10 days,213

Figure 52. A capture of the MS Project view based on DiMo graphical presentation in Figure 51.

The MS Project file was furthermore updated with lead times. In every element's task information an overlapping lead time evaluation was defined in order to get some estimate for the duration time of the whole project. The parameters used in the tasks were, "Start as soon as possible" and "Not effort driven". In the automatic project duration calculation the program started each task as soon as possible when taken into account the dependencies of the task. The second parameter meant that the duration was expressed only in work calendar days and with no resource allocation for the tasks.

The project calendar was set as the standard one which had five working days per week with eight hours working time per day. All other element tasks were marked with automatic scheduling on with one exception. The last element in the list was the final deliverable milestone that would end the project, “Start of Production (SOP)”. That element ending date was manually defined presuming that the entire project duration shall not take more than one calendar year.

4.5 Results from the tool analysis

4.5.1 Results with respect to the diagonal

The majority of over the thousand interdependences were placed below the diagonal after the partitioning. If the interdependences were analysed according to Gonzales-Rivas et al. (2011) categorizing (Figure 29) the outcome would show that almost 80 % of the interdependences fall in the area ”BAD” and 20 % to the area “GOOD”, and only 2 % are in the area “UGLY”. The “UGLY” elements are the deliverables from body shop sub-project and its trial run cycles. The distribution in these three categories is shown in Figure 53. The conventional viewpoint to the interdependencies locations is that only those marks that are located above the diagonal are bad. When the marks are under the diagonal the dependent tasks follow each other in descending sequence and this should allow the task to follow each other in the dependency order. The reason why Gonzales-Rivas et al. (2011) still categorize them to “BAD” is that they think that the data may be out of date if it was originated long time ago. That is actually the fact with information and data because that tends to change during time more than physical objects do. But Gonzales-Rivas et al. (2011) have not taken into account the fact that there may be a process to control the changes in the data. E.g. EBOM is created for the product in the early development phase and it will change several times afterwards but the OEMs have a controlled procedure to manage those changes. In the DSM that procedure is called LCM&CM (Lifecycle Change Management and Change Management) process. When this process that controls changes in the original data is defined then the markings below the diagonal should not anymore be “BAD”. So the infel-methodology does not fit to the DSM analysis in this study but it can still give some insights into the partitioning of DSM.

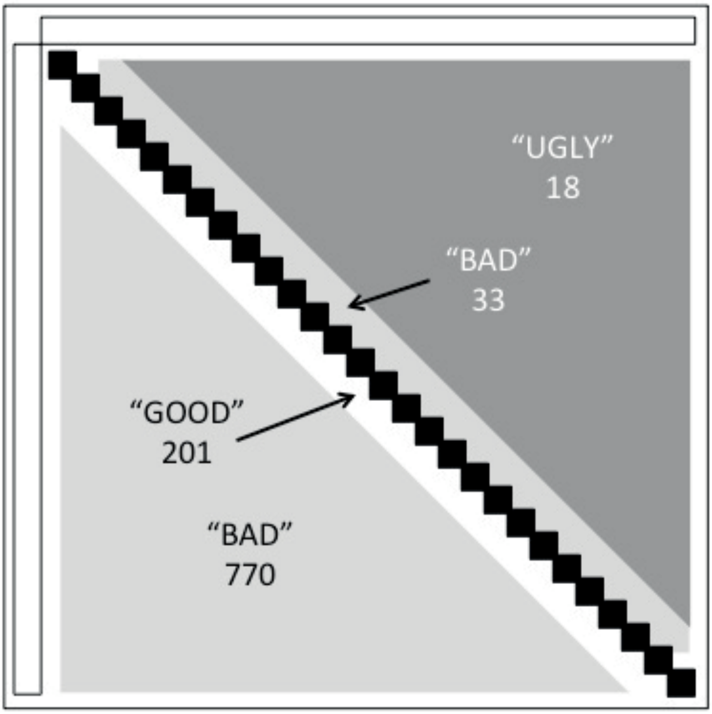


Figure 53. Distribution of element interdependences in a CCM project.

Partitioning of the DSM is one way to handle the sequencing of different tasks in projects. But when having time pressure it is not possible to do the tasks in sequence and waiting for the predecessor task to get finished before starting the successor task. It is necessary to overlap the elements as much as possible. Also Browning et al. (2002) have noticed that activities in engineering projects which were once distinct and sequential are now got mixed or overlapped, resulting in more interactions and a greater need for coordination.

4.5.2 Results with respect to the dependency type

One viewpoint to the interdependencies is to analyse the output generation source of them. Where does the output come from, is the actor external or internal? Koskela (1999) has categorized the preconditions for a task in construction projects (Figure 54). The outputs that affect a construction task are according to Koskela (1999) construction design, components and materials, workers, equipment, space, connecting works, and external conditions. When analysing a CCM project in relation to that categorizing the result is actually having the same groups as construction projects.

Ballard et al. (1998) have studied the reasons for being late in construction projects. They both found out that most of the reasons were internal. In CCM projects although being partly a construction project the influence of external causes is bigger. Internal elements can be managed inside the CCM whereas the CCM does not have the same power to influence external stakeholders and their outputs. These outputs may cause delay in the project time schedule depending on their importance for the project.

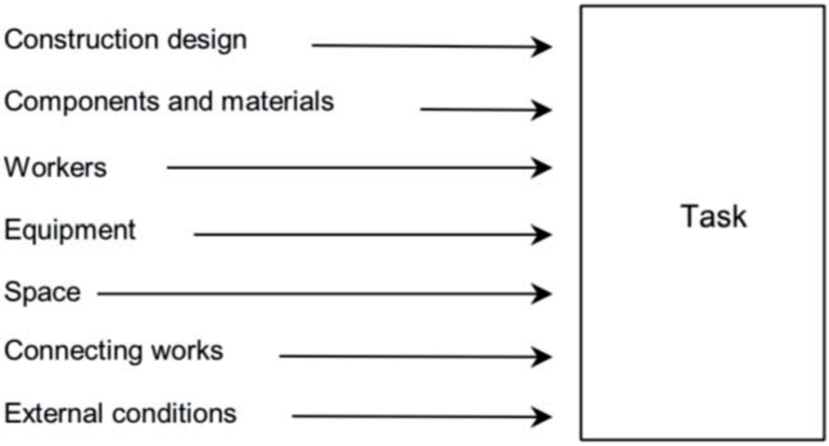


Figure 54. Preconditions for a construction task.

One large cluster of external elements is e.g. product data like specifications, EBOM, and 3D models. Their portion of all the dependencies is 30 % (Figure 55). This data is the essential basis to be able to design and construct the manufacturing facilities and so it is a must in all three manufacturing sub-projects as well as in OTC & SCM sub-project. It is important to get it in the early project phase as well as to define the procedures for managing their changes. This has been a challenge in every project. Even if the product is already in production somewhere else and the data is available in the customer's database there have always been issues how to publish it at the CCM and how to integrate the IT systems at the OEM and CCM to manage changes in the data.

The number of internal and external elements in the subprojects is shown in Figure 55. Most of the interdependencies are in body shop and almost two thirds of them are external. The main reason is because in body shop the manufacturing line and production cells have to be designed for each car model particularly. Engineering design of the line and its fixtures cannot be done without geometry data. In assembly shop the amount of dependencies is also large but there the proportion of external dependencies is smaller. In the assembly and paint shop the existing production line is in most cases only modified. The product data is needed there as well but not in the design of each workstation like in body shop.

Thereafter the dependencies per each element were counted and divided in two categories. Elements where the amount of dependencies was equal or more than five were put in the other category and the rest of the elements in the other. Body shop and assembly shop had the largest amount of elements in the first category. Also the amount of element deliverables was largest in body and assembly shop. That affected to large amount of dependencies as well.

Figure 55 shows the number of internal and external dependencies as well as total amount of dependencies in each sub-project. The red bar shows the number of elements in each sub-project that has over five dependencies. The lowest blue bar shows the total amount of elements in each sub-project.

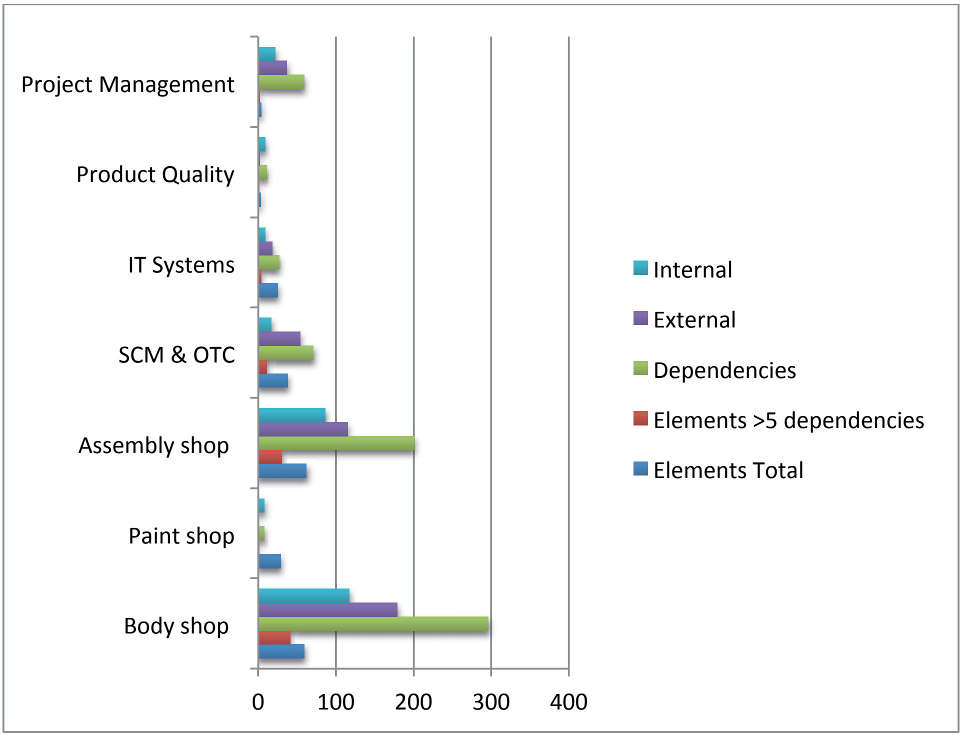


Figure 55. The amount of internal and external dependences in the subprojects of a CCM project

4.5.3 Results with respect to project duration

Two tools were used targeting to evaluate the project duration by giving initial assumption data for that. The first evaluation was done with the MIT Excel simulation tool and the second one with DiMo and MS Project.

4.5.3.1 Duration results with simulation

The simulation was done with the MIT excel macro. The simulation macro was originally developed because existing DSM models did not account for stochastic activity durations and they were also limited in accounting for concurrency in large activity sets (Browning et al. 2002). In this case study simulation results forecast that the body shop subproject would in every case last over five years. The five years duration for the body shop project is far more than what can be allowed in CCM projects. Furthermore, in reality the recent CCM projects have been completed in about one year's time period. The histogram in Figure 56 shows the results. The values in the x-axis are days for the project duration that is raffled from the DSM element durations. The values on the y-axis show the distribution of how many of the projects would belong to that duration group. This histogram is formed with thousand runs.

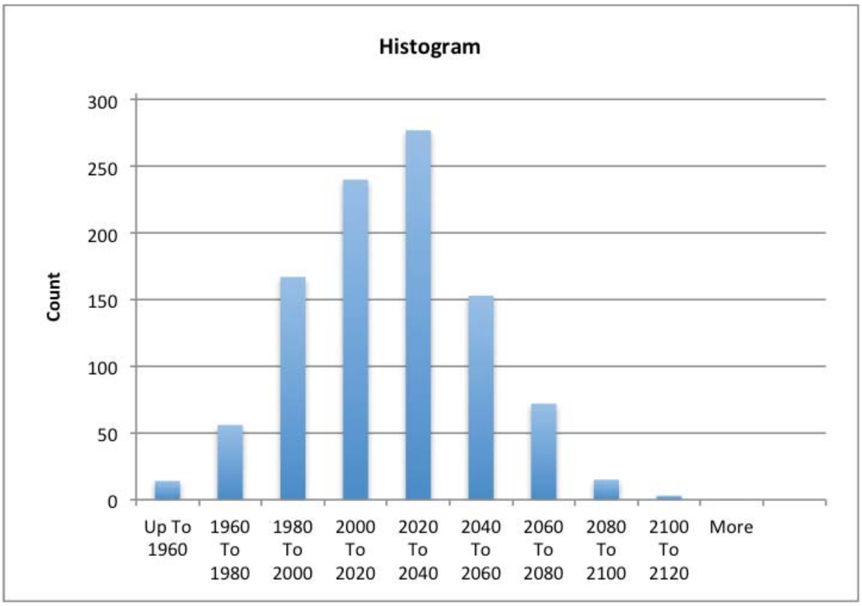


Figure 56. Histogram of raffled durations in the body shop subproject

The simulation macro syntax contained restrictions that did not fit with reality. There were three work policy rules that were built in to the macro calculation. 1) An activity may not begin until it has received all of its inputs from foregoing activities. This way of working is not possible in a CCM project because of the tight time schedule. The activities have to be overlapped as much as possible. 2) An activity can make assumptions about its inputs from "downstream" activities and they can work concurrently if the downstream activity does not depend on the upstream one for input. This does not either fit with reality. Assumptions have to be made in many activity dependencies and it cannot be restricted in this way. 3) Only neighbouring activities may work concurrently. But in reality also other activities have to work concurrently. These inbuilt restrictions were the main cause for the long project duration result and that is why this simulation tool is not so useful in the duration estimations.

4.5.3.2 Duration results with DiMo – MS Project combination

Like previously explained the MS Project schedule was manually updated with the task durations from project A's planning. After estimating the lead times for the predecessors the project duration calculation was set on automatic mode and that resulted in project duration for over two years and that exceeded the target time as well. Thereafter the ending date was set manually to the interval of one year from the project start. This made it possible to catch the critical elements, which did not match with the targeted project ending date.

The overall outcome is shown in Table 12 where the amount of critical elements in every sub-project can be seen. The most critical sub-projects when comparing the proportion of critical elements to the number of all elements in that sub-project were body shop and IT. In body shop project the number of critical elements was seventeen and in IT it was nine.

Table 12. The number of elements in each sub project and the share of the critical ones among them.

Sub project	**Elements critical**	**Elements total**	**Critical in percentages**
Body Shop	17	59	29
Paint Shop	6	29	21
Assembly Shop	4	62	6
Project Management	5	9	56
Quality	3	5	60
ICT	9	21	43
OTC&SCM	4	42	10

The critical elements in body shop were the trial runs of six production cells, Front End, Floor, Rear End, Side Panels (LH and RH), Framing Line, and Closures (Hood, Tailgate, Doors). Furthermore the installation of Rear End cell was critical as well as process verification in all the cells. The last two critical elements in body shop were worker training and process approval. The last two are a natural consequence because the workers cannot be trained before the cells functionality is adjusted and the process cannot be approved before the cells produce stable quality that conforms to the requirements. The criticality has been experienced in the cases during the trial runs where the production cells are adjusted in order to get the geometry and joints of the body to meet the quality requirements.

The IT system elements were the second largest group of critical elements. Systems that would not have been ready at project end day were MES, ERP, and Supplier Extranet Systems. Furthermore all the EDI connections would have not been tested yet and from the logistics systems the Inbound/outbound customs system, Internal logistics and Supplier Quality IT showed to be critical as well.

In paint shop critical elements were base coat testing process, 2K clear coat process modification's implementation, and spor repair line implementation. Furthermore the worker training, the whole process test run, and the paint shop process approval were critical elements as well.

In OTC sub-project four elements that consisted of purchase invoicing were all critical.

In assembly shop the most critical elements were line balancing, worker training, manufacturing line test run, and process approval.

Product quality off-line measurement systems, entire process approval, and supplier quality process definition were the critical elements in quality sub-project.

The last deliverables in a CCM project are those that strive for production process approval. Process capability is evaluated by measuring the quality during the manufacturing process as well as finished cars. The main quality areas are product and process quality. The targeted product quality can be reached in many ways but as profitability is important in serial production business, the operational quality has to produce the product quality in a lean way. The measure for that in the production is FTOK percentage, what is the proportion of manufactured cars with zero failures when they are finished from the corresponding production line. When the amount of cars per day is small, it is possible to produce quality cars by additional manual working but that causes a poor FTOK key ratio. By a high volume production manual rework is not anymore possible and the automatic process capability has to be trimmed to meet the targets. The final production process approval can be reached only when the product and process quality are in place.

4.6 Contribution to the research questions

Selection of the tools for modelling and analysing the CCM projects has been a laborious process for the author in this study. That is why there is so much weight behind the explanation of the selection and usage of the tools. The selected tools were anyway helpful in looking for the answers to the research questions.

The modelling started with presentation of the contract manufacturing transformation system with a big picture and conceptual model. They contribute to the answering of RQ1 what are the essential sub-projects in a CCM project.

Modelling with DSM, DiMo, and MS Project support the answering to the RQ2 and RQ3. These questions want to find out the most important interdependencies and obstacles for project flow. The results show the most important interdependencies and deliverables. If these deliverables are not available in time delay may be caused to dependent deliverables and this can be critical for the project finishing.

Furthermore, the attempts to find out the project duration showed how difficult it is in a complex project with many interdependencies. The experiments with the Excel macro showed that the tool was far too approximate for analysing duration in this kind of projects. With MS Project the results showed the interdependencies that formed the critical path and this was helpful in the analysis. These results support in answering RQ3 and RQ4 that looks for the answer of how to support the project flow.

The evaluation of the project with DiMo, DSM, and MS Project strengthened the author's opinion that in managing a complex project the interdependencies and their control has an essential role in project management. Therefore project management can definitely profit from the support that a flow model can give.

5 Findings of the study

The four research questions in this study were: 1) What are the essential sub-project areas in a CCM project? 2) What are the most important interdependencies between the different sub-project areas? 3) What are the obstacles in a CCM project execution that prevent it from flowing? And 4) How to support the project flow?

The research questions are answered in next Sections.

5.1 Essential sub-project areas in a contract car manufacturing project

The sub-project areas in a CCM project can be divided into two categories although the borders are not exact. One project category could be called “hardware” sub-projects where their design approach is structural. To the other category belong the “software” sub-projects where the design approach is functional.

The Body shop sub-project is similar to a construction project. It starts with the creation of the body shop concept and the design of the layout plan. The calculations for the required investments are made and the purchasing process for the robots and other equipment is started. Parallel to these actions the sub-project schedule is formulated and preparations for the construction are started. After the facilities have been built up and the production cells installed, the automation and robots need to be programmed. This is where the software part and functional design phase starts in which the robots and automation are programmed to produce applicable quality bodies. One very laborious process in this phase is the body geometry. The body in white is a system and when one production cell is adjusted, the influence to other cell adjustments often leads to an iteration loop between a group of cells and their adaptation to the change.

In the Paint and Assembly shop sub-projects, the existing manufacturing lines in the CCM projects were modified for the new car model. That is what they nearly always are because unlike in the Body shop their manufacturing process begins with the car body and the fixtures and conveyors can normally be modified for gripping and transferring the bodies with minor changes. To build up a totally new paint shop has not been an issue. The investments in this case would be very high. Totally new assembly lines have been used in situations where the production volume and the car models have been completely different as with low volume special cars for instance.

The OTC in the case company’s projects consists of business processes like car orders, their production planning, steering, and control. Delivery planning and execution of the finished cars as well as their invoicing are part of this sub-project, too. The ICT applications and customization of the existing software have been organized into the OTC project, although that could have been a separate sub-project as well because every sub-project needs their own implementation of ICT.

In the SCM sub-project the main part of work is connected with the supplier cooperation. It starts with collecting information of all the part suppliers. Agreements have to be updated with the changes caused by a new manufacturing plant. At least terms of part deliveries need updating. The prices possibly need upgrading, too. This depends on the agreement between the OEM and the supplier. And naturally in the case where the CCM is the first manufacturing site the supplier agreements have to be negotiated from the very beginning. Another laborious SCM task is the package design. MBOM defines the level with which the parts and sub-assemblies are arriving to the CCM. The packages have to be designed in a way where space is not wasted and the package is filled with as much parts as possible. 3D geometry data is requisite in designing the packages. Also requirements for safe transporting of the parts have to be known. For instance, airbag modules have to be secured against shocks, painted parts (especially large ones like fascia) have to be protected against grazing, and sheet metals against corroding. The transport carriers to Finland are different than when operating in Central Europe. There a train often delivers the parts and also the climate is milder. The transport way is longer as well and the packages have to be economically designed to save space in the carrier. This sub-project has to agree on the way and schedule of deliveries with each supplier, and because of the large amount of suppliers this process may take a while. Parallel with the suppliers and the identification of their geographic location, negotiations with the transport companies for the inbound and outbound deliveries can be started.

Quality is a sub-project that controls three quality areas in the project: product, process, and project quality. Product here means the finished car that has to fulfil specified quality requirements. That quality is measured when the car is finished. The failures are categorized according to the source. Process quality is measured during the manufacturing process in each department and categorized according to the source as well. The goal in the process is to reach a defined FTOK level within a certain time interval. To be able to do the measurements the required equipment has to be provided by the Quality sub-project. Project quality means that the CCM project has to follow the quality instructions of the company that are specified in the company's certified standards and rules.

The main project management that is coordinating the entirety controls all the sub-projects. The project finance with investment plans, actuals, and estimates has to be controlled as well. The project status has to be reported to many different groups inside and outside. The company steering group and directors need to know the financial development as well as the project status. Also the OEM and the investors want to know how the project is proceeding in relation to the timetable.

All the CCM projects in this study had the same sub-projects on the conceptual level. The project organization may vary and the sub-projects may have other names but every CCM project has to produce the same deliverables that are presented as elements in the DSM and DiMo. Features of the projects were presented in Table 5, Table 6, and Table 7. The differences may cause dissimilarities in the scheduling but the deliverable element names are nonetheless the same.

The conclusion is that the essential sub-projects are Body shop, Paint shop, Assembly shop, OTC, SCM, and ICT.

5.2 Most important interdependencies between the different sub-project areas

The interdependencies were analysed with Design Structure Matrix where the element rows were adapted from project A's schedule. The elements presented project deliverables on project management and coordination level. The number of elements on that level was 227 and the number of interdependencies was 1022. This analysis was performed in Sections 4.4 .

The most important interdependencies have three features. One of them is that they influence many other deliverables. The second one is that external stakeholders are responsible for providing them. And the third one is mostly in the case company's internal sphere of influence and includes the deliverables that take part in the iteration loops of production cell adjusting.

The interdependencies that influence many deliverables are important since they can cause delays in many other deliverables if not proceeding according to schedule. Product specifications, EBOM, and 3D models as well as CMA and Client business process definitions belong to this category. The customer is the owner the product data and they have to make it available for the CCM. Although it is common interest and obvious that these data are an absolute must for the CCM's process design, the practical implementation has always taken time because of several reasons. One of the obstacles has been the incompatible PDM system where the 3D files cannot be read properly. That could be corrected with an advanced data interface between the systems but unfortunately such has not been available. Furthermore there are always secrecy issues because a new car model is always a top secret before launch and these barriers need to be worked out before the CCM can get the data.

This brings us to the second group of interdependencies coming from external stakeholder outputs. They are important and have to be paid special attention to because it is not obvious that you get what you want from an external party within the required timeframe. You do not have the power to force them and sometimes you have to put a lot of effort in to get the data and information you need. Product data are the basis for the whole construction project. The number of interdependencies connected to those three deliverables was 344, which was over 30 % of the total. They affected mostly the sub-projects in the Body and Assembly shops as well as SCM and OTC.

Along with the customer the part suppliers are an important external stakeholder group. The car parts availability has to work perfectly when the manufacturing starts. But there are many phases to be processed before this is achieved. The number of suppliers can run up to six hundred depending on the car design and supply strategy. The purchase agreements have either to be created from scratch or updated if the car model is already in production somewhere else. The agreements have to be processed with every supplier individually and that will need resources and take time. If the car model comes from a start-up company, the suppliers have to be found first and the agreement negotiations finished before the part development with many approval reviews can begin. This will take time again. Even if the car model is already in production in other plants the supplier wants to update delivery agreements for a new plant and usually that has to be supported by the OEM who originally ordered the parts. Because of the amount of suppliers this takes time as well although not as much as when creating a new agreement. After the agreements are done the suppliers have to learn what kind of a delivery the new CCM plant expects and what kind of packages are going to be designed as well as to adapt itself to the delivery process. The packages have to receive mutual approval and the EDI connections have to be established and tested with the supplier.

The first study was adapted from Gonzales-Rivas et al. (2011) dividing the interdependencies into three groups, “good, bad, and ugly”. The 20/80 rules came true in this analysis where only 20 per cent of the interdependencies were good. This interpretation can be questioned because Gonzales-Rivas et al. (2011) also link the interdependencies that are lower to the diagonal into the bad ones if they are far away from it. The traditional DSM researchers would categorize everything lower to the diagonal into good ones (Steward 1981, Browning et al. 2002). Gonzales-Rivas et al. (2011) handle these interdependencies differently because their DSM elements are all information. They claim that the information can change in the course of a long time. The present study differs from that of Gonzales-Rivas et al. (2011) in that not all the elements are information and e.g. for EBOM, which is one of the bad elements in this category, there is a process deliverable (LCM&CM) that will control the changes in that data so these two deliverables are connected to each other.

According to Gonzales-Rivas et al. (2011) the ugly interdependencies are those that were located above the diagonal and not in the immediate nearness. In this study those kinds of interdependencies were all connected to Body shop trial runs of the production cells. They all depend from each other and when one cell gets adjusted that may affect the output of one or more of the cells. As this is a procedure that needs special attention the absorption in the problems may take quite a while. The Paint and Assembly shop processes are not as laborious to adjust because there is not such kind of loops as in the Body shop. But their processes cannot receive final approval until the body shop process has been approved, as the entire production process can only be approved as a continuous chain

The number of Paint shop interdependencies was not so large but the reason for that was in the base data, where the deliverables from e.g. external paint suppliers were not taken into account. The paint suppliers have a remarkable role in reaching the goals of paint process capability and process adjustment in order to find the correct paint tone. As they also are an external party, this dependency should also be paid attention to and their deliverables taken into account in the Paint shop planning procedure.

As a conclusion to this research question the most important interdependencies are the deliverables that need output from external stakeholders as well as the production cell trial runs that form an iterative process.

5.3 Obstacles of flowing in a contract car manufacturing project execution

In the third research question the author wants to find out the obstacles that stop the project flow. That means that the project execution proceeds under control and if obstacles show up they can be ejected rather proactively than afterwards. In such a mode the project proceeding is flowing. In the analysis these obstacles were approached with a hypothesis that when there is a flow in the project execution, the total duration time of the project does not exceed the planned schedule. When the project flows smoothly there is no waste work and the project delivers the planned results so that the ending date is fulfilled. In large and complex system projects, the evaluation of the duration is not easy.

In this study several attempts were performed to estimate the project duration. They were introduced in Section 4.5.3 Results with respect to project duration. The project target schedule was one year. The first duration estimates were made by random drawing durations for the body shop elements from a given data interval where the mean value was taken from the body shop project schedule. This was done via simulation macro in Excel. Overlapping was not allowed and that could not give results that were compatible with the reality, because today overlapping is a must in project execution when trying to stick to a schedule. The simulation gave five years as the duration time for the Body shop sub-project with minor overlapping and that proved the importance of overlapping.

In the second duration experiment the object was an entire CCM project (A) and the element durations were taken from the planned project schedule. MS Project allowed element overlapping as well as evaluating lead times that defined the amount of overlapping capability. But also this resulted in a duration time of over two years. The element durations were estimations from project planning right after the project start and not those actualized, which unfortunately was not available. The result could have been different with real duration times. Now the idea could be tested only in principle. Unfortunately the Body shop iteration loops could not be evaluated in the correct way because MS Project did not have a feature for handling feedback loops. To be more precise in the evaluation they should also be taken into account when using the model.

In most projects the surprises that make the schedule stumble have been the deliverables that come from external stakeholders. Furthermore these deliverables were at the same time the ones that had the most interdependencies like product specifications, EBOM, and 3D models.

5.4 Supporting of the project flow

Unfortunately the flow mode is often a dream in reality. In complex projects there are always spanners in the works and it would be good to be prepared for them. This can be done in the beginning of the project where the FMEA is created and the project risks are evaluated. The ones of the discovered risks that have large RPN key figures should be dismantled into details to find out what are the activities behind the specific deliverable. First when the activities are known the scheduling of that deliverable can be made realistic. Then it is possible to make realistic schedules for the dependent deliverables as well. If the deliverables require activities at external stakeholders these should be worked out together with all involved partners. The working can be done e.g. with RASI chart methodology. When the system model is transparent and all project partners can understand the interdependencies then the project execution and management can be made easier.

The project scheduling resolution level in the DiMo – MS Project experiment was that of project management and coordination. Using a more detailed resolution level for the elements and by changing the elements from deliverables to activities that are needed to produce the deliverables, the result will look different and help in planning more precisely. To be able to implement flow model scheduling in a project, the results would be more truthful if the elements were dismantled into the smallest tasks that produce the deliverable and their interdependencies defined. In this way one could better recognize the effects on other deliverables when something is not flowing. It has been noticed that when the deliverables are on a rough level then they are general for most CCM projects. But when the deliverable level is refined then differences can occur between separate projects. When going deeper in the deliverable background new risks may be found which again need to be taken care of.

5.5 Comparison of the contract car manufacturing projects

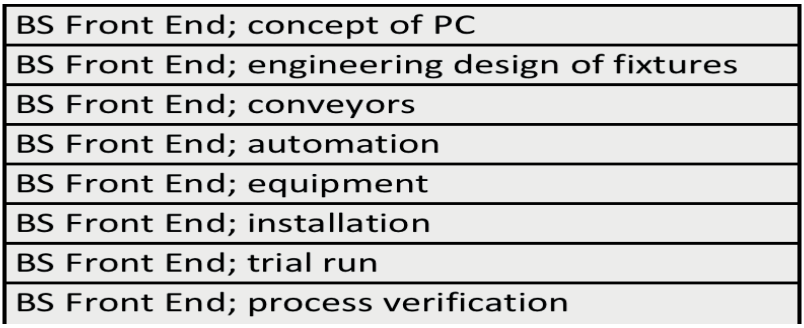
To be able to proof the hypothesis of this study let us examine the models that are presented in Figure 46, Figure 47, and Figure 49 starting in Section 4.1 Contract car manufacturing project elements.

The first one of them (Figure 46) is on a rough level. Before the CCM is able to produce a new car model at its plant the manufacturing facilities like Body shop, Paint shop, Assembly shop, and Quality Control functions have to be built up. That has always been the case until now and it is difficult to figure out a CCM project where they would not be needed. Furthermore the processes that support the production procedures by delivering the data (car orders and their status, part requirements for them, part delivery status and warehousing, car deliveries and invoicing) are all relevant functions for any car model in production. Running the car manufacturing business today is not possible without ICT systems. There are many possible names for those systems but the established system names are PDM, ERP, and MES. These are all needed in the CCM projects. The EDI communication is part of ERP system in this context. The case company has developed an additional system that is called Supplier Extranet and it provides a platform to manage the large amount of activities with part suppliers (part delivery plans and delivery notes as well as package location information). Also supplier quality statistics and part and delivery complaints are handled via that system tool. All these systems, processes, and manufacturing facilities have to be prepared for the new car model production.

The next resolution level to the transformation system is presented in Figure 47 and adapted from Gharajedaghi (2011) who calls it the mess. The deliverables in the previous Figure 46 have been broken up into “sub-deliverables”. Each of the manufacturing departments is not yet broken up separately as in the DSM model. There is only one production process that describes all three departments because the element names of each one can be adapted to all of them. Each production process needs in its design as input data the CMA with planned production volumes, product specifications, product 3D models, and EBOM. With that information they can start the layout and process design. Based on that they continue on engineering design on the workstations with equipment and tooling. After those activities the process build up may start and when the installations are ready it is time for process testing. The testing consists of several iteration loops and when the results are satisfying the OEM can finally approve the process. In OTC and SCM processes the needed input information is the client’s business process definitions that are connected to the CCM’s processes. Based on that information also data models for sales forecast, car orders, car deliveries, and invoicing are needed. Furthermore the Engineering Change Order procedure and data model definitions have to be cleared out because they influence on the material requirements calculations. In the SCM area the logistics process concept has to be defined and the contracts with the transport companies. Because the CCM plant location is in the northern part of Europe and most of the suppliers are often in central Europe the logistics role is important and has large influence on the transport costs. Furthermore to get all the supplier contracts updated as well as parts defined and packages designed the OEM ‘s support is needed because the OEM has done the contracts with the suppliers. All the system deliverables in the ICT area need support from the OEM because they have interfaces with each other’s systems.

Let us go further in the examination and study the projects considering the conceptual model adapted from Checkland (2009) (Figure 49). This model present the activities that are needed to build up the transformation system. The model is still on a relatively rough resolution level following Checkland’s (2009) instructions to keep it simple so that the big picture can be seen. The model presents only internal activities by name; those from external stakeholders are presented roughly with thick arrows outside the boarders. This is because the activities that those inputs need are performed at the external client and they have to be described by the OEM. Furthermore Table 5, Table 6, and Table 7 describe the attributes of them in the projects. One of the essential basic inputs for the development of manufacturing processes is MBOM and in every case it has to be defined in the very beginning. For that definition at the CCM the project needs 3D models and EBOM that is the starting point for MBOM creation and their origin is at the OEM. The author has experienced that all the definitions described in the conceptual model (Figure 49) have been needed in every CCM project. Thereafter the planning of design and development for various ICT systems, manufacturing facilities, and transport systems can start. After the planning has been accomplished the system implementation can be started. Hence all the CCM projects conform to the concept model on this level the hypothesis is true.

The more detailed resolution level of the model is presented in the DSM. Its elements have been derived from the mess model and conceptual model as well as from project schedule. When examining the elements one by one and comparing them to the other CCM projects no contradictions can be found. In reality, each project team has created their own schedules with elements but that would not have been necessary, because this element list complies with all of them. Differences may occur in the manufacturing sub-projects, e.g. in the Body shop while the body in white may be based on a different structure like the monocoque or space frame. In that case the production cells are only named accordingly but the next level still has the same titles for their deliverables, example in Figure 57. The production cells have to be designed according to the body structure and each cell has same deliverable names for their output (concept plan, engineering design of the cell fixtures, design of the conveyor system in the cell, automation procedures, and equipment). When that has been done and the deliverables are completed, the cell installation can begin. When the installations are done a trial run process including all production cells can start. The other two manufacturing departments, Paint and Assembly shops, can receive their final process approval after Body shop because they form the entire process together.



BS Front End; concept of PC
BS Front End; engineering design of fixtures
BS Front End; conveyors
BS Front End; automation
BS Front End; equipment
BS Front End; installation
BS Front End; trial run
BS Front End; process verification

Figure 57. Example of Front End production cell deliverables

Also the Assembly and Paint shops may have to do minor adjustments to their element list but in principle the basic list can be applied. If variations exist, the production cell names should simply be corrected and modified accordingly.

These models show that on the presented resolution levels and with the deliverables it is possible to use a universal model in CCM projects. When going into more detail and when the element deliverables are broken into activities the model may not anymore be as general and has to be modified according to the specific project.

To be able to manage the project with a flow model, the sub-projects should document a very detailed schedule at least in those areas where risks and uncertainties are expected in order to be aware of the interdependencies and to avoid delays. Preparing for these deliverables even the tiniest activity that is needed in order to finish that deliverable can be helpful in a situation where the project execution stops flowing.

5.6 The flow model and hypothesis

The hypothesis of this study claim that it is possible to create a general flow model for a CCM project and that it can be applied to different projects in the same context.

This flow model can visually be presented with DiMo (Figure 58). Because of the difficult readability of the model in this size the same information is available in a DSM, which is attached to this study in Appendix 2.

When starting to implement the model to a new CCM project the data in DiMo should be transferred to MS Project for scheduling. After scheduling the MS Project shows the critical deliverables, which thereafter have to be dismantled into actions that produce the deliverable. If the critical deliverables need actions from external partners such as the customer then the customer has get involved in this dismantling and scheduling. In this way the both actors realize better the need and their own share in creating the deliverable and a more executable plan can be developed.

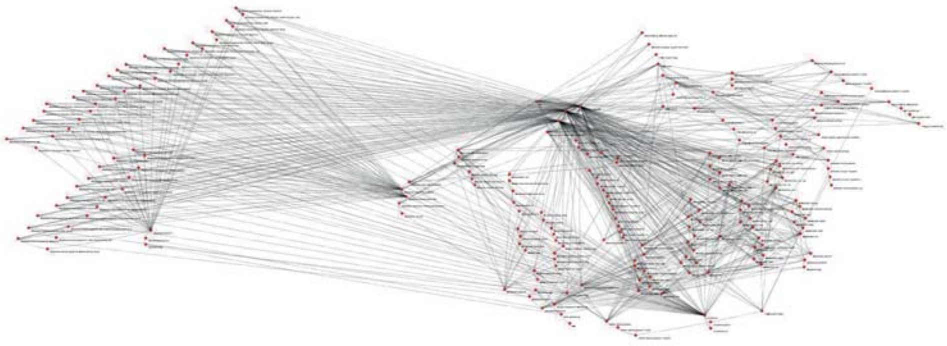


Figure 58. The flow model presentation of a CCM project.

The model creation was based on project A. The comparison of the other three projects to the model showed that the flow model fits also to them. Furthermore, based on the comparison the author claims that the model will fit as it stands to all CCM projects. Depending on the critical deliverables they can be dismantled into single tasks that produce the deliverable to get more precise model for each project.

Based on the comparison of the projects in Section 5.5 the conclusion is that the hypothesis, which claimed that it is possible to create a general flow model for a CCM project and that it can be applied to different projects in the same context, is true.

6 Conclusions and discussion

6.1 Research approach and methodology

The type of this study was a single case study with embedded units that were the four CCM projects (Yin 2009). This type of case study was chosen because the data from the projects was heterogenic. During the twenty years time period it was not anymore possible to get similar data from each project. Furthermore, the author's viewpoint to the project examination differed in each of them because her jobs had changed in between. This can also be seen as a benefit for the study by giving a broader view to CCM project as a phenomenon that Yin also recommends to have. In this way the author got diverse experiences while observing the project management from a different perspective in each project. Therefore CCM project analysis was done first thoroughly with the project A and thereafter the results were compared with the other three projects.

The reader may get tired of the extensive presentation of analysis tools and their usage in this study. The author did not want to leave this part out of the study because it was very laborious and frustrating to figure out the idea how to analyse the available data. The methods in describing the big picture of the whole project were selected of two different researchers because they had different approach to the issue. Gharadejaghi (2011) suggested to start with describing the mess where project deliverables were used. Checkland (2009) in turn recommended using verbs in describing the activities that produce the deliverables. In the flow model there is a need for both ways. Although DSM and MS Project are well known tools their usage in connection with the flow model is a new approach and supported in answering the research questions. DiMo in turn suited very well in showing the flow and connections between deliverables visually.

The research setting including both research questions and hypothesis has been under consideration. Leaving either one out was difficult because the RQs show the obstacles for a flowing project and create the basis for the model. Furthermore, the RQ findings strengthen the understanding of the flow model necessity in complex projects.

6.2 Theoretical contribution

The theory basis for this research lies on Design Science, Project Management, and Systems Thinking (Figure 5). This study has been built up on those three domains combining them from a practical industrial perspective.

Very few articles could be found that handled plant design in project management with integration to product development. Generally the researchers have been more interested in product development investigations. The same phenomenon can be found in Systems Thinking literature. When looking for studies that combine these three research domains not many publications can be found. Browning et al. (2006) come closest in combining these domains by noting that processes are today the key aspect of Systems Engineering. In their research they claim that processes are in the core of several approaches like Project Management and that engineering projects like PD projects consist of five systems (Figure 25), which create a System of Systems (SoS). These five systems are the Process System, the Product System, the Organization System, the Tool System, and the Goal System. In

Figure 25 the project draws a frame around this SoS. In the study by Browning et al. (2006) the product is considered a normal product, not a plant although it can be adapted to plant design.

Browning et al. (2006) studied also DSM modelling in their research and they noticed that although the way in which project tasks are executed may vary, the dependencies tended to be a stable part of the process. This thesis adds to their results a new finding: also deliverables are the stable part of the DSM although the activities that create them may vary. So when the flow model is presented with deliverables and their dependencies it can be applied to various CCM projects. In Fujimoto's (2013) words: Monozukuri is not only about creating an object but creating the design information for an object as well. The design information in all its forms is one of the most important deliverable in the whole CCM project and the engineers in the manufacturing site need to have this information from all product development phases. The author claims that the flow model contributes to the traditional project management methods in an essential manner. By extending the company boarders it supports in completing the deliverables that are on external partners responsibility and the flows can be made visible to every project participant.

The contribution to the three research domains is the method that emerged from the literature when the author read up on it. The flow model principle presented in this study contributes to all of the three research domains because the author claims that this kind of approaches have not been investigated in those domains. Also Koskela (2000) made demands towards reintegration of project management, design science and operations management.

6.3 Practical contribution

The practical utility of this research can be found when planning a new CCM project. The project flow model supports the project management and execution in future projects. The interdependencies that have been marked in the DSM and DiMo models are helpful especially when there is a risk for being delayed with a scheduled deliverable. The current project management tool that the case company uses do not take into account the interdependencies of different deliverables as thoroughly as the flow model does. Although it would be possible with MS Project, this feature is not utilized in it because in complex projects experience has shown that it is better not to make the usage of MS Project too complicated. The author claims that the flow model can be a helpful add-on to the project management tools in the case company.

The CCM project is a combination of construction and process development consisting of many systems. Like Hubka et al. (1988) already noted plant is one category of product when designing a technical system. And when talking about products the plant can be assimilated to a mechatronic system (Gausemeier et al. 2013). In their design both approaches have to be used, structural and functional and keeping that in mind is be helpful when planning the project. Figure 59 shows the system model of a CCM project adopted from Gausemeier. He recommends that Systems Engineering should coordinate the interacting of the different systems in project environment. On the right side of the picture there is the project time schedule with deliverables that have to be ready in time and on its right side there is the DiMo presentation with all the interdependencies among the deliverables, which affect on the time schedule. On the left side of the Figure 59 there is the factory aerial picture marking the target system of the project. The factory consists of the elements most left in the Figure 59. This presentation is describing the Systems, which form the CCM project context and what coordination of it is about.

The author claims that the case company can contribute from the model in future CCM project management. Furthermore, the flow model can be used for quotation calculations in new customer cases as well as for supporting tool when defining the terms of CMA in the commercial negotiations.

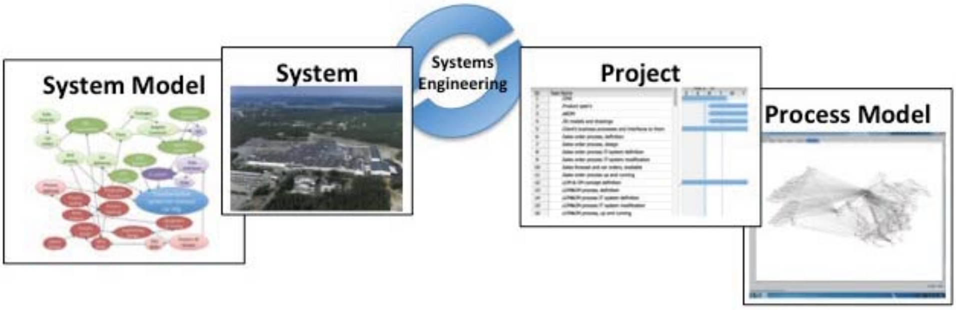


Figure 59. MBSE presentation of CCM project with its systems (adapted from Gausemeier et al. 2013)

An addition to the practical contribution can be found in other industrial environments. The author claims that the modelling principle in this study is possible to adopt in every kind of projects by using their specific deliverables and defining the interdependencies accordingly.

6.4 Answers to the research questions

Based on this study, the best answers to the research questions are as follows:

1. What are the essential sub-project areas in CCM projects?

The essential sub-project areas in CCM projects can be divided in two categories: The first one is preparing of the production facilities capability into a level where they can produce a new car model. These facilities are the three production departments, body, paint, and assembly shop. The other sub-project category includes all the processes, functions, and IT systems that will be needed in the future transformation process for vehicle production. These sub-projects are collected under the title OTC and SCM.

2. What are the most important interdependencies between the different sub-project areas?

The analysis showed that one group of the most important interdependencies is connected to the deliverables that need output from external stakeholders. Product specifications, EBOM, and 3D models as well as CMA and Client business process definitions are examples of deliverables that belong to this group.

The other group of important interdependencies is connected to the internal procedure of production cell trial runs. These runs form an iterative process within several different production cells that depend from each other. This procedure is in the case company's internal sphere of influence. Because of the iteration loops completion of these deliverables may take more time than expected. Furthermore, these important interdependencies influence many other deliverables and so they can cause remarkable delays for the project proceeding.

3. What are the obstacles in a CCM project execution and what prevents it from flowing?

The answer to this research question is correlating with the answer on the previous research question. The obstacles are in some way hindering the deliverables from getting finished. If the deliverables are on external stakeholders responsibility then the reason has often been that the responsibilities are not clear to each party or that the party has not enough resources to execute the needed activities. The other obstacle group is the complex connection of production cell manufacturing results and their iteration to get the desired quality into the products. A more detailed description of these hinders was presented in section 5.3.

4. How to support the project flow?

The project flow can best be supported when all the involved partners cooperate in the time schedule planning. The most risky deliverables should be dismantled into smallest tasks and their responsibilities defined. When the scheduling plan is transparent and all the project partners can understand the interdependencies between the deliverables then the possibilities to achieve flow mode level in the project execution are better.

6.5 Reliability and validity

The present study has dealt with four embedded units of analysis each of which was a CCM project in the case company (Yin 2009). The process was modeled and the system created on the basis of one project. That model was then compared with the other three projects on conceptual level.

According to Yin (2009) an embedded design may have pitfalls such as when the case study focuses only on the subunit level and does not take into account a larger unit of analysis. This can happen if the researcher goes very deep in quantitative project-level data and the evaluation becomes a project study. Then the study falls into the type of multiple-case study with different projects (Yin 2009, Figure 4). This has not been the risk in this study because there was no such data available for this study. The comparison of the CCM projects is based on experiences that the author had during her work in different projects and having a various role in each of them.

Furthermore, according to Yin (2013) a single case study is justifiable under certain conditions. One of them is when the case represents a rare or unique circumstance. The author thinks that a CCM company with its new project agreements is rather rare and unique especially from academic point of view and not much research can be found under this topic. Another issue according to Yin is that there should not be given too much attention to the subunits and that a larger, holistic aspect to them should be maintained. The author thinks that this also happened with the CCM projects because of the long time period and other issues mentioned previously.

Considering the validity of the created flow model the author claims that it can be adapted to several projects because it has been formed from deliverables on such a level, which fits every CCM project. Dismantling the deliverables to activities will lead to a project specific model but the deliverable level will work for all projects.

The author claims that on the grounds presented in this section this study can be considered reliable and valid.

6.6 Recommendations for further research

Future research could be carried out in the case company with new CCM projects where the compatibility of the flow model can be verified in reality. It can also be developed further and fine-tuned into detailed level so that each task and activity that is needed to complete a deliverable will be presented. After that the model will actually be developed to a project specific version and it will not anymore be a general model. This is because the dismantling of the deliverables into activities will lead to case specific solution. This development could be done with the most critical deliverables at first to see the effects. Furthermore it would be ideal if task duration history were archived in the model in future. This way the model would serve as a knowledge database for planning of future CCM projects and it can support in estimating the project schedules.

Some future research could also be done in the IT domain. The project reporting to the external stakeholders such as the OEM and investors are interested in the project proceeding. Supporting this with new software implementations that get their input data from the project schedule would save a lot of manual work. Another IT research object could be DiMo. It has already many good features but development should go further so that transferring the interdependencies data from a table to the graphical editor will result in a readable presentation and preferably in clusters. Furthermore, the scheduling software should also be evaluated once more. Whether the integration with MS Project is the best solution or would something else be better, e.g. a built-in scheduling in DiMo.

Additionally it would be interesting to have more plant design project research with integration to PD in Design Science. This study noted that the CCM project consists of structural and functional design areas. PD projects have approaches like radical and incremental design or Brownfield and Greenfield process applications (Pakkanen 2015). The author thinks that these kinds of approaches in plant design domain could offer interesting insights for new research.

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Appendix 1.

Sub-projects and their elements in the flow model

Sub-project	***Element***
AS	Assembly shop (AS) manufacturing concept
AS	AS process; assembly sequence planning
AS	AS process factory space arrangements
AS	AS process; assembly method planning and work instructions
AS	AS process; line balancing
AS	AS process sub-assembly mfg tools; Instrument panel; concept
AS	AS process sub-assembly mfg tools; Instrument panel; design and modification
AS	AS process sub-assembly mfg tools; Headliner; concept
AS	AS process sub-assembly mfg tools; Headliner; design and modification
AS	AS process sub-assembly mfg tools; Engine dress up; concept
AS	AS process sub-assembly mfg tools; Engine dress up; design and modification
AS	AS process sub-assembly mfg tools; Front end module; concept
AS	AS process sub-assembly mfg tools; Front end module; design and modification
AS	AS process sub-assembly mfg tools; Doors; concept
AS	AS process sub-assembly mfg tools; Doors; design and modification
AS	AS process line mfg tools; VIN Number equipment; concept
AS	AS process line mfg tools; VIN Number equipment; design and modification
AS	AS process line mfg tools; Instrument panel assembly equipment; concept
AS	AS process line mfg tools; Instrument panel assembly equipment; design and modification
AS	AS process line mfg tools; Sun roof installation; concept
AS	AS process line mfg tools; Sun roof installation; design and modification
AS	AS process line mfg tools; Glass robot modification; concept
AS	AS process line mfg tools; Glass robot modification; design and modification
AS	AS process line mfg tools; Skids off station; concept
AS	AS process line mfg tools; Skids off station; design and modification
AS	AS process line mfg tools; Marriage point ; concept
AS	AS process line mfg tools; Marriage point; design and modification

AS	AS process line mfg tools; Battery assembly; concept
AS	AS process line mfg tools; Battery assembly; design and modification
AS	AS process line mfg tools; Assembly equipment for labels; concept
AS	AS process line mfg tools; Assembly equipment for labels; design and modification
AS	AS process line mfg tools; Front end module; concept
AS	AS process line mfg tools; Front end module; design and modification
AS	AS process line mfg tools; Seats assembly equipment; concept
AS	AS process line mfg tools; Seats assembly equipment; design and modification
AS	AS process line mfg tools; Doors assembly equipment; concept
AS	AS process line mfg tools; Doors assembly equipment; design and modification
AS	AS process filling equipment; Brake; concept
AS	AS process filling equipment; Brake; design and modification
AS	AS process filling equipment; concept coolant filling
AS	AS process filling equipment; concept coolant filling; design and modification
AS	AS process filling equipment; Washer; concept
AS	AS process filling equipment; Washer; design and modification
AS	AS process filling equipment; Refrigerant; concept
AS	AS process filling equipment; Refrigerant; design and modification
AS	AS process filling equipment; Transmission; concept
AS	AS process filling equipment; Transmission; design and modification
AS	AS process filling equipment; Fuel (Benzin); concept
AS	AS process filling equipment; Fuel (Benzin); design and modification
AS	AS process filling equipment; Fuel (Diesel); concept
AS	AS process filling equipment; Fuel (Diesel); design and modification
AS	AS process testing equipment; Wheel alignment; concept
AS	AS process testing equipment; Wheel alignment; design and modification
AS	AS process testing equipment; Roller tester for manoeuvrability; concept
AS	AS process testing equipment; Roller tester for manoeuvrability; design and modification
AS	AS process testing equipment; Water leakage testing; concept
AS	AS process testing equipment; Water leakage testing; design and modification
AS	AS process testing equipment; Outdoor testing; concept

AS	AS process testing equipment; Outdoor testing; design and modification
AS	AS process worker training
AS	AS manufacturing line; test run
AS	AS process approval
BS	Body shop (BS) process concept planning
BS	BS process layout planning
BS	BS process factory space arrangements
BS	BS Front End; concept of PC
BS	BS Front End; engineering design of fixtures
BS	BS Front End; conveyors
BS	BS Front End; automation
BS	BS Front End; equipment
BS	BS Front End; installation
BS	BS Front End; trial run
BS	BS Floor; concept of PC
BS	BS Floor; engineering design of fixtures
BS	BS Floor; conveyors
BS	BS Floor; automation
BS	BS Floor; equipment
BS	BS Floor; installation
BS	BS Floor; trial run
BS	BS Rear End; concept of PC
BS	BS Rear End; engineering design of fixtures
BS	BS Rear End; conveyors
BS	BS Rear End; automation
BS	BS Rear End; equipment
BS	BS Rear End; installation
BS	BS Rear End; trial run
BS	BS Underbody Line; concept of PC
BS	BS Underbody Line; engineering design of fixtures
BS	BS Underbody Line; conveyors
BS	BS Underbody Line; automation
BS	BS Underbody Line; equipment
BS	BS Underbody Line; installation
BS	BS Underbody Line; trial run
BS	BS Side Panels LH&RH; concept of PC's
BS	BS Side Panels LH&RH; engineering design of fixtures

BS	BS Side Panels LH&RH; conveyors
BS	BS Side Panels LH&RH; automation
BS	BS Side Panels LH&RH; equipment
BS	BS Side Panels LH&RH; installation
BS	BS Side Panels LH&RH; trial run
BS	BS Framing Line; concept of Line
BS	BS Framing Line; engineering design of fixtures
BS	BS Framing Line; automation
BS	BS Framing Line; equipment
BS	BS Framing Line; installation
BS	BS Framing Line; trial run
BS	BS Closures; concept of PC's
BS	BS Closures; engineering design of fixtures
BS	BS Closures; automation
BS	BS Closures; equipment
BS	BS Closures; installation
BS	BS Closures; trial run
BS	BS Assembly Line; concept of Line
BS	BS Assembly Line; engineering design of fixtures
BS	BS Assembly Line; automation
BS	BS Assembly Line; equipment
BS	BS Assembly Line; installation
BS	BS Assembly Line; trial run
BS	BS process worker training
BS	BS process destructive tests
BS	BS process approval
IT	MTR MRP process IT-system, definition
IT	MTR MRP process IT-system modification
IT	MTR EDI connections, tested and running
IT	Inbound process IT system definition
IT	Inbound process IT system modification
IT	Outbound process IT system definition
IT	Outbound process IT system modification
IT	Inbound/Outbound customs IT system definition
IT	Inbound/Outbound customs IT system modification
IT	Purchase invoice IT-system, definition
IT	Purchase invoice IT-system modification

IT	SQ IT system definition
IT	SQ IT system modification
IT	IT ERP system ready to use
IT	IT PDM system ready to use
IT	IT MES system ready to use
IT	IT Supplier extranet ready to use
IT	Internal logistic process IT system definition
IT	Internal logistic process IT system modification
IT	Sales invoice IT-system definition
IT	Sales invoice IT-system modification
OTC&SCM	Product spec's
OTC&SCM	EBOM
OTC&SCM	3D models and drawings
OTC&SCM	Client's business processes and interfaces to them
OTC&SCM	Sales order process, definition
OTC&SCM	Sales order process, design
OTC&SCM	Sales order process IT-system definition
OTC&SCM	Sales order process IT-system modification
OTC&SCM	Sales forecast and car orders, available
OTC&SCM	Sales order process up and running
OTC&SCM	LCM & CM concept definition
OTC&SCM	LCM&CM process, definition
OTC&SCM	LCM&CM process IT system definition
OTC&SCM	LCM&CM process IT system modification
OTC&SCM	LCM&CM process, up and running
OTC&SCM	MBOM definition
OTC&SCM	MBOM available
OTC&SCM	Part supplier agreements, available
OTC&SCM	Part supplier purchase orders, available
OTC&SCM	Part supplier logistic manual, ready to use
OTC&SCM	Part supplier coaching, done
OTC&SCM	Part package requirements
OTC&SCM	MTR MRP process concept
OTC&SCM	MTR MRP process, definition
OTC&SCM	MTR forecast and part delivery plan, process up and running
OTC&SCM	MTR call offs at supplier, process up and running
OTC&SCM	VBOM ready to use

OTC&SCM	Inbound transport companies, agreements
OTC&SCM	Inbound transport concept design
OTC&SCM	Inbound transport process design
OTC&SCM	Inbound process up and running
OTC&SCM	Outbound transport companies, agreements
OTC&SCM	Outbound transport concept, design
OTC&SCM	Outbound transport process for cars, design
OTC&SCM	Outbound transport process for empty package, design
OTC&SCM	Outbound process up and running
OTC&SCM	Internal logistic, agreement with external service provider
OTC&SCM	Internal logistic concept, definition
OTC&SCM	Internal logistic process, design
OTC&SCM	Sales invoice process, definition
OTC&SCM	Sales invoice process, up and running
OTC&SCM	Production program volumes
PM	CMA
PM	Investment plan
PM	Investment procurement
PM	Investment follow-up
PM	Purchase invoice process, definition
PM	Purchase invoice process, up and running
PM	Needed headcount of BC and WC employees
PM	Manufacturing pre-series cars
PM	Start of Production (SOP)
PS	Paint shop (PS) manufacturing concept
PS	PS process definition of modifications
PS	PS process factory space arrangements
PS	PS skids, hangers, and hooks; design
PS	PS skids, hangers, and hooks; modification
PS	PS skids, hangers, and hooks; testing
PS	PS substrates; definition
PS	PS Base and clear coat concept for colours; definition
PS	PS materials attached to the car body; test
PS	PS phosphating; concept
PS	PS phosphating; testing
PS	PS electric coating; programming
PS	PS electric coating; testing

PS	PS car body sealing; concept
PS	PS car body sealing; specifications
PS	PS car body sealing; PC modification
PS	PS Masking station; concept
PS	PS Masking station; implementation
PS	PS Primer surfacer; automate programming
PS	PS Top coat; robot programming
PS	PS Base coat; testing
PS	PS 2K Clear coat modification; concept design
PS	PS 2K Clear coat modification; implementation
PS	PS Spor repair line; implementation
PS	PS Cavity treatment; concept design
PS	PS Cavity treatment; implementation
PS	PS process worker training
PS	PS Production cells; test run
PS	PS process approval
Q	Product Quality (PQ) audit space arrangements
Q	PQ market feedback; system and interface definitions
Q	PQ off-line measurement systems and equipment
Q	Supplier Quality (SQ) process definition
Q	Entire process approval

Appendix 2.

Element Full Name	*Depends on*
CMA	
Product spec's	
eBOM	Product spec's, 3D models and drawings,
3D models and drawings	Product spec's, eBOM,
Client's business processes and interfaces to them	
Investment plan	LCM & CM concept definition, MTR MRP process concept, Inbound transport concept design, Outbound transport concept, design, Internal logistic concept, definition, Body shop (BS) process concept planning, BS Front End; concept of PC, BS Floor; concept of PC, BS Rear End; concept of PC, BS Underbody Line; concept of PC, BS Side Panels LH&RH; concept of PC's, BS Framing Line; concept of Line, BS Closures; concept of PC's, BS Assembly Line; concept of Line, Paint shop (PS) manufacturing concept , PS process factory space arrangements, PS Base and clear coat concept for colours; definition, PS phosphating; concept, PS car body sealing; concept, PS Masking station; concept, PS 2K Clear coat modification; concept design, PS Cavity treatment; concept design, Assembly shop (AS)manufacturing concept, AS process sub-assembly mfg tools;Instrument panel; concept, AS process sub-assembly mfg tools; Headliner; concept, AS process sub-assembly mfg tools; Engine dress up; concept, AS process sub-assembly mfg tools;Front end module; concept, AS process sub-assembly mfg tools;Doors; concept, AS process line mfg tools; VIN Number equipment; concept, AS process line mfg tools; Instrument panel assembly equipment; concept, AS process line mfg tools; Sun roof installation; concept, AS process line mfg tools; Glass robot modification; concept, AS process line mfg tools; Skids off station; concept, AS process line mfg tools;Marriage point ; concept, AS process line mfg tools; Battery assembly; concept, AS process line mfg tools; Assembly equipments for labels; concept, AS process line mfg tools; Front end module; concept, AS process line mfg tools; Seats assembly equipment; concept, AS process line mfg tools;Doors assembly equipment; concept, AS process filling equipment; Brake; concept, AS process filling equipment;; conceptoolant; concept, AS process filling equipment; Washer; concept, AS process filling equipment; Refridgerant; concept, AS process filling equipment; Transmission; concept, AS process filling equipment; Fuel (Benzin); concept, AS process filling equipment; Fuel (Diesel); concept, AS process testing equipment; Wheel alignment; concept, AS process testing equipment; Roller tester for maneuverability; concept, AS process testing equipment; Water leakige testing; concept, AS process testing equipment; Outdoor testing; concept,
Investment procurement	Investment plan,
Investment follow-up	Investment plan, Investment procurement,
Sales order process, definition	Client's business processes and interfaces to them,
Sales order process, design	Sales order process, definition,
Sales order process IT-system definition	Client's business processes and interfaces to them, Sales order process, design,
Sales order process IT-system modification	Client's business processes and interfaces to them, Sales order process IT-system definition,
Sales forecast and car orders, available	Sales order process IT-system modification,
Sales order process up and running	Sales order process IT-system modification, Sales forecast and car orders, available,
LCM & CM concept definition	Client's business processes and interfaces to them,
LCM&CM process, definition	LCM & CM concept definition,
LCM&CM process IT system definition	eBOM, Client's business processes and interfaces to them, LCM&CM process, definition,
LCM&CM process IT system modification	Client's business processes and interfaces to them, LCM&CM process IT system definition,
LCM&CM process, up and running	LCM&CM process IT system modification,
mBOM definition	CMA, Product spec's, eBOM, 3D models and drawings, Inbound transport concept design, Body shop (BS) process concept planning, Paint shop (PS) manufacturing concept , Assembly shop (AS)manufacturing concept,
mBOM available	LCM&CM process IT system modification, mBOM definition,
Part supplier agreements, available	CMA, eBOM, Client's business processes and interfaces to them, mBOM definition,
Part supplier purchase orders, available	Part supplier agreements, available,
Part supplier logistic manual, ready to use	mBOM definition, Part supplier agreements, available, Inbound transport concept design, Outbound transport process for empty package, design, Purchase invoice IT-system, definition,
Part supplier coaching, done	Part supplier logistic manual, ready to use,
Part package requirements	CMA, mBOM definition,
MTR MRP process concept	Sales order process, definition, LCM & CM concept definition, mBOM definition,
MTR MRP process, definition	MTR MRP process concept,
MTR MRP process IT-system, definition	Client's business processes and interfaces to them, MTR MRP process, definition,
MTR MRP process IT-system modification	Client's business processes and interfaces to them, MTR MRP process IT-system, definition,
MTR forecast and part delivery plan, process up and running	MTR MRP process IT-system modification, MTR EDI connections, tested and running,
MTR EDI connections, tested and running	Part supplier agreements, available, Part supplier logistic manual, ready to use, MTR MRP process IT-system modification, MTR forecast and part delivery plan, process up and running,
MTR call offs at supplier, process up and running	MTR EDI connections, tested and running,
VBOM ready to use	Sales order process up and running, LCM&CM process, up and running, mBOM available, MTR MRP process IT-system modification,
Inbound transport companies, agreements	CMA, Client's business processes and interfaces to them, Part supplier agreements, available, Production program volumes,
Inbound transport concept design	CMA, Client's business processes and interfaces to them, Part supplier agreements, available, Inbound transport companies, agreements, Production program volumes,
Inbound transport process design	CMA, Client's business processes and interfaces to them, Part supplier agreements, available, Inbound transport concept design, Production program volumes,
Inbound process IT system definition	Client's business processes and interfaces to them, Inbound transport process design,
Inbound process IT system modification	Client's business processes and interfaces to them, Inbound process IT system definition,
Inbound process up and running	Inbound process IT system modification,
Outbound transport companies, agreements	CMA, Client's business processes and interfaces to them, Part supplier agreements, available, Part package requirements, Production program volumes,
Outbound transport concept, design	CMA, Client's business processes and interfaces to them, Part supplier agreements, available, Part package requirements, Production program volumes,
Outbound transport process for cars, design	CMA, Client's business processes and interfaces to them, Sales order process, design, Inbound/Outbound customs IT system definition,
Outbound transport process for empty package, design	Part supplier agreements, available, Part supplier logistic manual, ready to use, Part package requirements, Outbound transport concept, design,
Outbound process IT system definition	Client's business processes and interfaces to them, Outbound transport process for cars, design, Outbound transport process for empty package, design,
Outbound process IT system modification	Client's business processes and interfaces to them,
Outboundbound process up and running	Outbound process IT system modification,
Inbound/Outbound customs IT system definition	CMA, Client's business processes and interfaces to them, Inbound transport process design, Inbound process IT system definition, Outbound transport process for cars, design, Outbound transport process for empty package, design, Outbound process IT system definition,
Inbound/Outbound customs IT system modification	Inbound/Outbound customs IT system definition,
Internal logistic, agreement with external service provider	CMA, mBOM definition, Inbound transport concept design, Body shop (BS) process concept planning, Paint shop (PS) manufacturing concept , Assembly shop (AS)manufacturing concept,
Internal logistic concept, definition	mBOM definition, Inbound transport concept design, Body shop (BS) process concept planning, Paint shop (PS) manufacturing concept , Assembly shop (AS)manufacturing concept,
Internal logistic process, design	Internal logistic concept, definition, BS process layout planning, BS Front End; concept of PC, BS Floor; concept of PC, BS Rear End; concept of PC, BS Underbody Line; concept of PC, BS Side Panels LH&RH; concept of PC's, BS Framing Line; concept of Line, BS Closures; concept of PC's, BS Assembly Line; concept of Line, PS process factory space arrangements, PS 2K Clear coat modification; concept design, PS Cavity treatment; concept design, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning,
Internal logistic process IT system definition	Internal logistic process, design,
Internal logistic process IT system modification	Internal logistic process IT system definition,
Sales invoice process, definition	CMA, Client's business processes and interfaces to them, Sales order process, definition,

Element Full Name	*Depends on*
Sales invoice IT-system definition	Client's business processes and interfaces to them, Sales invoice process, definition,
Sales invoice IT-system modification	Sales invoice IT-system definition,
Sales invoice process, up and running	Sales invoice IT-system modification,
Purchase invoice process, definition	CMA, Client's business processes and interfaces to them, Sales order process, definition, Part supplier agreements, available, Part supplier purchase orders, available, VBOM ready to use,
Purchase invoice IT-system, definition	Purchase invoice process, definition,
Purchase invoice IT-system modification	Purchase invoice IT-system, definition,
Purchase invoice process, up and running	Purchase invoice IT-system modification,
Production program volumes	CMA,
Body shop (BS) process concept planning	CMA, Product spec's, eBOM, 3D models and drawings,
BS process layout planning	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning,
BS process factory space arrangements	BS process layout planning,
BS Front End; concept of PC	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Front End; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Front End; concept of PC,
BS Front End; conveyors	Product spec's, eBOM, 3D models and drawings, BS Front End; concept of PC, BS Front End; engineering design of fixtures,
BS Front End; automation	Product spec's, eBOM, 3D models and drawings, BS Front End; concept of PC, BS Front End; conveyors, BS Front End; equipment,
BS Front End; equipment	Product spec's, eBOM, 3D models and drawings, BS Front End; automation,
BS Front End; installation	eBOM, 3D models and drawings, BS Front End; concept of PC, BS Front End; engineering design of fixtures, BS Front End; conveyors, BS Front End; automation, BS Front End; equipment,
BS Front End; trial run	Product spec's, BS Front End; concept of PC, BS Front End; engineering design of fixtures, BS Front End; conveyors, BS Front End; automation, BS Front End; equipment, BS Front End; installation, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS Floor; concept of PC	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Floor; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Floor; concept of PC,
BS Floor; conveyors	Product spec's, eBOM, 3D models and drawings, BS Floor; concept of PC, BS Floor; engineering design of fixtures,
BS Floor; automation	Product spec's, eBOM, 3D models and drawings, BS Floor; concept of PC, BS Floor; conveyors, BS Floor; equipment,
BS Floor; equipment	Product spec's, eBOM, 3D models and drawings, BS Floor; automation,
BS Floor; installation	eBOM, 3D models and drawings, BS Floor; concept of PC, BS Floor; engineering design of fixtures, BS Floor; conveyors, BS Floor; automation, BS Floor; equipment,
BS Floor; trial run	Product spec's, BS Floor; concept of PC, BS Floor; engineering design of fixtures, BS Floor; conveyors, BS Floor; automation, BS Floor; equipment, BS Floor; installation, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS Rear End; concept of PC	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning, BS Front End; trial run,
BS Rear End; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Rear End; concept of PC,
BS Rear End; conveyors	Product spec's, eBOM, 3D models and drawings, BS Rear End; concept of PC, BS Rear End; engineering design of fixtures,
BS Rear End; automation	Product spec's, eBOM, 3D models and drawings, BS Rear End; concept of PC, BS Rear End; conveyors, BS Rear End; equipment,
BS Rear End; equipment	Product spec's, eBOM, 3D models and drawings, BS Rear End; automation,
BS Rear End; installation	eBOM, 3D models and drawings, BS Rear End; concept of PC, BS Rear End; engineering design of fixtures, BS Rear End; conveyors, BS Rear End; automation, BS Rear End; equipment,
BS Rear End; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; concept of PC, BS Rear End; engineering design of fixtures, BS Rear End; conveyors, BS Rear End; automation, BS Rear End; equipment, BS Rear End; installation, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS Underbody Line; concept of PC	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Underbody Line; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Underbody Line; concept of PC,
BS Underbody Line; conveyors	Product spec's, eBOM, 3D models and drawings, BS Underbody Line; concept of PC, BS Underbody Line; engineering design of fixtures,
BS Underbody Line; automation	Product spec's, eBOM, 3D models and drawings, BS Underbody Line; concept of PC, BS Underbody Line; conveyors, BS Underbody Line; equipment,
BS Underbody Line; equipment	Product spec's, eBOM, 3D models and drawings, BS Underbody Line; automation,
BS Underbody Line; installation	eBOM, 3D models and drawings, BS Underbody Line; concept of PC, BS Underbody Line; engineering design of fixtures, BS Underbody Line; conveyors, BS Underbody Line; automation, BS Underbody Line; equipment,
BS Underbody Line; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; concept of PC, BS Underbody Line; engineering design of fixtures, BS Underbody Line; conveyors, BS Underbody Line; automation, BS Underbody Line; equipment, BS Underbody Line; installation, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS Side Panels LH&RH; concept of PC's	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Side Panels LH&RH; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Side Panels LH&RH; concept of PC's,
BS Side Panels LH&RH; conveyors	Product spec's, eBOM, 3D models and drawings, BS Side Panels LH&RH; concept of PC's, BS Side Panels LH&RH; engineering design of fixtures,
BS Side Panels LH&RH; automation	Product spec's, eBOM, 3D models and drawings, BS Side Panels LH&RH; concept of PC's, BS Side Panels LH&RH; conveyors, BS Side Panels LH&RH; equipment,
BS Side Panels LH&RH; equipment	Product spec's, eBOM, 3D models and drawings, BS Side Panels LH&RH; automation,
BS Side Panels LH&RH; installation	eBOM, 3D models and drawings, BS Side Panels LH&RH; concept of PC's, BS Side Panels LH&RH; engineering design of fixtures, BS Side Panels LH&RH; conveyors, BS Side Panels LH&RH; automation, BS Side Panels LH&RH; equipment,
BS Side Panels LH&RH; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; concept of PC's, BS Side Panels LH&RH; engineering design of fixtures, BS Side Panels LH&RH; conveyors, BS Side Panels LH&RH; automation, BS Side Panels LH&RH; equipment, BS Side Panels LH&RH; installation, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS Framing Line; concept of Line	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Framing Line; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Framing Line; concept of Line,
BS Framing Line; automation	Product spec's, eBOM, 3D models and drawings, BS Framing Line; concept of Line, BS Framing Line; equipment,
BS Framing Line; equipment	Product spec's, eBOM, 3D models and drawings, BS Framing Line; concept of Line, BS Framing Line; engineering design of fixtures, BS Framing Line; automation,
BS Framing Line; installation	eBOM, 3D models and drawings, BS Framing Line; concept of Line, BS Framing Line; engineering design of fixtures, BS Framing Line; automation, BS Framing Line; equipment,
BS Framing Line; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; concept of Line, BS Framing Line; engineering design of fixtures, BS Framing Line; automation, BS Framing Line; equipment, BS Framing Line; installation, BS Closures; trial run, BS Assembly Line; trial run,
BS Closures; concept of PC's	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Closures; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Closures; concept of PC's,
BS Closures; automation	Product spec's, eBOM, 3D models and drawings, BS Closures; concept of PC's, BS Closures; equipment,
BS Closures; equipment	Product spec's, eBOM, 3D models and drawings, BS Closures; concept of PC's, BS Closures; engineering design of fixtures, BS Closures; automation,
BS Closures; installation	eBOM, 3D models and drawings, BS Closures; concept of PC's, BS Closures; engineering design of fixtures, BS Closures; automation, BS Closures; equipment,
BS Closures; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; concept of PC's, BS Closures; engineering design of fixtures, BS Closures; automation, BS Closures; equipment, BS Closures; installation, BS Assembly Line; trial run,
BS Assembly Line; concept of Line	Product spec's, eBOM, 3D models and drawings, Body shop (BS) process concept planning, BS process layout planning,
BS Assembly Line; engineering design of fixtures	Product spec's, eBOM, 3D models and drawings, BS Assembly Line; concept of Line,
BS Assembly Line; automation	Product spec's, eBOM, 3D models and drawings, BS Assembly Line; concept of Line, BS Assembly Line; equipment,

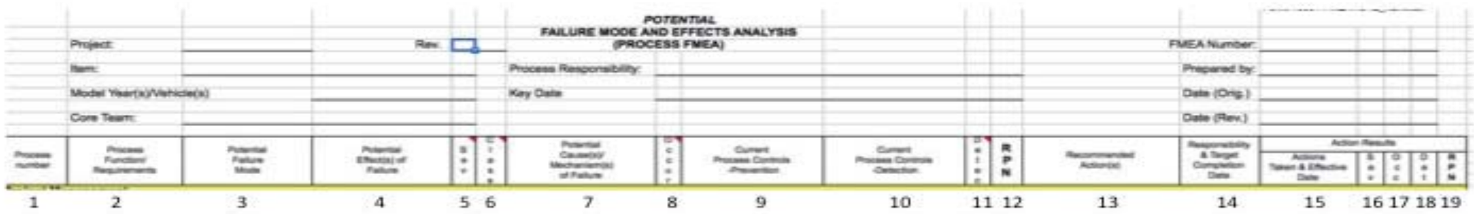
Appendix 2.

Element Full Name	*Depends on*
BS Assembly Line; equipment	Product spec's, eBOM, 3D models and drawings, BS Assembly Line; concept of Line, BS Assembly Line; engineering design of fixtures, BS Assembly Line; automation,
BS Assembly Line; installation	eBOM, 3D models and drawings, BS Assembly Line; concept of Line, BS Assembly Line; engineering design of fixtures, BS Assembly Line; automation, BS Assembly Line; equipment,
BS Assembly Line; trial run	Product spec's, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; concept of Line, BS Assembly Line; engineering design of fixtures, BS Assembly Line; automation, BS Assembly Line; equipment, BS Assembly Line; installation,
BS process worker training	BS Front End; installation, BS Floor; installation, BS Rear End; installation, BS Underbody Line; installation, BS Side Panels LH&RH; installation, BS Framing Line; installation, BS Closures; installation, BS Assembly Line; installation,
BS process destructive tests	BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
BS process approval	BS process destructive tests,
Paint shop (PS) manufacturing concept	CMA, Product spec's, eBOM, 3D models and drawings,
PS process definition of modifications	Product spec's, 3D models and drawings, Paint shop (PS) manufacturing concept ,
PS process factory space arrangements	Paint shop (PS) manufacturing concept , PS process definition of modifications,
PS skids, hangers, and hooks;design	3D models and drawings,
PS skids, hangers, and hooks; modification	3D models and drawings, PS skids, hangers, and hooks;design,
PS skids, hangers, and hooks; testing	PS skids, hangers, and hooks; modification,
PS substrates; definition	Product spec's,
PS Base and clear coat concept for colours; definition	Product spec's, PS substrates; definition,
PS materials attached to the car body; test	PS Base and clear coat concept for colours; definition,
PS phosphating; concept	PS process definition of modifications, PS materials attached to the car body; test,
PS phosphating; testing	PS phosphating; concept,
PS electric coating; programming	Product spec's,
PS electric coating;testing	PS electric coating; programming,
PS car body sealing; concept	Product spec's, 3D models and drawings,
PS car body sealing; specifications	3D models and drawings, PS car body sealing; concept,
PS car body sealing; PC modification	PS car body sealing; specifications,
PS Masking station; concept	Product spec's, 3D models and drawings,
PS Masking station; implementation	PS Masking station; concept,
PS Primer surfacer; automate programming	Product spec's, 3D models and drawings,
PS Top coat; robot programming	Product spec's, 3D models and drawings,
PS Base coat; testing	PS Top coat; robot programming,
PS 2K Clear coat modification; concept design	PS Top coat; robot programming, PS Base coat; testing,
PS 2K Clear coat modification; implementation	PS Top coat; robot programming, PS Base coat; testing, PS 2K Clear coat modification; concept design,
PS Spor repair line; implementation	PS 2K Clear coat modification; implementation,
PS Cavity treatment; concept design	Product spec's, 3D models and drawings,
PS Cavity treatment; implementation	PS Cavity treatment; concept design,
PS process worker training	PS process factory space arrangements, PS skids, hangers, and hooks; testing, PS substrates; definition, PS materials attached to the car body; test, PS phosphating; testing, PS electric coating;testing, PS car body sealing; PC modification, PS Masking station; implementation, PS Primer surfacer; automate programming, PS Top coat; robot programming, PS Base coat; testing, PS 2K Clear coat modification; implementation, PS Spor repair line; implementation, PS Cavity treatment; concept design, PS Cavity treatment; implementation,
PS Production cells; test run	PS process worker training, PS process approval,
PS process approval	PS Production cells; test run,
Assembly shop (AS)manufacturing concept	CMA, Product spec's, eBOM, 3D models and drawings,
AS process; assembly sequence planning	Product spec's, eBOM, 3D models and drawings, mBOM definition, mBOM available,
AS process factory space arrangements	Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning,
AS process; assembly method planning and work instructions	Product spec's, eBOM, 3D models and drawings, mBOM available, AS process; assembly sequence planning, AS process factory space arrangements,
AS process; line balancing	AS process; assembly method planning and work instructions,
AS process sub-assembly mfg tools;Instrument panel; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process sub-assembly mfg tools;Instrument panel; design and modification	Product spec's, eBOM, 3D models and drawings, AS process sub-assembly mfg tools;Instrument panel; concept,
AS process sub-assembly mfg tools; Headliner; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process sub-assembly mfg tools; Headliner; design and modification	Product spec's, eBOM, 3D models and drawings, AS process sub-assembly mfg tools; Headliner; concept,
AS process sub-assembly mfg tools; Engine dress up; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process sub-assembly mfg tools; Engine dress up; design and modification	Product spec's, eBOM, 3D models and drawings, AS process sub-assembly mfg tools; Engine dress up; concept,
AS process sub-assembly mfg tools;Front end module; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process sub-assembly mfg tools;Front end module; design and modification	Product spec's, eBOM, 3D models and drawings, AS process sub-assembly mfg tools;Front end module; concept,
AS process sub-assembly mfg tools;Doors; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process sub-assembly mfg tools;Doors; design and modification	Product spec's, eBOM, 3D models and drawings, AS process sub-assembly mfg tools;Doors; concept,
AS process line mfg tools; VIN Number equipment; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; VIN Number equipment; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; VIN Number equipment; concept,
AS process line mfg tools; Instrument panel assembly equipment; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Instrument panel assembly equipment; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Instrument panel assembly equipment; concept,
AS process line mfg tools; Sun roof installation; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Sun roof installation; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Sun roof installation; concept,
AS process line mfg tools; Glass robot modification; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Glass robot modification; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Glass robot modification; concept,
AS process line mfg tools; Skids off station; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Skids off station; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Skids off station; concept,
AS process line mfg tools;Marriage point ; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools;Marriage point; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools;Marriage point ; concept,
AS process line mfg tools; Battery assembly; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Battery assembly; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Battery assembly; concept,
AS process line mfg tools; Assembly equipments for labels; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,

Element Full Name	*Depends on*
AS process line mfg tools; Assembly equipments for labels; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Assembly equipments for labels; concept,
AS process line mfg tools; Front end module; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Front end module; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Front end module; concept,
AS process line mfg tools; Seats assembly equipment; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools; Seats assembly equipment; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools; Seats assembly equipment; concept,
AS process line mfg tools;Doors assembly equipment; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process line mfg tools;Doors assembly equipment; design and modification	Product spec's, eBOM, 3D models and drawings, AS process line mfg tools;Doors assembly equipment; concept,
AS process filling equipment; Brake; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Brake; design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Brake; concept,
AS process filling equipment;; conceptoolant; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment;; conceptoolant; design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment;; conceptoolant; concept,
AS process filling equipment; Washer; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Washer; design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Washer; concept,
AS process filling equipment; Refridgerant; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Refridgerant; design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Refridgerant; concept,
AS process filling equipment; Transmission; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Transmission; design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Transmission; concept,
AS process filling equipment; Fuel (Benzin); concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Fuel (Benzin); design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Fuel (Benzin); concept,
AS process filling equipment; Fuel (Diesel); concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process filling equipment; Fuel (Diesel); design and modification	Product spec's, eBOM, 3D models and drawings, AS process filling equipment; Fuel (Diesel); concept,
AS process testing equipment; Wheel alignment; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process testing equipment; Wheel alignment; design and modification	Product spec's, eBOM, 3D models and drawings, AS process testing equipment; Wheel alignment; concept,
AS process testing equipment; Roller tester for maneuverability; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process testing equipment; Roller tester for maneuverability; design and modification	Product spec's, eBOM, 3D models and drawings, AS process testing equipment; Roller tester for maneuverability; concept,
AS process testing equipment; Water leakige testing; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process testing equipment; Water leakige testing; design and modification	Product spec's, eBOM, 3D models and drawings, AS process testing equipment; Water leakige testing; concept,
AS process testing equipment; Outdoor testing; concept	Product spec's, eBOM, 3D models and drawings, Assembly shop (AS)manufacturing concept, AS process; assembly sequence planning, AS process factory space arrangements,
AS process testing equipment; Outdoor testing; design and modification	Product spec's, eBOM, 3D models and drawings, AS process testing equipment; Outdoor testing; concept,
AS process worker training	AS process sub-assembly mfg tools;Instrument panel; design and modification, AS process sub-assembly mfg tools; Headliner; design and modification, AS process sub-assembly mfg tools; Engine dress up; design and modification, AS process sub-assembly mfg tools;Front end module; design and modification, AS process sub-assembly mfg tools;Doors; design and modification, AS process line mfg tools; VIN Number equipment; design and modification, AS process line mfg tools; Instrument panel assembly equipment; design and modification, AS process line mfg tools; Sun roof installation; design and modification, AS process line mfg tools; Glass robot modification; design and modification, AS process line mfg tools; Skids off station; design and modification, AS process line mfg tools;Marriage point; design and modification, AS process line mfg tools; Battery assembly; design and modification, AS process line mfg tools; Assembly equipments for labels; design and modification, AS process line mfg tools; Front end module; design and modification, AS process line mfg tools; Seats assembly equipment; design and modification, AS process line mfg tools;Doors assembly equipment; design and modification, AS process filling equipment; Brake; design and modification, AS process filling equipment;; conceptoolant; design and modification, AS process filling equipment; Washer; design and modification, AS process filling equipment; Refridgerant; design and modification, AS process filling equipment; Transmission; design and modification, AS process filling equipment; Fuel (Benzin); design and modification, AS process filling equipment; Fuel (Diesel); design and modification, AS process testing equipment; Wheel alignment; design and modification, AS process testing equipment; Roller tester for maneuverability; design and modification, AS process testing equipment; Water leakige testing; design and modification, AS process testing equipment; Outdoor testing; design and modification,
AS manufacturing line; test run	AS process worker training,
AS process approval	AS manufacturing line; test run,
Product Quality (PQ) audit space arrangements	CMA, Product spec's, 3D models and drawings,
PQ market feedback; system and interface definitions	CMA, Product spec's, Client's business processes and interfaces to them,
PQ off-line measurement systems and equipments	Product spec's, 3D models and drawings, mBOM available, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run,
Supplier Quality (SQ) process definition	CMA, Product spec's, mBOM available, Part supplier agreements, available, Part supplier purchase orders, available, Part supplier logistic manual, ready to use, Part package requirements,
SQ IT system definition	Supplier Quality (SQ) process definition,
SQ IT system modification	SQ IT system definition,
IT ERP system ready to use	Sales order process IT-system modification, LCM&CM process IT system modification, MTR MRP process IT-system modification, Inbound process IT system modification, Outbound process IT system modification, Inbound/Outbound customs IT system modification, Internal logistic process IT system modification, Sales invoice IT-system modification, Purchase invoice IT-system modification,
IT PDM system ready to use	
IT MES system ready to use	Sales order process IT-system modification, VBOM ready to use, BS process approval, PS process approval, AS process approval,
IT Supplier extranet ready to use	Client's business processes and interfaces to them, Part supplier logistic manual, ready to use, Part supplier coaching, done, Part package requirements, Outbound transport process for empty package, design, SQ IT system modification,
Needed headcount of BC and WC employees	Production program volumes, Paint shop (PS) manufacturing concept , AS process; line balancing,
Manufacturing pre-series cars	VBOM ready to use, BS Front End; trial run, BS Floor; trial run, BS Rear End; trial run, BS Underbody Line; trial run, BS Side Panels LH&RH; trial run, BS Framing Line; trial run, BS Closures; trial run, BS Assembly Line; trial run, PS Production cells; test run, AS manufacturing line; test run,
Entire process approval	BS process approval, PS process approval, AS process approval,
Start of Production (SOP)	Entire process approval,

Appendix 3.

Example of a FMEA form



POTENTIAL
FAILURE MODE AND EFFECTS ANALYSIS
(PROCESS FMEA)

Project: Rev:
Item:
Model Year(s)/Vehicle(s)
Core Team:
Process Responsibility:
Key Date
FMEA Number:
Prepared by:
Date (Orig.)
Date (Rev.)

Process number	Process Function/ Requirements	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current Process Controls -Prevention	Current Process Controls -Detection	Detec	RPN	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
														Actions Taken & Effective Date	Sev	Occ	Det	RPN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Tampereen teknillinen yliopisto
PL 527
33101 Tampere

Tampere University of Technology
P.O.B. 527
FI-33101 Tampere, Finland

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