Abstract

This master thesis was conducted at Volvo Car Corporation, VCC, in Gothenburg within the Manufacturing Engineering department. It is based on the P11-project (the new model S40) where the process verification has been examined and analyzed. The purpose of the thesis is to investigate the reasons behind remaining and new problems at late stages in the development process, as well as possibilities for improvements during pre-series work. Based on this, the objective is to identify and account for problem areas which significantly influence verification activities. Furthermore, recommendations for future in-depth studies, within these specified areas, are presented with the aim to continue the investigation conducted in this thesis. Through the description of the current challenges combined with future, more precise research, the performance of pre-series verification will be enhanced.

VCC has recently introduced virtual pre-series at early stages of the verification process in order to enable a more efficient product and process development. The aim is to improve the use of virtual methods, such as advanced simulation tools used to simulate manufacturability, thereby reducing the need for time and cost consuming physical pre-series. Achieving improvements in virtual pre-series will allow for front-loading in terms of identifying and solving problems earlier. This thesis focuses on virtual verifications and emphasizes the possibilities for improvements within that area. The investigation was performed as a case study and information was gathered from a database, where process related problems are managed, and through interviews with parties involved in the verification process.

Gathering information about basic questions, such as when problems are identified and solved, enabled an observation of the disproportionately large number of problems handled during physical pre-series. Thus, confirming the importance of applying the front-loading theory. By focusing on identifying the reasons for the present situation, this investigation resulted in extensive input providing a broad perspective where a few areas of significance were identified. Four areas with a considerable effect on the quality of the virtual pre-series are emphasized; technical limitations, defective virtual build meetings, poor handling of models, and lack of knowledge transfer. At present, they all contribute to the amount of problems at late stages, thereby implying the need for improvements. The technical limitations are of a tangible nature, directly affecting the performance of simulations, and limiting the handling of problems by postponing verifications to the physical pre-series. The remaining areas refer mainly to aspects regarding working methodology and how it is implemented and perceived by the concerned parties. Partly, the working methodology is affected by immeasurable issues such as confidence in virtual methods, motivation for work, and informal communication.

Key words: Virtual verification, process verification, pre-series, manufacturing simulation, virtual prototype, automotive industry, knowledge transfer

Sammanfattning

Detta examensarbete genomfördes på Volvo Personvagnar AB, Volvo PV, i Göteborg, inom beredningsorganisationen. Det är baserat på P11-projektet (den nya S40-modellen) där processverifieringen har undersökts och analyserats. Syftet med examensarbetet är att undersöka de bakomliggande orsakerna till varför återstående och nya problem finns kvar sent i utvecklingsprocessen, samt möjligheter till förbättringar under förseriearbetet. Grundat på detta är målet att identifiera och redogöra för problemområden som i stor utsträckning påverkar verifieringsaktiviteter. Dessutom ges rekommendationer till framtida fördjupade studier inom de specifika områdena med målsättningen att föra denna undersökning vidare. Genom att tillhandahålla en beskrivning av utmaningarna i dagsläget och kombinera den med framtida och mer preciserade undersökningar kan kvalitén på förserieverifieringarna höjas.

Volvo PV har nyligen introducerat virtuella förserier under tidiga skeden av verifieringsprocessen för att möjliggöra en mer effektiv produkt- och processutveckling. Målet är att förbättra användandet av virtuella metoder, till exempel avancerade simuleringsverktyg som används för att simulera tillverkningsbarhet, och därigenom minska behovet av de tids- och kostnadskrävande fysiska förserierna. Förbättrade virtuella förserier möjliggör "front-loading" vilket syftar till att tidigarelägga identifiering och lösning av problem. Examensarbetet inriktar sig på virtuella verifieringar och förtydligar de förbättringar som kan göras inom området. Undersökningen genomfördes som en fallstudie där information delvis insamlades från en databas där processrelaterade problem hanteras, samt genom intervjuer med personer involverade i verifieringsprocessen.

Insamlandet av information kring grundläggande frågor, som när problem upptäcks och löses, ledde till iakttagelsen att oproportionerligt många problem hanterades under fysiska förserier. Därigenom kunde vikten av teorin om "front-loading" bekräftas. Genom att fokusera på identifierandet av och förståelsen för de bakomliggande orsakerna till problemsituationen, resulterade undersökningen i ett omfattande material som sedan sammanfattades i ett fåtal betydande områden. Tonvikt har lagts på fyra områden som i stor utsträckning påverkar kvalitén på de virtuella förserierna; tekniska begränsningar, brister i virtuella byggnationer, bristfällig modellhantering, samt avsaknad av kunskapsöverföring. I nuläget bidrar samtliga områden till den mängd problem som kvarstår i sena faser vilket tyder på att förbättringar är nödvändiga. De tekniska begränsningarna är av en mer påtaglig karaktär genom att direkt påverka simuleringarna negativt och göra fysiska förserier oumbärliga. De återstående områdena berör till största del aspekter som kan hänföras till arbetsmetodik samt hur den implementeras och uppfattas av de inblandade parterna. Till en viss del inverkar även mjuka faktorer på arbetsmetodiken, till exempel förtroendet för virtuella metoder, arbetsmotivation och informell kommunikation.

Nyckelord: Virtuell verifiering, processverifiering, förserier, produktionssimulering, virtuell prototyp, bilindustrin, kunskapsöverföring

Acknowledgements

During the work with this master thesis an extended period of time was dedicated to understanding and getting a grip on the complex processes constituting the development of a car. As a consequence, we had to ask people at VCC all sorts of questions in order to obtain the necessary information ("Where is the cafeteria?" or "How does Robcad work?"). Therefore, they all deserve our greatest thanks and appreciation.

First of all, we would like to express our gratitude to both our supervisors; Bertil Nilsson for making the effort of visiting us once in a while and provide us with support and enlightening us, and Dan Lämkull for introducing us to the organization of 81900 as well as sharing his knowledge and encouraging us while providing useful feedback.

Thanks to Anders Sundin for giving us the chance to escape the VCC environment ones in a while, but most importantly for providing additional input and points of view.

Jeanette Gillser and Per Denovan; thank you for dedicating your time and effort aiding us in our research by suggesting approaches and introducing us to the verification process.

Our appreciation to everyone participating in the interviews, thereby providing us with invaluable insight into the actual work performed during pre-series. Without your contribution, it wouldn't have been much of a thesis.

Finally, thanks to Anders Carlsson for giving us this opportunity.

Gothenburg, February 2004

Martin Carlsson & Linda Sjöö

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1 Introduction

In this chapter the background for this thesis is presented. A brief description of the subject studied is given as well as the challenges resulting in this thesis. Furthermore, the area in focus and the range of the study are specified.

1.1 Presentation of Volvo Car Corporation

> *"Cars are driven by people. The guiding principle behind everything we make at Volvo, therefore, is and must remain – safety."*
> Founders of Volvo, Assar Gabrielsson and Gustaf Larson.

Since the first series produced car left the factory in 1927 there has been a great deal of changes both regarding the company and the cars. The mission of today is to create the safest and most exciting car experience, which clearly relates to the vision of Gabrielsson and Larson. The core values of Volvo Car Corporation, VCC, are safety, environmental care and quality. Through excellence in these fields VCC aims to be the worlds most successful and desirable premium car brand.

In 1999 VCC became a part of the Ford Motor Company, FMC. VCC belongs, together with Land Rover, Aston Martin, and Jaguar, to the Premium Automotive Group, PAG, which is the division within FMC for high-class vehicles. The headquarters of VCC, as well as some of the production and development facilities, are located in Gothenburg. This thesis was performed at VCC's location in Gothenburg providing close relations with departments concerned with product and process development.

1.2 Background

Car manufacturers of today face a tough climate in terms of competition and growing market demands. VCC is no exception. In order to stay competitive in such a market VCC has to increase both the production rate and number of model releases as well as delivering products with superior quality.

1.2.1 General concerns

Three main aspects are in focus when developing new products in the business environment of today; *time*, *cost* and *quality*. Companies that develop products efficiently at low costs and offer well targeted products of high quality to markets before their competitors, achieve competitive advantages. The difficulty is to improve the efficiency of the development process without sacrificing the quality of the final product.

When striving to achieve advantages towards competitors the aspect of time is of vital importance, especially time to market. A delay in market introduction not only decreases the time for profit making but may also result in competitors gaining market shares on your expense. A late introduction also results in an increased total cost of the development process which in turn affects the time until product profits equals the development investment. Supreme quality in the final product offered is of equal importance to create satisfied customers and thereby enable market growth. To reach this and to gain competitive advantage, quality thinking must be integrated throughout the development process.

1.2.2 The development process

With such complex products as cars a well structured and defined development plan is a must, enabling the organization to reach the expected results. It is not only a matter of designing components that meet the requirements, they must all fit together and interact in the desired way. Furthermore, the process of manufacturing and assembling all the components also must be developed as to work in the most effective way.

Within the development process there are three major stages, each with certain objectives and purposes. It starts off with the concept stage, followed by the pre-study stage and finally there is the industrialization stage, as visualized in figure 1. During the concept stage the prerequisites for the project are agreed, for example the definition of characteristics as well as establishing connections with the partners and organizations to be involved. In the pre-study stage the basis for the developing of the selected systems, in both product and production process, are formed. Also all the prerequisites from the concept stage are to be fulfilled. When the industrialization stage starts all the systems of the product are defined and the production adaptation is possible. Within this stage the focus is on fitting the new product to the plants where production will take place, for example manufacturing the needed tools and ramping up the production.

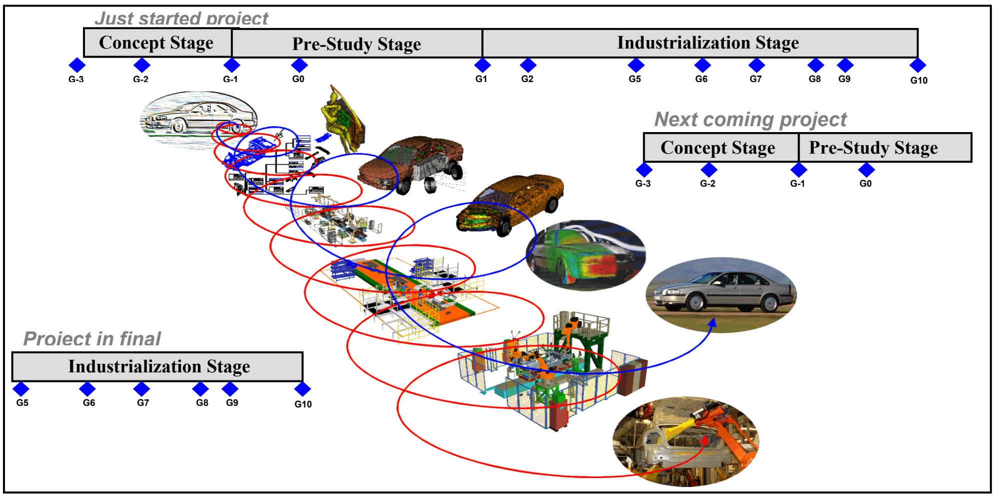

Figure 1. Stages of product and process development.

VCC handles the aspects of a car development project by using what is called a gateway system. This can be seen as a kind of roadmap for the project, consisting of a number of gates (as seen in figure 1) where certain targets are to be met in order to proceed to the next stage. The entire development process, passing through the various gates, is made up of several parallel process flows, each contributing to the overall project in different ways. At early stages the components and systems are designed by the Design Engineers at the Research and Development, R&D, organization. Along with their work, preparations of the manufacturing processes are done by the Manufacturing Engineers, in close collaboration with the designers. The work is carried out as repeated loops where new solutions are tested and evaluated over and over again. When a project has passed through the stages in the development process, the final manufacturing solution is transferred to the factories responsible for manufacturing the car.

Worth mentioning is the necessity to have several car projects running at the same time in order to maintain competitiveness. Figure 1 visualizes how diverse projects overlap each other in a continuous manner with constant recurrent project starts and ends.

1.2.3 The verification process

Once the concept of the product is established, development work proceeds in order to create the defined product as well as the manufacturing processes supporting it. Throughout the development process continuous verifications must be realized. So called pre-series are carried out with the purpose of testing and verifying current solutions in order to discover any problems and deviations, see figure 2. This is an opportunity to verify the complete set of components and systems fitted together. A main concern for these pre-series is to secure the manufacturability of the products in the factories, ensuring the expected quality of the product is reached when starting the production. The Manufacturing Engineering department is responsible for assuring this and is therefore deeply involved in the pre-series. A number of issues are addressed with regards to manufacturing, such as cost, performance, ergonomics, tooling, robotics, etc. Achieving high quality and efficient pre-series is crucial for the final product to meet the demands and goals set forth for the project.

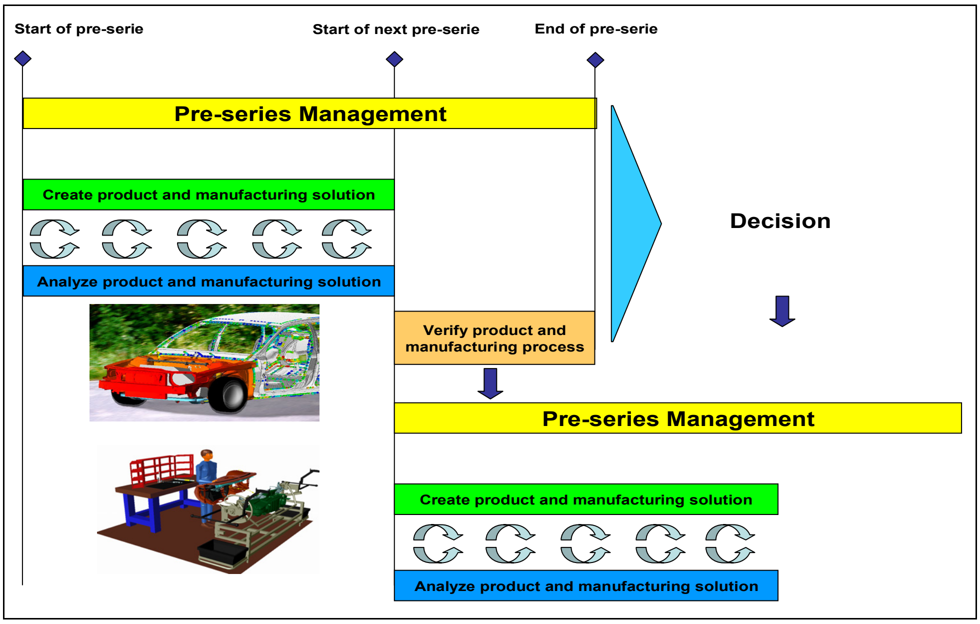

Figure 2. Verification pre-series. Visualization of the continuous flow of verifications during product and process development. Two examples of computer based models used during virtual development.

The verification process affects time to market, development costs and quality of the final product to a great extent. During the last ten years the automotive industry has been implementing virtual simulation in the verification process. Virtual verification is defined as verification of the product and manufacturing process by the use of virtual prototypes and computer based tools. Virtual verification is a major challenge to be able to shorten time to market and stay competitive. To reduce the need of highly time and cost consuming physical verifications the aim is to increase and improve the use of virtual methods. The advantages of virtual methods, if used correctly, are several; the development costs will be reduced as the demand for physical prototypes decrease, an efficient development will reduce lead-times and will ensure quality at an early stage. This simplifies concurrent engineering by enabling early verifications of product and process fit as well as providing indications for purchasing and tooling. A term called "front-loading" has been introduced to describe this new way of working. The vision of front-loading is to increase the efforts of verification at earlier stages than today, thereby relocating problems by identifying and solving them sooner.

Since the use of virtual verification is a new method in the development process there are still obstacles to overcome and experience to be drawn. A methodology that supports the use of virtual methods must be implemented throughout the organization. This includes the beliefs of the employees and their confidence in the change of methodology. Additionally, virtual methods have their limitations as they are not capable of handling all details of the product and process in a correct and realistic manner in accordance to the physical reality. For example tolerances, flexible materials, friction and forces such as gravity and pressure cannot be virtually described correctly. Thus, there are potential improvements in the use of virtual methods which will enable further advantages.

1.2.4 Studies of the verification process

Numerous studies have been carried out in order to improve performance in pre-series. This implies the importance of focusing on manufacturing engineering at a high quality level. To make this possible a thorough research of the present situation has to be conducted to highlight problem areas and enable improvements. Virtual methods play an increasingly important role in the work of manufacturing engineering of today, though further efforts still have to be made to take advantage of the full potential.

This thesis is a further development of a previously conducted study of the P28-project, Volvo XC90, at VCC. The P28-project was the first project to completely apply the working methodology of virtual verification throughout the development process. A former employee at VCC in Gothenburg, Lennart Bengtsson, realized an investigation of the virtual versus physical pre-series of that project with the purpose of identifying the reasons for remaining problems in physical pre-series. This investigation was conducted as a Black Belt project which is part of the Six Sigma approach to increase customer satisfaction by eliminating defects in products and processes. The outcome of his investigation, accounted for in appendix 4, resulted in a foundation for this thesis as there was a need for an additional and more thorough investigation of the problem areas identified. Of interest to examine is whether the investigation results of this thesis recognize the same problem areas as the most important to take action against to improve the quality of virtual verifications.

Parallel to this thesis there is a study performed by Anders Sundin from the National Institute for Working Life, NIWL. The purpose of his work is to identify necessary prerequisites of an improved cost efficiency of ergonomics simulations. The basis for his study is interviews with a number of selected middle-management persons within the organization of VCC at Torslanda concerned with methods and working methodology of simulations. Anders Sundin's study is of interest since it touches the area investigated in this thesis and provides additional information and input. Anders Sundin is a Ph.D. and European Ergonomist, working in the group *Organization of Product Realization* at NIWL. His interest is within human simulation, the organization of ergonomics simulations and participatory ergonomics, a mean to enhance the effects of ergonomics activities. The research group has earlier been working with VCC in the development of P28/XC90.

1.3 Problem definition

At present VCC is aiming to reach customer satisfaction number one, CS#1. Customer satisfaction is the measure of how VCC succeed in the efforts to fulfill the customer's expectations in all areas where they meet VCC products or services. For this to be achieved VCC has to increase the quality of the products through an even more efficient development. Improving the verification process is one way of reaching CS #1.

VCC have made a big progress in the field of virtual verification compared to its competitors. However there are still needs for improvements when implementing this new virtual methodology. The challenge is to eliminate remaining and avoid new problems at late stages in the development process. These kinds of problems require more resources, such as time, and are more cost consuming than problems discovered and handled earlier in the process. Certain questions arise when confronted with problems related to the verification process and the improvement possibilities. This thesis will discuss the following issues regarding the verification process:

- When are the problems identified in the development process?
- When are the problems solved?
- For how long are the problems present in the development process?
- What are the reasons for remaining and new problems at late stages in the development process?

The first three questions will from here on be referred to as basic questions. The last question is a continuation of the research, based on the information obtained from the basic questions. The basic questions thereby serve as a foundation for a further in-depth investigation, which is realized through the fourth question. The discussions will be divided into these two different research levels.

1.4 Purpose and objective

The purpose of the master thesis is to investigate the reasons behind the remaining and new problems at the end of the development process.

The objective is to create a holistic description of the current situation and the challenge areas within the verification process. Based on this, recommendations for future in-depth studies of the complex area will be presented, with the aim to improve the verification process.

1.5 Scope of master thesis

To reach the objectives of this thesis certain limitations were formulated. First of all one of the many car projects currently running was chosen. For this study the **project P11**, or more commonly known as the new S40, seemed to be a good choice since it was a completely new model and it was just about to go into mass production. Because of this, the information about the work was in fresh memory of the ones involved and also it was possible to get a good overall picture. However, a project of this magnitude is difficult to comprehend and analyze entirely. Therefore the scope was limited within P11 as well. The manufacturing of a car is dependent on both the products that make up the car and the processes to bring these parts together. The processes are divided into three major areas, body in white (A-shop), surface treatment (B-shop) and assembly (C-shop). The limit here was to focus only on the **assembly process**. With the study's purpose being to follow up how the work with pre-series was performed and can be improved it was of most interest to focus on the stages of the development where these are carried out. Therefore, the thesis was limited as to comprise of the study of identified problems **between virtual pre-series 2.2 to the time of pre try-out, PTO**, when the car for the first time is assembled at the real production plant. Due to a change-over of problem handling system there is no information available earlier than virtual pre-series 2.2.

1.6 Target groups

Two different target groups are identified. First and most important this thesis is aimed towards VCC and its personnel. The thesis is of interest for numerous parts of the organization as it highlights important problem areas in the work with pre-series. Especially targeted are certain groups, more directly concerned with the outcome, such as the Manufacturing Engineering department and other departments involved with the development and implementation of methodology for virtual and physical series.

The other target group is final year students in the masters programs to whom it may provide some interesting insight to how case studies are used and conducted when analyzing projects. It is also helpful as a complementary guideline when writing a master thesis. Furthermore, this thesis may provide students with an interest in writing a thesis at VCC with topics of significance based on the recommendations for future in-depth studies presented here.

1.7 Disposition

As an aid to readers a brief description of the content of each chapter is here given. Additionally, appendix 1, Abbreviations, may be helpful when reading since the thesis contains numerous abbreviations used within VCC.

Following this introduction is a chapter of *methodology* where the research approach to the investigated area of the thesis is described and motivated. Different methods for gathering of data are discussed as well as an explanation of the terms validity and reliability.

Chapter three, *Frame of reference and theory*, presents a theoretical foundation found relevant for the work with this thesis. It aims to provide the reader with an in-depth understanding of the challenges of product and process development. This information is gathered through various literatures.

In the fourth chapter, *Development process at VCC*, the VCC specific development process is accounted for, with a focus on the verification process. Furthermore, the organization supporting the process is described in brief as well as the virtual verification tools used.

Chapter five, *Results*, contains the various results found during the research. They are divided into quantitative and qualitative findings.

The *discussions* in chapters six and seven are based on the theory presented in chapter three and the information about VCC in chapter four. A thorough analysis of the results, accounted for in chapter five, is made. Chapter six discusses the three basic questions whereas the in-depth question is discussed in chapter seven.

Finally, chapter eight, *Conclusion*, summarizes the most important aspects discussed in chapter seven. Here the objectives of the thesis are outlined as a conclusion to the investigation.

1.8 Reading guidelines

As this thesis is directed towards a broad group of people with varied insight into the VCC organization and its processes a guideline of recommended reading is presented below. Three main types of readers are identified:

1. Any person within VCC concerned with the work of verification who wishes to get an overview of the conducted investigation.
2. Anyone from outside the VCC organization who wishes to obtain knowledge of work with pre-series during the development process.
3. Any person within VCC with genuine interest in the field of verification processes as well as those concerned with further investigations of the problem areas.

Table 1. Reading guidelines

Chapters	1	2	3
Introduction	x	x	x
Methodology			x
Frame of reference and theory			x
Development process at VCC		x	x
Results	x	x	x
Discussions		x	x
Conclusion	x	x	x

2 Methodology

> *"Research is hard enough without books about methodology. Using books about methodology makes it basically impossible."*
> Extract from preface of methodology literature.

This chapter accounts for the approach to the investigated area and the research method applied, both in theoretical and practical terms. It begins with a presentation of various levels of ambition. The case study methodology as well as different types of data is described and their relevance for this thesis is motivated. In conclusion, the concepts validity and reliability are explained and the gathered data discussed and criticized in these terms. Each part starts with a theoretical description and is followed by an explanation of the practical approach of the thesis.

The theory described in this chapter is gathered mainly from methodology literature written by Eriksson et al. (1997), Lundahl et al. (1982) and Ejvegård (1996).

2.1 Investigative approaches

Given the description of the problem the challenge is to find and apply a suitable level of ambition in order to reach the objectives. Based on the purpose of the investigation there is a choice of different levels of ambition.

- **Explorative investigation**
  This is a basic investigation to formulate and specify a problem. It aims to give the investigator an insight to the problem area and the questions related, often through raising various hypotheses. It creates a basis for further extended investigations by providing a plan for a more precise problem definition including the purpose and suggested research methods.
- **Descriptive investigation**
  A descriptive investigation is used to describe a certain situation or phenomenon with the purpose of creating a basis of knowledge within the research area. When undertaking this kind of investigation it is of high importance to be clear about from whose perspective the investigation is conducted and for whom it is aimed in order to give a relevant and correct description.
- **Explaining investigation**
  This type of investigation has the objective of answering the question *why*. The investigator aims to identify the factors causing the formulated problem, which is often obtained by testing previously raised hypothesis.
- **Diagnostic investigation**
  The purpose of a diagnostic investigation is to identify the cause of a certain situation or phenomenon. Furthermore it aims to present distinct solutions and methods of implementation for managing concrete problems originated from the situation or phenomenon.
- **Evaluating investigation**
  An evaluating investigation aims to analyze and measure the effects of a certain implemented action.

The different levels of ambition are coherent in the sense that the problem formulated in the latter level are based on the results from the preceding. According to this, all investigations begin with examining results from previously conducted investigations in order to reach an objective at a more extensive level.

The request from VCC was to conduct an investigation of the verification process of the P11-project. As a starting point, an explorative investigation is carried out with the intention of acquiring knowledge of VCC and the product development process. Additionally, a more precise problem definition is formulated. This is followed by a descriptive investigation aiming for an in-depth report of the situation related to the problem area. The reasons for problems at late stages in the development process are identified using an explaining investigation approach.

2.2 A case study

There are several methods to apply when performing an investigation. Once the purpose and the type of investigation were determined it was decided to perform this investigation as a case study. So what are the characteristics of a case study and why was this methodology chosen for the thesis?

2.2.1 When to use a case study

The first important aspect to take into account when deciding to use a case study is what kind of situation to be studied. A case study is an investigation of a specific occurrence, a person, a group of people, or a course of events. By examining the chosen object the aim is to create a broader understanding of other events. This thesis fits into that category by focusing on certain types of events, the verification process of product development within a well defined project, the P11.

Three main issues should be taken into consideration when deciding to use a case study; the type of questions asked, the amount of control over and possibility to manipulate relevant variables, and the degree of focus on current situations as opposed to historical events. Case studies are suitable when it comes to questions like "how" and "why" and when the researcher has little or no possibility to manipulate or control the variables and parameters of a current situation to be examined. The case study methodology was found to be appropriate for the master thesis after reflecting upon the issues mentioned. The investigation included questions like *how* the problem-solving worked and *why* there were problems remaining at late stages. Furthermore, the study was to be performed without affecting or controlling any of the observed variables or events. A decision was also made to choose a current and ongoing project as the basis for the study.

2.2.2 Planning a case study

Once a case study method is chosen it is important to develop a plan that ensures the reaching of the objectives at the right ambition level. It should serve as a roadmap guiding the work between the opening questions and the final result. This process is made up of certain crucial activities that must be performed in order to be successful, i.e. collecting and analyzing relevant data.

A number of questions should be raised and dealt with when creating a plan for the case study; which problems to be studied, what kind of data is relevant, what data should be collected, and how the results should be analyzed. These questions form a foundation for the working plan and addressing the following issues will result in a well defined case:

- Problem definition – what type of questions the study is aimed to investigate.
- Assumptions – by making certain assumptions an idea about where to look for answers to the research questions is obtained. The assumptions also help in limiting the work.
- What to be analyzed – define the case. Here limits are formulated regarding the scope, in terms of organization, time, and project, of the investigation.
- Connection of data to assumptions – compare the assumptions with the facts found in the analysis.
- Interpreting the results.

Having a clear and well defined case is the basis for collecting important and relevant data. By focusing on the problem areas of the case data can be gathered, through for example interviews with key persons. Though working in this way will be helpful for attaining relevant data it does not ensure the validity of the conclusions drawn. For this reason it is necessary to apply some verification of both the data collected and the conclusions reached.

Our thesis has evolved by working in loops. In this way we got from a general state, with a broad perspective and problem description, to a more in-depth and detailed investigation. It was not so much a choice as a necessity to do it in this way, because of the amount of new and complex information we needed to handle and get a grip on. Therefore we have at certain times returned to reevaluate the case and its prerequisites in order to keep it manageable and relevant. This is most obvious in the case of delimitations where we have gone from a wide and basic scope towards a more distinct and limited one as we understood the magnitude and complexity of the issue investigated. By gradually gaining deeper insights into the organization, the working methods, and the specific problem, more energy could be spent on actual root causes.

2.3 Data

Gathering and screening of relevant data is an important activity in any research and has to be conducted carefully and with a critical approach. An awareness of the type of data as well as the way it was acquired is essential in order to draw valid conclusions.

2.3.1 Qualitative and quantitative data

An important aspect when performing an investigation is whether to use qualitative or quantitative data. Quantitative methods are characterized by measurable data. A quantitative investigation is highly standardized and structured and is often conducted through questionnaires with pre-designed questions to respondents. A qualitative method focuses on non-measurable characteristics, such as attitudes and values. This type of data is often collected through flexible and non-structured interviews which enable broad discussions. The purpose of a qualitative investigation is to gain an in-depth understanding of the area studied.

This thesis is based on both quantitative and qualitative data. VCC uses a database, Volvo Quality Deviation Control, VQDC, to administer technical deviations in quality matters. VQDC will be thoroughly described in chapter 4.4.2. The system VQDC generates a large amount of quantitative data, which is used to examine statistically the problems registered into the system. In order to find the underlying causes of the problems, a more thorough study with the purpose of obtaining qualitative data must be carried out. Hence, interviews are realized to obtain a broader perspective of the identified problems.

2.3.2 Gathering of primary data

In order to investigate and analyze the problem formulated, information must be gathered. There are two main types of data to use for this purpose; secondary and primary data. Primary data is gathered by the investigator himself. Gathering of primary data is carried out through the use of different techniques:

Observations imply that the investigator observes a course of events relevant to the investigation during a period of time. As an objective spectator the investigator reaches a comprehension of the situation without interfering or disrupting. Hence, the investigator does not have to rely on second-hand information. Worth mentioning is the possibility of the investigator affecting the course of events and the behavior of participants by his presence, and thereby the results of the observation. Likewise, the investigator might be influenced by the behavior of the people observed. The observation technique is restricted by the impossibility to study values and opinions.

To obtain a more in-depth understanding of the manufacturing process and the problems related we visited the assembly factory at VCC's location in Gothenburg. This can be designated an observation study where we followed the flow of manufacturing processes of assembling a car. Additionally visits to the pilot plant, test facilities, and virtual build meetings contributed to the knowledge gathering. It is also worth mentioning that during the entire course of this thesis we were located at the VCC headquarters, provided with our own workplace in the office landscape. This gave us the possibility to observe the daily work of people surrounding us. However, one must be careful not to get too affected in the way of thinking by this, remembering that it is important to maintain a critical and objective attitude towards the case being investigated.

Interviews are a method for gathering data where an interviewer asks respondents questions and raises a dialogue. It is important to clarify the purpose of the interview to the respondent in order to receive as relevant and specific answers as possible. Furthermore, the selection of respondents must be done thoroughly. An interview can be carried out with different degrees of standardization. In a standardized interview the question formulations and sequences are decided in advance and may not alter for different respondents during the investigation. The main purpose with a standardized interview is to analyze the results quantitatively. A non-standardized interview enables a more flexible and adaptable approach. With the single objective of collecting the information necessary for the investigation, a deeper understanding of the area studied is obtained. Often, a combination of the two types of standardization is used when interviews are carried out. A semi-standardized interview is characterized by questions decided in advance, yet with room for flexible discussions related to the problem area.

The primary data used in this thesis was gathered through interviews and a list of questions asked can be seen in appendix 5. Since we were in need of a precise and in-depth understanding of the verification process and the problems related, interviews appeared most suitable. The answers would enable us to identify the most significant problem areas and analyze their causes. As newcomers at VCC without a network of contacts we had to rely on our tutors to select suitable respondents. Some might argue that this selection method is not objective enough as there is a possibility of unknown and underlying reasons for the choice that we are not aware of. However, if we were to make our own choice of respondents not only would it require more time but also, there would be a risk of choosing some that would not be very relevant to the thesis. As a starting point eight Manufacturing Engineers were chosen for their thorough and extensive knowledge of the verification process and involvement in the P11-project. Due to the time limit of the thesis it was not possible to perform a larger number of interviews, something that would have been desired to verify the information more thoroughly. In order to receive a broad perspective and as extensive input as possible we chose to interview Manufacturing Engineers with diverse responsibilities from different divisions. As a complement we carried out interviews with Simulation Engineers, Virtual Manufacturing Technicians and a Pre-Production Engineer to get their opinion of the reasons for problems arisen in the development process. These interviews resulted in a large amount of possible causes of problems. In order to reach an understanding of the most important problem areas and how they affect the development process, additional interviews were realized. We therefore chose to interview a number of people with the responsibility of developing working methodologies as well as being involved in the business development of the process verification, thus investigating some problem areas more thoroughly. A brief description of the various roles will be presented in chapter 4.2.1.

The interviews realized during the work with this thesis were performed as semi-standardized interviews, due to the type of information necessary for us to gather in order to enable an identification of problem areas. Questions formulated in advance were asked with a flexible approach and a possibility to add or remove questions related to the topic and the answers of respondents. A discussion was encouraged in order for us to reach a more thorough knowledge about the development and verification process. The purpose of the interviews was not to enable a quantitative study of the results but a qualitative analysis.

Questionnaires are characterized by gathering of standardized information. The respondents answer the same questions during similar circumstances, which allows a quantitative analyze of the results. A questionnaire can be formulated with either tied answer alternatives to choose from or open possibilities of answers, which enable discussion. Answers are delivered to the investigator in writing. The questionnaire technique is effortless and low in cost, which makes it suitable for investigations with an overall and broad approach. On the contrary, questionnaires are time consuming.

To a smaller extent the primary data used in this thesis constitutes of quantitative data gathered at the interviews with Manufacturing Engineers. At the end of each interview we asked the respondent to rank possible causes of problems discovered and remaining at late stages in the development process by using an in advance created questionnaire. Through that form we wanted to verify the respondent's answers as well as obtain a comprehension of which problem areas might be the most significant. Since the number of respondents was too small to properly be used as a quantitative analysis, the outcome from the ranking list served more as a hint than an actual result. It provided, together with the respondent's answers, an indication of which problem areas to focus the continuous work of the subsequent in-depth interviews on.

2.3.3 Gathering of secondary data

Contrary to primary data, secondary data already exists, by being previously collected and documented by another person or organization. The advantage of using secondary data is its relative low cost and the possibility to save time. This thesis is based on, besides the primary data gathered through interviews, different types of secondary data collected through diverse sources.

As mentioned in the background chapter, the basis for this thesis is the results from the study conducted by Lennart Bengtsson. The available material from Lennart Bengtsson, presented in appendix 4, is secondary data. Since the P28-project studied in his investigation differs from the P11-project, we had to assume that our results might deviate from his. The P28-project in focus for Lennart Bengtsson's study was the first project to use virtual verification in the development process and it is therefore most likely to assume that the working methodology has changed since then. The problem areas he identified have for that reason only served as a guideline for our approach to reach the objectives for this thesis and have been supplemented with primary data related to the P11-project.

VCC provides all its employees access to an intranet. The intranet consists of a large amount of information ranging from the latest news letters and internal department sites to corporate material such as Business Management System. During the work with this thesis the intranet has been a great source of useful information when trying to build a base of knowledge about the verification process during product development. Most of the material presented in chapter four when describing the development process at VCC is retrieved from the intranet. With the vast amount, and complex structure, of that material it is often important to verify the information in order to make sure it is valid and updated for the purpose of this thesis. Additional knowledge has been gathered through the conducted interviews mentioned above.

Problems and deviations discovered in the manufacturing engineering work in the development process are reported in the Volvo Quality Deviation Control system, the VQDC-system. Since the purpose of this thesis was to investigate the reasons behind remaining and new problems at late stages in the development process, the starting point and the foundation of the thesis was the problems reported in the VQDC-system. The database is an extensive system and it contains profound information about the problems registered. The problem information was used as secondary data to create a statistics of when and where the problems were identified during the development process. In some cases the VQDC-information about reported problems was not entirely complete making it hard to perform more detailed statistics. The statistics was subsequently used to formulate question frames in order to enable a more thorough investigation of the problem situation.

Another source of secondary information is the material gathered at VCC by Anders Sundin. As described in the introductory chapter his investigation has a different scope and objective than this thesis. Yet, the area researched in his study is in close relationship to parts of this thesis and his results are therefore of high relevance. Some of the questions asked during the interviews performed in his investigation were coordinated with the interview questions that constitute the basis of the work with this thesis. The interviews conducted by Anders Sundin provided additional material as they were aimed towards persons at higher levels within the organization than the targeted persons in this thesis. The synchronization of the interview questions enabled a comparison of results and served as a verification of the gathered material and its validity. It is important to realize that questions asked by someone else might be formulated, or perceived, slightly different and therefore the answers to such questions have to be interpreted more carefully. A good communication with the person realizing the supplementary interviews allows for a debriefing to be made, thus minimizing misinterpretations.

After having established a knowledge foundation of the problem situation in the P11-project, the next step was to explore existing research and theories through a widespread search of literature. Since the area of virtual verification in the development process is a rather new field of research it was quite hard to find detailed information within that area. A couple of investigations recently conducted at VCC[1] with related topics were studied as well as an amount of articles. Additionally, literature focused on more overall challenges in product development and supporting working methodologies and organizations were examined. Especially the three aspects of time, cost and quality and their effects on the development process and the profitability were studied. Chapter three, Frame of reference and theory, will give a detailed description of the theory related to the current problem situation and the challenges faced during product development.

2.4 Validity and reliability

By discussing the validity of the research it is possible to determine what may be differing between the created theories or results and the reality. It is reached by knowing what to measure, how to get the most accurate data, and by choosing a correct method that corresponds with the formulated problems and goals. The quality of the work based on these decisions can be measured by three criteria:

- **Internal validity:** establishing a causal relationship, whereby certain conditions are shown to lead to other conditions. This kind of validity can also be called credibility.
  In order to reach a good internal validity in our thesis we decided to look upon the problem from a few different angles, especially during the process of the interviews where various types of respondents were chosen. The interviews were then carried out by us and in some cases in cooperation with Anders Sundin. We left the choice of respondents to be made by the Verification Leader of the P11-project[2] after a thorough discussion regarding the purpose of the interviews. Manufacturing Engineers that would be relevant to our case were chosen with an even distribution across departments. When carrying out the interviews we found that after a while the information received was more or less saturated with regards to newness. Furthermore, we ensured a high validity by giving the interviewees a summary of the responses so that they had the possibility to comment or correct misconceptions or errors.
- **External validity:** formulating the domain to which a study's findings can be generalized within. In other words, can the outcome of this case study be valid for other cases, and if so which ones?
  To fulfill the purpose of the thesis there has to be a high level of external validity. Otherwise it would not contribute much to VCC and their future work since it has to be possible to apply the knowledge in more cases than the studied one. It is not easy to evaluate how transferable our conclusions, of this qualitative study, are to a different type of case where the prerequisites are different.

[1] Almgren (1999) and Paulin (2002)
[2] A description of a verification leader is presented in chapter 4.2.1

- **Reliability:** the possibility to reproduce operations, i.e. data collecting, with the same result each time. This reliability is to be used within the case and will not guarantee that the procedures can be repeated with the same results in another type of case.
  When performing a qualitative study like this one the reliability may be difficult to reach completely as the source of our data, the people involved in the project studied, may change over time.

A way of visualizing validity and reliability is to think of it as arrows thrown at a dart board, see figure 3. The left picture shows a case of good validity but a poor reliability, meaning the darts have good general accuracy but they are spread over a large area. The other dart board shows a case of poor validity but a good reliability, in other words, the darts all miss the target but the aim is the same each time.[3]

Figure 3. Validity and reliability.

[3] www.infovoice.se, 2004-02-03

3 Frame of reference and theory

The *Frame of reference and theory* comprises a theoretical foundation for the thesis. The theory presented in this chapter supports and aids the analysis and discussion of the investigation results. It is aimed to provide the reader with a background to the aspects and challenges of product and process development, in particular the verification processes.

The chapter begins with a description of the general business environment in terms of competition and the forces driving efficient development. It continues with emphasizing on the time aspect of development by describing the product life-cycle and the return map. Further, the verification in the development process is addressed, followed by an account of the virtual and physical pre-series used for verifications in terms of quality, cost and time. The concept of front-loading is described together with the challenges and implications related. In conclusion, the importance of knowledge management is addressed and reflected upon from several different perspectives.

3.1 Challenges for efficient development

In the harsh business environment of today it is necessary to focus on the ability to develop new products and processes with perfection in order to maintain competitiveness on the global market. The international competition has become more intense as the world trade has increased with companies trying to conquer new markets. The number of world-scale competitors capable of delivering high-quality products to customers has increased, resulting in the challenge of today; to compete on previously unexplored and inaccessible market areas. At the same time, markets have become more fragmented as costumers have grown more demanding. Equipment previously considered extraordinary are standard requirements today. Sophisticated customers with a desire for personal solutions have increased in number resulting in an amplification of product variety. Products must be adjustable in order to suit diverse demands and satisfy customers. Similarly, the rapidly changing technologies are an important aspect in the dynamic competitive environment. New opportunities have been created as an effect of broad technological knowledge. Through diverse technology development a variety of solutions have been made possible, resulting in wide product characteristic offers. The mentioned aspects can be summarized in three main imperatives for successful product and process development which are of vital importance and need to be maintained in focus[4]:

- **Fast and responsive development**
  In order to shorten development cycles and offer better targeted products companies must be responsive to changing technology and customer expectations while observing the moves of their competitors. Companies must be fast in identifying opportunities and respond to them.
- **High development productivity**
  As product life-cycle has shrunk companies must deliver a larger number of new products to markets in order to remain profitable. To achieve this, the number of successful development projects must increase, implying different projects must be run at the same time, which requires resources well distributed among them.

[4] Wheelwright et al. (1992)

- **Products with distinction and integrity**
  When competition is intense it is essential to be capable of attracting and satisfy customers to a greater extent. The products offered must be of high quality and distinction to reach and exceed customer expectations and maintain competitiveness. The total quality and experience of the product must be in focus.

The imperatives for successful product and process development are coherent and consequently equally important. In order to obtain an advantage in the market place a company must be able to manage and make use of these imperatives. A company capable of developing products and processes while fulfilling the imperatives will turn into a fast-cycle competitor. Such a competitor has a number of options to choose from. One way is to release a new product before the competitors, thus achieve a market advantage. Another possibility is to delay the start of a new developing project in order to acquire better information about the market demand and customer expectations, resulting in a better targeted, high-quality product introduced at the same time as its competitors. A third option is to make use of the resources freed through effective development and relocate them to additional development projects. [5]

3.1.1 Product life-cycle and return map

A consequence of the intense global competition is the decreasing product life-cycle. The product life-cycle refers to the period from the first launch of the product on the market until it is finally withdrawn. As new products are introduced at a higher rate to the market, the existing products grow out of fashion more rapidly. As a result, the time for profit making is reduced. [6]

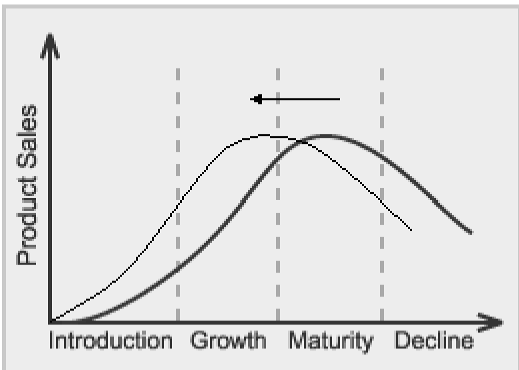

Figure 4. Product life-cycle. The product sales as a function of time. [7]

A product passes through a number of life-cycle phases illustrated in figure 4. During the **introduction** phase the company seeks to establish the product on the market. The **growth** phase is characterized by rapidly increasing sales as marketing efforts pay off. Then, follows a phase of **maturity** where the strong growth in sales diminishes and the company

[5] Wheelwright et al. (1992)
[6] www.quickmba.com, 2004-02-03
[7] Ibid.

aims to maintain their position on the market. Finally, as the product grow out of fashion, product sales decreases in the **decline** phase.[8]

Time to market is a critical success factor in today's business environment. The challenge is to reduce the development cycle without sacrificing the performance and quality of the product.[9] The decreasing product life-cycle further emphasizes the importance of delivering new products through an effective development process to maintain profitability. The effect time has on profit and cost is well illustrated by the return map (figure 5), developed by Hewlett and Packard.[10]

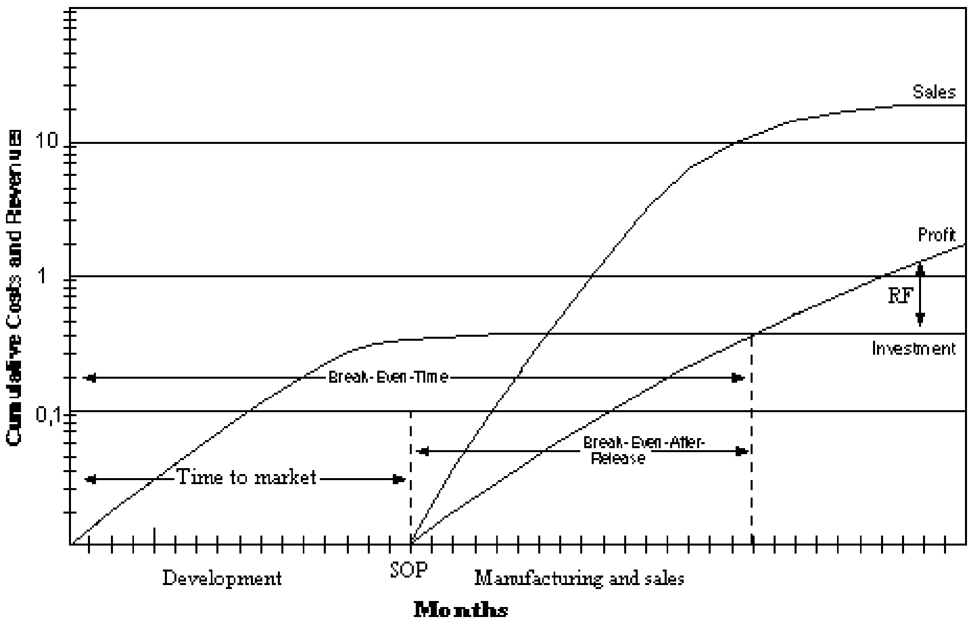

Figure 5. The Hewlett and Packard return map.[11]

The total development time, from the beginning of the product development until the point where manufacturing starts at SOP (Start Of Production) and the product is introduced to the market, is defined as the **Time-to-Market.** The **Break-Even-Time** is the total time from the start of product development until the product profits equal the investment of the development project. To measure how efficiently the product was introduced to the market the **Break-Even-After-Release** is used. It refers to the time from the start of manufacturing and market release to the Break-Even-Time. Finally, the **Return Factor, RF,** is a calculation of the profit divided by the investment at a certain time during the manufacturing and sales phase, which gives an indication of the total return on the

[8] www.quickmba.com, 2004-02-03
[9] Cohen et al. (1996)
[10] Almgren (1999)
[11] www-mmd.eng.cam.ac.uk, 2004-02-03

development investment at that specific point in time.[12] Summarized, the return map provides an indication of product development and release effectiveness.

Bill Hewlett, founder of Hewlett and Packard said, "*You cannot manage what you cannot measure",* implying that employees need an understanding of the interrelationship between different functions and how their work affects and contribute to the overall product success. The development phase of the return map covers all the different functions in the company such as R&D, marketing, and manufacturing engineering. Following, in the manufacturing and sales phase of the return map, the factory and sales departments, amongst others, become responsible for the product. The return map can be used to analyze the impact of changes in different functions on the entire product project. The most important feature of the return map is to visualize the effect of a delay in market introduction on the other measures.[13] This thesis is directed towards the main part of the development phase of the return map and will emphasize on effectiveness during that phase.

3.2 Verification in the development process

All development projects include verification processes. Verification can be defined as an activity conducted to evaluate the new product and its manufacturability with the purpose to[14]:

- Eliminate product errors regarding certain parameters
- Ensure that the instructions for assembly are correct
- Confirm the production process

In other words, verification consists of activities ensuring that the new product can be produced at the right time, with the right quality at the right cost.[15]

It is important to perform the verification process continuously, throughout the development process, in order to make needed adjustments, thereby assuring that goals will be reached. There are a number of different types of activities used when verifying the product and process developed. For example laboratory testing, Failure Mode and Effect Analysis (FMEA), mock-ups[16], pilot manufacturing processes and field tests. Depending on the parameters subjected to verifying and when it is done, one or more of these methods are used.[17]

The Manufacturing Engineering department uses verification to assert that all the parts or components can be successfully assembled, and also disassembled, by either humans or robots at the factories, or service stations[18]. Since the process is highly dependent on the product, any problems identified, or changes made, in components, or systems, affect the production process and vice verse. By applying Design for Manufacturing, DFM, during

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[12] House et al. (1991)
[13] Ibid.
[14] Paulin (2002)
[15] Ibid.
[16] A mock-up is a full size structural model built accurately to scale chiefly for study, testing or display.
[17] Sandholm (2001)
[18] Gomez de Sá et al. (1999)

the development process the product-process fit can be optimized through simultaneous design. DFM aims to reduce development cost and time by minimizing mismatches between product and process design, thus improving the problem-solving of the verification process.[19] In order to focus on linking product and process design, a well established cross-functional communication throughout the organization is required.[20]

3.2.1 Virtual and physical pre-series

The verification process introduced above is handled by the use of a number of repeated pre-series. A pre-series can be described as a set of activities performed, during a defined time period, in order to reach a more defined product and process as a whole. First of all iterated work loops are carried out with the purpose of reaching the desired quality of the product and its manufacturing process. At the end of a pre-series a formal verification is performed using prototypes for both product and process. Two different types of pre-series are used; virtual and physical. During early stages of the development process a number of virtual pre-series are performed. This implies the use of digital models and simulations when developing and verifying the product and process. Virtual prototypes are widely used in product development today because of its advantages of cost and time efficiency. Physical pre-series are of a more conventional character, using hard tools and real prototypes as test objects.

Today, focus when developing products is on the use of virtual methods. The existing research performed in the area of virtual verification and development, all emphasize the advantages of using virtual methods in different areas of the product development process. Few studies mention the evident reality; the continued usefulness and value of the physical prototypes. There are several advantages of physical prototypes well worth mentioning. Firstly, there are some technical limitations of the virtual verification tools making the physical pre-series indispensable. In the virtual world it is difficult, or not even possible, to control and verify all details of the product and production process. Virtual simulation tools may give a result which not corresponds accurately to the reality, resulting in mismatches during construction of physical prototypes if there is a lack of awareness of this. Physical prototypes are superior when it comes to visualizing the product. It enables employees involved in the development process to actually look at the product, thus facilitating communication of problems and solutions concerning the product. A well defined balance between physical and virtual prototypes is preferable.[21]

3.2.2 Pre-series quality

The effectiveness of the development process depends on the quality of the virtual and physical pre-series. Good quality in this sense refers to the reliability and validity of the pre-series which is affected by the status of the models used.[22] Since virtual models are increasingly used in the development process for problem-solving, and as a base for decision making, it is important to validate their status. A valid model is defined as a model with an acceptable range of accuracy consistent with its intended application. A virtual model must be developed with a specific purpose, describing its intended use and status. When the model is used for problem-solving and decision making its validity is determined

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[19] Almgren (1999)
[20] Wheelwright et al. (1992)
[21] Vasilash (2003)
[22] Almgren (1999)

regarding to that purpose. In other words, the simulation result must be evaluated with respect to the status of the models used. An accurate simulation will increase the quality of the analysis. Another aspect of problem-solving and decision making with virtual models as a basis is the user confidence of the model validity and the accuracy of the simulation results. In order to use a model and the information related, model credibility is required. To reduce the number of physical pre-series, decisions must be made with the support of a confidence in the virtual models. Accessible models shared between concerned parties enable high quality pre-series, which in turn allows for concurrent engineering and DFM. Consequently, this results in increased development efficiency.[23]

In order to maintain customer satisfaction, quality methodologies must be implemented throughout the pre-series work. Efficiency and quality are closely interrelated and to obtain an efficient development throughput and a high-quality final product several methods can be used. Quality Function Deployment, QFD, is a way of thinking to ensure the improvement of quality and productivity. It focuses on close awareness of customer desires together with integration of organizational functions in the design of new products.[24] QFD is important during the early stages of the development process where the product design and targets are set and implies increased resources to be spent during early product development to create a better targeted product and avoid engineering changes at later, more time and cost consuming stages.[25] By continuously verifying the quality of the product with regards to market requirements and future end customers, non-value-added activities and redesigns that will not benefit the final product will be removed. QFD serves as a method of planning and control of product design and quality meeting customer demands, resulting in a more efficient and less variable process. This type of awareness is important to ensure the quality of the final product and should be present throughout the development process in order to maintain customer demands in focus.[26]

3.2.3 Pre-series cost

The development cost of a product is set at the design stage, where prerequisites for the product and process characteristics are formed. The main cost however, is spent at the manufacturing stage. Furthermore, costs within the manufacturing engineering work changes over time. The cost required to make product and process changes increase quickly as a development project progresses. Any changes made to the product during the virtual stage should have little impact on the total product development cost. However, changes made during the physical pre-series stage, invariably adds heavily to the cost.[27] This is partially due to tooling commitments where firms are often forced to "lock-in" design choices as early as possible.[28]

For these reasons it is preferable to discover problems early which provides for a less costly change to be carried out. Experience has shown that substituting some of the first physical pre-series with virtual ones can cut the costs a great deal.[29] But what is actually driving this cost reduction when using virtual pre-series? Firstly, the ability to manufacture the first real

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[23] Sargent (2001)
[24] Rosenthal (1992)
[25] Wheelwright et al. (1992)
[26] Rosenthal (1992)
[27] Rooks (1998)
[28] Thomke (1998)
[29] Thomke et al. (2000)

car with as few problems as possible saves money from being spent on expensive redesigns of both product and tools. Conflicts between components may for example be discovered in the virtual pre-series, and then be easily solved. These would otherwise cause large costs in physical pre-series due to the high expenses of for example new tools, concepts or even factory changes. Furthermore, performing pre-series in a digital manner is far less expensive than building physical ones. Resources used are mainly computers, which are by now relatively cheap in relation to their capacity, software licenses, and engineering hours. Building a virtual prototype is therefore nowhere near as expensive compared to building a physical one, where every component and part must be manufactured, often using new methods and tools. Digital simulations also provide a good basis for taking the right decisions at an early stage, thereby reducing the amount of poor judgments often leading to expensive makeshift solutions.

3.2.4 Pre-series time

Cutting the total development time puts a pressure on all activities involved to be carried out more effectively and at a quicker pace. Improving the verification pre-series will be one important contribution to this goal. Not being able to handle changes in product and process in an effective way during the ongoing development may delay the launch of the product, with consequential effects on sales and costs.[30]

The total development time can be shortened if the problem-solving rate is increased by carrying out design and test cycles more rapidly. These cycles can be compressed by restructuring prototype build and test process.[31] Previously, the only way to verify the product and the process was to build physical prototypes. This is a very time consuming activity since it relies on all the levels of subcontractors and their ability to deliver new versions, often produced with new tools. With virtual pre-series as a complement to the physical ones, it is now possible to perform build and test cycles more frequently as they can be carried out faster. Designers, production engineers, suppliers, and subcontractors can all view and interact with the digital prototype using various CAx tools[32]. Decisions on design changes and improvements can be made in minutes and hours rather than the days and weeks it takes when a physical model is used. Through system networks, up-to-date modifications can be accessed by all the concerned parties. This is a major contributor to concurrent engineering, a truly time saving development strategy.[33]

As a vision, manufacturers see the physical mock-ups replaced by digital ones, resulting in a ramp-up of production straight from virtual models of both the product and the process.[34] This scenario will not be realized for a long time but in the mean time major improvements can be made by combining the testing of hardware prototypes with simulations of computerized ones.

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[30] Rooks (1998)
[31] Thomke et al. (2000)
[32] CAx is common name for computer-aided design (CAD), engineering (CAE), and manufacturing (CAM).
[33] Rooks (1998)
[34] Gomez de Sá et al. (1999)

3.3 Front-loading

Problems discovered during the development process can be defined as a gap between the current design (plan, process, or prototype) and the customer needs, the customer being both the factories as well as the end user.[35] Managing problem-solving is vital for industrial companies in order to perform their product and process development in a superior manner. Today there is a great concern about identifying problems at an earlier stage since this becomes increasingly time consuming and costly as projects progress. The term "front-loading" is often used in this context. It can be derived from the wishes to reengineer the development processes by moving, or "loading", the problem identification and solution backward in time, to the "front" of the process. Figure 6 visualizes the concept of front-loading. Thomke and Fujimoto define front-loading problem-solving as *a strategy that seeks to improve development performance by shifting the identification and solving of [design] problems to earlier phases of a product development process.* [36]

When measuring the performance of the development process three dimensions are of most interest; lead time, productivity, and product quality. The time it takes for the firm to move a product from a concept phase to the market is called the development lead time, whereas the productivity measures the resources (e.g., engineering hours, material, equipment) required to accomplish the same objective. The output of the process results in a product, where its complexity and the extent to which it conforms to customer expectations are key drivers of the product quality. Problem-solving by front-loading, as mentioned above, is an approach to improve these performance dimensions. Benefits from early problem identification and solving can be quite remarkable and provide an area of great leverage for improving product development performance.

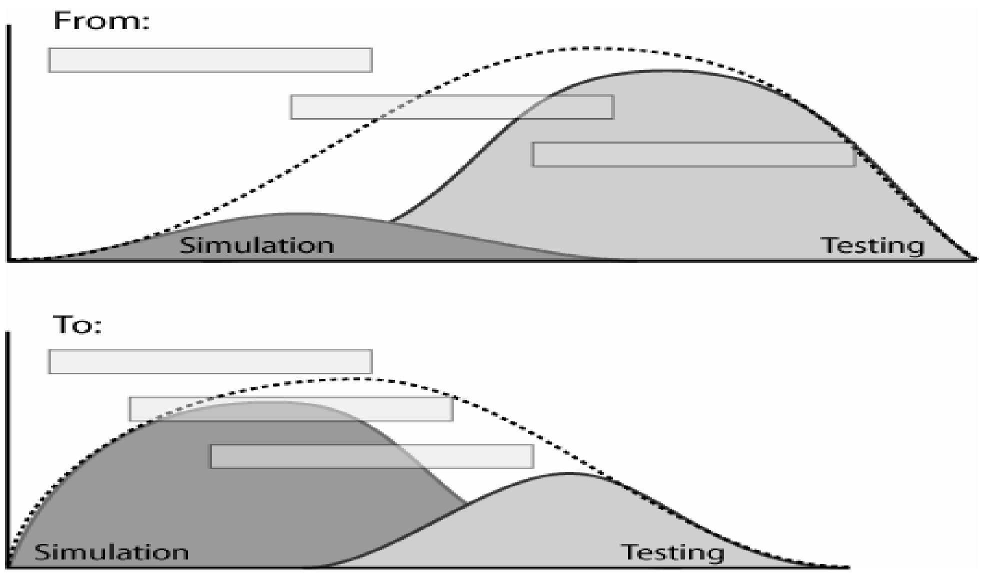

Figure 6. Front-loading visualized[37]. The three rectangles in the figure can symbolize different types of activities performed during the verification process, i.e. product development, procurement, and marketing.

[35] Wheelwright et al. (1992)
[36] Thomke et al. (2000)
[37] VCC Intranet

Automotive development consists of series with numerous problem-solving cycles, basically containing four steps; design, build, run, and analyze (d-b-r-a). These problem-solving cycles vary in size, some being small and perhaps only including a single simulation experiment whereas others are large and involve several development groups. These cycles tend to include more complete models as projects progress. Once a problem is framed, the first step of the problem-solving cycle is to conceive of, and design, one or more alternatives as solutions to the problem. When this is done the various aspects of the new solution has to be visualized by building a relevant prototype. During virtual pre-series it is done by creating computerized models which are tested by using simulation software and then run in so called digital mock-ups. The final step aims to analyze the results in order to take decisions regarding how to proceed, depending on whether the solution corrected the problem or not.

The models, both virtual and physical, used in the problem-solving cycles are sometimes incomplete because it may not be possible to economically incorporate all aspects of "reality" or that one simply does not know them. It may therefore be more economical to build incomplete models, reducing them through leaving out irrelevant aspects of "reality". For example, testing a car in a wind tunnel does not require the interior for the test to accurately show aerodynamic performances.

Achieving effective front-loading can be realized through several different approaches. One approach is called *project-to-project knowledge transfer*. It involves the transfer of problem and solution specific information between development projects to reduce the number of unique and new problems to be solved during the development phase. For this to work the information must be created, made available, and recognized by concerned parts of the organization. However, it is a hard job bringing about an effective way of implementing this knowledge transfer, often resulting in the rediscovery of old problems in new products and processes. Another approach to front-loading is that of *rapid problem-solving*, which is obtained by using advanced technologies and methods to increase the overall rate at which development problems are identified and solved. The use of low costing and faster computer-aided tools (CAx) permit a high rate of problem-solving, particularly at the early stages of the development. Furthermore, this allows faster and more frequent d-b-r-a cycles.

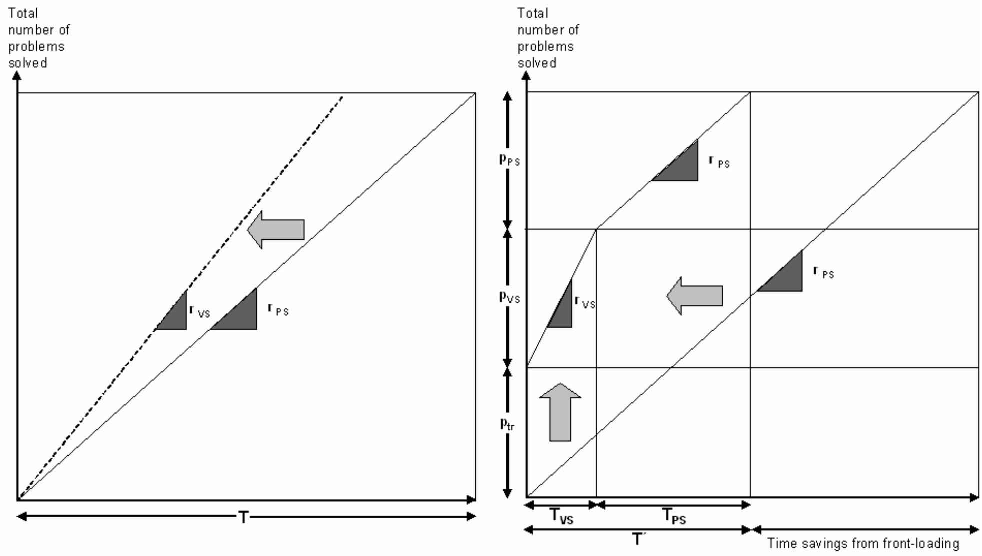

Figure 7. Effects of front-loading approaches.[38]

A way of illustrating the two different approaches to front-loading is seen in figure 7. The left graph visualizes a situation where problems are being solved only with physical prototypes at the rate r_{PS}, depending on the frequency of the d-b-r-a cycles, and all problems are then solved in the time T. The aim of rapid problem-solving is to increase this rate and that can be realized if the cycles are iterated more often, resulting in a steeper solution curve. Using virtual prototypes is a way of achieving more frequent d-b-r-a cycles. The rate of problem-solving can then be increased and is seen as r_{VS}. It is however not possible to reach this shift completely as there exist a profound need for physical prototypes. To the right, both approaches of front-loading are incorporated showing their contributions to the shortened development time. First of all, if project-to-project knowledge transfer is applied it is possible to start the overall process with a number of problems already being solved, or "avoided", seen in the graph as p_{tr}. If, when commencing with the d-b-r-a cycles, virtual prototypes are used the rate of problem-solving is r_{VS} and a number of problems are solved in this way, p_{VS}, during the time T_{VS}. As the development process enters the stage where physical prototypes are used in the problem-solving cycles there is a decrease in the solution rate, r_{PS}. Solving all the problems related to a project can, through the combination of the two approaches, be realized in a shorter period of time, T´.

The benefits of virtual development are, as described above, obvious when it comes to shortening the lead time of product development through rapid problem-solving. It is however important to combine these efforts with traditional hardware prototyping as virtual models are not yet of high enough fidelity. When it comes to project-to-project knowledge transfer it is not enough to only transfer information on problems in order to reach the proposed effects. A significant part of the transfer is communicating the reason for why the problems occurred. Equipped with such information, developers may be even more responsive to identifying and solving problems early. As a conclusion to these arguments, Thomke and Fujimoto[39] state that shifting problem-identification and problem-solving to

[38] Thomke et al. (2000)
[39] Ibid.

earlier phases in development can be seen as an explicit objective for automotive firms. Faster development will then be an indirect benefit of having solved more problems at these earlier stages.

3.4 Knowledge management

In the present product development environment, knowledge has become a key resource. Companies have previously focused on making their plants and manufacturing processes as efficient as possible through managing physical and tangible resources. However, the area of emphasis has shifted from productivity towards managing knowledge within the organization.[40] Knowledge management can be described as a process of facilitating activities such as creation, capture, transformation and use of knowledge.[41]

Any product or process can be copied and transcended by competitors. In contrast, knowledge is sustainable and embedded in the competences of a company and its employees.[42] In order to survive in a complex and dynamic environment, organizations must be efficient in managing knowledge.[43] At the same time as the need for an efficient knowledge management increases, the globalization and decentralization of companies contribute to augmented challenges in succeeding that task. Global firms face difficulties with differences in languages, cultures and mindsets. Furthermore, the configuration of development teams is dynamic and variable, and team members are often spread across different departments, countries and companies. The internet revolution has facilitated the distribution and availability of information. Through for example company intranets information is shared to a greater extent, as it is accessible for employees worldwide. However, the increased computerization has also contributed to an enormous amount of available information, resulting in difficulties finding and handling relevant and useful information.[44]

Ensuring knowledge sharing is of vital importance for large organizations which are geographically dispersed in different locations. By sharing knowledge throughout the organization's different locations, the employees are likely to increase their knowledge and thereby contribute to increased efficiency.[45]

3.4.1 Individual and organizational knowledge

Defining knowledge is not easily done. Its intangible and obscure nature results in various apprehensions of how to define it. Nevertheless, knowledge can be described as an organized combination of ideas, rules, procedures and information.[46] Knowledge can be divided into two different types; explicit and tacit knowledge. Explicit knowledge is objective knowledge that can be coded and stored, and is transmitted in formal systematic language. Tacit knowledge on the other hand, is personal and contains sets of values, conventions and sensations which constitute a basis of both theoretical and practical

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[40] Davis (2001)
[41] Bhatt (2002)
[42] Mohrman et al. (2002)
[43] Bhatt (2002)
[44] Mohrman et al. (2002)
[45] Bhatt (2002)
[46] Ibid.

knowledge. It represents the knowledge we possess without being able to formulate it explicitly and is therefore more difficult to communicate.[47]

Only a part of the tacit knowledge is internalized by the organization, it often remains with the employee who possesses it. For that reason it is essential for organizations to ensure sharing of knowledge. Through sharing tacit knowledge with other employees, it can eventually be made explicit and formalized in documents accessible throughout the company.[48] If individual knowledge is not shared with others, it will not contribute much to the organizational knowledge foundation. Hence, an important challenge for management is to facilitate and encourage employee interactions, thus enable a more extensive organizational knowledge.[49]

3.4.2 Learning from development projects

The success of product development depends on companies´ ability to retain knowledge and learn from experience. When concerned with product and process development, learning from experience signifies learning from development projects. In order to improve and maintain development performance it is vital to preserve experience from previous development projects. However, post-project learning is not necessarily a natural occurrence. Firstly, the connection between cause and effect may be considerably separated in time and place, which complicates the identification of connections and relations. An outcome of interest may not be evident until long past project closure. Secondly, organizations tend to press forward towards the preceding development project without paying much attention to the past project. If management does not emphasize the importance of post-project learning it is unlikely that employees will devote any time for that purpose. Furthermore, it is important to point out that learning from experience does not only imply learning by encountering and solving problems, but also learning from those things that went well. [50]

The aim of post-project learning is to ensure that the lessons learned from each development project are shared and applied throughout the organization.[51] Often, employees in different parts of the organization rediscover problems or reinvent already existing solutions. By establishing systems of information and making them available for employees, "they will know what the organization knows" and avoid lessons being learned twice.[52] If the experience and knowledge obtained through the realization of a product development project are used in preceding projects, numerous problems and complications can be avoided. As a result, a more efficient, high-quality development process can be carried out in less time and to a smaller cost.

[47] Johnson et al. (2002)
[48] Mohrman et al. (2002)
[49] Bhatt (2002)
[50] Wheelwright et al. (1992)
[51] Ibid.
[52] Mohrman et al. (2002)

4 Development process at VCC

In this chapter certain parts of the development process at VCC will be accounted for. The emphasis will be on the phase of the development project during which the pre-series and the verifications are performed. Furthermore, parts of the organization supporting the verification process and the role descriptions of those concerned are presented in brief. Additionally, the virtual tools used during the development process are described. At last, two of the most important verification tools used during the verification process are presented. By providing a description of the current situation we aim to create a better understanding of the development process and the possibilities for improvements within that process. The account of this development process, within the defined scope, is a foundation for the discussions held in chapters six and seven.

The information presented in this chapter is to a great extent gathered from the material available on the VCC Intranet. Additional knowledge has been attained through the interviews conducted during the research work of this thesis.

4.1 Product development

An important core competence necessary for VCC, as any producing company, is the ability to always develop products in the most effective way with regards to the environment and context they are part of at any time. As those circumstances constantly change it is a tough challenge to perform well as it often requires an organization to be both agile, in terms of implementing new working methodologies and technologies, and patient enough for new ideas to have the desired effect. Product development is a broad term encompassing almost the entire organization and therefore it is not possible to give an extensive view of all its parts and how they are performed. Hence, focus will here be on areas chosen because of their relevance to this thesis.

4.1.1 Common platforms

Since a few years back VCC is part of Ford Motor Company, FMC, and together there are efforts being made as to making use of the possible advantages this collaboration permits. FMC is a large corporation including various brands such as Volvo, Mazda, Land Rover and Jaguar. The impacts of the relationships within this concern are of course of a complex and extensive nature and they affect VCC as a whole. For the product development there is one important aspect necessary to mention in this context. Some of the products developed by these brands are of similar types, for example medium sized sedans or Sport Utility Vehicles, SUV:s, and therefore there is a desire to take advantages of this when developing new cars. One way of doing this is to jointly develop platforms that are common for different brands, thereby sharing the costs as well as reducing the development time. With so many different development organizations involved, sharing the same parent company, it is a desired opportunity to make use of the best practices developed. The so called common platforms constitute foundations of the product that are shared and reused by different brands, for example system or component solutions that are used by a number of projects. In the case with P11, it was the first project that truly incorporated the use of a common platform, called the C1-platform and developed together with Ford and Mazda. An effective development of this type requires good synchronization of the work performed in order to enable for all parties to affect the outcome by taking part in shaping the prerequisites. Creating commonality between brands is a big advantage, though it requires a lot of planning and organizing to be carried out effectively. For that purpose, efforts are made to create a Global Product Development System, GPDS, which will facilitate the joint development programs by aligning and integrating the processes of the included brands.

4.1.2 Volvo Product Development System

Product and process development constitutes a complex set of activities involving a lot of people and is carried out over a long period of time. For this reason it is of vital importance that the projects are managed and run in an organized and effective manner. The overall business needs drive the continuous development efforts at VCC. This approach to product development has been named Business Driven Product Development and has resulted in a need for a method that comprises three main areas of development processes; Business, Commercial, and Product and Manufacturing. The three development processes are all dependent upon each other and to manage the interaction between them the Volvo Product Development System, VPDS, is used. Figure 8 presents the output objectives of the interactive VPDS, as well as the focus and responsibilities of each area during the development process. The research area for this thesis lies within the product and manufacturing development process, which will therefore be described in further detail here.

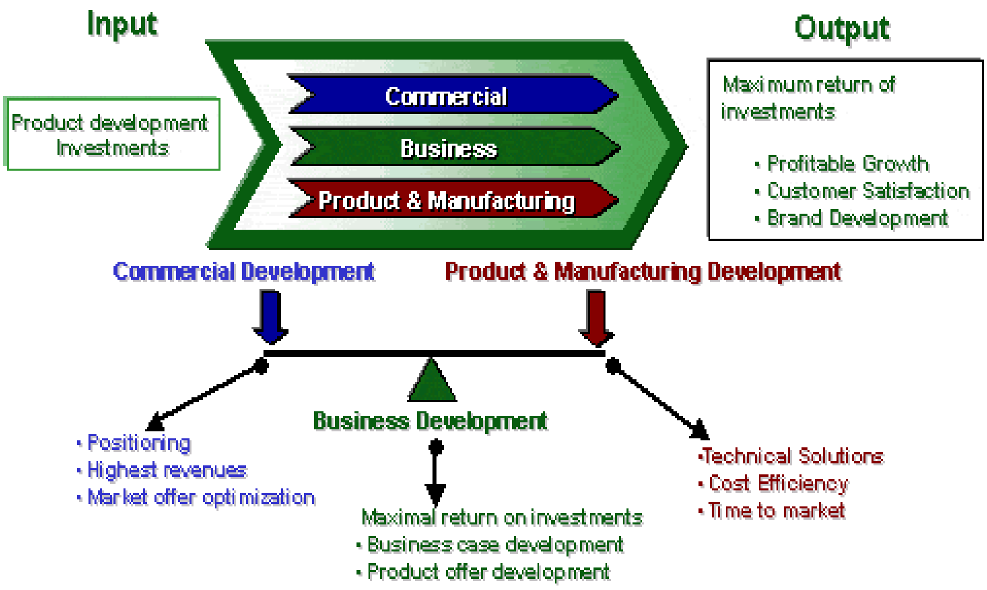

Figure 8. VPDS. Visualization of its three sub areas; Commercial, Business, and Product & Manufacturing.

The Product and Manufacturing Development Process within VPDS focuses on a few major issues. How well the development of technical solutions is performed is expressed as *quality of execution,* whereas *cost efficiency* aims to control its own working costs. Furthermore, *time to market* measures the period of time required to finish a project as well as when the benefits will be received.

Each development project follows an overall plan. Since the thesis focuses on the Manufacturing Engineering department a description of their processes, within the overall plan, is presented in figure 9. The Manufacturing Development Process, MDP, contains information of what and when activities are performed during the development. The purpose of MDP is to secure an efficient and validated work procedure for manufacturing engineering. In the manner of concurrent engineering several activities are carried out simultaneously within the MDP. As clearly visualized in figure 9, the MDP consists of numerous activities interacting in a complex manner. Some of the processes will be further presented at a later stage in this chapter, while others are left out since they are not part of the scope for the thesis.

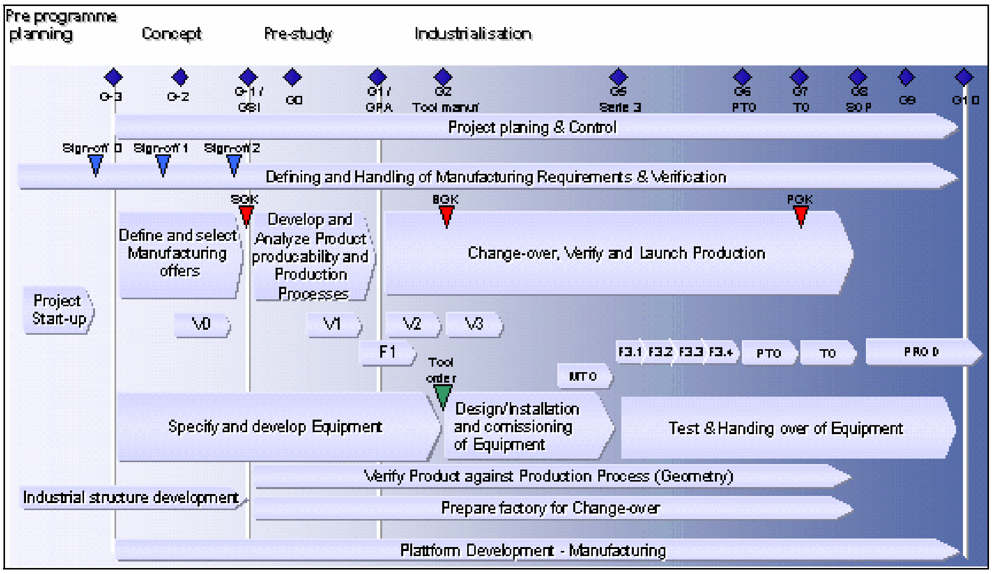

Figure 9. Manufacturing Development Process. The figure visualizes the complex interactions of activities that are run in parallel within the Manufacturing Engineering department. The scope of this thesis stretches from G1 to G7.

In the broadest sense there are three phases during development, namely the concept phase, the pre-study phase, and the industrialization phase. The phases are represented in figure 9 as the three areas separated by the vertical lines. In the concept phase the foundations for the product are set. Decisions are here made regarding what kind of product should be developed and which market segments targeted. The product and the manufacturing processes are defined regarding for example design, system solutions and commonality with other projects or brands. Planning of the pre-study and industrialization phases is also realized. The purposes of the pre-study phase are to develop and start verification of the product and manufacturing processes based on the concept chosen and delivered from the previous phase to ensure a high quality final product. The target of the industrialization phase is to perform final verification of the product and the manufacturing process to assure the final demands set fourth are met. In the later stages of this phase, the solutions are implemented at full scale and production ramp-up starts.

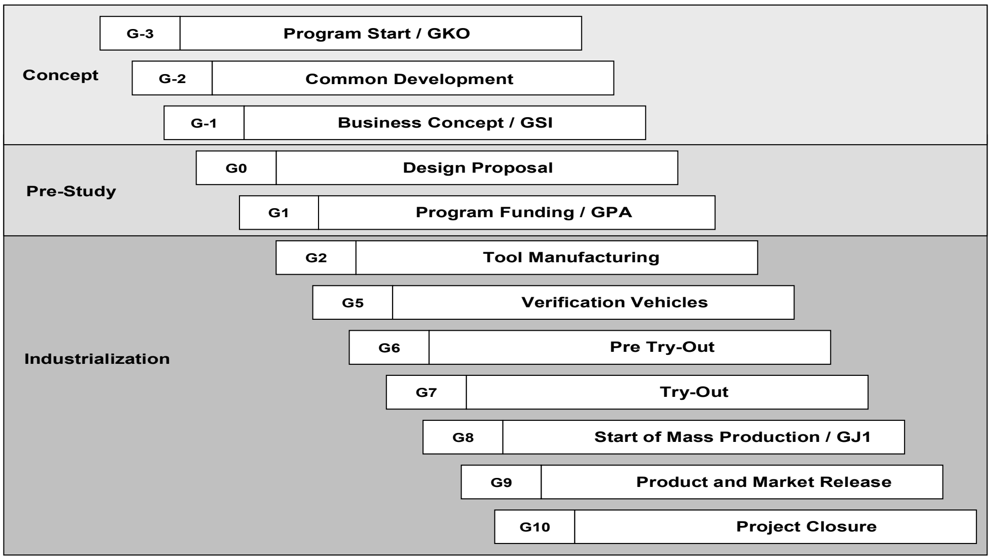

Figure 10. Gateway matrix.

The activities within the development phases are performed in order to reach the goals set forth and followed up by what is called the gateway system. This system consists of a number of gates, starting with a kick off at G-3 and ending with project closure at G10, each with specific targets that need to be achieved in order to proceed and guarantee the quality of the ongoing project. Figure 10 visualizes the different gates, which are also visible in the MDP chart in figure 9, and their main targets. The verification process studied in this thesis stretches from G1 up to G6. Thereafter, the manufacturing solution is introduced at full scale into the factories and mass production begins. At G10, when the project closes, the experiences of working methods and processes are documented as *Lessons learned* in order to be transferred to subsequent projects.

4.2 Organization

The main area of the organization in focus for this thesis is the Manufacturing Engineering department, numbered 81000 at VCC. This is the department responsible for delivering the future manufacturing processes in accordance with the decided product program. Organizational maps for all the parts of the organization discussed here are presented in appendix 2.

The Manufacturing Engineering department develops and implements quality assured production systems that bring about an effective production at body, paint, and final assembly plants. By driving forward and coordinating manufacturing engineering activities in the design and product development, a process driven product development is ensured. This implies working in close relation with another main area within VCC, namely the Research and Development, R&D, department. The R&D department is responsible for developing the technical solutions for the various components and systems of the car.

The two above mentioned departments each have their way of organizing themselves, both based on the structure of the car. The Manufacturing Engineering department is organized in what is called the Manufacturing System Structure, MSS, shown in figure 11. A similar structure, with close links to the corresponding department at the MSS, is found within R&D. That structure is called Product System Structure, PSS.

As mentioned in the first chapter, the scope of the thesis is limited to activities directed towards the C-shop, the assembly plant. For that reason, a further description of the R&D organization will not be given here. The sublevels of the C-shop each have their departments within 81000 as well as some departments for supporting functions. One of these supporting departments is Quality, Analysis, and Verification, 81900. It is responsible for coordinating the work performed within the Manufacturing Engineering department with a focus on assuring the overall quality by leading the verification processes until the start of production, SOP. Furthermore, 81900 is involved in the development of virtual manufacturing methods and tools as well as performing advanced virtual simulations.

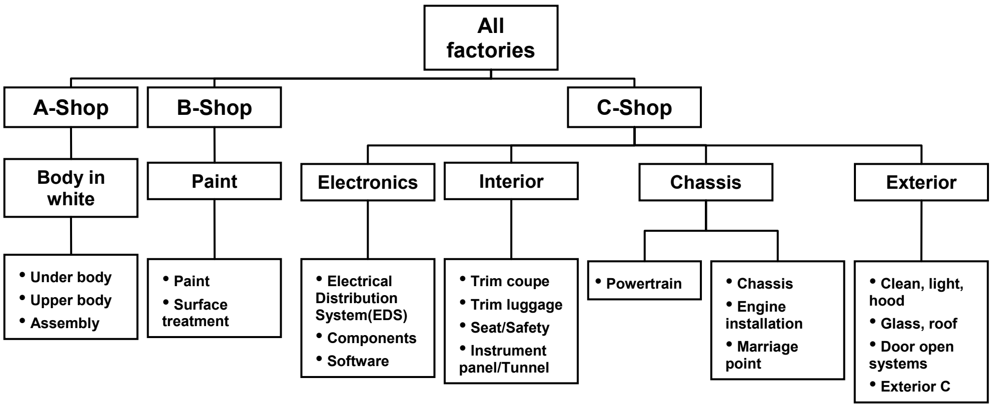

Figure 11. MSS chart

One of the subgroups of 81900 is the verification group, 81970. They are in charge of organizing and coordinating the various verification processes in all development phases, from virtual simulations in early stages throughout the work of development and final verification until start of production. The Verification Leaders, described below, are in charge of running the verification work for the various car projects.

Two important parts of the organization necessary to account for when it comes to virtual development are the manufacturing simulation groups. These two groups are support functions to the manufacturing departments, 81950 focuses on A/B shop and 81960 deals with C shop. They provide an objective and quantitative basis for decisions regarding manufacturing system design. This is achieved through the use of simulation tools which make alternative manufacturing scenarios possible to analyze. To reach these targets, Simulation Engineers with knowledge and experience in the simulation softwares are employed in these groups. Apart from Simulation Engineers, there are within 81960 also some Virtual Manufacturing Technicians with skills in visualizing the products and processes at so called arenas where virtual build meetings are held, something that will be further discussed later.

4.2.1 Role descriptions

Development and running of car projects requires a vast number of people at various positions. For the verification process, and specifically the virtual pre-series, studied in this thesis there are a few roles of particular interest which will therefore be given a brief description below. Representatives from these positions have been interviewed when gathering data for the thesis.

Design Engineer, DE. The main tasks of the DE are developing and verifying systems and components against given specifications, including cost estimates and component time plans. This work is to be performed in a cross-functional way in order to fulfill requirements on various performances. It is their responsibility to deliver 3-D models, at certain stages of the development project, for the use in virtual verification and for the development of prototype tools and materials for physical verification. These models are entered into product databases.

Manufacturing Engineer, ME. These engineers lead and coordinate the manufacturing process activities, within a certain department, in order to create and approve suggestions for effective manufacturing solutions. They also describe and visualize the planned assembly method as well as the manufacturing disposition, the workplace design. At early stages this is analyzed and verified virtually which means they have to have basic knowledge about virtual tools, for more complex simulation tasks they can receive help from Simulation Engineers. There are no clear instructions stating what the ME is responsible for when it comes to simulations, and what is to be realized by the Simulation Engineers. This varies between each ME depending on their skills in virtual tools. Their work results in the creation of Process Inspection Instruction, PII, for the assembly of the product at the factories. For this reason they take part in the introduction of the product and its manufacturing process in the plant by leading the teams that solve technical issues as well as initiating the education needed for the assembly personnel.

Verification Leader, VL. The Verification Leaders perform and lead process verification work according to the project schedule and towards the A-, B- and C-shops. They also have the role as chairman of the process verification occasion for both virtual and physical assembly. Other deliverables include writing verification reports, composing the analysis and verification needs, and establishing verification parameters.

Simulation Engineers, SE. These engineers are the specialists when it comes to simulations with advanced simulation tools. They support and work together with the Manufacturing Engineers and the Design Engineers by performing the simulations they order. The SE:s are responsible for ensuring that the simulations are based on accurate models.

Virtual Manufacturing Technician, VMT. With the introduction of the virtual series and especially the virtual build, during which the complete set of components and systems of the cars are visualized virtually, there is a need for someone who can run the visualization of the product and the production process. This is done at auditoriums, so called arenas, fitted with large screens and projectors. Therefore VMT's are very busy just before and during the virtual build, where all the 3D-models must be available and the presentations prepared. Their tasks also involve helping the Manufacturing Engineers with their simulations as well as supporting them in their virtual work.

Process Developer. Work in a group within MDP where they are responsible for supporting and ensuring the continuous development of working methodologies. As there is a focus on virtual development at present, the Process Developers are mainly involved in issues affecting that work.

Pre-Production Engineer, PPE. These engineers belong to the factory organizations. At early stages during development PPE:s provide the ME:s with competences and experiences from the production facilities. Furthermore, they support ME:s in the virtual analysis and verification of manufacturability of the product as well as the capability of the process.

4.3 Account of Virtual Manufacturing

In this chapter an overview is presented as to what is meant with virtual methods and how VCC is taking on this new kind of product and process development. An approach to achieving the benefits of for example front-loading is the use of virtual techniques and therefore a brief description of the way of working with this, as well as the tools used, is given here.

4.3.1 Virtual Manufacturing Center

The use of virtual methods during development of manufacturing processes at VCC took a leap forward as a result of a project called Virtual Manufacturing Center, VMC, performed between 1998 and 2001. The purpose of VMC was to make the development of new car models more efficient by cutting the lead times and lowering the costs. This strategy required a new way of working and a new set of tools in order to develop and verify the manufacturability before start of production. Work with virtual manufacturing technologies was already being performed at VCC but for the activities to succeed in improving the efficiency they needed to be coordinated.

CAx tools were previously used in a fragmented way and without integration and continuity during the development process. Addressing these issues and coordinating the activities was the main aim of VMC and it was done by creating a cross-functional team consisting of representatives from involved parties. Their work resulted in a new methodology for the development process supported by and based on virtual tools and technology. The VMC was run in parallel with the P28-project as a support and aid during the implementation of the new working methodology. The P11 is the second major project to implement the results from VMC by using virtual methods to coordinate and focus the efforts.

The advantage of the virtual working methodology is that it allows VCC to prepare and verify large sections of their product and process solutions in less time without investing in expensive physical prototype equipment. An area of particular interest is the final assembly at the factories, being also the focus for this thesis. Here, virtual manufacturing help to answer questions about a proposed future work place, whether it is ergonomically acceptable or if specific product variants can be built in the proposed assembly sequence.

4.3.2 Purpose of series

The method established by VMC, for the final assembly, is valid between gate -1 and gate 5. The major change was the introduction of virtual pre-series, VS, as a complement to and preceding the existing physical ones. During VS the car and its manufacturing processes are developed and verified in continuous loops using virtual computer models. This will provide for a car with an ameliorated status when proceeding into the physical pre-series. The use of virtual pre-series has decreased the number of physical prototypes required during the development process, thereby increasing efficiency.

Each series, virtual as well as physical, has an in advance determined purpose. The purpose of the different VS is described using a generic reference model of demand, presented for the first time prior to the concept phase. The specific purpose of the series is revised before the beginning of every new series. The purpose of series is necessary in order to establish a list of deviations from the generic reference model and enable a discussion of the progress of the project. These are essential in order to get an overview of a particular project's status, and to compare it with the anticipated status. The purpose of the series described contains an explanation of what the specific series will be used for and what status the enclosed material should have. Additionally, the purpose together with the project plan provides prerequisites and aid for purchasing and supplying as well as establishing the need for analysis and verification. At certain points in time the material for the virtual prototype developed so far is frozen to enable compilation of all the information from the development at that time. This allows for the product and process solutions of the specific series to be evaluated and verified according to its purpose.

The virtual pre-series work contains numerous activities interacting within the development work. In figure 12, a visualization of the activities and the involved parties of most relevance for this thesis are presented. The figure leaves out several parties which perform additional work of importance during the VS. However, due to the scope of the thesis, as well as the time frame for the research, it was not possible to account for the entire process. It was therefore necessary to disregard some involved parties and processes as time did not allow for an analysis of these in the discussions of chapters six and seven.

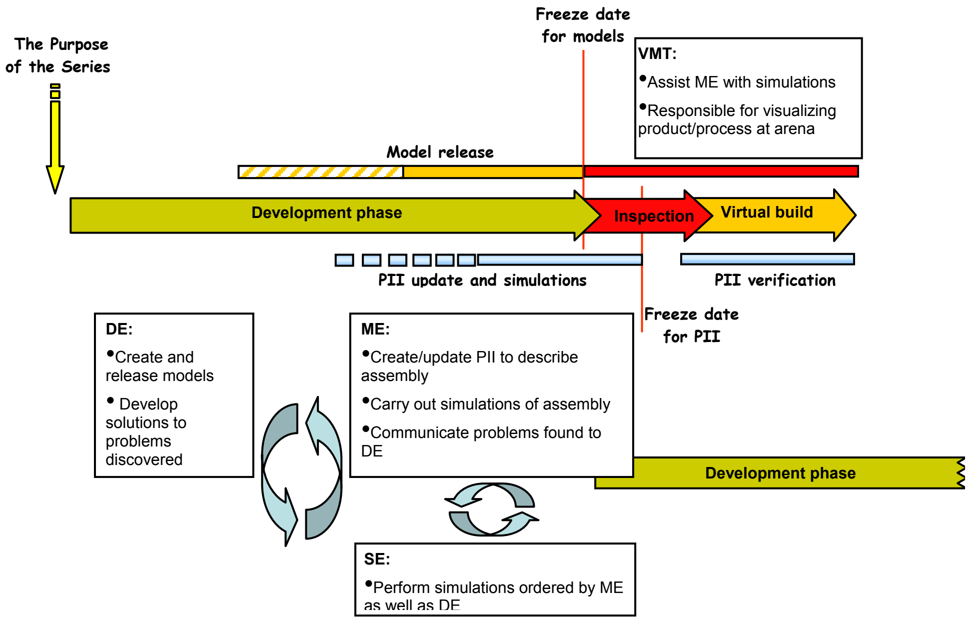

Figure 12. Virtual pre-series, an overview.

4.3.3 Day-to-day work

A virtual series is divided into three main parts as visualized in figure 12. The different phases involve various responsibilities for the concerned parties, all with the objective of reaching the overall purpose of the series. The everyday work strives for delivering accurate material for verification in the end of each series in order to evaluate the progress of the project. The overall development work performed in the development phase is at a point in time frozen, an important deadline for the work within pre-series. This allows for the models developed so far to be revised in the inspection phase. Once the revision is realized, the virtual build completes the VS with a verification of the product and process solutions.

The DE:s are mainly involved during the development phase of the VS. During this period they develop component solutions and verify them in collaboration with the ME:s in continuous loops to ensure manufacturability. The DE:s are responsible for delivering virtual models which corresponds to the purpose of the series at the time for deadline and evaluation. The models are released continuously during the development phase with an increasing rate as the freeze date approaches. Once passed the freeze date, the DE's work of component development continues until it is time for the models of the subsequent series to be frozen. As clearly visualized in figure 12, the virtual series overlaps which results in an uninterrupted development work of the DE:s with developing components and making adjustments when problems are discovered during verification. As a result of the overlapping, the models used for verification in the virtual build are at the same time being updated and further developed by the DE.

The work of the ME:s begins and increases over time as the virtual models become accessible. The main responsibility of the ME:s is the establishment of Process Inspection Instruction, PII. PII is a small part of the total manufacturing process describing how components are to be assembled and in which sequence. In other words, it is an instruction for the factory personnel of how and when the specific component is assembled. The work of the ME is consequently built on the models released by the DE:s. Once the models are obtainable the ME:s begin revising and updating their PII:s. During the preparations of the PII:s, the ME:s verify the manufacturability by using virtual simulation tools. The PII:s are to be fully updated in time before the virtual build phase where they are verified against certain parameters such as ergonomics, tooling and assembly method.

The SE serves as an aid and support for the ME, and to some extent also the DE, when verifying the manufacturing solution virtually. Like the ME, the workload of the SE increases as models are released. The simulations performed by the SE must be delivered to the ME well in time before the virtual build phase to enable analysis of the simulation result and updating of the PII. A simulation order may be agreed by verbal communication between the ME and the SE. However, there is an administrative system for handling simulation orders and results, called simulation report. Simulation report is still under construction and at present a web-based system is developed in order to facilitate the handling of simulation orders. Simulation report is also thought to be used as a database for transferring experiences.

For the VMT, the main work starts after the freeze date and continues throughout the virtual build phase. During the development phase the VMT assists the ME by performing some of the simulations of a less complicated nature in order to unload the SE:s.

Figure 12 visualizes how the virtual series overlap with each other to some extent. This implies a nearly continuous work even for those parties that are mainly involved later in the series. For that reason there is no time for twiddling one's thumbs while waiting for the preceding work to be completed. Furthermore, many parties are involved in more than one project at the same time with different time schedules for virtual series.

4.3.4 Virtual build meetings

At certain points in time an overview of the status of the ongoing project and the current series compared to its anticipated status is required. The development work of the project is then frozen in order to compile information during the inspection phase, and enable the series to be evaluated. For this purpose a virtual build meeting is realized at the end of each VS using the frozen and revised virtual models. This activity is carried out in so called arenas, equipped with computers, projectors and large screens, where the complete set of components and systems developed at that point in time are visualized virtually. The purpose of these virtual build meetings is to have the product and manufacturing process verified in an as factory like environment as possible in order to analyze the present solutions and update the status of the project. The aim of the virtual build meetings is also to gather people from various departments to achieve an overall and unbiased perspective.

During the virtual build meetings the car is assembled in accurate sequences corresponding to its anticipated assembly in the factory. The visualization of the line, the models and the sequences of the product and its manufacturing process in the arenas is handled by the VMT:s. The ME presents the PII:s he or she is responsible for and accounts for the assembly. If any identified complications exist the ME describes the problem and visualizes it if possible. A line responsible presents the line layout and pays attention to the assembly solutions presented by the ME:s from a production perspective. The virtual build meetings are lead by the VL responsible for the project. The VL ensures the time schedule is followed, presents a scorecard summary for each PII and leads any problem discussions.

Apart from the above mentioned, additional parties should attend the virtual build meeting according to the established working methodology. The System Manufacturing Engineer, who is responsible for a group of ME:s and the overall work with PII:s they perform, should participate in order to support the ME:s and obtain an overview of the project status. Furthermore, the MSS Managers should participate during the virtual build meetings as often as possible. *The virtual series must be an issue for the whole team*, as expressed in the established information of working routines during virtual build meetings.

4.3.5 Software

Over the years the development of software tools that aid design, manufacturing, and database handling, as well as the performance of personal computers, has been greatly improved. There are at present a number of various tools to use in different situations during the development process, and most of them may be run on basic computers.

There are three main groups of software used in the work with developing products and processes at VCC. The common name for this group is CAx and it includes; Computer Aided Design, Computer Aided Engineering, and Computer Aided Manufacturing. Computer Aided Design, CAD, is used for drawing and designing components and work cells etc. Creating CAD-models for all the various parts of the car is the foundation for virtual work. The product designers are responsible for creating these models for each component, and for this purpose the most widely used program is CATIA, an acronym for Computer graphic Aided Three dimensional Interactive Application. Computer Aided Engineering, CAE, is another type of tool used during research and development of products. Often when dealing with various functions of a product, such as strength of materials, fluid simulations of air and liquids, and other mechanical dynamics, developers are aided in their analyses through the use of CAE. In order to use CAD-created models in simulations of the manufacturing processes, software like Computer Aided Manufacturing, CAM, are used. These programs are used for visualizing and analyzing the assembly of components.

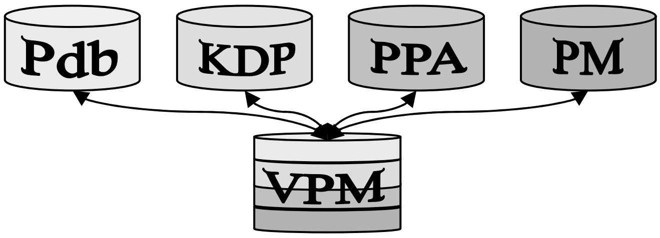

Figure 13. Management of models through various databases.

When the Design Engineers have created a model with a CAD program every unique component is given an article number for identification. Component solutions are then continuously stored in the Product Manager, PM database, seen in figure 13. Once all the necessary models are made, for either a certain system or for the entire car, they must be given a location in the car. This generates another database called the Position database, Pdb. For components needed in several positions, i.e. bolts or tire rims, models are only created once and entered into PM. In the Pdb that component is given its exact location for every time it is being used. Furthermore, a database called Konstruktion Data Personvagnar, KDP, is used to store and handle additional product information connected to the models. It is necessary to keep track of the car variants to be manufactured and when they will be used for pre-series or entered into the production line. This information is used by the purchasing department when planning procurement. KDP, combined with PM and Pdb, makes it possible to visualize the entire product in its final state. It is mainly the R&D department that is responsible for entering data into these three databases. This is of course not enough as nothing describes how each component is to be assembled in the manufacturing process, through which methods and in what sequence. For that purpose there are yet other databases containing the additional information needed for assembly. A database called Product Planning Administration, PPA, manages sequencing and structure of the components to be assembled. This information is connected to the PII:s, created by the ME:s, and the KDP in order to enable sequencing and structure of manufacturing at the specific factory for the project. All these databases are brought together in an overall system called the Virtual Product Manager, VPM, as seen in figure 13.

The VPM works as an interface between the various other databases and the users such as ME:s, SE:s, and VMT:s. when simulations are to be performed models are retrieved from VPM, which is updated every night to contain the most recent versions of every model. When creating a digital mock-up, as the virtual prototypes are called, for visualization at the arenas it can be done using two different bases, an assembly digital mock-up, ADMU, and a product digital mock-up, PDMU. These two variants are substructures of VPM and contain the same models but they are organized differently. The ADMU arranges the models in a convenient way for viewing the assembly sequence and the content of the PDMU is organized in functional groups, i.e. engine bay, cock-pit, or luggage compartment.

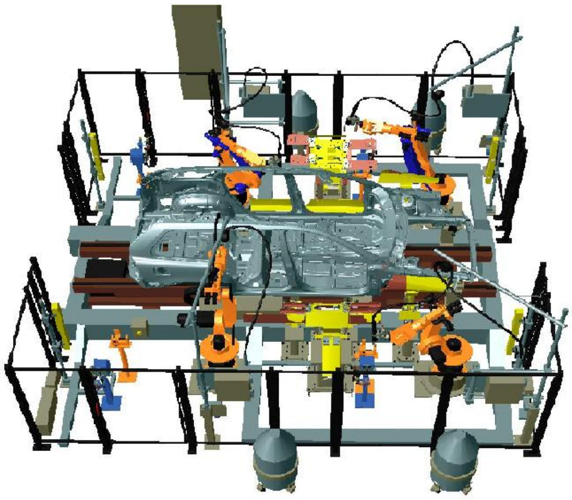

Figure 14. View of a robot workcell as seen when using Robcad. In the center the car is shown as it moves along the factory line, and surrounding it are a number of robots performing certain operations specific for this cell.

As mentioned above the ME:s, SE:s, and VMT:s retrieve models from VPM in order to carry out simulations of various aspects. Depending on the type of analysis needed different simulation softwares are used. DMU Navigator, DMN, is a viewer where simulation and verification of 3D-models can be done. It is a program mainly used by the ME:s and VMT:s for analyzing component fit in order to find problems such as conflicts between parts or other deviations in the models. In some cases the simulations are too complex for DMN to handle the analysis, for example when it comes to advanced robot kinematics or other difficult workcell[53] operations. A tool called Robcad is then used since it is well suited for such simulations. An example of a robot workcell as seen when using Robcad can be seen in figure 14. However, Robcad often requires special education as it provides the user with a vast number of specialized functions and it is therefore mostly used by the SE:s. When planning the manufacturing process at a factory it is important, for many reasons, to consider the working situation for the assembly personnel, having an ergonomically correct working environment. It is not until recently that simulation software has become sophisticated enough to simulate the complexity of the human body in an assembly process. The program mainly used today at VCC is called RAMSIS and it provides the ME:s with a good analysis of how the future work place affects the people working there. This allows for actions to be taken well in advance in order not to create an unhealthy working environment. Two examples of RAMSIS simulations can be seen in figure 15. However, RAMSIS is also a rather demanding tool to work with, requiring some experience, and therefore mostly used by SE:s.

[53] A workcell is a part of the factory line where robots perform the assembly for example.

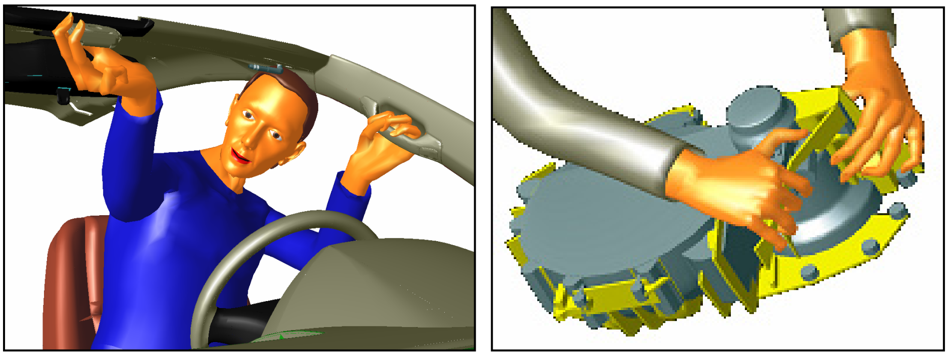

Figure 15. Examples of ergonomics simulations

It must be pointed out that not every aspect of a car, or its manufacturing process, may be virtually tested. There are limits as to what can be simulated through the use of softwares commercially available at present. These are for example:

- *Flexible materials*. Anything that is soft and can be "deformed" in any way is basically impossible to simulate. Examples of such components are cables, hoses, wires, or mats.
- *Forces*. A virtual environment is not affected by forces such as gravity or friction.
- *Tolerances*. In the physical reality, as opposed to the virtual one, no two components are exactly the same. It is however impossible to predict, using virtual methods, how the slight, and permitted, deviations in the shape of a component affect the fit for example.
- *Leaks and fillings*. Handling fluids is not an aspect well handled by virtual methods. For example one cannot test how the filling of hydraulic oils, or other fluids used in a car, will work. Nor can leaks in fluid compartments be tested.

When working with common platforms as described in 4.1.1, it is necessary for the involved parties to be able to transfer and access models of such commonality. A project called CAD/CAM/CAE Product information exchange Next Generation, C3PNG, currently running has the purpose of working out a common IT-concept for FMC. It will in the long run replace all the above mentioned databases as well as creating a commonality with regards to the simulation software to be used.

4.3.6 Rapid prototyping

During the virtual series there are several physical alternatives to be obtainable well worth attention. The Concept Center within the VCC organization focuses on the early stages of development and manufactures everything from single parts to fully functional concept cars in order to enable verification of new systems and solutions. They provide rapid prototyping of physical test-components using for example clay and plastics. Hence, there is the possibility to, while still in virtual series, order a manufacture of a physical prototype in order to verify the solution without being limited by technical limitations of the simulation software. By combining the virtual series with rapid prototyping a more efficient development is possible since it provides shorter lead times and lower costs than an actual physical component supplied by a subcontractor.

The area of rapid prototyping is extensive and comprises several advanced methods for manufacturing of test objects. A detailed description of the available methods and the equipment is not presented in this thesis as it is out of range of the scope. However, we found it important to point out this alternative and complement to virtual models since rapid prototyping provides aid of great value and may contribute to an optimization of the performance of virtual series.

4.4 The verification tools

Keeping track of projects and their status is necessary for the organization to function in a complex development process. For this reason there are various tools enabling data, like problems and deviations, to be recorded and analyzed in different ways. We will present the two main systems used during verification of the product and manufacturing process.

4.4.1 Process Verification System

In order to get agreements between internal suppliers and customers of the processes, regarding the situation of product related process changes, VCC uses what is called the Process Verification System, PVS. The evaluation of the process is done at the so called PII-level. PII:s are small parts of the process describing how the assembly of components will be performed in the factories. Each PII is evaluated against certain chosen parameters, as can be seen in the interface shown in figure 16. There is a scorecard for every PII where the assessments made result in a status for all parameters, i.e. Y if it is OK, N if it is not OK, NR for not being relevant and NE when it has not been evaluated. The writing and updating of the PII:s is done by the Manufacturing Engineers, who thereby become the suppliers of the process. Pre-Production Engineers, who may be seen as the customers of the process, also update the status of the PII:s from their point of view.

Figure 16. Interface of the verification scorecard, PVS.

During the verification series the PVS is used to keep track of status of the PII:s, in other words how the parameters are being fulfilled. Every pre-series has an overall scorecard connected to that series. These are available on-line and contain all the PII:s for each particular pre-series. The work of updating scorecards provides an overview of the status for the entire project since it shows which PII:s are OK and which are not. For each pre-series there are targets for what percentage of the PII:s that should be confirmed OK in order to be on track.

4.4.2 Volvo Quality Deviation Control

To administrate technical deviations in quality matters related to the manufacturing process Volvo uses a database called Volvo Quality Deviation Control, VQDC. It is a tool, used throughout the pre-study and industrialization phase, where problems affecting the manufacturing process are registered and kept track on. VQDC is a pc-based system introduced in the autumn of 2002, in the early phases of the P11-project, to replace the predecessor Volvo Car Customer Quality, VCCQ. The most significant difference and improvement with VQDC is the possibility to attach files to the description of the problem which provide a better understanding of the problem as it enables visualization.

In order to enable work with analysis and verification of problems, VQDC is a great source of information. All employees, involved in the development process of new products, can log new problems and solutions and have access to existing information in the database. An important aspect of VQDC is that knowledge is shared throughout the different levels and departments of the organization. This prevents work from being done twice and allows a person who discovers a similar problem to view previous solutions. By viewing previous problem areas, VQDC can contribute to improve the work of designers. VQDC is mainly not used for measuring the status of a project, for that purpose there are other systems such as PVS described previously, as it only shows the amount and type of problems discovered during the development process.

Problems identified during the development process are registered and handled in VQDC in a certain sequence of work. The identification and registration of problems discovered take place either during the virtual build meetings in the arenas or in the everyday work in the pre-series. "If the problem is not found in VQDC, it does not exist", as said in the instruction manual of VQDC. A simplification of the working methodology is shown in figure 17 and will be described in detail below.

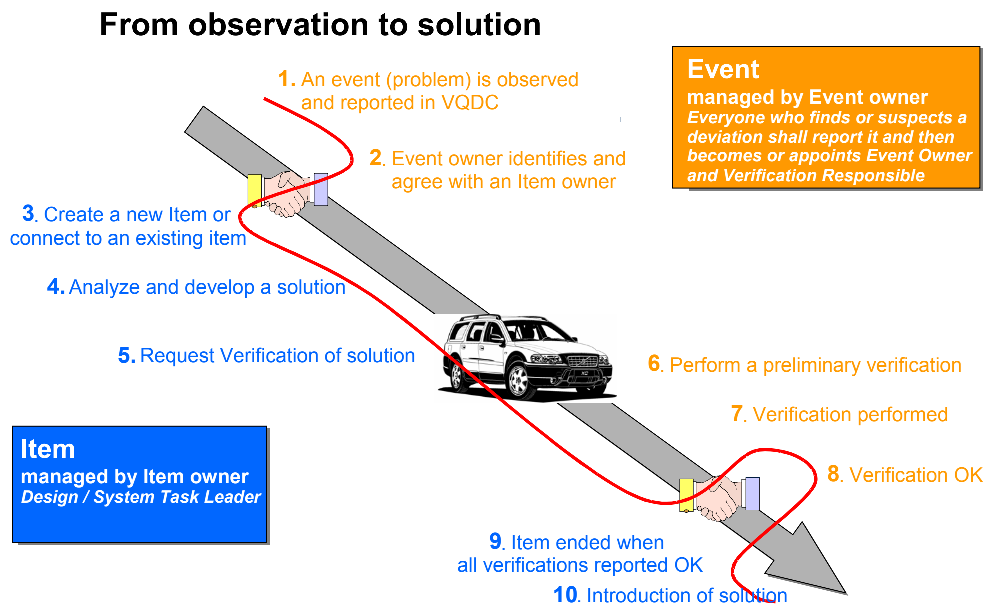

Figure 17. VQDC – From observation to solution. Working methodology for handling problems in the VQDC-system.

Everyone who discovers a problem or a deviation during the product and process development is responsible for reporting it in the VQDC-system. It may be for example the Pre-Production Engineer in the factory, the Manufacturing Engineer responsible for a realization of a simulation, or a test driver. In order to discover a problem there must be some kind of object to connect the problem to. These are called test objects, TO, and may be virtual prototypes, physical test cars, or production facilities. Several problems may of course be connected to one TO. The person who identified the problem or the deviation makes a registration in the VQDC-system along with a correct problem description and a basic analysis. The problem registered in VQDC is called an event and the Manufacturing Engineer responsible for the area concerned becomes the Event Owner. An example of a registered event and its interface in the VQDC-system is shown in figure 19. The Event Owner agrees with an Item Owner, usually a Design Engineer, who is responsible for finding a solution to the problem. The agreement procedure is called a handshake. When an event is transferred to an Item Owner it becomes connected to an item; an active element in the work of an Item Owner with finding a solution. The Item Owner must control if the new event is related to another already reported event, and in that case attach the event to the existing item. A description of the relationship between TO, event, and item is shown in figure 18.

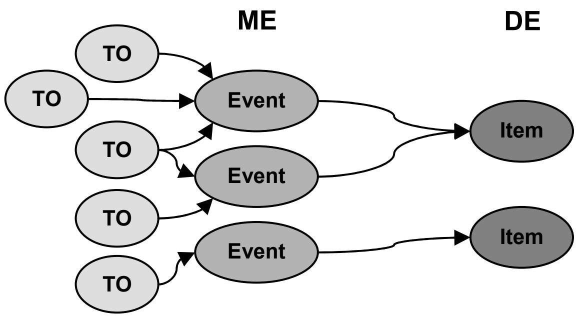

Figure 18. Relationship between TO:s, events and items.

The Item Owner, a Design Engineer for example, performs a thorough problem analysis, constructs a solution and realizes a preliminary verification of the solution. The preliminary verification is performed together with the Event Owner in order to improve the probability of the proposed solution being approved in the final verification. When the Item Owner states that a final verification of the solution is possible, a handshake is made in the opposite direction with the Event Owner. A suitable time for both parties involved is set, the final verification is performed and if approved, the event is closed. If the problem persists the event is returned to the Item Owner for a development of a new solution and another final verification date. To close an item all events connected must be verified with a positive result. In other words, several events can be connected to one item at the same time, whereas to exist, an item must be connected to at least one event. Finally, the solution is introduced and implemented.

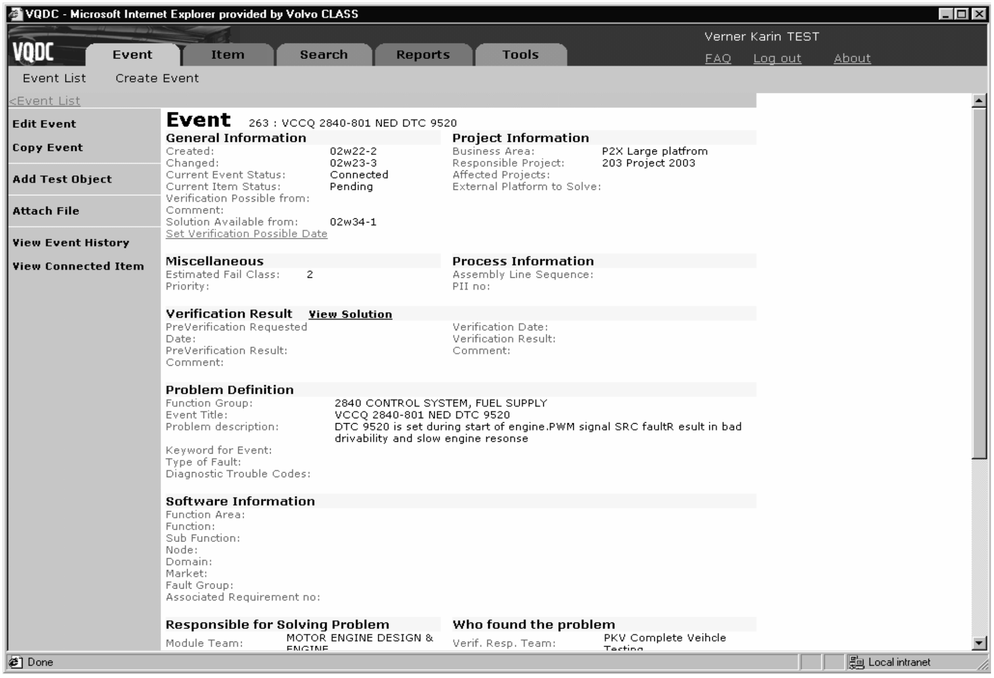

Figure 19. Interface of VQDC showing the description of an event.

There are two ways of rating the problems registered in the VQDC-system. They are used to simplify the solution work as they show the severity of the problem and thereby give an indication of the amount of time that needs to be spent on finding a solution. Furthermore, the ratings are an aid in prioritizing when there is a large quantity of problems to handle. In order to rate the events in the VQDC-system regarding their degree of gravity an Estimated fail class is used. The Estimated fail class is determined from the viewpoint of the final customer, which then can be derived to the implications on the manufacturing process. Events not likely to be verified with a positive result before start of production are assigned a priority. This priority is used late in the development process in the last pre-series before production. The events are divided into three categories; **Must**, **Later** and **Not**, depending on their level of urgency.

The VQDC-system contains registered problems related to the manufacturing process. That is for example ergonomically concerns and changes in the product or factory layout, which affect the manufacturing process. During the P11-project a specific methodology for what kinds of problems should be registered in the VQDC-system was not established. As a result certain amounts of problems were registered which were not actually belonging in the system.

5 Results

In this chapter the results of the investigation realized within this thesis is presented. Since the work with the thesis has been divided into two parts, the results will accordingly be accounted for in two sections. The first part, Presentation of data, consists of visualizations of the answers to the three basic questions stated in the problem definition, in the form of various tables and charts, as well as a description of the method used to compile them. In the succeeding part, Presentation of interviews, the continuous in-depth investigation is presented. It contains a brief description of the interviews performed and a table of possible answers to the fourth question; *why are there remaining and new problems at late stages in the development process.*

5.1 Presentation of data

The starting point of this master thesis was the basic questions concerning when problem was found, when they were solved and for how long they were present in the VQDC-system during the development process. In order to answer these questions the information registered and accessible in the VQDC-system was used. Since there is a large amount of information to be found in the database the first step was to refine the information to data relevant and useful for the purpose of this thesis. The refinement was made using certain parameter settings to limit the search to registered problems within the scope of the thesis. The search criteria are presented in appendix 3.

A specification of the problems in each department was made with the purpose of answering the basic questions formulated in the problem definition:

- When are the problems identified in the development process?
- When are the problems solved?
- For how long are the problems present in the development process?

The result of the basic questions is presented in tables 2-5:

Table 2. Chassis Design / Power train Architecture

Reported:		Solved in each series:							
Series	Total	VS22	VS23	VS31	PS3	PS31	PS32	PTO	Rest
VS22	112	9	23	13	20	31	11	3	2
VS23	51		7	10	7	13	12	1	1
VS31	18			1	2	11	2	0	2
PS3	31				7	13	4	6	1
PS31	24					5	6	9	4
PS32	113						37	25	51
PTO	47							27	20
Total solved:		9	30	24	36	73	72	71	**81**

Total number of problems registered between VS22 and PTO: **396**
Total number of problems solved between VS22 and PTO: **315**

Table 3. Electrical Systems

Reported:		Solved in each series:							
Series	**Total**	**VS22**	**VS23**	**VS31**	**PS3**	**PS31**	**PS32**	**PTO**	**Rest**
VS22	**124**	17	28	5	7	31	21	5	10
VS23	**41**		2	2	5	19	9	2	2
VS31	**23**			7	2	0	9	2	3
PS3	**29**				2	3	10	3	11
PS31	**47**					4	16	14	13
PS32	**114**						33	39	42
PTO	**65**							33	32
Total solved:		17	30	14	16	57	98	98	**113**

Total number of problems registered between VS22 and PTO: **443**
Total number of problems solved between VS22 and PTO: **330**

Table 4. Exterior Design

Reported:		Solved in each series:							
Series	**Total**	**VS22**	**VS23**	**VS31**	**PS3**	**PS31**	**PS32**	**PTO**	**Rest**
VS22	149	26	17	16	27	40	9	5	9
VS23	66		12	9	15	15	6	3	6
VS31	22			3	5	7	3	2	2
PS3	4				1	0	0	1	2
PS31	31					5	16	0	10
PS32	137						51	19	67
PTO	61							33	28
Total solved:		26	29	28	48	67	85	63	**124**

Total number of problems registered between VS22 and PTO: **470**
Total number of problems solved between VS22 and PTO: **346**

Table 5. Interior Design

Reported:		Solved in each series:							
Series	**Total**	**VS22**	**VS23**	**VS31**	**PS3**	**PS31**	**PS32**	**PTO**	**Rest**
VS22	237	52	45	30	42	32	4	12	20
VS23	52		13	8	10	10	5	4	2
VS31	56			15	31	9	0	0	1
PS3	53				31	10	6	4	2
PS31	46					9	14	9	14
PS32	101						39	26	36
PTO	85							38	47
Total solved:		52	58	53	114	70	68	93	**122**

Total number of problems registered between VS22 and PTO: **630**
Total number of problems solved between VS22 and PTO: **508**

In the column for "Reported", the tables show the number of problems identified per pre-series and then registered in the VQDC-system. Horizontally, in the columns for "Solved in each series", it is shown when the identified problems from each pre-series are solved, hence how the solutions for these problems are distributed over time. The column "Rest" refers to the number of problems not solved during the time period studied and remained to be solved after the PTO-phase. These problems were not investigated in this thesis since they were out of range for the scope of the thesis. The time period studied, from VS 2.2 up to PTO, ranges from November 2001 till June 2003.

From the same VQDC data, charts that in different ways visualize the contents of tables 2-5 have been created. However, we have chosen to present the data as a total of the four departments studied. Charts specific for the four different departments are presented in appendix 3. The trends, clearly visible in these charts, are the same for all departments and a total chart is therefore not misleading. Furthermore, in order to obtain an overall apprehension of the development progress, an overview of the entire project is of interest.

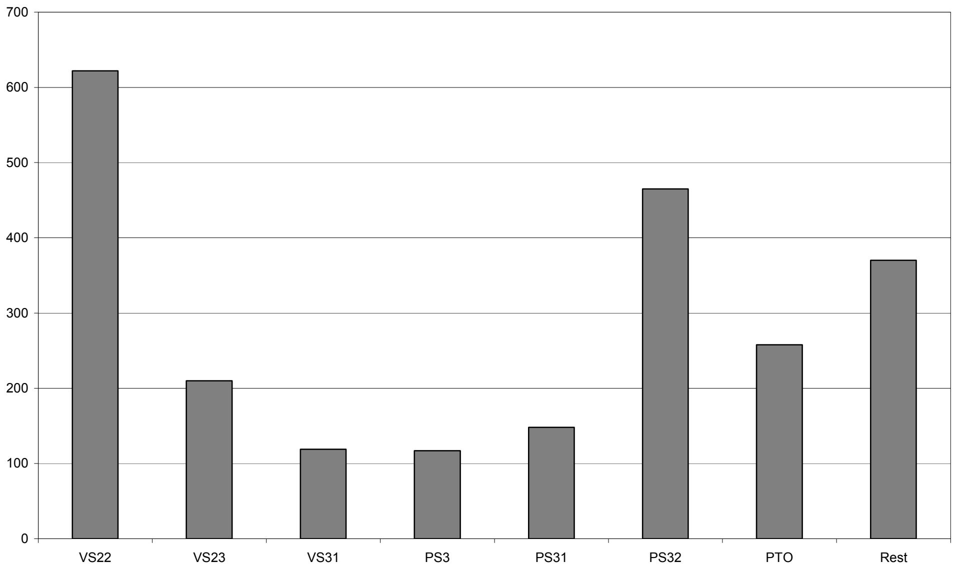

Figure 20. Total number of problems created in each pre-series.

The chart in figure 20 describes the distribution of the problems found between VS 2.2 and PTO. The last column, called "Rest", shows the number of problems found after PTO and up until the time for the extraction of data from the VQDC database, which was done in December 2003. The Rest-column will also in the preceding charts represent an amount reported after the PTO and up to December 2003.

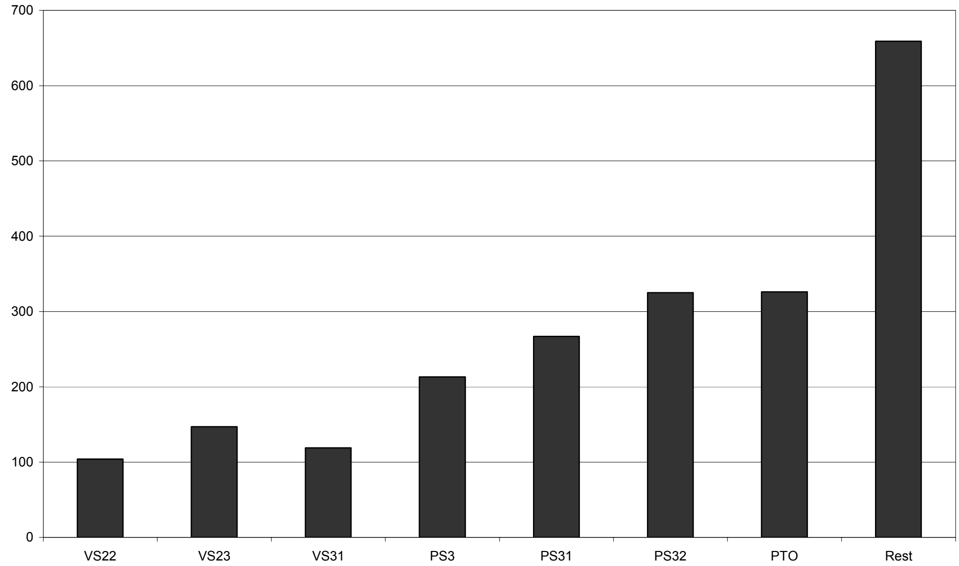

Figure 21. Total number of problems solved, ended and dismissed, in each pre-series.

Figure 21 provides a chart which visualizes when solutions to the problems are reported into the VQDC-system. The columns comprise problems considered as solved both through being ended as well as dismissed.

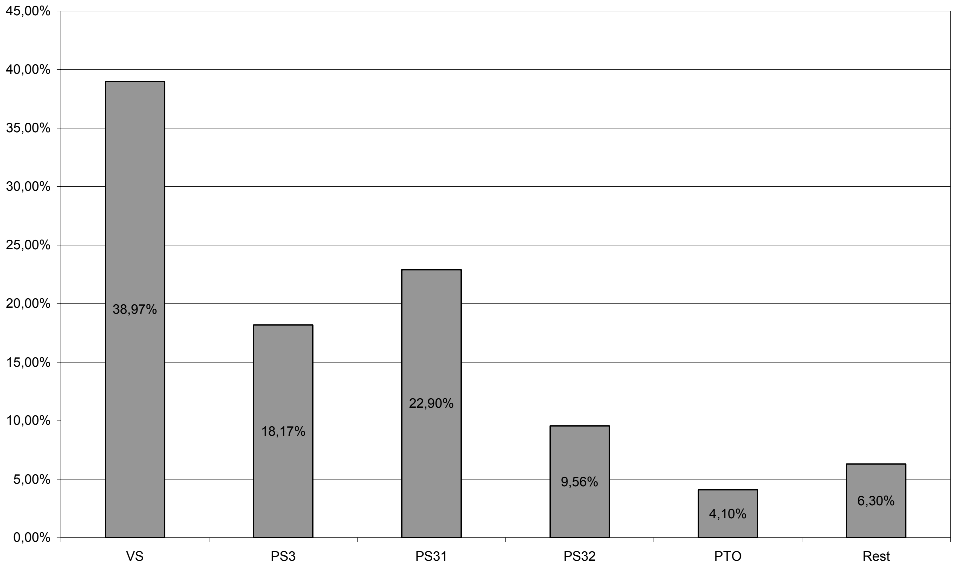

Figure 22. When problems found in VS were solved. The distribution of when solutions were registered, as a percentage, of the total number of problems created in virtual pre-series.

Since focus for this thesis is on the virtual verification process and the possibilities for improvements, it was interesting to describe how the work of problem-solving for the problems identified during the virtual pre-series was carried out. Figure 22 illustrates when the problems discovered during the virtual pre-series are solved as a percentage of the total amount of problems found in virtual series. The chart shows that approximately 39 % of the problems discovered in virtual pre-series are solved with virtual methods, leaving the rest to be taken care of in physical series.

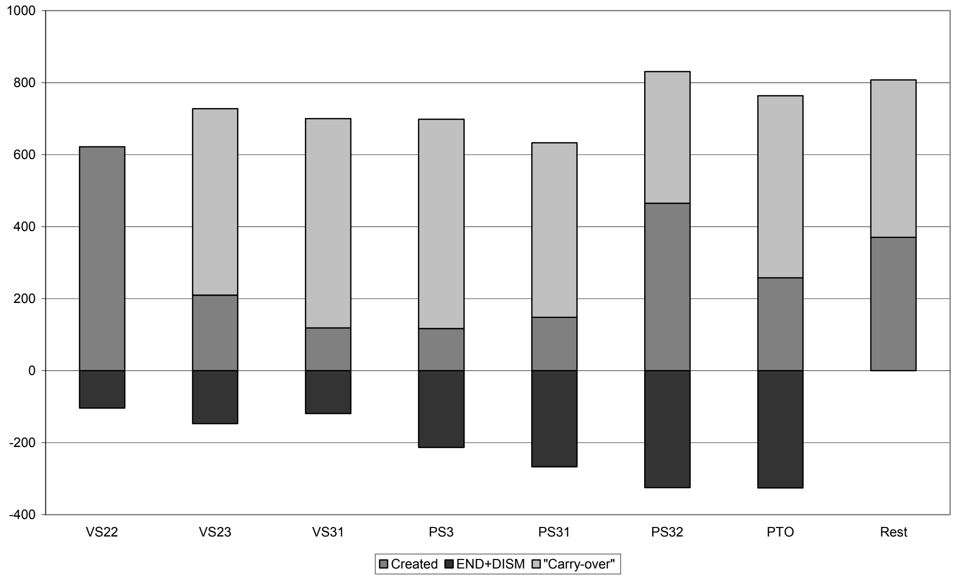

Figure 23. Total number of problems created, solved and carried-over from preceding series.

Finally a graph depicting a combined view of found and solved problems was compiled from the VQDC data, see figure 23. The dark-grey parts of the columns show the total amount of created events, corresponding to figure 20. Similarly, the black parts correspond to figure 21 and represent the number of problems solved in each pre-series. Since the number of solved problem most often is less than the number of problems created in the same pre-series, an amount of problems remain to be solved in the subsequent pre-series. These problems are called carry-over and are presented in the light-grey parts of the columns.

5.2 Presentation of interviews

A large number of interviews have been conducted in the course of this research in order to gather information about the verification process. The purpose of the interviews was to create an understanding of the present situation and the problems related to the work of pre-series, and thereby enable an identification of certain factors with significant influence on the development work.

People with various roles and responsibilities were interviewed in order to obtain a broad perspective of the situation and being able to answer the four questions presented in the problem definition. For that reason, Manufacturing Engineers from the different MSS areas within C-shop; Interior, Exterior, Electronics, and Chassis and Power train, were interviewed. Furthermore, interviews with Simulation Engineers, Virtual Manufacturing Technicians and a Pre-Production Engineer as well as persons concerned with the development of working methodologies, were realized. Appendix 5 contains a list of the questions asked during the interviews. Additionally, the interviews performed by Anders Sundin contributed with supplementary information.

We have chosen to present the interviews in the form of quotations woven into the discussion in chapter six and seven. The most interesting and significant quotations have been selected in order to reflect the overall findings. For integrity reasons the quotations are signed with position and department, while the names are left out. The only result from the interviews presented in this chapter is table 6. The table is a result of a survey conducted at the end of each interview with the Manufacturing Engineers. A number of possible reasons for remaining and new problems at late stages in the development process were stated, and the Manufacturing Engineers were asked to rank them according to what they considered to influence the process. The Manufacturing Engineers were given a total of 100 points to distribute amongst the possible causes, with a high mark indicating a significant negative influence on the development process. However, the table must be viewed only as an indication since the number of respondents was too few to allow for an accurate quantitative analysis. Furthermore, the number of respondents from each department varies, which results in a slightly misleading statistics if comparing them. Nevertheless, the table provides a verification of the problem areas identified during the interviews and clearly visualizes the main areas considered to affect the progress of the development negatively.

Table 6. Possible causes for remaining and new problems at late stages

Cause	Int	Ext	Chassis/Pt	El	Total
Low confidence for virtual simulation	0	5	10	0	15
Lack of time / heavy workload	10	5	55	30	100
Inexperience of virtual verification tools	20	5	1	20	46
Virtual simulation not possible	40	10	88	40	178
Low priority results in long lasting problems	0	5	20	20	45
Wrong article status	25	10	35	15	85
Missing or insufficient models	5	20	90	35	150
Communication problems	15	25	15	10	65
Working methodology	65	5	41	20	131
Decision making	20	10	45	10	85

6 Discussion of basic questions

The discussions presented in this chapter are structured according to the problem definition formulated in the introduction. The chapters three and four are kept in mind throughout this discussion as they represent both the formal theory behind development and verification processes as well as the needed information about VCC in this regard. The results presented in chapter five are analyzed. Additionally, the interviews conducted have been incorporated in this chapter and are presented as quotations in appropriate contexts throughout the discussion.

Handling problems and deviations during the development process of a project is a major issue. When dealing with difficulties in this process it is important to understand how the current performance affects the development progress. For this reason the results from the questions brought up at the very beginning of this thesis are here discussed; when problems and deviations are found and solved, and for how long they were present. These questions are called basic since they form an introduction and foundation for further discussions, in chapter seven, as to why there are difficulties in the verification process.

6.1 When are problems identified in the development process?

During the development of a new product, as well as its manufacturing process, it is crucial to identify all deviations that may cause problems for the final product or at the production facilities. In order to find the deviations continuous verifications are performed, resulting in a product and a process that is thoroughly tested for quality and manufacturability. The aim is to find problems at early stages of the development process since the cost of finding, and then correcting, problems increase drastically the closer it gets to production start. Early identification of problems will also affect the overall time it takes to reach the final demands for the project. In order to reach this type of front-loading it is necessary to know what the situation is like at present.

During the P11 there was a great variation in when the problems were identified and entered into the quality system, VQDC. The optimal case would be if more problems were found in the beginning, and then less and less problems as time goes. This was not the case and there are several reasons for this. As can be seen in the results in chapter five, there is a large number of problems identified at early virtual pre-series, especially the series VS 2.2. Then there is a big decrease in the next few pre-series before another increase in the series PS 3.2. This was seen as a general tendency for all the studied departments with only slight variations, mainly in terms of the amount of problems (can be seen in appendix 3). The only exception really worth mentioning is the fact that interior did not have the same kind of increase of identified problems in PS 3.2 as the other departments.

> *"During the first virtual series there were some strange problems entered into VQDC, related to lack of models or such."*
> ME Interior

First of all it must be noted that the policies for what is to be entered into VQDC as a problem has been changed during the course of the P11-project. In the beginning, problems were logged when a model for some component was missing at the virtual build meetings.

Later it was decided that problems of this kind was not to be seen as a problem belonging in VQDC. This is by all means a major issue and will be further discussed later. However, because of the previous policy, and the problem with **lacking models during early virtual series**, the amount of events registered in for example VS 2.2 is affected by this old way of thinking. At present, problems are only to be reported if it affects the product or the process and from this point of view it is of course possible to argue that a missing model does not in itself cause such a problem. One very important aspect of this issue is that though some might say that the former policy caused an overflow of problems logged, it is not known how many new problems might have been discovered if in fact the missing models were available for verification at that point.

> *"The problems are often smaller and less complicated in the physical pre-series. It is hard to notice these in the virtual pre-series as the necessary time and possibility to examine simulation results in such detail is not available. You cannot think of everything in the virtual pre-series, and then it is more rough problems."*
> ME Interior

> *"Conflicts can be observed but it is difficult to judge whether it will be a problem or not."*
> ME Electronics

Furthermore, there is a relationship between the **type of problem** and when it is discovered. Certain things cannot be foreseen at early stages. At early pre-series the problems are generally of a more rough nature and not so specific. For example the problem might in the beginning be that a component does not fit at all and as time goes it changes and is more of a trimming issue in order to get a nice finishing look. There is a difference between the kind of problems found in the virtual pre-series and the physical ones. In the VS the focus is not so much on the very detailed level as it is on making sure that every component fits. The fact that it is not possible to simulate tolerances of the product in an accurate manner, limits the results from the VS to a large extent. Sometimes this may cause an uncertainty regarding whether a conflict between components is a serious problem or if it is a necessary conflict.

> *"More components as well as better and more complete models are presented in the later pre-series, making the number of found problems increase in PS 3.2."*
> ME Electronics

> *"Some* [problems] *might have been possible to discover, though there will always be problems not found until the physical pre-series because that is the first time you use real tools and correct material."*
> ME Exterior

One of the reasons for the varied number of problems found in different pre-series is the **status of the product** and all the component models it contains. At later pre-series the status of the product is better; the car is more complete in terms of different variants of components to be included. This provides the possibility to test and verify more accurately and with higher demands. Also, it is not until the PS that the real tools are used. These are contributors to the large increase in new problems discovered at PS 3.2.

"Sometimes the wrong judgements are made in the virtual pre-series, whether a problem exists or not, which may result in problems arising in physical pre-series. That is seen as a problem discovered late."
PPE

Another important aspect concerns the **technical limitations** connected to the use of virtual work. A vast number of problems are discovered in the later pre-series because it was not possible to test certain issues during VS. These are for example flexible materials such as cables, hoses, mats, squeak and rattle, leaks and fillings. Finding problems related to these areas are very hard and therefore many of these are not found until there is an actual physical prototype. As the software used for simulations get better, some of these issues will be possible to verify during the VS. However, until simulation software is improved to such an extent, it is important to realize the significance of experience of the persons performing and analyzing the virtual results. Experience when interpreting the virtual simulations may well contribute to the effect of front-loading in the sense that problems are noticed earlier instead of coming as a surprise at a later stage.

"Some things are not found until late because you haven't built a certain variant earlier, or at least not enough of them. The specific problems with these variants are not focused enough upon."
PPE

"Some variants are not built until later."
ME Chassis / Power train

An example of problems found late concern **product variants** that will not make up such large volumes in the coming production, for example the right-hand driven versions. These versions are not tested to the same extent as the left-hand versions are during virtual development. Therefore, problems found in the right-hand versions are sometimes not taken as seriously because they are not seen that often. This may however, be experienced as a large problem once the cars are manufactured in the factory where they occur more often.

"Especially for the Electronics department there is a great need for a physical car in order to find all the problems."
ME Electronics

When studying the time for when problems are discovered it would be interesting to get an idea of how the **various departments differ** in this aspect. This, however, is not easily done in a fair manner. There are too many differences between the four main departments studied in this thesis in order to judge and compare their efforts when it comes to finding problems. For example they do not have the same number of PII:s, thereby not the same basis. Also these PII may be of varied coverage at the different departments, from the simplest ones to extremely complex operations.

Also affecting the rate and time at which problems are found is to what extent virtual tools may be used. It is a well known fact that the Electronics department is having some difficulties finding problems at an early stage due to the amount of cables involved in their work. The virtual tools are not able to provide enough feedback to the Manufacturing Engineer in terms of what may cause problems. This limitation not only affects the

Electronics department but also others since they often have to take the position of the cables into account.

There is a disparity between the departments when it comes to the work with virtual methods. Some have more experience in that field, often because of the performance results it gives them. A department able to use simulations in a more accurate way are then of course more likely to trust and make use of the methods in the hunt for potential problem areas.

A major difference between the departments is their mutual relationship when it comes to which phase their work is in at a certain time. Some have to do their work well in advance because of long lead times for tools and material or that they have to be synchronized with other parts within FMC. An example of this is the department for Chassis and Power train which depend heavily on the common platform developed together with, among others, FMC. This forces them to focus a lot on how to handle problems related to that, therefore sometimes prioritizing the use of the FMC quality system, AIMS, more than VQDC in order to get the requests for necessary changes across. The problems when **departments are at different phases** also affect the quality of the virtual build. This is due to the fact that some departments, such as Chassis and Power train, are so far ahead they know they cannot really do any big changes. It is more for the others to see how they can adapt to the ones that are ahead, something that of course is a very important part as well.

> *"The different departments must be allowed to have slightly different working methods. However, there should be final goals common for everyone."*
> Process Developer

All in all there are some big differences in the working methodology, partly due to the above mentioned aspects. This is probably a must in order to work with such a complex product in this large scale organization.

6.2 When are the problems solved?

Equally important as discovering problems is the work of solving them. The aspect of front-loading not only refers to identifying problems at earlier stages but also solving them sooner. However, being able to solve problems at early stages of development involves challenges regarding several aspects. To enable improvements during the development process of VCC certain areas will be discussed here, based on the results of the VQDC-summary presented in chapter five, *Results*.

When analyzing the tables and charts in chapter five, several questions arise concerning the variations of when the problems are solved. As seen in the tables in chapter 5.1, the number of solved problems varies between different pre-series. There are also differences if comparing virtual and physical pre-series. As visualized in the tables, there is a trend of an increasing amount of problem-solving as development work progresses. During early stages there are many changes when different solutions are tested while trying to determine the final concept. As development work progresses a more complete car is built, new problems are identified and an increased number of problems are possible to verify and solve.

> *"The aim has from the start been to solve the problems discovered in virtual series before the first physical series."*
> Process Developer

"Some problems can't be solved in the virtual pre-series"
ME Electronics

"Generally speaking; 80% trust the virtual result while the remaining 20% postpone the verification to physical pre-series to be on the safe side."
SE

When moving into the first physical pre-series, the goal is to not have any remaining virtual problems. However, with the simulation tools of today, this is not possible. The consequence of the **technical limitations** is the impossibility to verify certain types of problems until the physical pre-series. These are problems involving for example flexible materials and tolerances. An extended and reworded vision due to technical limitations is to not have any remaining problems at the time for the PTO. This objective seems reachable to a greater extent but, as shown in the previous chapter, there are still improvements to make. There are problems possible to solve virtually, nevertheless not solved until physical pre-series. Even though it appears the **confidence** in virtual methods is good, suspiciousness is obvious throughout the organization. As a consequence problems identified with virtual methods are set for final verification in physical pre-series. This clearly indicates a lack of confidence and contributes to the larger number of problems solved in physical pre-series. The physical world is still preferable when it comes to visualizing and ensuring the accuracy of the solutions.

"In the late physical pre-series one becomes aware of the too big amount of problems and focuses on solving them."
ME Electronics

Generally the opinion is that problems in the physical pre-series are more serious than the ones in virtual pre-series. As a result, an increased emphasize on solving the problems to any means occurs in the late physical pre-series. There seem to be an existing belief that during the virtual pre-series there is still plenty of time for making changes. Another aspect of the higher rate of problem-solving in physical pre-series is the **type of problem** handled. Several complicated and extensive problems, which need a thorough solution work over an extended period of time, are identified in early pre-series and contribute to the number of problems solved late in the development process. The exact opposite situation occurred as a result of the number of problems related to insufficient models during the virtual pre-series reported in the VQDC-system. These problems are easily solved as it only involves updating of models and increase the statistics of the number of problem solved in virtual pre-series.

"Is the problem solved when the solution results in several new problems to handle?"
PPE

An important aspect when discussing when problems are solved is the **requirements for considering a problem solved.** If a problem has the effect of creating several subsequent problems, how is it handled? This type of incident is dealt with in two ways; the basic problem is reported solved and the subsequent problems reported individually for the development of separate solutions, or the basic problem is not considered as solved until all of the related problems have accurate solutions. As a consequence the number of solved problems reported and the time for their registration varies depending on how the situation is managed.

Many of the problems solved at late stages in the development process are related to physical tools and components produced by subcontractors. In these cases a solution is often established, but one needs to take the required **lead time** into consideration. Tools are often expensive to produce and as a result they must be trimmed in continuous loops during development in order to allow for adjustments in small steps. As a result of too large changes, the tools may have to be remade with high cost and time consuming consequences. The same discussion is valid for components. For this reason, this type of problem is solved late in the development process.

6.3 For how long are the problems present in the development process?

In order to improve development efficiency the rate of problem-solving must increase. As is shown in the tables and charts of the VQDC-information in chapter 5.1, several problems are present an extended period of time during development. There are even problems identified in the VS 2.2 still remaining to solve after the PTO. When discussing for how long time a problem is present in the development process one must pay regards to the problem type. It is not possible to specify a length of life generally valid for all the problems. The period of time a problem is present in the development work depends on several aspects, both regarding the type of problem and the working methodology for establishing a solution. Several topics of interest regarding the variations will be discussed in order to provide for an understanding of the complex development work and the improvement possibilities.

> *"The time period required to solve a problem depends on the problem type."*
> ME Exterior

Some problems are rather easy and do not require an extensive work of finding a solution. As an example of problems with a solution quickly developed are those related to **lack of or insufficient models.** This type of problem was reported into the VQDC-system in the early virtual pre-series as a result of inexperience and lack of education of the system. Consequently these model problems, solved fast in the virtual pre-series, contribute to a misleading statistics since they are not considered as problems relevant for the VQDC-system. However, this situation may be viewed from another perspective. What would have happened if accurate models were obtainable? There is a possibility that an accurate model would have resulted in the identification of several problems, problems that were not found at that time due to missing models. From this perspective the statistics may be misleading the other way around. As a result of lacking or insufficient models, several problems are identified at later stages in the development process.

> *"Some problems are left for final verification in physical pre-series."*
> ME Interior

> *"Inexperience may be a reason for problems with an extended solving work."*
> ME Electronics

When discussing the period of time required for solving a problem one must take the **technical limitations** into consideration. When there is an uncertainty regarding whether or not the simulation results are misleading due to the software limitations the suspected problem and its solution is left for final verification in physical pre-series and thereby increasing the statistics of problems with an extended length of life. These types of problems will not be possible to solve virtually until the software is improved. However, to some extent it is possible to get around this problem. During the research interviews of this thesis it became obvious that through **experience** with virtual development some problems can be verified in the virtual pre-series even though the simulation results imply the opposite. After having worked in a number of virtual development projects the involved parties will know from experience if a problem exists or not, and learn to read between the lines in the simulation results. On the other hand, a number of respondents pointed out the danger of trusting experience. If relying on past experience, sooner or later misjudgments or overlooks will occur. As a consequence problems will be identified or rediscovered at later stages resulting in an increased time period of problem-solving. When discussing the effects of experience it is worth mentioning that the P11-project was only the second project to use the new working methodology for virtual development. It is likely that inexperience caused an extended work of problem-solving in some cases due to an insufficient implementation of the new working methodology.

> *"It looks good virtually, but the problem reoccurs in physical pre-series."*
> ME Electronics

> *"It is not easy to predict what might happen when the car is built in the accurate environment in the everyday manufacturing process."*
> ME Electronics

There are a number of problems which are solved at some point during development but are rediscovered at later stages in the development process, resulting in an increased time period of problem-solving. This situation occurs when problems are identified and solved both virtually and physically. Due to technical limitations or lack of experience in virtual methods a solution verified OK in virtual pre-series may be discovered as inaccurate or non-functioning in physical pre-series. When this occurs, the problem event is reopened and a new solution must be developed with an additional problem-solving time. To prevent this, a solution is at times developed and verified gradually in order to keep a close eye on it. An event may also be reopened due to unexpected defects in the physical material or if the material is not according to the specifications, which are impossible to predict and foresee. Yet another example of **reoccurring problems** arises when the car and its manufacturing process are introduced and implemented in the factory. Since the physical pre-series are built in a pilot plant and beside the actual manufacturing process with different resources than during normal conditions, it is most likely to identify unexpected complications. There is a big difference once building a car in its regular manufacturing environment even if there have not been problems previously. The process may seem problem-free in the pilot plant but that is not a guarantee for a well-functioning ordinary process. However, problems such as these may be avoided to some extent through experience and involving suitable parties during development.

> *"Components and tools that need to be trimmed are looped several times."*
> ME Exterior

> *"Problems that are solved at late stages may depend on lack of materials or defects."*
> ME Interior

An important topic, discussed previously to some extent, is problems related to **trimming and fitting** with an extended time consuming solving work. Since the tools are costly they need to be trimmed in continuous loops to avoid remakes. The final decisions concerning tools are often made as late as possible to be sure of the prerequisites and not make unnecessary changes, resulting in the problem being present for a long time. According to this, tools are often deliberately being made too big to allow for trimming in small steps. In these cases it is worth pointing out that there is no lack of a solution, but the slow progress is to avoid high costs and an even more time consuming remake. The component fitting work proceeds in the same manner; as the technical limitations result in the impossibility to virtually simulate tolerances, several components must be fitted in continuous loops.

When proceeding to the physical pre-series **subcontractors** affect the development progress. Due to delays in the time of delivery from the suppliers or defects in the delivered material, the time period of problem-solving increases. Another reason for an extended solving time is the tight period of time between the physical pre-series. In some cases there is not enough time for the suppliers to update their material or tools from one pre-series to the next with the consequence of an extended problem length of life. Accordingly, when collaborating with external suppliers it is important to pay regard to the required lead-time and plan the development thoroughly.

> *"Problems difficult to solve arise when working with Ford solutions."*
> ME Chassis/Power train

> *"There was a lack of communication regarding common C1-solutions."*
> PPE

> *"A better planning is essential to be able to influence at an early stage while it is still possible to make changes."*
> ME Chassis/Power train

During the interviews performed in the research work with this thesis a clear frustration was pronounced regarding working with solutions together with Ford. Especially the Chassis department has experienced negative effects of having to **adapt to Ford solutions**. Since Ford has had a lead during the P11-project it has been difficult for VCC to get changes realized. In most cases VCC were too far behind in the development process to be able to affect the joint development. As Ford has a completely different manufacturing process and demands of ergonomics a conflict of interest arose. To be able to avoid this problem in the future it is important to plan and adjust the development process to better fit Ford's time schedule, and thereby enable a possibility to influence. Another aspect of working with common platforms is to make solutions related accessible for all of the involved parties. In some cases when VCC has had problems, there has been a Ford solution on the very same problem. However, the lack of a well functioning communication contributed to VCC's unawareness of the existing or updated solutions, resulting in unnecessary work. These different problems related to Ford were often present during an extended period of time during the development process. An improvement in this area would enable a more efficient and less time consuming development. However, it is worth mentioning that the P11-project was the first one to use common platforms and many of the problems related will most likely be avoided through experience in the future.

> *"The large number of problems makes it hard to prioritize the solving work in a correct manner."*
> ME Interior

At late stages in the development process the **large number of problems** that need to be solved affects the development progress. At present, when development work proceeds, the number of problems increases. As long as the amount of solved problem does not exceed the amount of identified problems, there will always be a large number of problems to handle at a late stage. Consequently the work of solving needs to be focused on the most serious problems while leaving the rest to be solved later. This implies that not all problems require a long period of time to be solved. On the contrary, it is a lack of resources that causes problems to be present during an extended period of time.

> *"The problems remaining after the pre try-out are often concept related defects."*
> ME Chassis/Power train

Many difficult and complicated problems are found early. These require an extensive work of problem-solving over a long period and are therefore present during a considerable development time. The opposite, rather non-complex problems, are found in later series and solved fast. As is shown in the tables and charts in chapter five, there are a number of **problems remaining to be solved after the pre try-out**. Even though the total amount of solved problems compared to the total amount of identified problems during the period, expressed in percentages, is considered rather high, there are still problems to solve at stages where the aim is to only handle new and unexpected problems. However, the problems that remain to be solved after the pre try-out seem to be, in a number of cases, concept related defects. They are not considered an actual problem as they are related to the solution not being considered as sufficiently good regarding the design. In these situations a judgement is made in order to find out whether or not the final customers will notice the defect and what affect that may have.

> *"A problem may cause subsequent problems."*
> ME Interior

An aspect of the time required to solve a problem is **when the problem is considered solved**. It is not unusual to have a number of problems as a result of solving a first one. How is such a "solution" viewed? Is a solution that causes subsequent problems a correct solution? As discussed earlier this situation is handled in two ways; either the basic problem is not solved until all the subsequent problems are, or the basic problem is reported solved while the subsequent problems are reported as new events. The first approach results in an extended solving time.

> *"Problems that are verified several times will be present an extended period of time in the development process."*
> ME Interior

"Numerous NOK-verifications may depend on pleasing the system and the organization."
ME Interior

Many of the problems that are present during a long period of time have several reported NOK-verifications in the VQDC-system. When analyzing this occurrence one wonders why a solution is not found earlier. There is of course the evident answer to that question; the problem is complex and finding an accurate solution is difficult resulting in **re-verifications**. It may also depend on disagreements regarding the solution between involved parties, which entails development of new solutions and new verifications. However, during the performed interviews a rather different answer was given. Several respondents drew attention to a way of satisfying the VQDC-system and the project organization. Due to the pressure from the organization on the realization of verifications, a date for verification is at times set without expecting an approved solution.

6.4 Summary

The discussion so far has been concerned with an analysis of when problems were found and corrected and for how long they where present, as well as a brief introduction of the reasons behind this situation. Figure 25 provides a summary of the findings and allows for the most important problem areas to be more clearly extracted. As is shown in figure 25, the three questions have several issues in common, thus implying the significance of a few major issues.

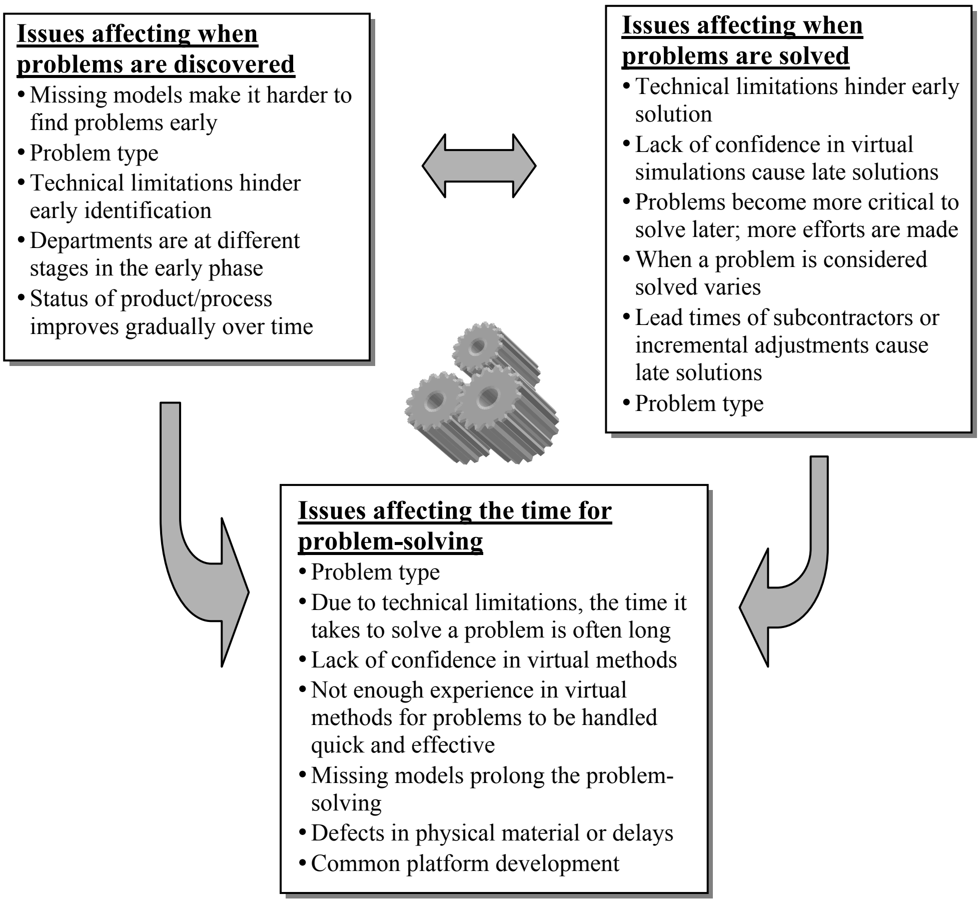

Figure 24. Illustration of main issues found from analysis of basic questions.

7 Discussion of in-depth question

The discussion presented in this chapter is held according to the in-depth question in the problem definition formulated in the introduction, thereby fulfilling the purpose of the thesis. Similarly to the previous discussion, about the basic questions, the theory and background in chapter three and four are relevant for the discussion in this chapter. It provides a more detailed insight into the various problem areas seen to be most important when examining the P11-project. This is done by approaching the issue from a couple of different angles. These issues were expressed by the respondents during the interviews and are presented in this chapter through various quotations.

The analysis and discussion of the three basic questions in chapter six resulted in an identification of certain issues. As a continuation, it is desirable to extend the analysis and further investigate the reasons for the present situation by adding the question *why*, corresponding to the fourth question in the problem definition. The summary in figure 25 has been further concluded resulting in three main problem areas, as visualized in figure 26.

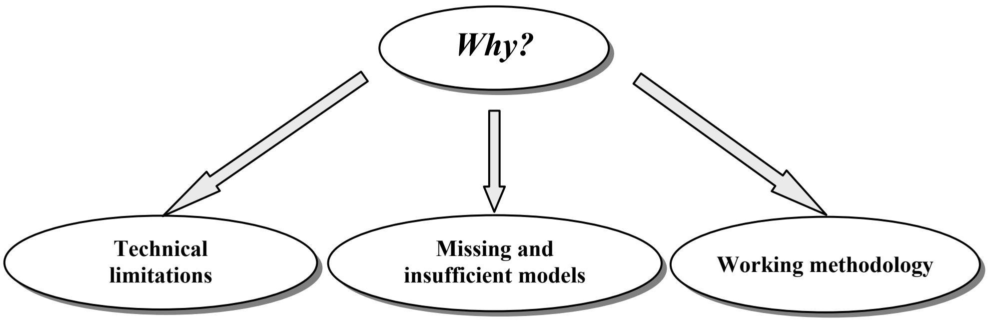

Figure 25. Overview of chapter seven, the further discussion of why there are problems with verifications in pre-series

The large number of interviews conducted had the main purpose of giving an explanation of what causes the identified problems and thereby trying to answer the fourth question. During the interviews several topics of importance were discussed. Due to the time range of this thesis it has not been possible to perform an in-depth study of all these interesting areas regarding improvement possibilities. Therefore, in order to limit the investigation, focus were placed on the possibility to discover and solve problems at earlier stages in the development process according to the theory of front-loading. In line with this terminology, to move the identification and solving of problems backwards in time, one possibility to reach the targets is to improve the virtual development work. However, it is important to understand how the physical pre-series are affected, or even how they affect the virtual pre-series in turn. Issues brought up here are often linked together in a very complex manner, sometimes resulting in issues being discussed in more than one area, however, with different approaches.

7.1 Technical limitations

As mentioned earlier there are limits to what the virtual tools are able to perform at this present time. Some parameters and aspects are not yet possible to evaluate and verify through virtual simulations in a satisfying manner. Eliminating physical pre-series, thus saving both time and money, is one of the foremost aims when developing and implementing virtual pre-series. However, due to a number of practical issues still needing improvement in the virtual work, there is a profound need for the physical pre-series in order to reach the desired results. The question at the moment is how to make best use of the tools available at present as well as knowing what areas are most important to improve.

In the result from the surveys conducted at the interviews with the Manufacturing Engineers, it can be seen that the main reason for late and long lasting problems is the fact that it is not possible to perform virtual simulations. Hence, what are the main technical hindrances when it comes to virtual development? First of all, problems are often caused by the basic difference between virtual and physical models; the fact that virtual models are always of a nominal character, both with regards to shape and position, as opposed to physical ones that assume actual values. By nominal is meant that virtual models are expected to behave in certain ways, they are of a particular size and are located in an exact position. In reality however, each manufactured detail will vary in size and shape due to small variations in the manufacturing process or in the material of the component. This results in a great difficulty when analyzing, in a virtual environment, for example the fit of a component in a tight compartment or with small allowances for deviations. Each millimeter is in many cases of significant importance, with deviations causing unacceptable conflicts. From experience over a long time it is well known that tolerances have to be taken into account since any two parts manufactured will not look exactly the same.

> *"The way of working with nominal positions should be improved making it possible to perform simulations with tolerances and "worst case scenarios". The more flexible solutions then received would give a more accurate picture of the real production process."*
> ME Interior

> *"The virtual environment being of a nominal character is a big disadvantage."*
> ME Chassis/Power train

The main consequence when working with **nominal models** is that conflicts are not always apparent at early stages. Though it will probably never be possible to fully predict the exact outcome of physical components and their fit there are ways of handling this dilemma. It is important to realize the significance of experience when it comes to analyzing the simulations. By knowing how materials perform as well as what kind of tolerances to account for, the simulations can be carried out in a more realistic manner. It is a difficult task though predicting how a complete system is affected when a number of its components are slightly deviating from there nominal values. A large number of the ME:s interviewed have expressed a wish for some kind of aid when dealing with tolerances, enabling for example the possibility to check what worst case scenarios might look like when tolerances are used to their limits.

> *"Some things cannot be simulated, for example rubber mats that cannot be bent and folded in the virtual environment. You can see the final position which is good, but the components are only placed in the right position without showing how they got there. When it comes to cables you often only check the contacting."*
> ME Electronics

> *"The software always limits, and there has not really been any real development in this aspect. Programs that can handle flexible materials must be developed."*
> SE

Another major obstacle experienced when performing virtual simulations is the handling of **flexible or soft materials**. When asked "What advantages and disadvantages do you see regarding virtual development work?" almost all the respondents replied in one way or another that there was a disadvantage of not being able to get any kind of accurate simulations of flexible materials. Primarily it is most obvious when talking to representatives from the Electronics department. This is of course because of the amount of cables involved in their work, one of the types of flexible components not possible to simulate. Often it is possible to see the final positions of the cables, but the simulation programs are not capable of handling the assembly process where the cable bends in unpredictable ways. Although the Electronics department is directly affected, this problem also has consequences for other areas. Sometimes the cables might obstruct holes for clips used by for instance the Interior or Exterior departments. Also it is not only cables that are difficult to simulate, other flexible components are mats, foam plastics, wires and hoses.

> *"It is desired to create a virtual environment describing the factory, with for example ergonomics etc. It would make the people from the factories more interested, thereby attending the virtual build meetings where they would get a better understanding for the changes by viewing simulation films shown there. That would give them a better picture of what is to come, and how they can prepare themselves."*
> VMT

At present, handling the issue of flexible materials would require a very complex and advanced software taking into account a number of hard to determine parameters. Other aspects of the product and its process that are hard, or even impossible, to simulate are filling of liquids, leakage, various forces, squeak and rattle. Furthermore, simulations of line speed at the factories or access to material for the assembly personnel are not carried out.

> *"Sometimes the confidence* [in virtual simulations] *is even a little high, they* [ME:s] *may trust the simulations, and what they show, a little too much. It is important to be aware of the limitations."*
> SE

> *"Through experience it is also possible to determine whether squeak and rattle exists, despite the fact that simulation programs cannot handle those kinds of problems."*
> ME Interior

How does this lack of appropriate virtual tools affect the verification process apart from the direct consequences mentioned here? First of all, the identification of new problems is hindered by not enabling concerned parties to visualize certain aspects of the product and process. If the tools are not accurate enough, and the users not experienced enough in analyzing the virtual simulations, there might be misconceptions as to what might cause problems. In some cases problems might not be identified at all until physical pre-series and in other cases something could be seen as causing problems which it is actually not. Not identifying problems soon enough is of course the more serious aspect of these two.

> *"Before, it was the software that wasn't so good, today there are problems caused by poor speed of the servers. There are troubles with the networks, hardware problems."*
> SE

A different aspect of the technical limitations is the performance of the computers at the arenas during the virtual build. Because of the complexity of the virtual models to be shown, the computers (UNIX-based during P11) had difficulties managing **large and complex systems.** Making such simple operations as rotating the car on the screen could take up to one minute each time and sometimes the program would simply fail completely. This is a very frustrating situation for everyone involved, having to spend valuable time just staring at a frozen model waiting for something to happen.

In the future it is hoped that a lot of these technical limitations will be solved resulting in numerous improvements for the virtual pre-series. More problems will be found, and hopefully also solved, at an earlier stage, the confidence for simulation and virtual build will increase, and maybe yet another physical pre-series could be eliminated.

7.2 Missing and insufficient models

As discussed previously, missing or insufficient models influence the development work to a great extent as it affects when the problems are discovered and solved. During the interviews it became clear that this problem area is a big source of frustration in the virtual pre-series work. There appears to be several aspects related to this topic in which considerable improvements may be realized. Since the virtual working methodology is aimed to enable a decreasing number of cost and time consuming physical pre-series, focus must be on providing accurate prerequisites for them. Without correct models, the virtual pre-series will not contribute as much as they have potential for. In order to enable front-loading of the identification and solving of problems, the full potential of virtual development methods must be applied. Since the basis for all virtual pre-series work is the models, it is essential to use accurate models in order to make use of the advantages which the virtual pre-series provide.

Most of the problems related to missing or insufficient models are interrelated with working methodology aspects. However, we have chosen to present a discussion concerning model handling as a part separated from the rest of the working methodology discussion, which will be presented in succeeding parts. The reason for this is that we believe the model aspects to be such an important area with extensive improvement possibilities, and that it is discussed and highlighted better if handled separately.

The Black Belt assignment realized by Lennart Bengtsson resulted in a number of areas to be further investigated, presented in appendix 4. One of the areas emphasized is the problems related to virtual models during the development process. His investigation had a different approach and problem definition than the ones in this thesis. Nevertheless, his results support our findings of the problem situation related to model handling which is highlighted in this thesis.

When approaching the problem area of virtual models two questions arise; why are there missing or insufficient models, and what effects do they have on the development process. Since this problem area is of importance, the following discussion has the objective of trying to answer these two questions. By providing an understanding of the current situation we aim to enable improvements. Worth mentioning is that not all changes are extensive and difficult to implement. Even small adjustments may provide for improvements.

There are numerous reasons for why models are missing or insufficient during the development process. During the interviews, an obvious frustration due to the amount of inaccurate models was expressed. The Design Engineers were often accused of causing the problem situation. However, due to the time limit and the scope of this thesis it has not been possible to perform interviews with the Design Engineers and investigate their opinion of the problem situation. It is most likely to assume that they have a different view of the model problem. Probably, shortage of time for example may be a reason.

> *"The freeze dates during virtual pre-series are not respected and models are released too late"*
> ME Chassis/Power train

> *"The Design Engineer should be more responsible. They need to understand the consequences of late or insufficient models."*
> ME Chassis/Power train

> *"Avoid private models and release them on a continuous basis."*
> ME Electronics

The most significant problem when discussing the handling of models is that the **freeze dates** are not respected. The models are released too late or not updated at all before a virtual build. In order to receive useful results from the virtual build meetings, correct models are a prerequisite. When this is not the case, the whole development process is affected negatively. The Design Engineers seem to, in many cases, keep their models in status private, where they are not official and accessible for concerned parties until the release just before the freeze date or even later. By not making the models official and withholding them from the subsequent parties, conflicts of interest may arise. If a private model, which the surroundings are not well-informed on, suddenly is released, it may lead to several unexpected changes and remakes. However, this may be avoided if the Manufacturing Engineer and the Design Engineer have a well-established and continuous communication. A constant communication would provide for and verify that they are both working in the same direction while preventing surprises. A reason for why the Design Engineer keeps his models in status private may be a resistance to release a model which is not yet finished. The majority of the Manufacturing Engineers would prefer a more open component development in collaboration with the Design Engineer. If the models were continuously released, no matter what their status are, the Manufacturing Engineer could constantly control the progress and keep the development under control. An insight into the work of Design Engineers would aid the Manufacturing Engineer to plan his own efforts. Today, it is considered to be a lot of unnecessary work with putting pressure on the Design Engineers and hunt for models. The Design Engineers must be aware of how a late model influences the development process to enable improvements regarding the model handling.

> *"When models are released just before freeze date there is not enough time to update the PII:s"*
> ME Chassis/Power train

> *"After the freeze date the Simulation Engineer has one week to perform all simulations. It is impossible!"*
> SE

It is not unusual for models to be released by Design Engineers as late as possible. The highly variable load of work is to a great extent caused by the working methodology where the majority of **models are released just before the freeze date**. It is experienced as rather frustrating having to wait for the models until last minute, resulting in a large amount of updating work once received; the Simulation Engineers have not time enough to perform all the simulations required, the Manufacturing Engineers are short on time for updating their PII:s and the Virtual Manufacturing Technicians have little time to prepare the virtual build meetings. If the models were released on a more continuous basis the work load would be more evenly spread over time. The lack of time may also affect the quality of the work as the stressful situation may influence the accuracy of the work performed.

> *"The simulations are limited by a lack of or insufficient models."*
> ME Interior

The **virtual models affect the simulations** to a great extent. Obviously, simulations can not be performed if models are missing and, as discussed previously, the simulation result may be misleading if the models are inaccurate. Simulations that are to be realized after the freeze dates and before the virtual build will be negatively affected by late models. A delay in model releases results in less time to perform the simulation which may lead to the simulation not being performed at all, or a poor quality of the simulation due to lack of time. The status of the models has a big influence on the quality of the simulations. In order to use the virtual simulations to their full potential it is important to validate the status of the models and assure their accuracy. Furthermore, the simulation results must be analyzed and decisions made while paying regards to the prerequisites and the status of the models used. Since the aim is to decrease the number of physical pre-series, the quality of the simulations is an important aspect to maintain in focus in order to reach that goal.

> *"Late models may result in changes of the freeze date."*
> Process Developer

> *"It would be better to put off the virtual build meetings until accurate models are at hand."*
> ME Chassis/Power train

Another consequence of late models is the possibility of being forced to **postpone the freeze date** in order to receive accurate models for the use in the virtual build. This does not only affect the time schedule of the project, but also, it may result in decreasing respect for delivering models in time for freeze dates. In the future it may be even more difficult to get models released in time. During the interviews it was expressed at several occasions that to achieve better results from the virtual build meetings it would be better to postpone them until correct models are accessible. This clearly indicates the frustration of late models and its consequences.

"To reduce the number of problem, correct models must be released in time."
ME Interior

"Lack of models may be a reason for problems not being discovered until physical pre-series."
ME Chassis/Power train

Lack of models has extensive consequences on the development process. Improving the **working methodology of model handling** is a challenge well worth the attention as it is the basis for improving the work with virtual pre-series. To enable front-loading of problem identification, a lack of models must not be accepted. Missing models may result in problems not being discovered until later stages, which do not correspond to the front-loading terminology. Additionally, it is essential that accurate models are released in time in order to identify problems at early stages, as well as being able to solve them and reduce the number of problems remaining to solve at later stages.

"In physical pre-series, it is considered very serious if models are missing, while at the same time there always seems to be a lack of interest in virtual pre-series."
VMT

"The project managers do not communicate well enough the importance of correct model releases in time."
Process Developer

The virtual build meetings are an attempt to replace the physical pre-series. For this to be achieved the virtual pre-series must obtain the same **level of importance** as the physical ones. For the same reason as a physical car is not manufactured if components are missing, the virtual build of the same car should not be done until accurate models corresponding to the purpose of the pre-series are presented. If the freeze dates were respected and kept more exact, the status of the virtual build results would contribute more to an efficient development. For that reason, it is important to create an understanding of the affects of inaccurate models throughout the parts of the organization concerned with virtual development.

"During the virtual pre-series the departments had different model statuses"
ME Exterior

"VCC has been behind of Ford during the development of the common platform."
ME Chassis/Power train

The departments' different time schedule has caused additional problems related to models during the virtual pre-series work of the P11-project. As the departments were in different phases of development progress, the consequence was models with various statuses. Problems due to different **model statuses** arose both between VCC and Ford, and between departments within VCC. The Chassis department, for example, was behind the common platform development. As the common platform was more or less in the final stages of development, it was experienced as rather impossible to have changes made. Instead the Chassis department had to adjust to the decided solution which in many cases caused complications. To avoid this problem in future projects when working together with Ford on common solutions, the VCC time schedule must be worked out to better fit a collaborating development.

The same occurrence was present between departments at VCC. Some departments are ahead in development since they, for example, are responsible for tools and components that requires an extended lead time. As a consequence, the different parts of the car had different statuses and did not fit together during the virtual build meetings. For that reason, the virtual build results were of variable accuracy. This type of problem is not easy to prevent, since the departments have to pay regards to lead times and manufacturing sequence. The departments are dependent on each other's components and manufacturing processes and their development work must therefore progress in sequences.

> *"The Ford models are difficult to handle."*
> ME Chassis/Power train

Another problem related to model handling is complications due to **compilations and storage of models**. Since Ford and VCC have different software and the databases containing models are not linked together, complications arise. The Ford models are considered difficult to handle as they need to be converted to fit the VCC software. The problem affects the development progress as unnecessary time and effort are required in order to make use of the common platform models. However, the C3PNG-project, described in chapter four, includes the development of a common system solution for managing this problem.

> *"One gets easily confused amongst the large amount of models."*
> SE

> *"A number of Manufacturing Engineers seems to be confused of the differences between PDMU and ADMU."*
> VMT

An additional problem related to model handling is expressed by the Simulation Engineers and the Virtual Manufacturing Technicians. Due to the **large number of models** it is at times difficult to know which model is of interest for the simulation to be performed. For this reason it is essential that the Manufacturing Engineer is clear on what models to include when ordering the simulation. If not, the simulation result may be misleading and either imply problems that do not exist, or disregard problems that would have been identified if the correct models had been used.

During the virtual build meetings a problem causing delays and disruptions is **missing models in ADMU**. It is experienced as frustrating for the Virtual Manufacturing Technician having to convert the models from PDMU to ADMU in order to run the virtual build. This is considered the responsibility of the Manufacturing Engineer and should be done during the preparations for the meetings. Furthermore, it is not unusual for models to end up in the "slop pail" due to uncertainty of their sequences, resulting in additional work for the Virtual Manufacturing Technician with trying to find the model.

> *"Subcontractors have different working routines."*
> Process Developer

> *"Misunderstandings with subcontractors regarding the design of the component have a negative affect on the development process."*
> Manager Interior

To some extent complications with models are related to **subcontractors** as a part of the design work is outsourced. The subcontractors may not have the same routines as VCC during component development. Misunderstandings and conflicts of interest regarding the component as well as delays in the model delivery influence the development progress. Although this is a very interesting area, this thesis will not further discuss the relationship with subcontractors and how they affect the development process. Due to the limits of the thesis this is left for future in-depth investigations.

7.3 Working methodology

During the course of this investigation a lot of opinions about how the virtual verification process was working, and what should be done to improve it, were expressed. Some of them have been discussed in detail above but many others fall outside those categories and are therefore recalled for in this part of the chapter. "Working methodology" was chosen as a heading for this sub-chapter since the areas discussed here are all somewhat related to the way people work and how that affects the outcome of this particular part of the development process. Within this sub-group of problem areas, focus will be on five different issues; education/experience, communication, virtual pre-series in general, resources such as time and people, and the use of VQDC (see figure 27). Once again recalling the work by Lennart Bengtsson it can be noted that he also found that the working methodology could be seen as one of the causes for problems arising during the verification process. As a result of his work he suggested a project be carried out investigating how the interaction between the different manufacturing departments is handled.

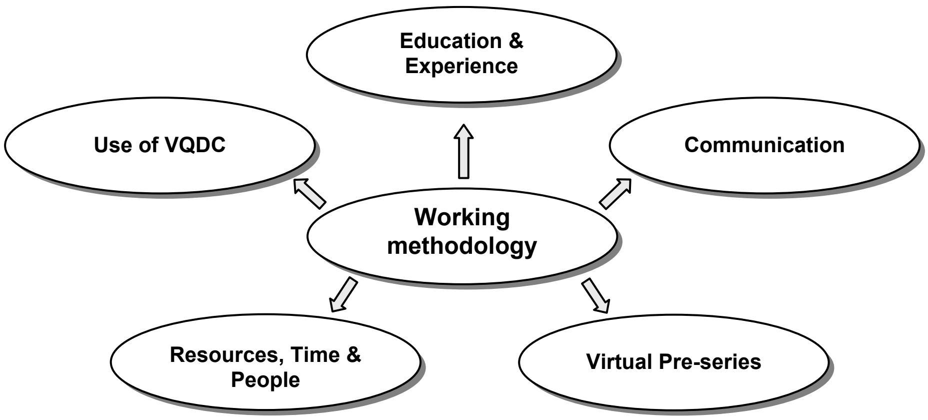

Figure 26. Issues of working methodology.

7.3.1 Education and Experience

Implementing an extensive new working methodology such as the introduction of virtual verification series is not an easy task. Apart from the fact that all big changes require a lot of work for the organization to adapt, the case of virtual manufacturing calls for even more adjustments. For many of the involved in the P11-project, working with virtual tools was a new experience. Getting acquainted and familiar with this takes its time, for example learning to view models on a screen during digital mock-ups.

> *"Many of problems in the P11 can be referred to the fact that in that particular project there were a lot of changes, a whole new working methodology. The virtual methods are new to most of us but the work gets better and better as time passes."*
> ME Electronics

Adapting an organization to change is an organic process. First of all, the parties involved have to understand *why* the change is needed in order to be motivated. Without a widespread **trust for the new way of working** it is hard to get a good momentum for the implementation. However, this trust is often achieved after some time when the positive effect of the new working methodology is proven. This illustrates the difficulty of implementing change. A more thorough discussion about implementing changed working methodologies will not be further accounted for here but it must be understood that such changes require time to set in before the efforts pay off. Therefore, and for many other reasons of course, projects should be studied with an understanding of the context it is in. In this case one important aspect is the fact that the VMC project was just about to end when P11 started. VMC was the biggest contributor to the creation and implementation of virtual manufacturing processes, and as such it offered necessary support and focus for the newly introduced virtual pre-series. But as all projects, it had to come to an end and the lessons learned had to be brought out and anchored to each concerned part of the organization. For this reason there was a decrease in the focus and support when the P11-project was to stand on its own feet, so to speak. As the organization continues to work with the issues connected to virtual development, it will gradually become more adapted to the situation through constant adjustments and gained experience.

> *"An ME should according to the role description be able to retrieve models* [from the databases] *but not everyone can. It would be nice not having to perform such meaningless and unnecessary jobs."*
> SE

It was seen in this investigation that there are no clear **areas of responsibilities** stating who is responsible for what when it comes to performing certain virtual simulations. The simulations can be done by the ME, SE or VMT. In general the everyday, and rather simple, simulations are performed by each responsible ME. When confronted by a complex case or simulations of for example ergonomics, they rely on the help from the SE, who master the more complicated simulation softwares. Sometimes the ME:s are assisted by a VMT, especially when it comes to simulations done in the DMU-navigator software. There is a large variation in how the ME:s work with the virtual tools, i.e. how experienced they are, that is reflected in the kind of jobs that are performed by the SE:s and the VMT:s. The lack of clear and formal requirements for these roles, in this particular aspect, can probably be due to the fact that there is a need for flexibility in the organization at this stage. It takes time to provide the involved people with the right education in order to get a common level of competence needed for better defined role descriptions. Reaching a more uniform and higher level of competence in the field of virtual work would avoid unnecessary time to be spent by the SE:s performing simple operations such as loading a work cell.

"At the physical pre-series you relax in the sense of virtual methods and loose knowledge during those months, having to refresh that knowledge again for the next virtual period. With the coming of parallel projects, this problem will probably decrease."
Manager Exterior

Some get really good at virtual work, and then they work in a physical environment for about a year, thereby loosing knowledge. That is unfortunate and it makes it hard for me to run the work as people are moving in and out [of the virtual environment]."
Manager Exterior

"The programs should be used continuously in order to not loose the knowledge about the programs."
ME Interior

One problem the Manufacturing Engineers face is that their work with virtual tools is of a **periodical character**. During some time they are very involved in virtual development, in all the virtual pre-series, and then follow a period when they are fully occupied with physical pre-series where the work with virtual simulations is basically set aside. Maintaining the knowledge of simulation softwares is therefore rather difficult.

It is important to keep this aspect in mind when implementing new softwares for the ME:s, making sure they get sufficient training, not only initially but also perhaps in the form of refreshing courses at the start of periods with virtual series. When it comes to the Simulation Engineers, they are the experts on the simulation software. This is one of the reasons they belong to the same group within organization, which is helpful when it comes to drawing experiences from each other and keeping updated on any new programs.

"You have to be careful, not working too much virtually. It is necessary to have enough experience from the physical reality. It is not possible to fully trust the results from simulations without sufficient experience."
ME Electronics

"Everything can be virtually simulated. The reason not all PII are simulated is that it can be both time consuming and misleading in some cases."
ME Electronics

Apart from the knowledge in virtual tools it is very important to acknowledge the experience drawn from the reality of production facilities and its procedures. With such experiences simulations can be carried out in a more correct and relevant manner.

"It still doesn't feel as good when you are watching a virtual detail as it does with a physical one."
ME Chassis/Power train

"In the future, experience from previous virtual work will improve the results."
ME Electronics

"More problems could have been discovered virtually. Experience was lacking for more problems to be found. Now, as we know more what to look for, we will find more problems sooner."
ME Interior

There is also another aspect of experience, which has to do with the **skill in analyzing** the simulations. In some cases there is still a little reluctance when it comes to working with a virtual visualization of an object, as opposed to an actual physical object. It takes time getting used to handling and viewing digital models and knowing how they behave in the virtual environment. As the simulations are limited for technical reasons, discussed in 6.2.1, it is crucial to make up for this shortcoming through experience. By gaining knowledge of how simulations actually fall out in physical object, better analyses can be done in future cases.

"PII:s of a simple character are not simulated. Experience is sufficient to judge if they work."
ME Chassis/Power train

"With experience and "carry-overs" you don't have to simulate everything. However, it is a good idea to run simulations anyway in order to check if something has changed or has been forgotten."
ME Chassis/Power train

"If you start reasoning that some PII are unnecessary to simulate, you will end up forgetting or missing something that may cause problems at a later stage. It is not a good idea to start bending the rules."
ME Interior

When it comes to **how much should be virtually simulated**, how many of the PII for example, the opinions differ. This is believed to be something that will change over time as there was some degree of uncertainty and lack of knowledge as to what was to be verified virtually through simulations at the time of the P11-project. Some respond that everything should be simulated in order not to risk missing anything. Yet others are of the belief that the most basic PII are not necessary to simulate as that would require too much time and not contribute with any relevant information, perhaps even with misleading information in some cases. They also hope that solutions from common platforms will provide the possibility to reuse components and systems, thereby reducing the need for some simulations.

"The Manufacturing Engineers trust experience a lot and will therefore not simulate everything. Simple simulations do not contribute with any added value and it won't do in the future either. However, more simulations should be performed. Only trusting experience will result in something being missed. The simulations must be examined more closely."
SE

"I will make use of the experience from the P11-project in order to get a better understanding as to what is important to simulate and examine more closely."
ME Interior

All in all, everyone agrees that more simulations will be performed in the future. However, experience in the field of virtual simulations, gained over time, may lead to simulations being performed in the right cases, at the right time, and with fewer misinterpretations. It is felt that simulations are often needed in order not to oversee any problems, even though they are of a simple characteristic. Therefore, many ME:s have responded that more simulations will be carried out in the future.

7.3.2 Communication

As in all cases when a large group of people are working together towards a common goal the communication between the involved parties is crucial. In the case studied in this thesis, there is a vast number of different departments involved in developing the new product and its manufacturing process. The Manufacturing Engineers belong to different MSS areas, Design Engineers are organized in PSS areas, and SE:s and VMT:s aid the ME:s. All of these groups must communicate in a good way since they are dependent on each other in order to perform in the most effective manner. Lennart Bengtsson noted in his project that one of the big issues causing problems to remain until physical pre-series was the fact that there was a lack in interaction, in terms of communication, between different manufacturing departments. In a lot of cases a problem caused by one department may not affect that particular department itself, but instead another one. It is not possible to organize the departments in a way that would eliminate problems that affect more than one department because of the complexity of the product. Every department is in one way or another dependent on all the others.

It was during the course of this thesis not a main aim to focus on how communication affects the problem-solving process. However, it was expressed at several interviews that this aspect might be one contributor to the problems experienced. Since this corresponds to the findings of Lennart Bengtsson, a broad discussion as to why this might be the case will be held here.

One of the main problems concerned with the communication and coordination of the various manufacturing departments is due to the fact that they are not all at the same stage of the development process. The reason for this is the differences in lead times when it comes to development and manufacturing time, of both the product and the tools necessary, for in-house as well as outsourced components and systems.

> *"The different* [manufacturing] *departments are not always synchronized and are out of phase with each other because of varying lead times. The departments that are behind must keep a close eye on the ones ahead in order to be able to influence issues related to them."*
> Process Developer

In this regard it is in some ways **hard to synchronize the work** with the common platforms, developed together with FMC for example. A consequence of this is the necessity for some departments to work towards development schedules that are well ahead of the ones at VCC. For example the Chassis department has to be heavily involved in such work in order to get needed platform changes across at an early stage. Due to this there are a lot of difficulties; it is not easy to predict the needs of the departments involved later. If there are not enough communications between the departments with such issues, problems may arise that could have been foreseen. Therefore, it is important that departments starting their development work at a later stage keep themselves updated with the ongoing work of the ones ahead. The introduction of the virtual build meetings, during the virtual pre-series, has facilitated this communication as they are an important gathering of the involved parties at an early stage.

> *"The interaction between the departments is good during the digital mock-ups at the arenas.*
> ME Chassis/Power train

The virtual build meetings provide an opportunity to communicate not only existing problems but also to update each other so that actions can be taken sooner in order to avoid some future problems altogether. During those meetings each ME get a certain amount of time to present their PII:s and this gives others, who might be affected by any changes, a chance to come with remarks and questions, or simply seeing a broader picture of it all.

> *"Between the virtual build meetings you don't have any real idea of what the other departments are doing."*
> ME Chassis/Power train

> *"There is only communication between the departments when there's a need for it, in other words when there are problems. It works fine."*
> ME Chassis/Power train

However, the **communication between manufacturing departments** is not always kept very active between the gatherings in the arenas. During that time ME:s from different departments have a much more sporadic contact, mainly when any new problems arise or when there are new solutions present affecting other departments. For this communication to work properly personal contacts in other departments are central as there are not so many other natural meeting places for the specific ME:s from different areas.

> *"When problems are found to be in a grey zone between departments, conflicts sometimes arise as to who is responsible for taking care of the problem.*
> ME Exterior

> *"There should be better defined areas of responsibility. Make it more clear who is to do what when conflicts arise between groups or departments within manufacturing."*
> Process Developer

> *"At present you work with blinders, no one wants to have a VQDC problem which causes conflicts. The department doing the change should also be in charge of the problem. Departments are too focused on delivering good results; it should look like they have done a good job."*
> ME Chassis/Power train

When it comes to handling the problems found, communication between departments once again is of significant importance. There are many cases when problems are not easily related to a certain area. They may instead be affecting several different areas or in other cases affecting a different department than the one causing it. As there is some reluctance when it comes to dealing with new problems, arguments sometimes arises as to who is responsible for a solution. During the interviews a common view on this aspect was noted.

The one suffering from the problem is the one to be responsible for developing a solution. Expressed in another way, a ME must check the assembly up to and including his job and if there are problems discovered afterwards it is the job of the following ME to solve it. Even though this policy seems to be well anchored in the various departments, there appears to be some difficulties being consistent when implementing it. Also, the question of who is really suffering from a problem, and thereby responsible for solving it, often remains resulting in disagreements between departments.

> *"There is no real understanding between the Design Engineers and the manufacturing departments."*
> ME Electronics

Apart from the communication within the Manufacturing Engineering division, it is also important to establish and maintain good **contact with the R&D division** where the DE:s are located. This is vital for DFM to work as intended, but also not the least for the daily work to be made easier. A better communication between these two areas would facilitate several aspects of the verification process. First of all there is a great need for an improvement in the handling of models as discussed in chapter 7.2. Better understanding of the effects each part has on the other would be reached through an ameliorated communication. Furthermore, a frequent contact, with useful feedback, would keep both parts more updated on what is going on at different departments. This will make the ME:s better prepared when it is time to perform simulations based on the work done by the DE:s. It is experienced, within the manufacturing division, that the DE:s are too often not open enough in their communication. One aspect that might contribute to the difficulties in the communication between ME:s and DE:s is the fact that it is not unusual for DE:s to rely on, or even themselves belong to, external subcontractors.

> *"There is an unknown number of ME:s that don't order simulations. The reason for this might be that either they perform the simulations themselves or they don’t do them at all, something that may be caused by lack of confidence in simulations."*
> SE

> *"Our communication works in a good way! Since we are situated amongst the Manufacturing Engineers most of them are aware of our existence and the way in which we can assist."*
> SE

The third aspect of communication studied in this thesis is the one concerning **the contact between the ME:s and the SE:s or VMT:s.** This communication is typically done on a daily basis though there is a more intense contact just before the running of the digital mock-ups in the virtual pre-series. As the SE:s, and to some extent the VMT:s, constitute a supporting function providing services to the ME:s, it is mainly the ME that initiate contact. They are seen as the experts on the softwares used in the field of virtual simulations.

Earlier the information about the SE:s and VMT:s, and how to make use of their competences and services, was not completely made aware to the ME:s. However, as time goes, and the word is spread across the departments, more and more ME:s take advantage of the experts. Although the SE:s are organized as a separate group they are physically located at the different departments. This is an important aspect since it facilitates the communication as well as making everyone aware of the possibility to get help with simulations.

> *"In most cases the simulation order is placed verbally even though it says in the working methodology described, that simulation report should be used. Simulation report is good as it forces the ME to carefully consider the order, really thinking it through, as well as it provide us with an overview of the total amount of work."*
> SE

The more formal way of communication between these parts is done through the **simulation reports,** SR. The thought behind simulation report is that it is a way for the ME:s to order simulations. It has not been fully implemented yet and most of the contacts are still made verbally. An aim with SR, seen by the SE:s and VMT:s, is that it will give them more needed and complete input, as to what is to be simulated and how, from the ME:s who will have to think through the order more. At times, the information from the ME:s is not very detailed causing problems and a lot of time to be spent for the experts to find out for example which components to be included, which versions to use, and what the tolerances are.

> *"There ought to be some kind of feedback to us! We have no idea really of how the simulations turned out, how it worked in reality."*
> SE

> *"Feedback is only received if there is a frequent personal contact with the ME and we ask, out of curiosity, how the simulations worked."*
> SE

In general the communication between ME:s and SE:s/VMT:s work well. There is however one aspect that the experts feel is somewhat neglected and that is the feedback after simulations have been delivered to the ME. A better feedback would provide the SE:s/VMT:s with more experience that can be useful for future simulations. It would also serve as a motivation knowing how their work really came to use.

7.3.3 Virtual series

Each virtual series include an extensive work. Consequently, there are several aspects of interest to discuss when analyzing the virtual work. In this part of the discussion we have chosen to gather the analysis of the working methodology related to the virtual pre-series. It is worth mentioning that during the research investigation of this thesis, a problem seeking approach was used. However, when asking the respondents of their opinions about the new virtual working methodology, we received nothing but positive answers. In general there are beliefs and expectations throughout the organization of a more efficient development through the use of virtual methods. Nevertheless, there are still numerous improvement possibilities to point out.

> *"During the P28-project the virtual work was kept in focus. However, the enthusiasm moderated after the project closure."*
> Manager Chassis

As mentioned previously, the P11-project is only the second to use the new virtual working methodology. However, the P11-project has not had a supporting project running in parallel with the objective to supervise and aid the implementation of virtual methods, as was the case with the VMC-project during the development of the P28-project. The VMC-project had the effect of maintaining **focus and priority on the virtual work** resulting in an extensive interest throughout the organization and the involved parties. Unfortunately, there seems to be a descent after the closure of the VMC-project as the charm of novelty has diminished. Additionally, during the P11-project the new way of working had to be carried on by the ordinary development organization without the supporting project running. The everyday work since then has not been successful enough in continuing the progress of implementing the virtual methods and the development has ceased. Furthermore, several new Manufacturing Engineers and Design Engineers who were not given the introduction and education during the VMC-project have been involved in the P11-project.

> *"The working methodology during the virtual phases must be improved in order to enable identification and solving of problems at earlier stages."*
> Process Developer

The descent in interest is however not unusual when implementing news in an organization. The main challenge faced today is to increase the focus of the virtual pre-series in order to obtain a more efficient development. The influences of model releases on the virtual pre-series' quality have already been discussed. However there are several additional aspects that will be accounted for below.

> *"The virtual build meetings are meant to replace physical prototypes and should be viewed equally important."*
> VMT

> *"The purpose of the virtual build meetings must be better communicated."*
> Manager Exterior

> *"If managers were present during the virtual build meetings to a greater extent it would create a pressure on the involved parties to deliver the material they are responsible for."*
> Process Developer

> *"A project leader should always be present during the virtual build meetings. Then, everybody would do one's every utmost"*
> VMT

During the interviews many respondents expressed their critical opinion of the virtual build meetings. Since they are the conclusion of each pre-series, where all the work performed during the period of time for the virtual pre-series is presented, they play an important role during the development process. The virtual build meetings are the equivalent of manufacturing a physical car and these occasions provide a visualization of the manufacturing process without using physical prototypes. For that reason the meetings should have the same priority as the physical pre-series. Today, they appear to by viewed mainly as a check of the project status. To increase the **focus on the virtual build meetings** not only the model handling must be improved.

Firstly, the **purpose of the virtual build meeting** must be communicated across the departments involved in the virtual development process. All of the involved parties, down to the individual, must obtain an understanding of how their role affects the virtual process. By creating an understanding of the individual influence and participation the interest will be increased. Knowing that your work makes a difference and contributes to the development process helps generating job satisfaction, which in the end will result in an improved efficiency.

Secondly, and often a result of a well communicated purpose, the **attendance during the virtual build** meeting must be enhanced. During the VMC-project when much attention was paid on the virtual development, the presence during these meetings was good. However, during the P11-project the attendance is considered as appallingly poor. When respondents were asked what they considered necessary to improve regarding the virtual build meetings, they all pointed out the presence. In general, the lack of interest shown by not attending is experienced as frustrating. There is a widespread wish for an increased number of involved parties to be present. In order to make full use of the virtual build meeting and obtain better results, individuals concerned with virtual development must attend to see how their work affects the progress of the project. In particular, project leaders and managers within the manufacturing division must imply the importance by attending on a regular basis. Persons of high station affect the result of the virtual build meetings to a great extent. By being present they put pressure on the responsible parties to perform their preparation work thoroughly and deliver correct material to be visualized. As a result, the entire work of the virtual pre-series will be improved. If not managers find the virtual build meetings important enough to participate in, it is not possible to expect the rest to find them of significant interest. Managers must come to an understanding of how they can put pressure on the meetings and through that enable a more efficient virtual development.

> *"During the P11-project one missed out on including the Simulation Engineers at the virtual build meetings."*
> Process Developer

It is not only managers that need to participate during the virtual build meetings. Several others would support and favor the virtual development with their presence. **Simulation Engineers** should attend in order to see the results of their simulations and through that obtain feedback. By knowing the simulation result they may achieve an understanding of whether or not the simulation was performed well, and if the result may be improved by realizing the simulation in a different manner next time. Their attendance would provide for an understanding of the general picture of all of the manufacturing processes, and not only the parts where they have personally been involved. At the meetings they would also be able to answer any questions other parties may have regarding the simulation.

Design Engineers should participate during the virtual build meetings to a greater extent. Through their attendance they would achieve knowledge of how their component affects the surrounding environment and better pay regard to wishes and suggestions related to the component from other affected parties. They would also obtain an understanding of how a lack of or insufficient models influence the development progress.

> *"If the virtual build meetings are not improved one might just as well abolish them."*
> SE

"Due to missing models, the virtual build meetings were at times experienced as unnecessary."
ME Chassis/Power train

If the organization does not understand **the importance of raising the focus on virtual build meetings** it will become very difficult to reach the goal of decreasing the number of physical pre-series even more. The present situation must not be accepted. It is at times even considered as meaningless and not worth the time spent on being present until the status is ameliorated. Since the total work performed during the virtual pre-series to a great extent is affected by the pressure on the virtual build meetings, actions must be taken. Not until the virtual pre-series are improved, front-loading of identifying and solving of problems are possible.

"The running virtual work is a big lift for the organization. Although the missing models are frustrating, the virtual build meetings still provide a good check of the project status."
SE

"The advantage of virtual work is the savings of time and money. It also enables an identification of problems without having to build an entire physical car."
ME Chassis/Power train

"In the long term, if we manage to create an accurate attitude and atmosphere and the decisions we make are adjusted to the virtual development methods, it will result in an amazing penetration and enable decreased lead times. Today we are not making use of its full potential."
Manager Interior

Although many critical voices regarding the work in virtual pre-series have been heard, all **respondents still see the opportunities** it will bring if optimized and used accurately. It seems the criticism and opinions are aimed to contribute to improvements. The objective and advantages of using virtual methods appear to have been well-communicated throughout the organization. There is an understanding of how the virtual working methodology will contribute to a more efficient and less time and cost consuming development. However, there is also an awareness of the virtual methods not being optimally used at the moment and that improvements have to be made.

"The confidence in the virtual work is doubtful. Often, physical final verifications are preferred as a result of not fully trusting the virtual result.
ME Chassis/Power train

"In general, 20% of the ME:s does not trust the simulation result completely and whishes to verify in physical pre-series."
SE

In order to improve the virtual working methodology a large step is to increase the **confidence in the virtual methods**. It has been obvious during the interviews that contradictions are present throughout the organization concerned with the virtual development. Generally the confidence in virtual working methods is expressed as good in the organization. However, this is contradictory to the fact that many appear to prefer physical verifications. This indicates a loss of confidence in fully trusting the virtual results. Partially, this may depend on the technical limitations but it also seems to be the case when not limited by the software performance. The lack of confidence may to some extent originate in the decreasing focus on virtual pre-series. Missing models that influence the result of the virtual build meetings contributes to misbelief.

> *"Even if doubting the accuracy of the virtual simulation result, there is still no need for postponing verification until physical pre-series. There are other ways!"*
> Process Developer

> *"It is possible to rapidly verify in virtual pre-series by using physical prototypes."*
> ME Chassis/Power train

When working with and implementing virtual methods one is easily simplistic. As focus is set on the virtual development methods, the additional physical aids are often disregarded or forgotten. If an uncertainty exists regarding the simulation result, it is important to emphasize supplementary **physical alternatives** in order to not delay and burden the development process by postponing verifications. By using, for example rapid prototyping and test materials, a virtual solution can be physically analyzed and verified during virtual pre-series. To avoid putting off problems to be solved at later stages this is an excellent alternative still rather low in cost compared to awaiting physical pre-series. Rapid prototyping may result in the ability to avoid additional problems related to the solution that otherwise would not have been discovered until at later, more costly, stages. Physically verifying solutions while still in virtual pre-series also contributes to avoiding problems with prioritizing, arising when there is a large number of problems to solve. If the physical prototype is made due to a lack of confidence in the virtual simulation result it may be a way of convincing the surroundings of their accuracy. In the long term this will result in an augmented confidence in virtual methods. An optimization of the combined use of virtual simulations and physical verifications in the virtual pre-series would be preferable. Through this an efficient development is possible even though technical limitations and misbelieves are present.

7.3.4 Resources, time and people

The issue of resources, their availability and allocation, is central when working towards shorter and more effective development processes. There are always incentives for new products to be developed using less resources with maintained quality and prices, thus increasing the profit. The idea of front-loading is once again relevant as an approach to reaching this. In this thesis the focus on resources will be their availability and how they are used when it comes to the verification process. Mainly the aspects of time and human resources are discussed, while the economical resources are left out. It is important to realize what the effects of the resource allocation have on the development process. Making a bigger effort at earlier stages, i.e. being more pro active will hopefully result in fewer problems found towards the end, where they become more costly. However, assigning resources to such preventive work can sometimes be difficult as effects are not usually seen immediately.

"More resources could be useful, at least during the early stages. It is better to have more people in the beginning so that a better base can be achieved than having to put the resources at the end just to solve the problems not taken care of earlier."
ME Interior

"The work load varies a lot with high peaks before the virtual build meetings, just before SOP, and when projects collide with each other."
ME Exterior

"There is a very uneven distribution of the workload; it goes up and down a lot. During the P11-project it was felt that the workload was rather heavy."
ME Electronics

Planning and allocating the right resources during the course of the development project is a tough job. The reason for this is the very nature of the work, varying a lot over time. There is a **variation in workload** at the overall development project but also within each pre-series. With so many different projects running parallel to each other it is even harder to schedule activities in an optimal way for all parts involved. The consequence of this is that planning and prioritizing, of for example handling of problems, is crucial in order to give more serious issues the right attention.

"We have great ambitions, but as it is today we have limited resources when it comes to personnel."
SE

"The workload has increased now, even for the periods that were previously not so intense. We are fewer people now but we are still expected to perform the same amount of work. There is more to do than there are resources available."
SE

The virtual pre-series were introduced with front-loading as an objective. In that sense more problems are to be found earlier through the use of more simulations and tests. As no real cars are produced during those pre-series the **time allowed for virtual pre-series** was a lot shorter than for the physical ones. Because of the problems related to models, discussed in 7.2, there is a lot of work to be performed during a very short time period before the virtual build meetings. This puts a very big workload on for example the SE:s and the VMT:s, making it harder for the ME:s to get hold of them at that time, when the need for their help is the greatest. Planning the time is made harder since it is difficult to know when final versions of the models will be released and made available. Also the fact that the presence of the experts has become more known to the various departments results in more simulations being ordered. Despite this increase in work for the SE:s/VMT:s they are even reduced in numbers. More is to be done by fewer people as it is today. The emphasis on virtual pre-series should be reflected in the resources given to the simulation groups, thereby creating some important prerequisites for the evolution of virtual development work.

Furthermore, it is sometimes felt that too little time is spent on the virtual build meetings. It is felt that they are somewhat stressed and enough room is not given for discussions and questions needed in order to reach better results. Another aspect of this is that if the virtual build meetings are not improved, some even question the existence of those gatherings. If they do not contribute enough it is reasoned that the time spent on virtual build meetings could be better used in the daily work.

> *"A limiting factor is that there are not enough licenses for simulation softwares as well as computers that are able to handle those softwares."*
> ME interior

Finally, it was noted that departments are not provided with enough hardware and software for simulations to be carried out by the ME:s themselves. As it is, they often do not have the possibility to just sit down whenever they want to start working with simulations because there are no available computers. If there were more such resources more simulations could probably be done by the ME:s resulting in some weight off the back for the experts.

7.3.5 Use of VQDC

Since the problems registered in the VQDC-system is the foundation of this thesis, a short discussion regarding the system itself will be presented in this part of the discussion chapter. The VQDC-system is an important tool to manage problem handling during development and it is essential that it is used accurately in order to enable front-loading of problems. During the interviews we asked respondents a number of question related to the VQDC-system in order to investigate their opinion of the system and the working methodology supporting the use, as well as trying to clarify if the system itself may cause problems during the development process.

> *"The VQDC-system is a very large system with an extensive framework of information about the problems."*
> ME Interior

In general the VQDC-system is considered as good throughout the organization. It is however, at times experienced as rather complicated and complex if not familiar with the system. The education in the handling of the system has been expressed as defective, which is rather unfortunate as the progress of the development process is depending on a well-functioning system for problem handling. On the other hand, the system is fairly new and like all innovations, a time for learning is required. An extensive and rather complex system is a necessity in order to include all relevant information to be used by everyone involved in solving the problem.

> *"The VQDC-system is thought to be used for recycling of solutions in succeeding projects to avoid the same problem to arise."*
> Process Developer

> *"The Design Engineers do no not have time for searching the system in order to find relevant solutions."*
> ME Interior

One of the purposes with the VQDC-system is that it should be used as **a transfer of experience** from one project to another. The DE:s are supposed to view the system as an aid during early development to avoid complications. Additionally, the solutions stored in the system are thought to be used as a help and support when dealing with similar problems. If the system were used to collect experiences from preceding projects, it would be possible to avoid similar problems to arise, while at the same time limiting the number of process related solutions and simplifying the manufacturing process. However, in the present situation the system is not used for this purpose. It seems the reason for that is a lack of time, though it would result in a decreased load of work in the long term. On the other hand, it may depend on the purpose not being sufficiently communicated or a working methodology supporting it not thoroughly implemented. Since the objective of using the VQDC-system as a database of experience to a great extent would affect the efficiency positively, it would be well worth the effort to introduce that way of working.

During the interviews some **suggestions for improvements** of the system were expressed. Some considered it too complicated to register a problem and suggested that unnecessary menus would disappear as a choice is made. Another wish was for a facilitation of the possibility to make changes and updating the events. It was pointed out that the system must not be too complex as it would result in a resistance for reporting problems.

8 Conclusions and recommendations

In this chapter the objectives of the thesis are accounted for as a conclusion of the investigation. The chapter summarizes the most significant areas discussed in chapter seven. Areas, which considerably affect the overall verification process, and their implications, are concluded. Furthermore, recommendations for future in-depth studies to enable improvements and allow for front-loading are presented. The areas of most significance for further research are shaded in figure 28.

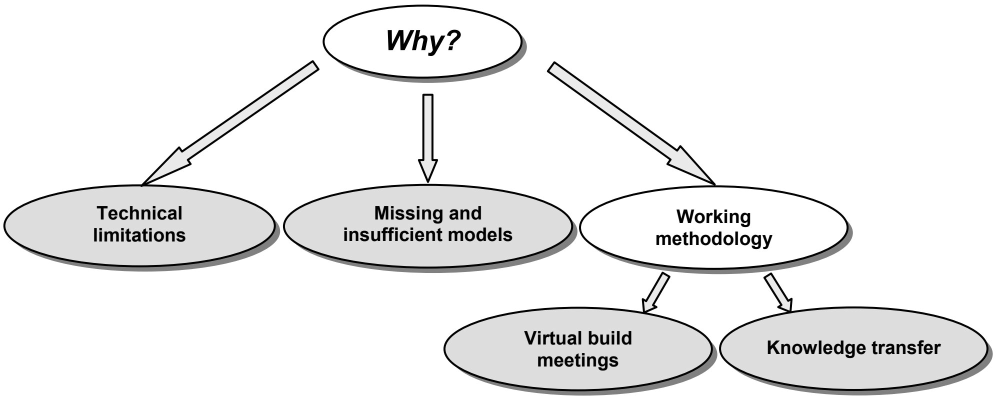

Figure 27. Areas of significance for further research.

Why are the technical limitations such a serious problem?

It is commonly known throughout the organization that the technical limitations to a great extent hinder the verification process. By not being able to virtually simulate all PII:s with a reliable result, the identification and solving of problem are postponed to physical pre-series. As a consequence, the physical pre-series are indispensable, and until the simulation tools are improved they will continuously contribute to a high cost and time consuming development process. Furthermore, the evident technical limitations result in a diminishing confidence in the use of virtual methods, which affects the overall development negatively.

At present, the VCC organization must become skilled at working around the technical limitations, and focus efforts on optimizing the software's current usability by making use of supplementary alternatives. Firstly, experience from past development projects and education in virtual simulation tools will contribute to improved performance. Secondly, while working in virtual pre-series one must not disregard the available physical alternatives in terms of rapid prototyping, in order to avoid postponing of identification and solving of problems. Finally, by allowing more resources, in the form of time and people, for virtual pre-series, the opportunities to discover and handle problems at earlier stages are enhanced.

In order to make full use of the virtual simulation tools and thereby ameliorate efficiency, the following recommendations for future in-depth studies are stated:

- *An investigation that examines how the virtual development can be optimized by using rapid prototyping.* What is the optimal combination of virtual tools and rapid prototyping? How are their uses balanced most advantageously during the virtual development stage?

- *An investigation with the purpose to thoroughly determine what can and cannot be virtually simulated.* Is it a lack of knowledge and education, or doubtfulness that limit the simulations and not the performance of the simulation tool itself? Is there a connection between late identification of problems and PII:s not simulated, and if so, what are the reasons for not simulating these? Are there certain types of problems that are present during an extended period of time?

Why is it so important to have the right models at the right time?

If handling of models is not performed efficiently enough there might be some serious consequences. First of all, problems will not be found until later as verifications concerning missing models have to be delayed. For this reason the solutions are also not realized soon enough, thus not fully enabling front-loading. Furthermore, problems with models significantly affect the quality of the virtual development since it hinders the daily work, where models constitute an important part. The virtual build meetings are clearly affected by this aspect since the usefulness of such visualizations is deteriorated by the lack of proper models. The right time is not always the same as the final deadline, or freeze date, but may also suggest that models need to be available whenever they can be of use. Not acting in this way may result in heavy workloads at certain times. Last, but not least, model related problems may be part of the main contributing factors when the SOP has to be postponed.

It is found that one of the most important and primary approaches to improving the work in this regard has to do with respecting the dates for when models are frozen, a fundamental prerequisite for virtual pre-series to work as intended. It is however further desired that the handling of models is improved in more ways than keeping the deadlines. Through a better communication overall, between ME:s and DE:s, the significance of this issue can be communicated. This will enhance the daily work overall, and handling models in particular.

In order to deal with this problem area it is recommended that handling of models is investigated more thoroughly, with all its aspects.

- *An in-depth study of the handling of models will allow for an understanding to be reached as to where the cause for the problem really exists.* Such an investigation should consider the relationship between ME:s and DE:s specifically as this thesis has only been performed from a one-way point of view. How do models make their way from the beginning of the development process all the way to its physical use during mass production? What are the crucial stages in the handling of and work with models? Can different types of models be categorized, in order to follow examples from each category through the product and process development?
- *As models are often developed by subcontractors it is suggested that a study of their involvement is conducted.* How are models used and handled from their start when ordered by VCC, through refinement by CAD softwares, and ending up as finalized solutions in the production process?
- *An investigation viewing the verification processes from a R&D point of view.* It was not an aim for this thesis to investigate whether a similar study, as this one, is important to conduct within R&D department in order to reach better front-loading. Nevertheless, since this thesis is biased in terms of the investigated area it

would most likely be beneficial to receive another view of the problem. For example, what do the DE:s see as reasons for problems found or solved late?

Why is it essential to have well-functioning virtual build meetings?

An important activity during the virtual development process is the virtual build meetings. As they allow for an overall verification they provide a status for the progress of the project. The meetings are an opportunity to receive a broad perspective of the entire project and the interactions between different departments. Well-functioning virtual build meetings are essential in order to decrease the number of physical pre-series and enable cost and time reductions. Virtual build meetings of high quality will provide for front-loading of problem handling.

It is generally expressed that the virtual build meetings must be improved and there are several approaches to enhance the quality. Firstly, the priority and focus must be increased. A major step to enhance priority is to increase the number of concerned parties attending and participating during the virtual build meetings, which will improve the results. By thoroughly communicating the purpose of the meetings and providing the employees with an understanding of their contribution, the attendance will increase. Furthermore, the presence of managers on a more regular basis will imply the importance of the virtual build meetings and raise the interest. Secondly, the confidence in the virtual working methodology must be augmented. At present, contradictions within the organization are obvious; the confidence in virtual methods is expressed as good, nevertheless, physical verifications are preferred in several situations. The virtual pre-series, including the virtual build meetings, must be provided with correct prerequisites in order to be improved, which to a great extent are about relying on the accuracy of the virtual methods and make full use of its potentials.

Further investigations within this problem area are recommended with the purpose of enabling improvements.

- *An investigation with the purpose to examine and analyze the working methodology supporting the virtual build meetings.* Are the virtual build meetings realized according to the established working methodology? Has the working methodology been thoroughly implemented? What improvements and modifications should be considered? Are the virtual build meetings organized and arranged optimally?
- *Investigate how resources, such as time and people, are used and allocated within the verification process.* Are the resources used in the most optimal way at present? Is it possible to deploy more resources at earlier stages?
- *An investigation that analyzes requirements, during virtual development, for increased comprehension and motivation and the advantageous consequences entailed.* What soft factors, such as job satisfaction and incentives, affect the development progress? How does the leader's role and influence affect the overall performance?

Why is it important to transfer knowledge?

Knowledge is a very important and delicate resource in an organization and if it is used, and more importantly reused, in an effective way, problems may be avoided. Transferring previously acquired knowledge is particularly valuable in order not to make the same mistakes once more, one of the two imperatives for front-loading. Furthermore, knowledge from earlier projects, either within VCC or from other common FMC projects, would prevent work with solutions to be carried out that have already been realized previously. If problems may be avoided or easily solved through the use of prior knowledge, the problem-solving efficiency during process development may be increased.

Making the most of knowledge and experience from preceding projects can be achieved in various ways. Apart from the tacit knowledge, that everyone involved in the development possesses, it is necessary to have a formalized way of dealing with additional knowledge. An example of such a system is VQDC, where all the previously experienced problems, as well as their solutions, are stored. However, it is also useful to give some feedback regarding work that resulted in good solutions, without causing trouble, in order to keep doing the right thing. An important aspect of feedback concerns the exchange of information between involved parties during virtual pre-series. As virtual simulations aim to reflect the physical reality at production facilities, it is important to bring back information as to how accurately the virtual mock-up manages to agree with the finalized solution.

As a recommendation it is proposed that the aspects of knowledge transfer are further investigated, particularly with regards to the effects it has for reaching front-loading.

- *Study the possibilities of using VQDC for the purpose of preventing the reoccurrence of previous problems*. What are the limiting factors for this, i.e. time, or the system? What may the expected benefits be; is it possible to make a prognosis as to what the profits may be from this, or what type of problems that should be avoided in this way?
- *Investigate if the established working methodology sufficiently supports feedback and/or knowledge transfer.* How should experiences and outcomes from verification activities be communicated across to concerned parties? What are the informal feedback possibilities; are the right communication channels available?

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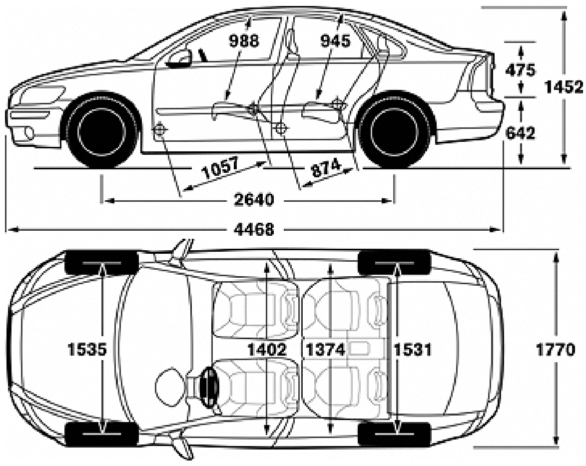
Interviews

A decision was made not to present the names and roles of interviewed persons here as that would not contribute with any relevant information necessary for the understanding of this thesis. Information about how the interviewees were chosen and what roles they have in the organization is presented in chapter two, Methodology.

The All New Volvo S40



Technical specifications:

Engine:	1.8	2.4	2.4 i	T5	2.0 Diesel (geartronic)	T5 AWD
Volume:	1798 cc	2435 cc	2435 cc	2521 cc	1998 cc	2521 cc
Effect:	88 kW (125hp)	103 kW (140 hp)	125 kW (170 hp)	162 kW (220 hp)	100 kW (136 hp)	see T5
Torque:	165 Nm/ 4000 rpm	220 Nm/ 4000 rpm	230 Nm/ 4400 rpm	320 Nm/ 1500-4800 rpm	320 Nm/ 2000 rpm	see T5
Acc, 0-100 km/h:	∗	10.2 s. (man) 11.1 s. (aut)	8.2 s. (man) 8.9 s. (aut)	6.8 s. (man) 7.2 s. (aut)	9.5 s	∗
Speed: max km/h:	∗	205 (man) 200 (aut)	220 (man) 215 (aut)	240 (man) 235 (aut)	205	∗
Fuel cons: l/100 km	∗	8,4 (man) 9.1 (aut)	8.5 (man) 9.1 (aut)	8.7 (man) 9.4 (aut)	5.6	∗
CO2: g/km	∗	199 (man) 217 (aut)	203 (man) 217 (aut)	208 (man) 224 (aut)	148	∗
Env. class:	2005	2005	2005	2005	2005	2005

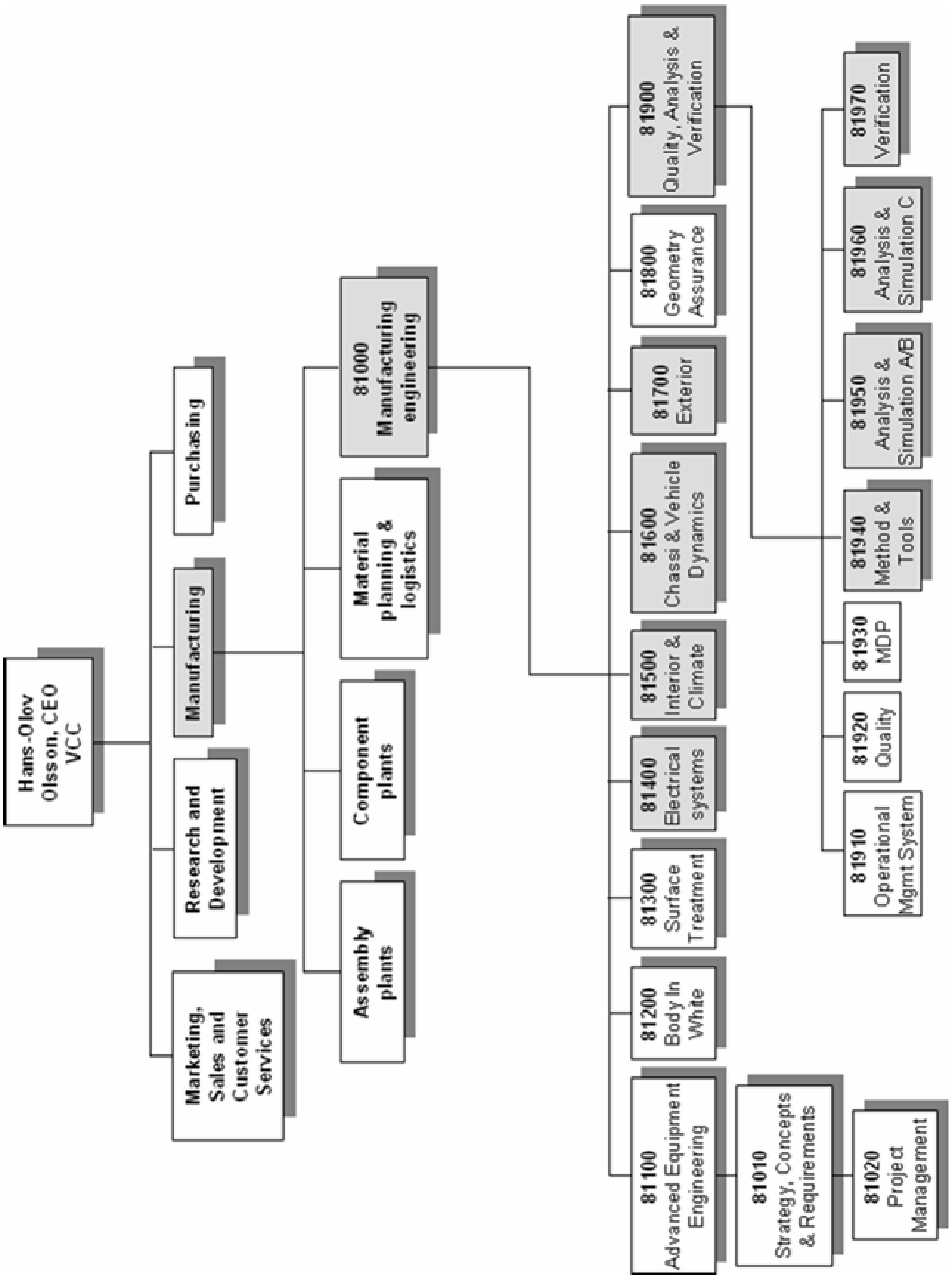
Price from 190 000 SEK
∗ : No information yet available

Appendix 1 – Abbreviations

ADMU	Assembly Digital Mock-Up
AIMS	Automated Issues Matrix System
A-shop	Body-In-White plant
B-shop	Surface treatment plant
C1	Small platform jointly developed between VCC, Ford of Europe, and Mazda
C3PNG	CAD/CAE/CAM Product information exchange Next Generation
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CATIA	Computer graphic Aided Three dimensional Interactive Application
CS#1	Customer Satisfaction number one
C-shop	Assembly plant
DE	Design Engineer
DFM	Design For Manufacturing
DMU	Digital Mock-Up
DMN	DMU-Navigator
FMC	Ford Motor Company
FMEA	Failure Mode and Effect Analysis
GJ1	Global Job 1, Ford common global gate
GKO	Global Kick Off, Ford common global gate
GPA	Global Project Approval, Ford common global gate
GPDS	Global Product Development System
GSI	Global Strategic Intent, Ford common global gate
KDP	Konstruktion Data Personvagnar
MDP	Manufacturing Development Process
ME	Manufacturing Engineer
MSS	Manufacturing System Structure
NIWL	National Institute for Working Life
PAG	Premium Automotive Group
Pdb	Position database
PDMU	Product Digital Mock-Up
PII	Process Inspection Instruction
PM	Product Management
PPA	Product Planning Administration
PPE	Pre-Production Engineer
PS	Physical Pre-Series
PSS	Product System Structure
PTO	Pre Try-Out
PVS	Process Verification System
QFD	Quality Function Deployment
SE	Simulation Engineer
SOP	Start Of Production
SR	Simulation Report
SUV	Sports Utility Vehicle
TO	Test Object
TO	Try-Out

VCC	Volvo Car Corporation
VCCQ	Volvo Car Customer Quality
VCG	Volvo Cars Gent
VL	Verification Leader
VMC	Virtual Manufacturing Center
VMT	Virtual Manufacturing Technician
VPDS	Volvo Product Development System
VPM	Virtual Product Manager
VS	Virtual Pre-Series
VQDC	Volvo Quality Deviation Control

Appendix 2 – Organizational Charts



Appendix 3 – Department Charts

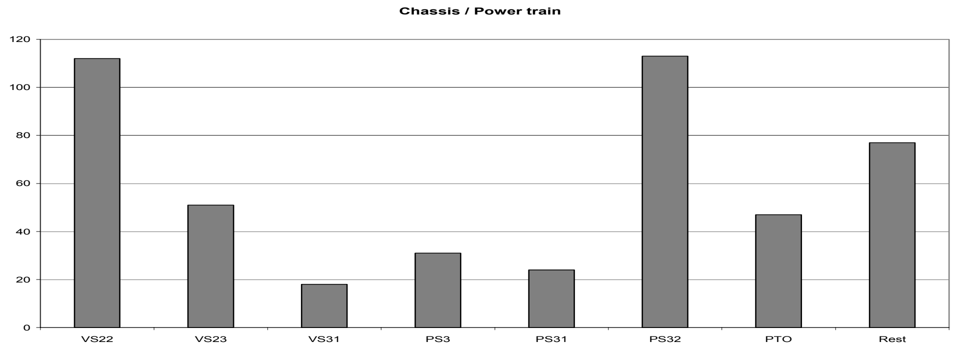
Search criteria for VQDC information

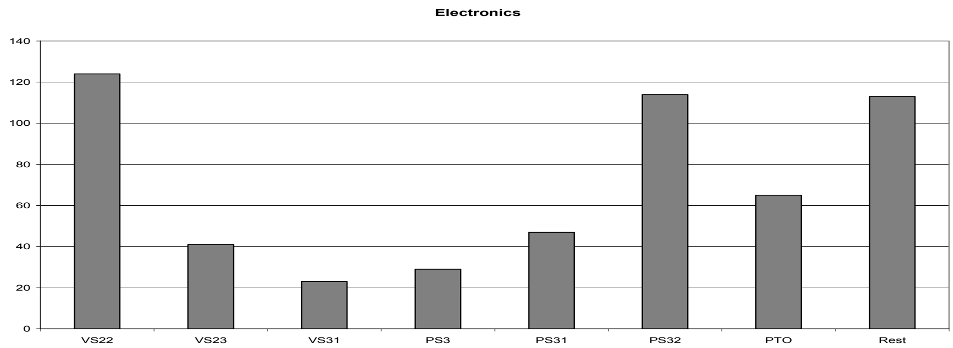
Firstly, the P1-platform was chosen, and then project P11 and P12[54]. To restrict the search to project P11, the date corresponding to the start of production for this project was chosen. The VQDC-system offers the possibility to divide the registered problems into the departments responsible for them. We found it useful to be able to distinguish between the different departments and their problem situation, yet cover the entire car project. The following departments were for that reason included in the search criteria: Chassis Design, Electrical Systems, Exterior Design, Interior Design and Power train Architecture. Furthermore, Pre-Production Engineer in Gent (PPE-VCG) was chosen to limit the search to problems related to the manufacturing process, according to the scope of the thesis.

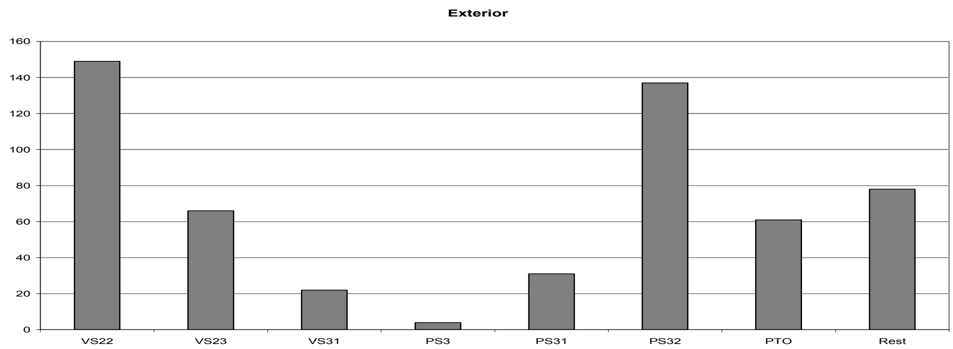
Once the list of problems was extracted from the VQDC-system the work of dividing the problems into useful categories begun. The VQDC-system contains information about the dates corresponding to when the problem was registered and when the status was changed throughout the development process. By knowing the freeze date of the pre-series and combining them with the dates registered for when the event was created and ended, a distribution of the problems into different pre-series was possible. Finally the departments, and the information about the problems related, were separated in order to enable a study of each department separately. Since Chassis Design and Power train Architecture are managed by the same department in the manufacturing structure it was natural to unite and investigate them as one department.

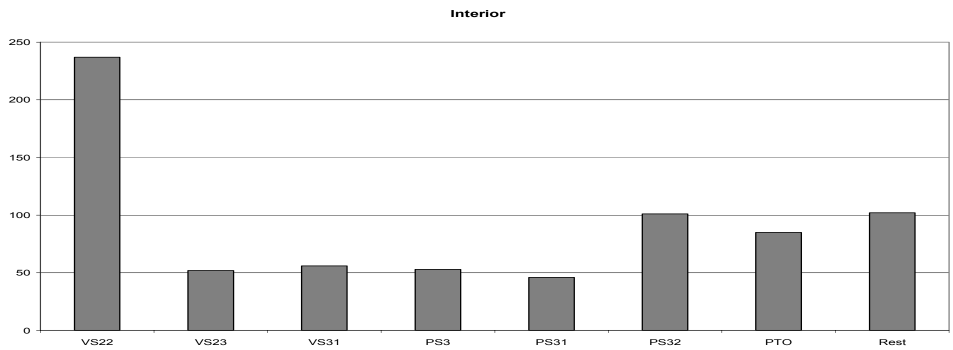
[54] The P12-project is the development of the new V50, which is based on the same platform as the P11. P11 and P12 have to some extent been developed together.

Number of problems created in each pre-series

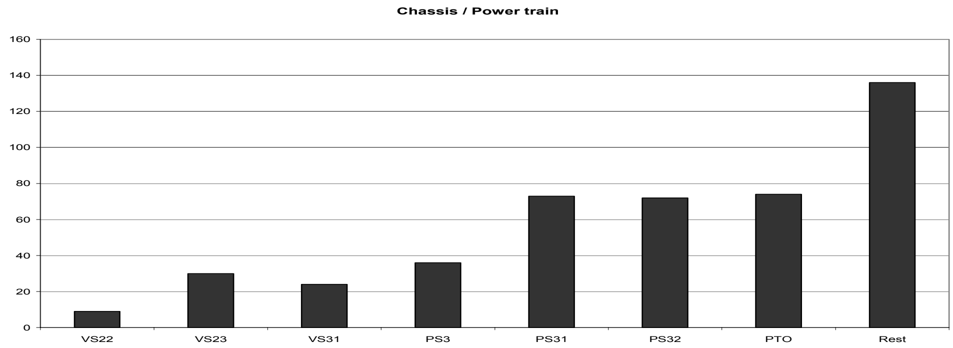


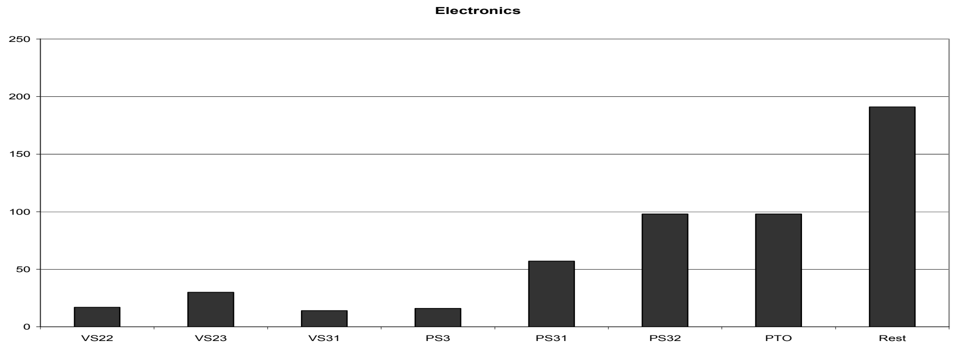


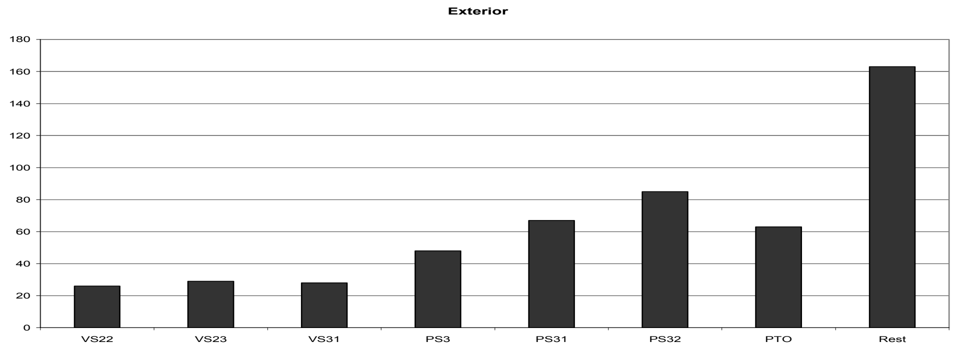


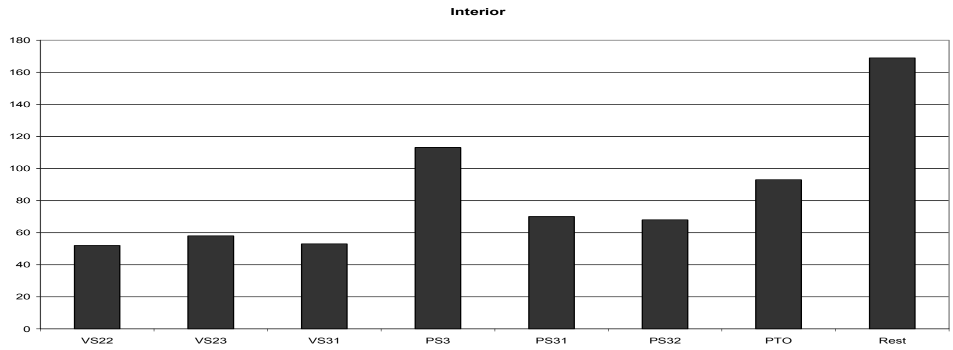


Number of problems solved in each pre-series

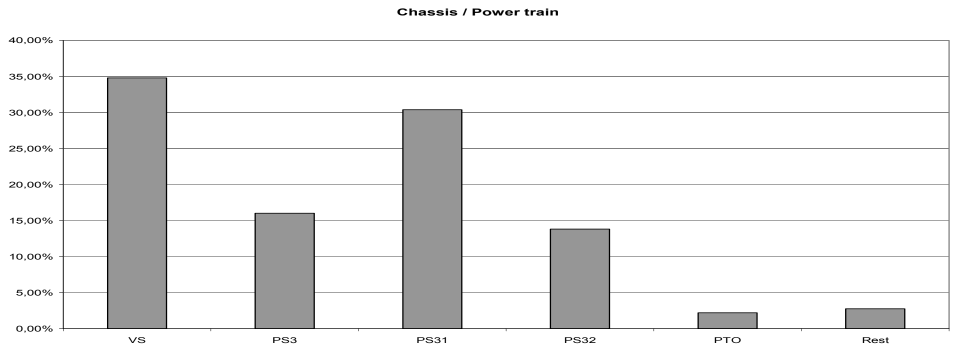


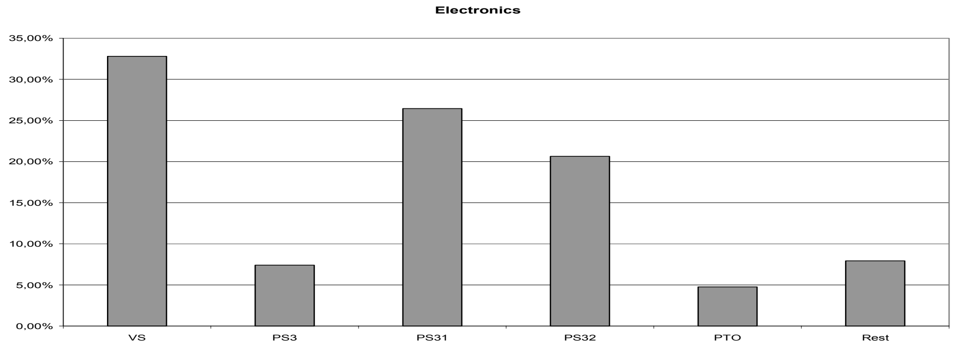


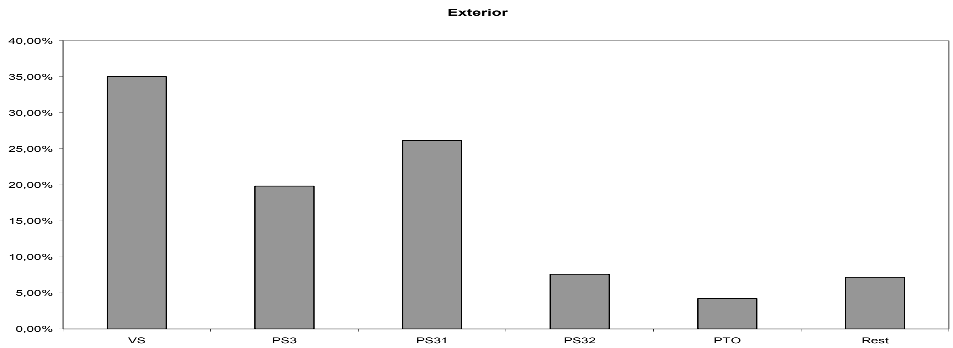


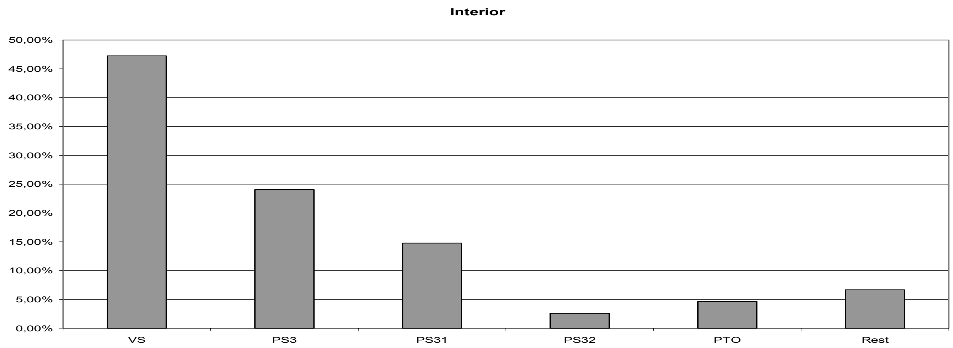


Number of VS problems solved in each pre-series



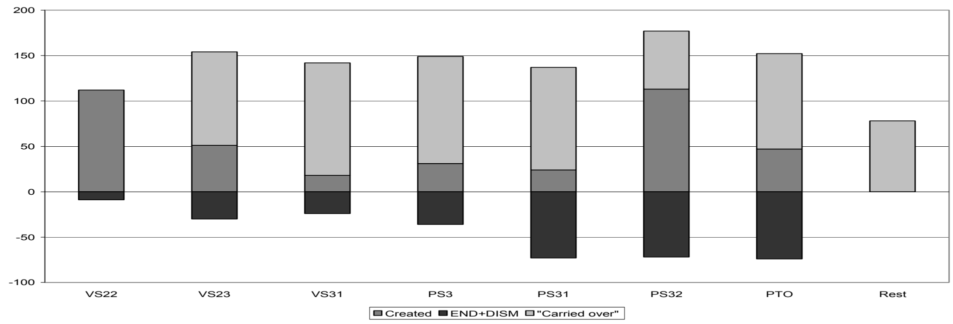




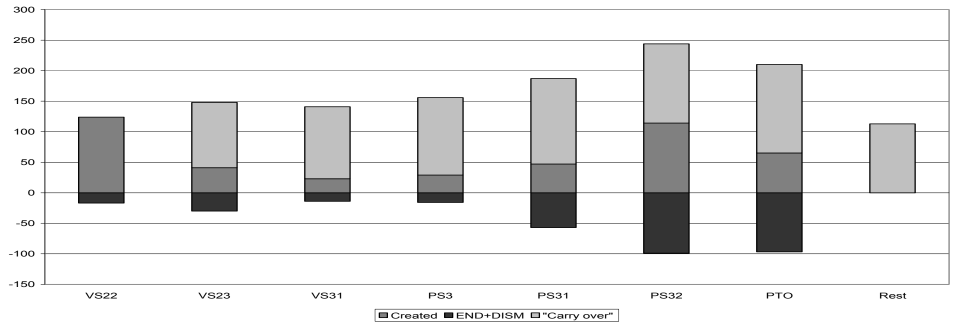


Number of problems created, solved and carried-over

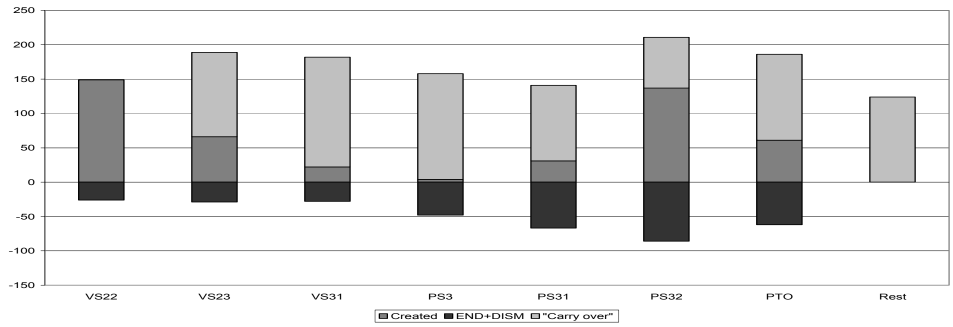
Chassis / Power train



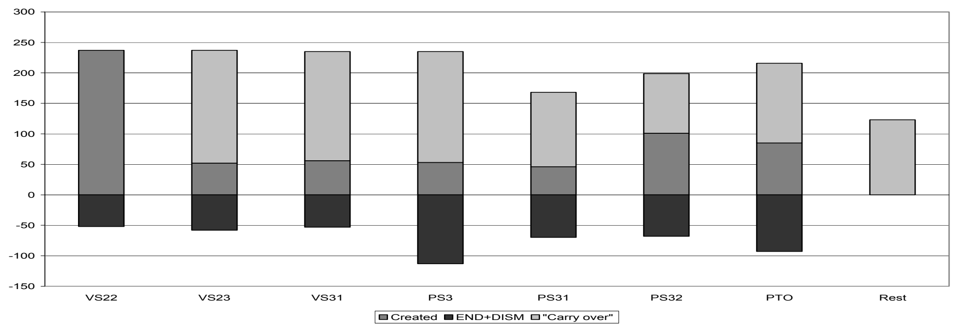
Electronics



Exterior



Interior



Appendix 4 – Results from investigation of P28

This table and Pareto diagram shows the total result of the responsible Manufacturing Engineers distribution, expressed as a percentage, to the question "What is the reason to the remaining VCCQ point in P28 FS 3.1?".
(The question was made for every single PII that had a VCCQ remark.)

	Modeller saknas/ Konstruktionen ej klar (För låg problem-lösningshastighet)	Fel artikel-status vid byggn	Problemet orsakat av annat berednings avsnitt	Lämpligt virtuellt verifierings-verktyg saknas	Oerfarenhet beträffande virtuellt verifierings-verktyg	Samsyn med annat modulteam saknas	Ej tillräcklig beredar-erfarenhet	Tidsbrist. (För många uppdrag per beredare)	Annan orsak	Går ej att verifiera virtuellt	Forcerad beredning. (Lämplig beredarresurs saknas eller har saknats)	Lågt förtroende för vituell verifiering
D/U	290	580	110	30	90	0	0	0	0	0	0	0
EL	1295	380	800	890	15	180	40	30	30	0	40	0
INT	1465	220	1185	790	255	0	105	105	100	75	0	0
ITR	910	1420	210	100	0	0	20	0	0	40	0	0
Totalt	**3960**	**2600**	**2305**	**1810**	**360**	**180**	**165**	**135**	**130**	**115**	**40**	**0**

All the respondents were given 100 points to distribute amongst the provided reasons for remaining problems in PS 3.1. A high mark indicates a significant influence on the development process.

Appendix 5 – Interviews

Questions – Manufacturing Engineers

Opening questions

1. For how long have you been working at Volvo? Are you a consultant or a VCC employee? For how long have you been working as a manufacturing engineer? What other positions have you had previously at VCC?

2. Describe your role as a manufacturing engineer. Responsibility, deliverables, resources etc. during virtual and physical pre-series.

3. Describe your work situation with regards to the work load. Is the work load distributed evenly or are there highs and lows during some times?

4. Do you have any possibility to affect time planning for VS and PS within the project? How do you experience the time planning?

Virtual series

5. How do you experience working with virtual development at present?

6. What are your visions for working in virtual pre-series, generally and within your department?

7. What are the pros and cons with virtual development? Possible improvements?

8. What is the confidence and trust like for virtual work? Personally and within your department?

9. To what extent are the virtual methods used? How many PII are simulated virtually out of the total amount?

10. How many PII can be virtually simulated at present?

11. Is there a need to be able to simulate all PII virtually?

12. Will you simulate more in the future?

13. What are the limits when it comes to virtual simulations; technical limitations, lack of education/experience in the software, insufficient competence when ordering simulations?

VQDC

14. How do you experience working with VQDC, is it used in the right way?

15. Are there any shortcomings? Improvement possibilities?

16. How does the decision making about VQDC-problems work?

17. Statistics from each department and questions concerning that data.

18. To what extent could problems found in physical pre-series have been discovered in VS? What are the reasons for not observing them in a virtual environment?

19. Can some problems not be solved using virtual tools?

20. Why are some problems so long lasting?

21. What may be improved in order to solve problems earlier; organization, software, working methodology, resources, planning?

22. How serious are the problems that are left and have to be dealt with after PTO?

23. Some problems are ended but then later reopened again, what are the reasons for this?

24. Some problems have been verified NOK several times, why is no final solution found earlier?

25. How is the work with solving problems prioritized; priority, created etc.?

26. Are failclass and priority connected to each other? Who assigns failclass and priority for a problem?

27. Is there any connection between length of life and priority?

Miscellaneous

28. How do you experience the communication between departments?

29. How do you experience the communication concerning the software; 81940, Tecnomatix, Volvo IT?

30. How do you experience the communication with subcontractors?

31. Incorrect models and article statuses may cause problems. Why isn't the right material available?

32. Are the right decisions made at the right time, generally?

Questions – SE:s and VMT:s

Opening questions

1. For how long have you been working as a SE/VMT?

2. What other positions have you had previously at VCC?

3. Describe your work situation with respect to workload! (The allocation)

Virtual series

4. How do you experience the work with virtual methods? (Today, P11)

5. What are the visions of the future for the VS?

6. What are the advantages and disadvantages of the virtual methods? Improvements?

7. How is the confidence of simulation orderers for the virtual methods used?

8. Will more simulations be performed in the future?

9. What limits the simulation; technical limitations, competence in softwares used, licenses?

Planning

10. Is there any long-term planning for the simulations that will be ordered?

11. Are you able to affect the long-term planning?

Areas of responsibility

12. Describe your role as a SE/VMT! (Responsibilities, demands, and resources in virtual and physical pre-series)

13. Are there any clear areas of responsibilities for the kind of work to be performed by SE:s/VMT:s/ME:S?

Communication when ordering simulations

14. How do you experience the communication between ME:s and SE:s?

15. What is the methodology for a ME to order a simulation?

16. Are there any shortages in form of competence when ordering a simulation?

Concluding questions

17. Is there anything in the working methodology for a SE that can be improved in order to facilitate work and make it more efficient?

18. What do you consider to be the main reasons for problems being discovered late and/or remaining at late stages in the development process?

Questions – In-depth

Working methodology

1. What are the basic responsibilities, with regards to virtual simulations, for the ME:s? Should there be a common standard for these? If so, what?

2. Can efficiency and quality increase by improving the education and experience in virtual tools and have clear responsibilities for the ME:s? If so, in which ways?

3. How was the P11-project affected by the lack of education and experience in virtual tools?

4. Simulation Engineers, what is the best way to make use of their knowledge; how to organize them, how to give them feedback.

5. Does the priority affect time and quality? If so, how? What is the best way to prioritize in order to get high quality solutions to problems as early as possible?

6. How are interactions handled between departments with respect to problem solving and changes in product and process?

7. How does the general communication between departments affect time and quality? What can be done to improve this?

8. Would a precise working routine facilitate the solution work when dealing with problems affecting different departments?

9. Is there a problem anchoring decisions completely at the different departments?

10. How to get the importance of VS across to all concerned parts? How to make it as important as a physical prototype?

11. What is needed in order to improve the presence during DMU:s?

12. Would more specific targets affect time and quality?

13. Why are the results from simulations not trusted? Is it because of attitudes, different cultures, knowledge? How can this be improved, and a greater confidence be reached?

14. What are the consequences of this with regards to time and quality?

15. What can be done in order to improve the number of problems identified and solved in VS? Not enough resources deployed at early stages ➔ expensive late changes

16. Is it possible to make the distribution of time more even? If not, is it because of the working methodology chosen?

17. What kind of feedback exists during development? How is this feedback used, for whom is it aimed to?

18. Is it sufficient with a learning process, without a formal feedback system?

Missing and insufficient models

19. What causes models being released late by the DE:s? What can be done to get releases at the right time? Is something being done in order to improve this?

20. What is the problem when departments are at different stages?

21. Can the latest models from each department be used to run the DMU:s at the VS?

22. How are the simulation results and engineering work affected by different model status? Does this effect the reliability and relevance of the DMU:s?