Requirements and needs for 3D-visualizations (a 3D-viewing platform)

An in-depth study of instances of research and development at Scania CV AB

Master of Science Thesis in the Master Degree Program Product Development

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Sammanfattning

Produktutveckling inom fordonsindustri går mot att arbeta mer med digitala 3D-modeller och mindre med konventionell 2D-ritning. När utvecklingen sker parallellt genom samarbeten mellan olika avdelningar ställs därför höga krav på tillgänglighet av relevanta och aktuella underlag. Vid konstruktionsarbete i 3D-miljö krävs en visualisering med stor spridning mellan instanser involverade i utvecklingsarbeten samtidigt som också en enkel åtkomst efterfrågas. Denna lösning skall efter implementering stöda de krav på korta ledtider och lägre utvecklingskostnader som föreligger.

I examensarbetet ligger fokus på att sammanställa och presentera behov av 3D-visualisering från olika grupper inom Scania som inte förknippas med CAD (dvs. instanser utöver konstruktörsrollen). Behoven innefattas i detta avseende av att det på Scania saknas visst metodstöd (dvs. avsaknad av verktyg som medför ett effektivt användande av relevant digital design). Detta beskrivs i ett försök att belysa användbarheten i ett tvärfunktionellt 3D-format. Behoven innefattas också av andvändbara funktioner som listats av de intervjuade instanserna på Scania. Dessa behov belyses både textuellt och som grafiska gränssnitt i konceptform som så kallade 3D viewers (programvara som används för att visualisera CAD-data).

Vidare har frågeställningar runt informationsspridning behandlats i förhållande till 3D-visualiseringar och dess inverkan på ledtider för iterationer i produktutvecklingsprocessen.

Kunskaper, idéer och erfarenheter har inhämtats dels från intervjuer med Scania-anställda (främst R&D, men även från inköp, produktion och eftermarknad), men också från referensbesök på Volvo PV, White arkitekter och SAAB Aeronautics. De sistnämnda har varit värdefulla genom sina erfarenheter av tidigare implementering av lösningar för ökad användning av 3D-visualisering.

Relevanta konsekvenser som belyses i detta arbete är att ett utökat användande av 3D-data medför att spridning och förståelse av designunderlag underlättas samtidigt som också graden av samarbete i relevanta projekt förbättras. Genomförda studier påvisar också att ett utökat användande av 3D data medför en utmärkt bas för att tidigt i ett processtadie utbyta kunskap mellan instanser som normalt inte förknippas med 3D-data. Detta skulle bland annat medföra att problem uppdagades i ett tidigare skede. Vidare slutsatser som kan dras från detta examensarbete är bland annat hur viktigt det är att använda en gemensam och aktuell databas. Det konstateras också att en ökad spridning och användning av 3D-visualisering kan leda till kortare ledtider.

Abstract

Product development within the automotive industry is progressing towards using more 3D models and less conventional 2D drawings. When development is done in a parallel cooperative way, demands for availability of relevant and current data are high. Engineering design in a 3D environment requires visualization that incorporates wide spread sharing and simple access, which after implementation would support demands for shorter lead times and reduced development costs.

In this master thesis a focus to compile and present requirements for 3D visualizations, from different groups not consistent with CAD at Scania, has been at hand. Being a design engineer means having access to intuitive 3D design data, but what about other instances of a developing company? The requirements are in this context consistent with the lack of supporting IT-tools (that is, a feeling of not being able to effectively make use of relevant 3D-data) the various groups of Scania experience. This need is highlighted in an effort to illuminate the usability in a common cross functional 3D format. The requirements in this thesis also entail functions of a 3D-viewing platform (a software used in order to render 3D-design data) expressed by the interviewed instances of Scania. The requirements are featured in both text and with a graphical concept (of a 3D-viewer).

Moreover has the framing of questions within the area of information sharing been treated with respect to 3D visualizations and their impact on lead times for iterations for the product development process.

Spread of information could be made easier if more people would gain access to 3D visualizations. According to our results from conducted interviews, problems could be detected earlier, providing means for an effective frontloading scheme. Knowledge and information share are also made more tangible.

Ideas and experience have been collected partly from interviews with employees at Scania (mostly R&D, but also from purchase, production and aftermarket), and partly from reference visits at Volvo Cars, White architects and SAAB Aeronautics. The reference visits have been a valuable source of information, providing experience from implemented solutions of 3D visualizations.

Relevant conclusions that can be drawn from the master thesis are amongst others the increased coordination capabilities common visual aids provide. Other conclusions entail the importance of using one common database and that spreading and using 3D visualizations could imply shorter lead times.

Preface

This Master of Science thesis was conducted during the autumn of 2012 on behalf of Scania CV AB. The thesis has been a collaboration between the master degree programs Information Technology at Uppsala University and Product Development at Chalmers University of Technology. We would like to thank the department RTPM for giving us the opportunity to conduct the thesis and giving us insight to the many facets of Scania. Special thanks are directed towards our supervisor Kent R Johansson. His feedback and support has enabled a vast and thorough consideration of many aspects connected to the thesis. Additional thanks are guided towards the thesis connected steering group, always giving us further inclinations of direction.

Thanks are also aimed towards supervisors of the two Schools, Andreas Dagman and Kristina Wärmefjord at Chalmers, and Anders Hast at Uppsala who have helped us assure the academic and scientific contents of the thesis. Thanks are also guided to the two schools for allowing the collaboration. It has been of great value assessing this study with contributions from two different backgrounds.

Further thanks are aimed at the firms and individuals that agreed to interviews. These interviews have provided a fundamental core on which to base the study and analysis. This includes all Scania connected respondents as well as Mikael Rosenqvist at Volvo Cars, Ola Lindblad and Erik Eriksson at White, and Michael Karlsson and Magnus Manke at SAAB Aeronautics. Special consideration are aimed at the respondents at Scania whose open-mindedness and enthusiasm provided further understanding to circumstantial aspects.

The presented study has given us great comprehension of the interdependencies, functions of R&D face and has allowed us to conceive the importance of a common visual reference point. Connecting and maintaining a consistent information flow is of vital concern of companies today.

Jon-Anders Syrén Henrik Jacobsson

Aspects investigated by respective author

This thesis is a collaboration of two different master programs and two different universities. This segment will provide a short description of what areas each author emphasizes in respect to program belonging.

As Jon Syrén is a student of the master program Product Development, the outmost weight of this student was to procure an investigative study that highlight factors in a product development context. This entail a responsibility that include reviewing the findings while considering aspects of product process planning, management, CAD and improvement ideas.

As Henrik Jacobsson is a student of the master program Information Technology, the outmost priority of this student was to investigate and conclude findings while considering aspects of visualization in an interactive environment. Also, the student needed to considered specific environmental circumstances affecting the investigated subject, e.g. effective interactive collaboration in a manufacturing environment.

Terminology

3DLive	3D application developed by Dassault
3DVia	3D application developed by Dassault
3DXML player	3D application developed by Dassault
3DXML	3D lightweight format
AROS	High-performance transaction server
CAD	Computer Aided Design
CAE	Computer Aided Engineering
Catia	Computer Aided Threedimensional Interactive Application
ECO	Engineering Change Order
Enovia	Data management system for PLM implementation
Gemba	Lean term meaning 'real place'
JT	3D Lightweight format
KS	Konstruktionsstruktur – Product structure employed by R&D department
MBD	Model Based Design
Mechanics	Employee working with practical implementation
ModArc	Model Archive
OAS	Object and Structure software
PD	Product development
PDM	Product data management
PLM	Product Lifecycle Management
R&D Factory	Established guidelines for research and development functions, adaptation of the Scania Production System
R&D	Research and Development
RQ	Research Question
Scania	Scania CV AB
SMOFS	Scanias ordering system
SOCOP	Start of customer ordered production
TCR	Translational Code Register
VCR	Variant Combination Register

Table of contents

1 Introduction

A background to the problem area is given, followed by a description and objectives of the master thesis. Furthermore three research questions are formulated.

1.1 Background

Traditionally, product development has been based on engineering instinct, being able to judge whether the desired outcome can be achieved with a certain solution. Fixed ideas have often served as the base on which to foster improvements with the end result being an effect of a successive increase in development steps. Evaluation was and is to a certain degree still carried out using physical prototypes in a lab environment. If however the assessment reveals inferior results, design changes have to be made and new tests carried out, generating unwanted costs and time delays. Introducing the reworked model to production can again reveal further implications, requiring additional resource allocation. (Johannesson et al., 2004)

In contrast, the product lifecycle is constantly being reduced, firms that maintain a fast and efficient response introducing products that well reflect the needs and expectations of target customers create significant competitive leverage. *In a turbulent environment, doing product and process development well has become a requirement for being a player in the competitive game; doing development extraordinarily well has become a competitive advantage* (Wheelwright and Clark, p.1 1992). In order to be effective, one must maintain the goal of continually improving methods and processes.

Organizational realities however, reveal several challenges in the product development process. Ulrich and Eppinger (2012) present one such aspect as being lack of cross-functional representations in the project team, meaning that key development decisions may be made without involvement of marketing, design, manufacturing, or other critical functions. This could imply inconsistencies in information conveyance and/or improper interpretations of project characterization.

Contemplating the annotation presented above, aspects connected to communication and model representation rise. The case can be held in conjunction to human perception, how to effectively converse desired information. Seeing as human insight to a large degree is associated to visual impression, designs can be a powerful instrument of expressing corresponding product properties, implying that information becomes more tangible (Johannesson et al., 2004). Then, if every concerned function is enriched with designs concurrent with projections of present status, the decisions made could possibly be founded on deeper understanding, increasing the probability of consistent success. In context, one can mention the facets of quality management which imply basing decisions on facts that are well founded (Bergman and Klefsjö, 2010).

The Japanese word jidoka is used in the lean (a highly praised production system originating from Toyota factories in Japan) context for describing *intelligent machines*, and specifically refers to a machine´s ability to detect a problem and stop itself (Liker and Meier, 2006). Swedish companies often refer to the concept of jidoka as *right from me*, relating the term to a built in quality way of conducting the operations required in various processes present in company context, locating problems as early as possible, allocating proper resources accordingly. Cross-functional integration becomes vital in managing knowledge and experience for the value adding intentions for problem solving and decision making. This requires tools made to not only suffice specific engineering functions such as simulation and design, but also to functions such as marketing and management. Elimination of waste is another central theme in the lean philosophy (Liker and Meier, 2006). Costly retakes are unwanted. Being able to mitigate any project misconception is highly motivated in this context.

The introduction of 3D CAD in product development has been motivated by the desire to increase development speed. There are however some existing issues that can be noted, one such issue is the fact that 3D CAD data is very large and cannot easily be distributed and shared, a second issue is the fact that 3D CAD systems are very expensive and complicated and therefore cannot be made available to everyone (Toriya, 2008). On the subject of improving engineering efficiency, the Aberdeen Group 2006 indicate that best in class performers are 24% more likely to take advantage of extended 3D modeling design capabilities. They are 55% more likely to use downstream capabilities. This raises several questions on how to advance this downstream use of tools connected to 3D.

The usage of a modular product system has given Scania CV AB the means to become one of the world’s foremost manufactures of heavy vehicles and marine engines. Continuous improvement is a highlighted aspect at Scania when considering competitive advantage. Efficiency is constantly scrutinized. One way of achieving higher efficiency is the introduction of useful technical implementations of 3D models, going beyond the general idea of 3D models being solely connected to CAD systems. The intent of this thesis is connected to needs and capabilities associated to 3D representations and the utilization of these in the product development process.

1.2 Problem description

The many facets of product development at Scania today creates several barriers for effectively detecting and communicating inconsistencies in product design. The fact that different departments use different software for committed department work creates further disadvantages in how irregularities are mitigated. Information conveyance is often carried out through physical contact, phone calls or e-mails, there exist no common standards in information sharing. Improvement thoughts at SCANIA has often been associated to the idea of creating parallel work formats for different departments, implying that people of different backgrounds being able to understand the indifferences and advancements existing in every concerned section. Product complexity advancements however, has seen the rise of even more multifaceted ways of conducting work, involving even more specialization. This creates further implications on cross functional integration.

The will to effectively distribute information amongst employees and suppliers has led SCANIA to start moving from conventional 2D(paper)- to 3D-model based drawings. The aspects of conflicting information share still remains however, there exist no standard format for conveyance of 3D information. The intent of this thesis is to investigate the needs and capabilities of such a format and suggest improvements strategies (involving the format) connected to the work flow.

1.3 Objectives

Firstly our objectives are to clarify the needs, possibilities and limitations for visualizing product models at Scania. Furthermore an analysis of today's workflow and processes has been conducted in order to find flaws when it comes to tools and methods for product development in areas where Computer Aided Design (CAD) and Computer Aided Engineering (CAE) play an important role. On this basis we have set out to describe relevant measures of improvement, such as giving examples of existing software that corresponds to the needs at Scania.

Secondly this process intend to showcase and exemplify the use of a 3D-viewer for the staff at Scania who could use such tool instead of using a 2D drawing for example. In this way we hope that existing methods will be conducted more efficient.

1.4 Research questions

Three research questions have been developed in order to fulfill the academic requirements of this master thesis.

- RQ1: In what way does the flow of information improve with the use of a 3D-viewer?
- RQ2: In what ways would an implementation of a 3D-viewer imply that potential problems in product development were discovered earlier? How does it affect work processes, for example preparation work?
- RQ3: What needs must be satisfied by the 3D-viewer software? Are there changes to the product development process that needs to be made in order for an implementation of a 3D-viewer to be possible?

1.5 Delimitations

The process of implementing 3D-viewing software has not been considered during the work of this master thesis. Furthermore the emphasis has been committed to the Research & Development (R&D) department even though some aspects from Purchasing, Service and other departments have been considered, but to a lower extent.

In regards for Scania's CAD-software, no analysis of 3D-viewers incompatible with Scania's current design tool, Catia have been studied.

1.6 Master Thesis outline

The main areas in this thesis are:

Introduction

The problem is introduced and research questions are presented in this section. Parts that are not included in the master thesis is described in the delimitation section.

Scania

An introduction to the organization at Scania is given, and especially how the R&D department handles its workflow.

Theoretical framework

The theoretical framework is divided into two parts, first a section about the research that has been done within the area visualization of 3D data, and secondly a section about the research on product development aided by visualization of 3D-models.

Methodology

Methods used during our interviews are outlined. The different ways of collecting data is also presented. This chapter is concluded with a section about how methods used are validated.

Results

Findings and results are presented.

Analysis & Discussion

Based on the theoretical framework and the methodology the results is analyzed and discussed.

Conclusions

Conclusions from analysis and discussion section are drawn.

2 Scania

This section covers fundamental annotations on Scania as an organization. Processes connected to R&D are presented in an effort to illuminate the methods and practices in place at Scania today. The intent is to understand various mechanisms behind information flow.

2.1 Organization

Established in 1891, Scania is now one of the world's leading manufacturer of heavy trucks and buses. Business segments also include industrial and marine engines. Sales and service organizations exist in more than 100 countries and production units are located in Europe and Latin America. The company provide work for approximately 37 500 employees, the head office in Södertälje, Sweden maintain a total of 5800 of these. Research and development operations are also located in Södertälje, employing approximately 3300 individuals. (Scania CV AB, 2012)

Objectives and core values at Scania are closely intertwined, creating foundations for developing the business. Customer first, quality and respect for the individual are key elements illuminated and maintained as a unified concept. (Scania CV AB, 2012)

By effectively upholding customer priorities throughout the entire value chain, Scania delivers solutions that help client profitability by means of high earning capacity and low operating costs while at the same time establishing grounds for a sustainable environment. Respect for the individual ensures that each employee's knowledge and experience is utilized, increasing job satisfaction and facilitating continuous improvement. Quality stem from the constant scrutiny of products and services, maintaining an effective elimination of all forms of waste. (Scania CV AB, 2012)

2.1.1 Research and Development

The product development process at Scania consists of three sub-processes; yellow arrow, green arrow and red arrow (see figure 2-1). Yellow arrow projects are pre-development projects and comprise research, technology development and concept development. Green arrow projects are projects driven towards a point in time for an assured market introduction and red arrow projects are projects intended for follow-ups, that is, managing and updating current product range.

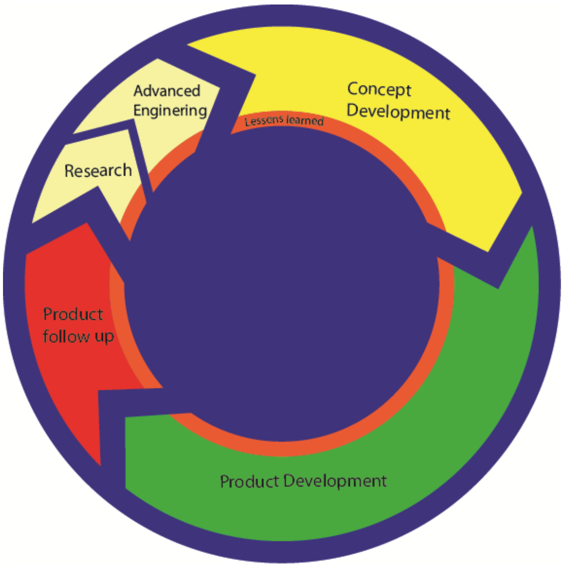


Figure 2-1. The product development process at Scania, illustration of the three sub-processes. Source: Scania CV AB (2011)

Projects coordinate development and industrialization, ownership however, is coupled to the line organization. Projects can never own the product.

Product development schemes include aspects of cross functional integration, maintaining a parallel work flow. All product development is cross-functional to a greater or lesser extent. The idea is to involve every function concerned with the project in initiation, staying involved until the product has been fully developed. This ensures that every function can influence product properties throughout the lifecycle, establishing prerequisites for a successful customer reception.

Scania accept uncertainties, rework and iteration is natural and necessary in product development. Keeping the lead time to customers as short as possible is achieved by organizing small, competent groups. By doing this, concepts can be generated and tested quicker. Green projects are activated only when concepts have been developed and sufficiently tested.

Configuring and establishing cross-functional working structures and milestones are initiatives that the team needs to set up in order to reach mutual project targets.

2.1.1.1 Pre-development

Pre-development projects or yellow arrow projects comprises research, technology development and concept development.

Research is key for exploring cutting-edge knowledge for future scenarios. The objective is to promote knowledge and theoretical understanding, creating grounds for technology advancements in strategic areas. The result from this research phase is used in the technology development phase.

As knowledge increases in the technology development phase, uncertainty decreases. This ensures that there exists proper justification for a possible implementation. After this phase, knowledge allows developers to judge whether the technology is suitable for Scania's products or services. If a technology passes this phase, the project is sent to the next yellow arrow activity *Concept development*.

No concepts are generated without a clearly described need. This need can amongst others be related to a customer, a legal requirement, a cost rationalization or to research and technology development. The focus of concept development is to reduce uncertainties even further and to satisfy customer need in the shortest possible lead time.

A concept is ready when:

- Performance/property objectives are described.
- Profitability analysis has been conducted.
- The concept can be planed.
- The concept has been modularized.
- The concept has been cross-functionally accepted.

2.1.1.2 Product Development

Green arrow projects are the development of Scania's products and services. The green arrow encompasses:

- Product development projects
- Design on line projects
- Special order projects
- Fit for use projects

Characteristics of these projects include a high degree of delivery precision, the outcome of which, will most likely be offered to the customer.

Product development projects are the ventures to which most resources are allocated. The project office provides methods and tools the project manager needs in order to coordinate cross-functional activities and the line organization has the outmost responsibility for delivering the desired result on the agreed time. Verifiable milestones are the main elements controlling the projects.

At an early planning phase, configuration is established. The project group initiates a configuration with a concept and a technical specification. Project variables are broken down into perceivable benefits, affected target applications and demands. Thereafter the project is configured in activities found to be the most effective in order to develop the specified product. This method is referred to as SPP, Scania Project Planning. Benefits of this planning format are the ability for it to be transferred to visual layouts. In this way, all the group's assignments can be communicated. The project definition is a result of the configuration, an approved project definition means that the project can be started.

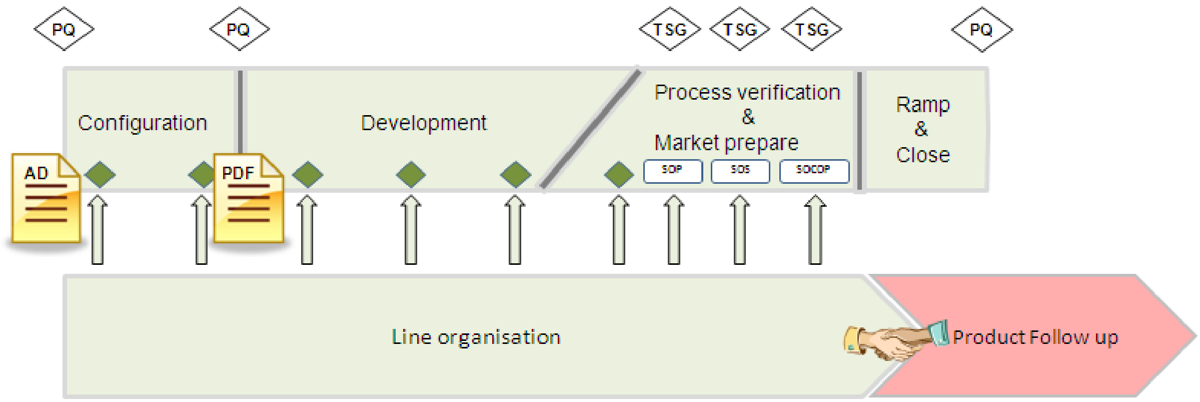


Figure 2-2. Project stages and connected instances. Source: Scania CV AB (2011)

Development continues in accordance with the project definition. After the development phase, focus is shifted to process and market prepare (see figure 2-2). At this stage, production process preparations are verified, if any inconsistency is found, resources will be allocated in order to correct them. The production of service market support and marketing information is completed in parallel to production preparation.

The ramp up of production initiates with the start of customer ordered production (SOCOP). The time this takes is very much dependent on the type of project in question. Lessons learned are evaluated and documented in a final report, which also includes details for following up the expected benefits. As ramp up is completed and the final report concluded, a request is sent for closure and the project is terminated.

2.1.1.3 Product follow-up

Red arrow initiatives include maintenance and update of current product range. The objective is to improve quality and/or reduce cost for all concerned. Changes are introduced continuously with the service market being informed. Activities are managed within R&D by the product follow-up organization with support from purchasing and production departments.

2.2 R&D Factory

When considering the deliberated thesis, properties must be held in regards to core attitude of the research and development process. The core values, the principles and the methods of R&D Factory describe the way Scania proceeds/thinks when taking on the many challenges of product development (Scania CV AB 2010). The intended outcome of the thesis must be held in conjunction to the features presented in this scheme. These aspects are very important when considering long term profitability of Scania. Any deviations from these fundamental values are highly unmotivated.

The R&D factory creates conditions for principles of modularization, property driven product development and cross-functional and parallel methods (Scania CV AB 2010).

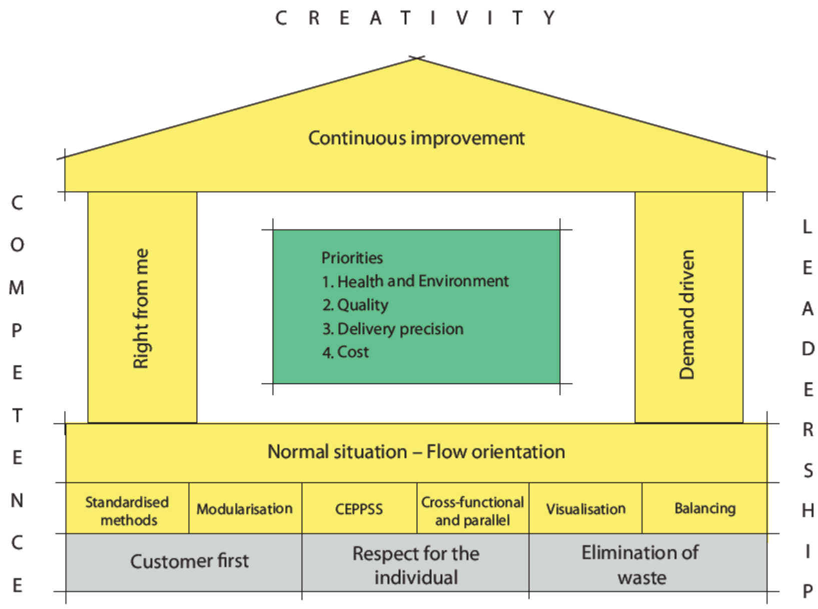


Figure 2-3. R&D Factory. Source: Scania CV AB 2010

By monitoring every result achieved, a better comprehension is achieved. It is this comprehension that forms the establishment for learning and realizing continuous improvements.

The core values, customer first, respect for the individual and elimination of waste serves as the foundation (see figure 2-3) and reflect the company's culture and what to jointly commit to (Scania CV AB, 2010).

2.2.1 Customer first

The focus is always the end customer, from R&D through purchasing and production to sales, financing and service delivery. The definition of value is established by the customer. In R&D, customers exist both at external and internal levels. The ability to judge and know what is of value to the customer is a prerequisite to doing things right. (Scania CV AB, 2010)

2.2.2 Respect for the individual

Respect for the individual include recognizing and using everyone's knowledge and experience. This creates basic fundaments in the search for continuous improvements. Skills, inspiration and new ideas are fostered in daily activity, ensuring higher quality and efficiency. Everyone can have an influence and by committing to both personal and unit responsibilities and acting in accordance by the established core values, the desired quality is achieved on time. (Scania CV AB, 2010)

2.2.3 Elimination of waste

Being continuously competitive is one of the effects of eliminating waste. Waste is anything that does not add value or provide benefit for customers (for example delivery delays or disruptions in processes). (Scania CV AB, 2010)

2.3 Success factors

Success factors of Scania R&D factory are listed in this segment.

2.3.1 Leadership and co-workership

Leadership is coherent with a way of thinking for both managers and employees, everyone is a leader in everyday activities. For example, a meeting chairperson acts as the leader when committed to the meeting agenda.

Scania's five leadership principles adhere to the concept of establishing reliable means for making leadership possible in every part of the organization, they include the following notations (Scania CV AB, 2010):

- Coordinate, but work independently and take responsibility. Maintain and act on ideas conceived both independently and cross-functionally. Take initiative, challenge while respecting established guidelines.
- Work with details and understand the context, take responsibility for your own and your unit's deliverables.
- Act now, but be aware of long term effects.
- Build knowledge through continuous learning. Improve both your own and your colleagues competency.
- Stimulate commitment through involvement. Be accessible and clear. Be a good listener in your leadership.

The established guidelines convey a message of the leader acting as a coach, simultaneously ensuring positive interaction between the manager, the unit and the employee. Taking responsibility is intertwined with the notion of not faring mistakes. Being afraid of mistakes will not yield any performance increases, it is thus vital to not fear responsibility because of the inherent risk of being blamed for mistakes. Mistakes are a natural and often necessary occurrence of product development. Calling attention to problems and deviations are highly motivated to jointly solve and learn from them.

Co-workership means having the possibility to influence surrounding circumstances and development work. Regardless of what instance of work maintained, everybody works towards establishing exceptional preconditions for an effective work format. (Scania CV AB, 2010)

2.3.2 Competence

Continuously gathering knowledge within the area of expertise and perfecting insight towards the big picture is a prerequisite for Scanias long term success. Making existing knowledge available and judging what fields additional competence is required is key to development. (Scania CV AB, 2010)

2.3.3 Creativity

Creativity and competence are closely linked in the sense that to create idea into innovation, competence is needed in the specific field of interest. In addition, understanding the end customer or the user situation (or user business) is vital for developing the right thing. Freedom is highly motivated by Scania in this context, this implies trusting that employees will work freely with ideas they believe in within the given time frame. (Scania CV AB, 2010)

2.4 Principles

The principles of Scania R&D factory are listed in this segment.

2.4.1 Normal situation – Flow orientation

Providing a common way of thinking, the principles serve as a familiar approach towards a successful flow orientation.

A normal situation is concurrent with knowing how to act and how to relate to current state, to always maintain the current state to agreed deliverables. A normal situation is the starting point for improving the process. Flow orientation is coherent with the focus on customer needs and creating optimized flows accordingly. The goal is to create a balanced, even and pulsed flow with standardized work methods. This, in order to directly react to any deviation.

Information and knowledge are the main elements in flow in R&D processes. Value is created by adding information to new properties developed and by adding new knowledge to the knowledge bank. Projects are closely linked to knowledge seeing as the two are often under way simultaneously. If issues are detected in any of the development processes, the new found inconsistency will be studied and hopefully solved, giving the proceeding efforts or projects the capability to use this extended knowledge. The extended knowledge can thus be used for enhancing technology developments or process improvements.

Aspects connected to projects and knowledge differs in terms of deliveries. As the acceptance criterion has been met, one delivery is made to the project. However, if for example, a test has met the acceptance criterion but there still exist a need to investigate and elucidate further properties, the test will proceed with the end result being a delivery to a knowledge bank.

Different needs provide fundaments for different flows. The circumstances surrounding a project can differ greatly from the circumstances surrounding another. The flow is thus handled differently if for example the project is a yellow, green or red project. One challenge mentioned in R&D Factory is the fact that groups or individuals often work in different flows (Scania CV AB, 2010). Effort allocation becomes of great concern in these instances.

Clearly defined deliveries are essential in transitional links of the flow. By explicitly understanding the interconnected links as well as recognizing the weakest links, aspects on which to improve and transitional efforts on which to develop can be established. Maintaining an even flow where deliveries are not met ahead of time or to late is the consistent manner in which Scania achieve results. The normal situation – flow orientation is a principle supported by six sub-processes; standardized methods, modularization, ceppss (continuous evolution of properties planned in small steps), cross-functional and parallel, visualization and balancing. (Scania CV AB, 2010)

2.4.2 Demand-driven output

The flow of events cannot adhere to anything other than the elements of specified demands. Deliveries are carried through when the next step in the chain demands so. This supports planning and minimizes waste. If a demand cannot be met, a continuous feedback between different parts of the flow is enabled. It is this feedback that act as the backbone of the demand-driven principle.

Highlighted efforts in this principle are connected to customer needs, small well-defined deliveries and simple, clear connections in the flow. Customers are in this sense not only end-customers but internal customers as well. Internal customers exist at every level of the company. This view will produce a basis for not processing more information than what the upcoming stage in the flow needs. Small, well defined deliveries ensure that a suitable flow is achieved by avoiding large build ups of information. Simple, clear connections are associated to standardized methods by means of that the standardized methods provide clear indications of what, when and to whom to deliver. (Scania CV AB, 2010)

2.4.3 Right from me

Right from me (jidoka, see section 1.1) means keeping to agreed deliverables and committing to resolving deviations. The objective is to do things right the first time following standardized procedures. If the standard has been followed but there still exist problems or deviations, a joint responsibility is committed to alter and improve the method in question.

Continuous feedback is yet again a vital aspect of this principle. Quality is assessed by the following link in the process flow, and it is this internal customer that verifies whether the intended outcome has been met. If for some reason a fault is discovered, the process step in which the fault arose should immediately be notified. It is this process actor’s responsibility to adjust any unwanted deviation.

Mistakes are easily made, investigative work for evolving methods and technology is thus highly motivated for increasing the effective utilization of built in quality. Quality assurance can consist of (Scania CV AB, 2010):

- IT systems that help comply to standardized methods.
- Design instructions and checklists
- Seeking proper competence for the area in question

The standard method used ensures that right from me is achieved.

2.4.4 Continuous improvement

Competence and knowledge is vital to continuous improvement. Improvements are linked to maintaining, challenging and improving the normal situation. Disturbances or deviations from the normal situation is waste, however, waste is also the greatest source for improvements. Resolving deviations frees resources that can be used for value adding activities.

Improvements are based on cooperation in operations, flows, systems and methods. The normal situation is the starting point for any improvement. In context, standardized methods serve as a very close reminder as to why one of the founding principles is a normal situation with flow orientation. Without standards or knowing what is normal in daily activities, there exists no point of reference. If there is no point of reference there is no way of knowing on what you are improving on. The standard, or normal situation is thus a vital prerequisite for any improvement work. (Scania CV AB, 2010)

2.5 Priorities

The four priorities of Scania are 1) Health and environment 2) Quality 3) Delivery precision and 4) Cost, see figure 2-3. In order to track and measure how well the company reflects these priorities, key performance indicators are generated to guide improvement efforts. A normal situation entails following theses priorities. An abnormal situation however still implies a customer focused agenda and different circumstances can thus change the order of the priorities and a compromise can thus be necessary. The order of the priorities should however still guide the compromise. (Scania CV AB, 2010)

2.6 Waste according to Scania R&D Factory

Eliminating waste is a highlighted agenda at Scania, but what is waste at Scania? This section will provide a brief introduction to the definition of waste at Scania. The definition is presented by Scania R&D Factory.

Improvements that ultimately reduce the total lead time, from customer demand to when the demand is satisfied, are value adding improvements (Scania CV AB, 2010). Overloading and imbalances lead to waste. A clear takt time or pulse will provide a balanced and even flow, establishing a clear distinction of waste.

The case can be argued by illuminating the fact that a surplus of time and resources between different links in the flow, only provides a false sense of security seeing as disruptions are then not clearly noticeable. Properly balanced lead times will illuminate any inconsistency and force concerned actors to immediately respond and mitigate any problem discovered. This because any misconception encountered will effectively hinder a leveled flow.

2.6.1 Examples of waste described by R&D Factory

The following notations are given examples of waste presented by R&D Factory. Noticeably, the examples are very much consistent with the viewpoints presented by Morgan and Liker (2006) (see theoretical framework). Short elaborations of the presented examples are listed in the following segment.

Doing more than necessary: This include producing more than is required by the following operations in the process. Examples include:

- Writing a report or a document that contains too much information.
- Inviting more people than necessary to meetings.

Not helping others, when my work is done: If intended requirements have been met, continuing to improve on the product is waste. Instead, time should be dedicated to helping others possibly lagging behind to catch up with targeted goals.

Not finding necessary information easily: When information is not easily accessible, waste arise. The example is also contingent to a clear definition, if it's not clear who is doing what or who is responsible for what, additional inconsistencies or waste will be produced. Examples include:

- Sending an e-mail to everyone instead of sending it to the person/persons who really needs it.
- Concluding a pivotal meeting without specifically deliberating clear responsibilities.
- Complex websites inhibiting an easy access to right documents or standards.

Missing or unclear decisions: Insufficient decisions or lack of respect for decisions made, generates waste in the sense of uncertainties.

Excessive lead times in the planning stage: Large lead times in beginning stages hide initial problems and create a false sense of security. Examples include:

- Many test objects in circulation to ensure a full use of test equipment, creating long lead times before new tests can be started.
- Drawings are completely finished without the relevant input of for example purchasing.

Documents with discrepancies and errors: Delivering documents that entail errors means that additional adjustments must be made before the next work flow activity. This means lost resources in terms of time. If the document proceeds uncorrected, further wastes might include scrapping of prototypes or prototype materials. A not so apparent example include a meeting with no clear purpose or agenda.

Having excessive waits. Examples of this waste include:

- Not enough licenses of Catia or Matlab, meaning that value adding activities are hindered.
- Not coming to a meeting on time, perhaps with the implication of the meeting introduction or initiation being pushed forward or restarted.
- Not using everyone's competence: This example is self evident and implies a lack of efforts for effectively maintaining a consistent determination of utilizing everyone's knowledge or competence.

2.7 IT-tools aiding R & D

In this section supporting it-tools of Scania research and development personnel is described in an effort to convey important specifications of product property aids.

The main domain of the PDM-system employed by Scania is deemed AROS. This domain offers product information. The user can attain information from four different segments, SPECTRA, ECO, RITS and AI (Wernstern and Hanna, 2012).

SPECTRA - In order to keep track of all modular and article property information data, Scania uses SPECTRA (Wernstern and Hanna, 2012). SPECTRA contains three structures, TCR, VCR and KS. The structure deemed KS (konstruktionsstruktur) is the product structure description employed by departments specifically connected to R & D.

The translation code register (TCR) keeps track of customer ordering specifications attained from SMOFS (Scanias ordering system), completing it with further specifications vital to product functionality but inconsequential to customer ordered preferences. The order continues in Spectra to VCR (Variant Code Register) where the order is checked for inconsistent variant combinations. If no inconsistent choices are detected, the last step includes transforming the VCR into KS which in turn can be sent to MONA, Scanias system for assembly purposes (Wernstern and Hanna, 2012).

ECO – Article development changes are documented with Engineering Change Orders. In short, an ECO should contain all necessary information connected to the development work undertaken. Each ECO are connected to one design engineer and one number. Every ECO is also connected to a level of security, where the last level (4) gives every part of the organization the authority to access it (Wernstern and Hanna, 2012).

RITS – This segment contains information about change manifestations for drawings and rules and regulations for articles (Wernstern and Hanna, 2012).

AI – Very much connected to the purchasing department. Contains product property information.

Enovia/ModArc – In order to store and reference 3D-models and drawings, Enovia and Modarc are used respectively (Wernstern and Hanna, 2012).

CATIA V5/V4 – The implemented CAD software at Scania is CATIA. Why V4 to a certain extent still is an active software is due to the fact that some models are still only supported in this environment (Wernstern and Hanna, 2012).

GEO – This abbreviation is short for GEOmetry assurance. It refers to a way of conducting product development in order to ensure quality (Brantefors and Gadman, 2007). The method comprises techniques aimed at ensuring that each item has a feasible position in reference to its surrounding components (Johansson and Sätterman, 2012). Unique for Scania, the software aims at exploring deviations and interference issues in an early stage of the development process.

GEO links two different systems together; CATIA V5/Enovia and SPECTRA. The CAD model and its connected reference system, the Part Axis (Scania denomination), is retrieved from Enovia. The items' geometric position, GP, is collected from SPECTRA. The GP is a coordinate referencing article location in terms of complete system location. GEO links the part axis with the GP, handling additional constraints set in CATIA (Brantefors and Gadman, 2007).

The intent with GEO is to provide design engineers the ability to publish article progress in early stages of the design process (Brantefors and Gadman, 2007). This could be a simple box, informing concerned engineers of geometry progress and constraints of intended design.

OAS – The intent with OAS, Scanias new platform tool is an effort to centralize management of objects and structures. Today, the same or similar information is manually maintained in several applications such as Spectra, Mona and Smofs (Scania Inline, 2012). The tool aims at replacing some of the current IT-tools for administrating product description. A main feature of the tool is that objects and object structures can be controlled with conditions, and adjusted with change orders within time (Scania Inline, 2012).

3 Theoretical framework

In this section, several theories connected to visualization are scrutinized in an effort to expose relevant features to be held in conjunction to the findings at Scania. Seeing as the proposed subject needs to be conveyed appropriately. This chapter aims at highlighting the motives and conditions maintained in reference to an implementation of 3D visualization tools within an operation of a successful manufacturer.

Process theories are presented in order to establish common grounds for achieving effective product development. Several ideas connected to information dependencies are presented in order to understand the subject in a product development process context.

CAD is discussed in an effort present the history of design rationalizations contingent to computer aided software. Visualization theories are illuminated to effectively describe what defines a good 3D interface representation. In addition, the notion of lightweight representations is introduced.

3.1 Viewer definitions

This segment aims at providing sufficient insight towards a 3D tool the deliberated thesis investigates. In this section, viewpoints of several thesis connected parties with knowledge of overall process specific computer tools is presented.

The intent of this thesis (see section objectives) is contingent to the notion of the many challenges engineering work face. Communicating and collaborating inefficiencies increase as non-compatible work formats increase. A 3D tool that provides the ability to coordinate efforts by visually presenting product properties is in this case motivated. The tool contemplated should provide a common point of reference and address the needs present at instances that are perceived as being able to increase efficiency with the help of visual representations of product data.

A viewer tool cannot change product properties in terms of design, neither can it change specific positioning of articles presented. In essence, no change in terms of design related data is manipulated. The intent is to provide development functions with no or restricted ability to view product design with a tool that enhance the conveyance of knowledge and understanding.

3.2 The Product Development Process

This segment aims at introducing the reader to the product development process. First a generic product development process is described pointing towards elements commonly found within an industry committed to development work. Secondly, a brief introduction of Lean product development principals is investigated in order to establish grounds for a definition of an effective and sustainable development process. Establishing these grounds are vital since the research questions of this thesis aims at providing insight towards the effects of how an increase of 3D visualizations influence work processes.

3.2.1 A generic product development process

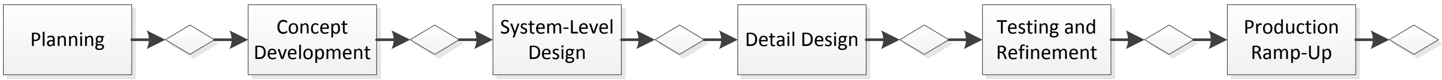
A process comprises a sequence of steps that transforms a set of inputs into a set of outputs. In accordance, a product development process is the sequence of steps or activities that an enterprise employs to conceive, design, and commercialize a product (Ulrich and Eppinger, 2011). The product development process is a process that is an element of a bigger corporate philosophy or perspective, which in turn is a constituent of a bigger societal framework or environment (Johannesson et al., 2004).

Many steps or activities employed in a company specific product development process are intellectual and organizational rather than physical (Ulrich and Eppinger, 2011). Some companies strictly follow predetermined process guidelines and activities, others may have trouble even describing their processes. The level of uniformity also varies from company to company, that is, there are no two companies utilizing the exact same process. Variations occur, some large, some very small (Ulrich and Eppinger, 2011).

According to Ulrich and Eppinger (2011) a well-defined development process is useful for establishing reliable grounds for quality assurance, coordination, planning, management and improvement. Quality is aided in the sense that phases and checkpoints are chosen to achieve desired deliverables conditional to quality. Coordination is aided by clearly defined responsibilities and dependencies. Planning is aided by the deliberated schedule of the overall project. By reviewing project status in context to predetermined process steps, a clear indication of performance is visible, giving management functions the ability to effectively run project steps in desired direction. Thus management is aided by aspects linked to performance. Lastly, if attention is guided towards documenting developments, indications can adhere to development inconsistencies or deviations, providing a fundament for improving organizational processes.

Modern product development often imply cross functional activities with main players being marketing, engineering design (and industrial design) and production/manufacturing (Johannesson et al., 2004). Generic phases of a product development process adhere to the illustrated example presented in figure 3-1. The process begins with a planning phase consistent to advanced research and development activities, this provides a mission statement. The mission statement provides the input to the following phase, the concept development phase. This phase serves as the starting point for a gradual refinement of concept/product properties (system level design, to detail design, to testing and refinement). Finally, as refinements has provided sufficient deliverables, production ramp up is initiated with the end result being market introduction. In figure 3-1 some activities correspondent to each function are also listed.

One way of viewing the development process is the gradual decrease of a wide set of alternative product concepts, and a consequent increase in specific product properties (Ulrich and Eppinger, 2011). This will gradually provide sufficient reliability in both product functionality and manufacturability.



Function	Planning	Concept Development	System-Level Design	Detail Design	Testing and Refinement	Production Ramp-Up
Marketing	• Articulate market opportunity • Define market segments	• Collect customer needs. • Identify lead users. • Identify competitive products	• Develop plan for product options and extened product family	• Develop marketing plan	• Develop promotion and launch materials • Facilitate field testing	• Place early production with key customers
Design	• Consider product platform and architecture. • Assess new technologies.	• Investigate feasability of product concepts. • Develop industrial design concepts. • Build and test experimental prototypes.	• Develop product architecture. • Define major sub-systemes and interfaces. • Refine industrial design. • Preliminary component engineering	• Define part geometry. • Choose materials. • Assign tolerances. • Complete industrial design control documentation.	• Test overall performance, reliability, and durability. • Obtain regulatory approvals. • Assess environmental impact. • Implement design changes.	• Evaluate early production output
Manufacturing	• Identify production constraints. • Set supply chain strategy.	• Estimate manufacturing cost. • Assess production feasibility	• Identify suppliers for key components. • Perform make/buy analysis. • Define final assembly scheme.	• Define piece/part production processes. • Design tooling. • Define quality assurance processes. • Begin procurement of long-lead tooling.	• Facilitate supplier ramp-up. • Refine fabrication and assembly processes. • Train workforce. • Refine quality assurance processes.	• Begin full operation of production system.
Other Functions	• General Management: Allocate project resources • Research: Demonstrate available technologies.	• Finance: Facilitate economic analysis.	• Service: Identify service issues.		• Sales: Develop sales plan.	• General Management: Conduct postproject review.

Figure 3-1. A representation of a generic product development process and corresponding work efforts of different functions. Source: Ulrich and Eppinger (2011)

3.2.2 Lean product development

These days company based Lean initiatives are commonplace. The production system that has made one of its founding companies (Toyota) very successful is based on principles including a focus on the customer, continual improvement, quality through waste reduction and tightly integrated upstream and downstream processes (Liker and Morgan, 2006). As noted in later sections, Scania does at this stage in time employ several processes and schemes contingent to a Lean philosophy. This section will therefore provide a short description of common depictions of a lean product development process.

In their studies, Liker and Morgan (2006) outline and illustrate the management principles of the Toyota Production System (TPS). Applicable to any aspect of a technical or service process, Liker and Morgan (2006) specifically present principles to a successful implementation of a lean guided approach to product development. These principles and their respective descriptions are presented in table 3-1 to table 3-2. Table 3-1 describes process principles of Lean product development, this table is presented in the text provided by Liker and Morgan 2006.

Principle	Despription
1. Establish customer-defined value to separate value added from waste.	Lean is a never ending journey of waste elimination. Waste is non-value added defined by first defining customer value.
2. Front load the product development process to thoroughly explore alternative solutions while there is maximum design space.	Defining the wrong problem or premature convergence on the wrong solution will have costs throughout the product life cycle. Taking time to thoroughly explore alternatives and solve anticipated problems at the root cause has exponential benefits.
3. Create a leveled product development process flow.	Leveling the flow starts with stabilizing the process so it can be predicted and appropriately planned. This allows product planning to reduce wild swings in work load. Predictable work load swings can be staffed through flexible labor pools.
4. Utilize rigorous standardization to reduce variation, and create flexibility and predictable outcomes.	Standardization is the basis for continuous improvement. Standardization of the product and process is a foundation for all the other process principles.

Table 3-1. Product development process principles of a Lean approach. Source: Liker and Morgan (2006)

People are the core of a lean product development system. In table 3-2, key principles for establishing a capable, energized and aligned high performing team (or organization) are presented.

Principle	Description
5. Develop a "Chief Engineer System" to integrate development from start to finish	The chief engineer is the master architect with final authority and responsibility for the entire product development process. The chief engineer is the overarching source of product and process integration.
6. Organize to balance functional expertise and Cross-functional Integration.	Deep functional expertise combined with superordinate goals and the chief engineer system provides the balance sought by matrix organization.
7. Develop towering technical competence in all Engineers.	Engineers must have deep specialized knowledge of the product and process that comes from direct experience at the *gemba*.
8. Fully integrate suppliers into the product development system.	Suppliers of components must be seamlessly integrated into the development process with compatible capabilities and culture.
9. Build in learning and continuous improvement.	Organizational learning is a necessary condition for continuous improvement and builds on all of the other principles.
10. Build a culture to support excellence and relentless improvement.	Excellence and *kaizen* in the final analysis reflect the organizational culture.

Table 3-2. Lean product development principles of establishing a people focused process scheme. Source: Liker and Morgan (2006)

3.3 Waste in product development

Waste or muda is by Morgan and Liker (2006) defined as any activity in a process that consumes resources without adding value for the customer. The general term lean is to a high degree only mentioned in production contexts. The idea of lean however, adheres to the entire enterprise and is not just a facet of an effective production scheme (Morgan and Liker, 2006). One neglected aspect presented by Morgan and Liker 2006 is the notion that engineering of product and processes becomes a critical constraint in production efforts. The ability to eliminate waste out of production is hindered.

Liker and Meier (2006) present seven categories of waste. These are presented in the context of production. Causes for waste in production will differ from the ones in product development, however, the categories of waste that adheres to production can be quite useful in revealing non-value-adding activities in product development.

The seven wastes are presented in table 3-3, in conjunction, comparative wastes of product development are listed.

Seven Wastes	What is it?	PD Examples
Overproducing	Producing more or earlier than the next process needs	Batching, unsynchronized concurrent tasks
Waiting	Waiting for materials, information, or decisions	Waiting for decisions, information distribution
Conveyance	Moving material or information from place to place	Hand-offs/excessive information distribution
Processing	Doing unnecessary processing on a task or an unnecessary task	Stop-and-go tasks, redundant tasks, reinvention, process variation-lack of standardization
Inventory	A buildup of material or information that is not being used	Batching, system overutilization, arrival variation
Motion	Excess motion or activity during task execution	Long travel distances/redundant meetings/superficial reviews
Correction	Inspection to catch quality problems or fixing an error already made	External quality enforcement, correction and rework

Table 3-3. The seven categories of waste and corresponding wastes in product development. Source: Morgan and Liker (2006)

In the following paragraphs, brief discussions of each waste are presented. These discussions are to a high degree based on the ideas presented by Morgan and Liker (2006).

Overproduction: In production or manufacturing, this means producing ahead of time, or ahead of what is actually needed by the next process or customer (Morgan and Liker, 2006). A product development equivalent adheres to unsynchronized cross functional processes. Real examples include (amongst others) working on the wrong activities instead of on activities that the next process really needs. Other examples include any task being completed before the next step in the work flow is ready to process it or conversely, downstream processes impulsively maintaining efforts guided towards upstream designs in an attempt to do concurrent engineering. The case is thus argued by presenting the notion that overproduction is the result of completing design work before validating its system compatibility or manufacturability.

Waiting: This waste is in manufacturing coherent with operators standing idle waiting for material or do nothing while their automatic machines are processing. In product development, the presented waste is contingent to the state of engineers being trapped in a perpetual motion. This means always rushing from meeting to meeting or being consumed by something on a computer screen. However, the essence of engineering, is from a work flow perspective almost certainly linked with a key activity, not doing this activity because of an insufficient base (for example unknown parameters or configurations) is waste. Routinely, engineers wait for reviews, decisions, permission, information, purchase orders, or some other transaction activity. Waiting is (according to Morgan and Liker, 2006) one of the most pervasive wastes in the product development process.

Conveyance: In production or manufacturing, this means moving parts or products without the need to. Equivalents found in product development include handoffs. Factors comprise the findings of handoffs between overly specialized activities, particularly information changing hands, be it word, picture or data exchange. This handoff leads to the loss of momentum, information, and accountability in the process. It is a commonly accepted dysfunction in traditional PD systems (Morgan and Liker, 2006).

Processing: In manufacturing, this waste adheres to unnecessary or incorrect processing. In product development processes, it includes engineering miscalculation/error or system flaws. Inadequate training and development can be one of the reasons for the former. It can also be a result from designing new components instead of utilizing carry over, or it can be a result of not complying to predetermined product characteristics or architecture or not making use of preexisting manufacturing capabilities, meaning that for each new product a new manufacturing process will be needed. Unnecessary apparent transactions and negotiations with suppliers is also an inconsistency that adheres to the category of waste discussed.

Inventory: Inventory is the direct result of overproduction. In product development, inventory implies excess information. This includes designs trapped in a state waiting for the next available resource. This type of information buildup is one of the most insidious wastes in product development (Morgan and Liker, 2006). This because of the high frequency of miscommunications in the information (e.g. wrong information or invalid information being transferred) or the fact that information gets lost or misguided. In this case, the circumstances will effectively hide these misconceptions to the extent that when they finally are discovered, the situation will require vast resources, with the unwanted effect of a drastic increase in lead time. In other words, as the buildup of information finally gets processed, problems are discovered too late to manage them effectively.

Motion: This waste is in production or manufacturing linked to the movement of the operator, contingent to the notion that operators move in ways that are unnecessary or cause strain. This idea is in product development concurrent to engineers attending unnecessary meetings, creating redundant status reports and preparing and participating in unnecessary project reviews.

Correction: *In manufacturing, this is inspection, rework, and scrap* (Morgan and Liker, 2006). In product development, this means program audits, reviews, testing new components instead of using proven ones, late engineering changes, excess tool tryout, and all forms of rework. Correction is a huge segment of product development, on average making up at least a third of the total allocated resources (Morgan and Liker, 2006).

3.4 Adapting technology to process

This section will discuss the relation between technology and process. Is one of them supposed to set the rules for the other and is thereby more important?

When it comes to implementing new technology and new tools in the product development process, Morgan and Liker (2006) stresses that the same technology can be bought by almost any company, but the process and people using the technology is unique. This is why it is important to adjust the technology and tools to fit the company's process and staff using it and not the other way around. Furthermore the authors describe five guidelines for companies when they choose tools and technologies to use in the product development process:

1. Technologies must be seamlessly integrated.
2. Technologies should support the process, not drive it.
3. Technologies should enhance people, not replace them.
4. Specific solution oriented: not a silver bullet.
5. Right size – not king sized.

The first point is about putting all the different tools together. It can for example be tools for testing, assembly, database and simulation that should be easily accessible from a single system. In this way engineers can switch between tools and get an overall picture of the process.

Secondly, companies should be careful when choosing tools and not always go for the latest technology only because it is new. The conclusion is that the technology should be well suited for the process and not the foundation on which the process is built upon. In today's world technology changes are fast and if a company always strives for acquiring the latest technology it might end up with a dysfunctional process.

In the third point, Morgan and Liker describes the common idea that new technology should replace people. Many investments in new tools are presented with figures of how much labor cost can be reduced, which is not satisfactory in a company with highly skilled staff.

A silver bullet is described by the authors as a *Holy Grail* (2006, pp.243) that would solve all technological problems for a company. This is probably not achievable, but the effort should lie with specialized solutions that support the work and process of the engineers.

The last guideline is connected to the first point, because it deals with having the latest, best and coolest system is of no good if it is used in the wrong way. Before technological tools made its entrance in product development, very much work was done with paper and pen. This kind of “work” should be supported and made easily available for the transition into a digital process to run smoothly.

3.5 Multiteam integration and the coupling of product architecture to organizational design

Reflecting on current work formats at Scania and in what way information dependencies are connected, the ability to explicitly describe several integrative mechanisms becomes vital seeing as these mechanisms allows for a deeper interpretation of characteristics connected to a viewing platform. A viewer tool should aid integration, but how does integration function and in what way are mechanisms connected? How are product and organization properties connected and how do you categorize a viewer and what effects can be illuminated? This section aims at providing sufficient insight to these questions.

Organization integration is central in the sense that trends indicate an increase in product complexity meaning an increase in integrated product teams and functional support groups (Browning, 1998). An effect of this increase is the increase in interteam information dependencies.

Product design can involve anywhere from a few to thousands of individuals making thousands (if not millions) of decisions over several years. Few of these decisions are made in isolation. Effects of design decisions involve trade-offs which influence many other product, process, organization, cost, and operational parameters. The widespread facilitation of information transfer between design groups is thus of vital concern. One inconsistency is however the common inability to understand the interaction between the design groups in question. The matter of how to facilitate and coordinate work efforts are seldom known in advance and therefore challenging. In addition, work allocation should consider task overlap and separation. If no attention is focused on these surrounding factors, unwanted consequences could adhere to redundant work efforts or work tasks falling between the cracks because of unclear system boundaries. (Browning, 1998)

The move towards a structure that involves parallel work flows involve further implications in terms of task sequencing, integrated product teams require coordination within and between subsystem and system development organizations. Special concerns must be guided towards the information that will flow between the integrated work teams as they work. *A team producing at the fastest rate humanly possible spends half its time coordinating and interfacing* (Rechtin, 1991 cited in Browning, 1998, p.3).

As product complexity increases (number of highly-coupled subsystems and components increases), integration of the organization becomes more demanding. The way in which specific subsystems solutions are connected usually imply a high level of dependency. In regards to this dependency, Browning (1998) depicts the issue:

Team A needs to know what values team B has set for parameters x and y; team B needs to know what values team C is using for parameters w and z; but team C needs to know the result of team A's activities to determine w and z.

This can imply a slow iterative process. Unfortunately, as complexity increase, a higher amount of interfaces can be required, especially if no consideration is taken to this increase in complexity (Browning, 1998).

Given these circumstances, the question of how to effectively relate product structure and surrounding circumstances to organization work breakdown structure turns interesting. Gulati and Eppinger (1996) explore the coupling of product architecture to development program organization structure, noting that decisions in one realm affect and even constrain opportunities in the other. Here, product architecture refers to a set of technical decisions for the layout of the product, its modules, and for the interactions between the modules (Gulati and Eppinger, 1996). In their research Gulati and Eppinger (1996) found that technical decisions relating to decomposition, architecture and integration are tightly coupled to both the capabilities and the design of the organization that must execute the development process. In a sense, the technical architecture of a product co-evolves with organizational design. *Organizations do simultaneously exhibit mechanisms of product architecture affecting organizational structure as well as patterns of organizational structure affecting product architecture.... architecture and organization is linked through the process of problem decomposition and system integration. Developers handle complex system design challenges by decomposing the large system into simpler ones which can then be designed or specified for outsourcing. (This decomposition process is repeated until the subsystems are simple enough to tackle.) At some point, the development organization's challenge is to integrate the various pieces together into a complete working system. In fact, decomposition and integration are generalized inverse problems* (Gulati and Eppinger, 1996). A figurative description of this coupling is depicted in figure 3-2.

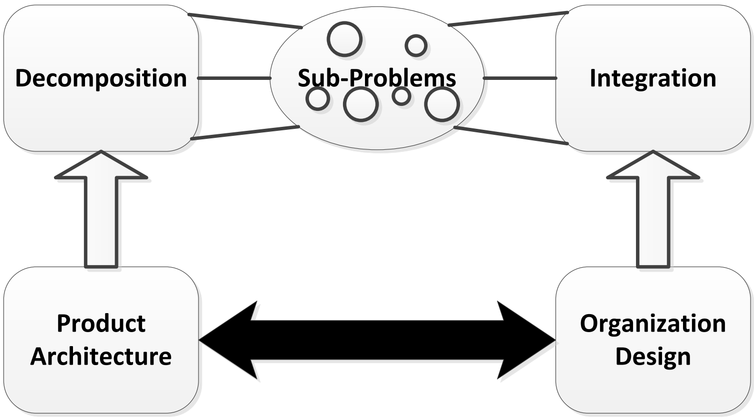


Figure 3-2.Problem relationships. Source: Gualti and Eppinger (1996)

The matter of allocating specific tasks the proper attention and maintaining a system that integrates the various subgroups' knowledge to achieve the best possible solution is no easy feat. Herein lies great potential for an approach that would consider the aspects mentioned above.

Integrative mechanism, which according to Browning (1998), are strategies and tools for effectively coordinating actions across teams and groups within a program (table 3-4). These mechanisms act as catalysts and facilitate information flow across communication barriers. These barriers are a company's or program's organization structure, incentive system, location, leadership style, cultural differences, and management traditions. The integrative mechanisms must not overwhelm or underwhelm its recipients (Browning, 1998).

Integration enablers

1. Systems engineering and interface optimization
2. Improved information and communication technologies
3. Co-location
4. Training
5. "Town meetings"

Integration maintainers

6. Manager mediation
   A. Management hierarchy ("up-over-down")
   B. Heavyweight product managers or integrators
7. Participant mediation

A. Conflict resolution engineers

B. Liaisons

	C. Engineering liaisons
8.	Interface "management" groups and integration teams
	A. Predetermined
	B. Impromptu
9.	Interface contracts and scorecards

Table 3-4. Integrative mechanisms. Source: Browning (1998)

The alleged viewer tool is in this context categorized as an improvement in information and communication technology. To a certain extent, discussions can also adhere to whether the desired intent connects to aspects of systems engineering and interface optimization. The tool is in any case considered an integration enabler. Drawing a contextual link between a viewing tool and CAD/CAM and CAE tools, effects of a viewing tool can be considered by studying the effects of the CAD/CAM and CAE tools.

Browning (1998) highlight the importance of these systems, stating that CAD/CAM/CAE systems are critical integrative mechanisms. They facilitate file transfers and standardized formats, aiding in design conversations, providing a flexible yet clear-cut design representation (Browning, 1998). The common point of reference these tools provide means that fewer interdisciplinary misunderstandings occur and conversations are more effective. Drawing on this observation, findings from the research by Robertson and Allen (1993) can be mentioned.

3.6 A viewer tool, a way of providing sufficient insight towards an efficient frontloading scheme?

In conjunction to section 3.6, Johannesson et al (2004) discuss theory and methods connected to a development process, adhering to the synthesis of development work and how method models answers questions like **WHAT** and **HOW**. Johanneson et al. mention that the continual effects of any implemented method can always be scrutinized. What benefits that are noticeable is not always straightforward and self evident, it very much depends on who carries out the specified task at the specified time (Johannesson et al., 2004). A design engineer who is forced to allocate a considerable amount of time to documentation rarely appreciates the intended purpose of this effort. It is just a time consuming activity. However, people involved in later activities are to a high degree dependent of this material meaning that a well executed documentation often implies a better foundation to base the continued work on (Johannesson et al., 2004).

In context, the idea of working towards a method including the notion of frontloading a process adheres to the scheme of mitigating late mistakes (Johannesson et al., 2004). Mistakes discovered late in the process are expensive and time consuming. The start of a project allows for great freedom in terms of changes, a change in initial stages of a development project is inexpensive. If however investments already have been allocated towards manufacturing tools, a change in design could have severe economic consequences. Johannesson et al. illustrates these changing circumstances by introducing figure 3-3.

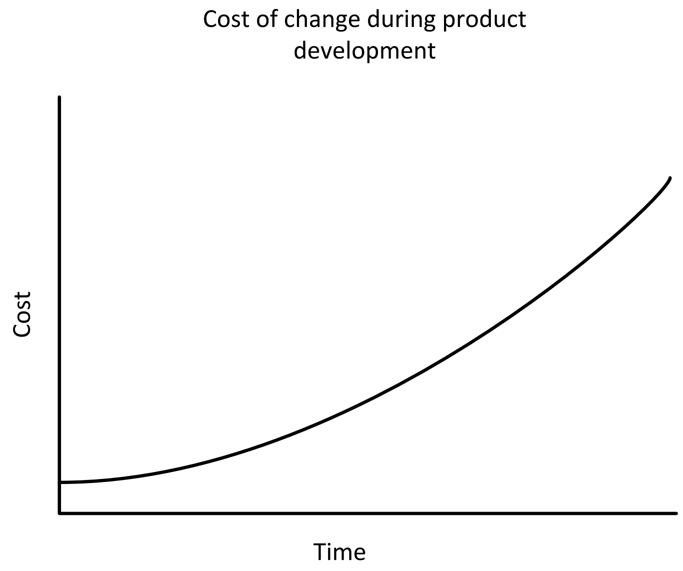


Figure 3-3. . Cost of change during product development. Source: Johanneson et al. (2004)

By frontloading or imposing a systematic development approach in preliminary stages of a development project, the intent is an enhanced foundation for creating the right product the first time around. In context, questions are raised towards a viewing platform. Does a 3d-viewer allow deeper insight from additional process actors, possibly mitigating late mistakes in the sense that knowledge and experience can be utilized earlier and more efficient?

3.7 A brief history of the capabilities of computer aided design

This segment of the thesis aims at providing the reader with sufficient insight towards the capabilities and history of CAD. This is important as the investigative study is contingent to spreading the information held and created within these software's.

The use of computer aided product development dates back to the 1960s, at that time computers were used for calculation and simulation. No specific software was at the time available, instead the software had to be developed in house. For every new problem encountered, a new software had to be developed. The 1970s saw the introduction of the first CAD-systems, working in 2D, the systems resembled what one could term an electric drawing board. It was not until the early 1990s when personal computers became powerful enough, a true implementation was noticeable. Today, 3D CAD platforms are totally dominant in terms of solid modeling. (Johannesson et al., 2004)

Initially CAD systems were developed to aid the creation of traditional hand drawn 2D drawings. With the support of these early systems the work undertaken by engineers could be rationalized. Changes could be achieved fast and easy and geometries could be copied and reused as many times as needed. In addition, CAD-systems provided the means for an effective distribution of the drawings created. The airplane industry soon found the need to numerically describe three-dimensional surfaces and bodies with complex geometries. This need soon resulted in elaborated CAD functionality, enabling control of 3D designs.

Today's CAD systems seems to be uninhibited in the sense that the systems manage completely defined solid-, surface- and volumetric 3D models, both static and parametric instances. (Johannesson et al., 2004) Further advantages of 3D CAD listed by Ulrich and Eppinger (2011) include *...the ability to easily visualize the three-dimensional form of the design; the ability to create photo-realistic images for assessment of product appearance; the ability to automatically compute physical properties such as mass and volume; and the efficiency arising from the creation of one and only one canonical description of the design, from which other, more focused descriptions, such as cross-sectional views and fabrication drawings, can be created.*

3.8 Aspects of usability and efficiency contingent to computer aided design

This segment illuminates findings of how efficiency improvements are linked to the use of CAD systems. This in an effort to reveal dynamics and possibilities maintained in reference to a spread of 3D design data (a 3D viewer tool). It must be emphasized that the text (Robertson and Allen, 1993) used in this section is old, raising questions to the validity of the explorations. However, it is not the technology that is scrutinized, it is the effects of the visual implementations. The text is thus considered relevant even today.

The authors (Robertson and Allen, 1993) investigated engineering work supported by CAD at three levels: design, analysis and communication. In their studies, Robertson and Allen surveyed 75 engineers in two gas turbine engine manufacturing companies.

Prominent findings in this study are two reasons why the use of CAD communication features may be related to engineering performance. One reason is that using CAD based functions lets engineers understand the interrelationship among parts of the product and the relationship of their part to the total product. This mitigates one major source of product assembly problem in the sense that it facilitates the discovery of interferences and other connected issues of physically fitting parts. Another reason is said to be the ability to access others' designs, making it possible to conceive probable answers to design questions. Geometric or kinematic dependencies can be learned without the need to spend time on face-to-face meetings. However, when such a meeting (inevitably) occurs, engineers arrive more informed of each others' work (Robertson and Allen, 1993). What must be stated however, is the notion of what seems to be the contributing factor. Simply put, Robertson and Allen (1993) cannot, on the basis on their study, conclude if high performing engineers to a greater extent use CAD tools for communication purposes, or if CAD tools provide a better foundation for an effective information conveyance. What has been proven though, is that technical communication is closely linked to engineering performance (Robertson and Allen, 1993). The authors (Robertson and Allen, 1993) emphasize: *To the extent that CAD enables and improves technical communication, it should* […] *lead to better engineering performance* […] *Designers of CAD systems should keep these results in mind and direct their efforts toward improving the ability to communicate through CAD. Structured message templates are one possible means of accomplishing this. A structured CAD message system would couple a text message template with the ability to capture CAD design geometry and include it in the message.*

Keeping these statements in mind, a natural response would be to allow further members with relevant knowledge (without access to CAD tools) equal capacity to conceive and respond to design elements vital to a project. In accordance, findings from a benchmark investigation (Aberdeen Group, 2006) are presented in the following paragraphs.

3.8.1 Aberdeen Group (2006) "The transition from 2D drafting to 3D modeling benchmark report"

In order to raise validity and possible performance increases, this segment highlights factors to be held in conjunction to 3D applications. Specifically pointing towards findings of a benchmark study (Aberdeen Group, 2006).

The report (Aberdeen Group, 2006) presents the migration from 2D drafting to 3D modeling. Seeing as the harsh conditions of a product development environment seldom allows for adoption of new technologies due to various time constraints, the text explore how best in class manufacturers manage to not only adopt new technologies to aid them in their performance but also to a greater extent achieve their initial targets. The report presents findings from a survey of more than 520 enterprises conducted in 2006.

Business Pressures		Strategic Actions	
Shortened time to market	65%	Improve product performance or quality	49%
Customer demand for new products	47%	Improve development efficiency	42%
Increasingly complex customer requirements	43%	Lower internal manufacturing costs	25%
Accelerating product commodization	29%	Develop markets with breakthrough innovation	17%
Threatening competitive products	27%	Decrease customer response time	17%

Table 3-5. Top business pressures and strategic actions. Source: Aberdeen group (2006)

Top business pressures and strategic actions are presented (table 3-5), identifying the prominent characteristic that manufacturers indeed are pressured into pursuing more complex products in less time. Manufacturers are responding with product innovation and improvements in product development efficiency.

Identifying best in class performers, the report presents implications leading to the outstanding fallout of these manufacturers. These include the following notations (excerpt from Aberdeen Group, 2006):

- Best in class performers are 40% more likely to have engineers use CAD directly to ensure they stay close to the design.
- Best in class performers are 24% more likely to take advantage of extended 3D modeling capabilities. They are 55% more likely to use downstream capabilities.
- All (100%) best in class performers acquired new hardware when adding 3D modeling, compared to 53% of laggards.

Questions then start to rise regarding to which extent the findings are relevant to the studied subject, the capabilities of 3D viewers. The findings include an increase in extended 3D capabilities and downstream utilization. Elaborating, conclusions can imply that the essence seems to be an initiative of directly connecting concerned actors to essential product data, seamlessly allowing users and developers to visually maintain control and understanding of current viewpoints. The case is thus argued in the sense where a 3D viewer platform is considered to offer very similar functions to the ones investigated in the report, provided the core of an implemented system provides a higher degree of engaged and enlightened parties.

3.9 Lightweight representation and the extended use of computer aided engineering.

This section is to a large extent based on the text provided by Ding et al. (2008) and the book by Toriya (2008).

What technologies exist for spreading 3D data and are they any different from the usage of ordinary 3D CAD systems? Why should one investigate the potential of such formats and systems? Answering these questions is the intent of this segment. Descriptions adhere to lightweight representations, a probable format for the conveyance of 3D data. In addition, case studies introduced by Toriya (2008) are presented. These case studies reveal industry circumstances in reference to technology implementations and allow for a quick review of possibilities connected to a lightweight (viewer) format.

3.9.1 Lightweight representation

Supporting users at different stages in the product lifecycle is the main priority of a lightweight representation, maintaining rapid browsing, and retrieval of product information. Efforts are amongst others being focused on compression methods for the reduction of file sizes and integrating markup languages for cross-platform support. Considering that there exist several suppliers of 3D CAD software, one of the challenges connected to the use of CAD is what system or format to use. Seeing as the same holds true for lightweight representations, the following paragraphs lists a few of the well-known formats and developers of lightweight representation techniques. Accordingly, CAD companies are likely to promote their own formats in relevant engineering applications.

Universal 3D (U3D) - Developed by Intel, Adobe and the 3D Industry Forum, this format aims at providing a universal standard for exchanging 3D drawing data. Most of the engineering data associated with the original model is eliminated, this in an effort to reduce the file size for quick download and fast rendering. Architecturally, multiple nodes may use the same resource, reducing the U3D file size additionally. Furthermore, U3D is a certified standard by ECMA, an industry standardization organization.

In 2006, Adobe launched 3D PDF (Portable document format) adding U3D to the very popular PDF format. The added U3D support allows 3D PDF to display 3D models in PDF documents. The Universal 3D File Format Standard (ECMA-363) and the associated implementation software has been released as open source. U3D is also supported from Version 7 Of Adobe Acrobat (PDF Version 1.6).

X3D - This format is developed by the Web3D Consortium. Considered a major upgrade from VRML, X3D adopts multiple compression algorithms. The format utilizes XML in order to make full use of the potential applications offered by web based application possibilities. X3D also offers certain customization of applications.

3D XML - Originally developed in Japan, one of Europe's leading CAD vendor, Dassault Systmes of France licensed XVL technology from Lattice calling it 3D XML. Dassault Systemes CATIA is the implemented CAD software at SCANIA and at several other automotive and aerospace industries. The format utilizes a sophisticated 3D graphics compaction algorithm. A reference/instance mechanism is used in order to enable reuse in one or more products by instantiation. 3D XML can be used by Dassault's product developers' tools.

JT - This format was originally developed by Engineering Animation and is now promoted by UGS. JT includes both polygon data for display and precision data for CAD data exchange. The format maintains two compression methods, standard and advanced. The advanced compression is said to support lossless geometry compression to a greater extent than the standard.

PLM XML - Also promoted by UGS, based on XML, the format aims at providing a common platform for all concerned actors in the product lifecycle by offering a standard protocol for data interoperability. Simply put, the format uses instances to describe relationships in order to reduce the amount of duplication of shape information.

3.9.2 Hiroshi Toriya (2008) 3D Manufacturing Innovation

This book describes trends connected to lightweight 3D data, illuminating the reality that 3D design is becoming standard. The book presents several valid statistical aspects reflecting process environments, connecting applied IT tools to surrounding industry circumstances. Contemplating the fact that many figures presented in the book adhere to 2004 or later, one can raise question regarding the validity of such numbers today. The belief however, is that these representation holds true even today in the sense that current trends often imply a heavier use of computer aided development schemes, while at the same time advancing the associated technology.

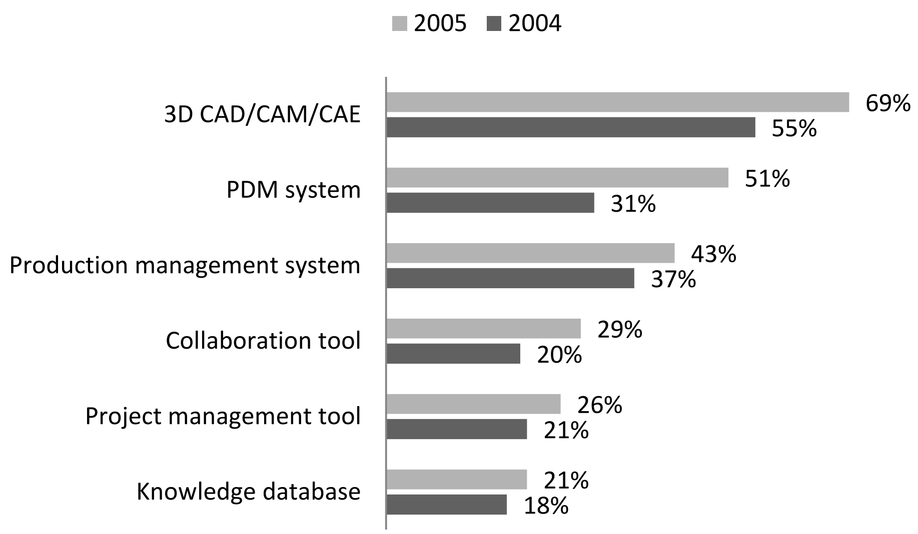


Figure 3-4. Manufacturing industry investments in IT infrastructure. Source: Toriya (2008)

Reflecting on the use of IT in manufacturing, figure 3-4 is presented, this figure indicates that 3D CAD/CAM/CAE plays a pivotal role in technology and manufacturing oriented industries. Noticeable is as well the increased amount of product data management systems in use between 2004 and 2005, indicating a growth in the amount of 3D data, underlining the idea of a growing amount of engineering data being created with the help of computers.

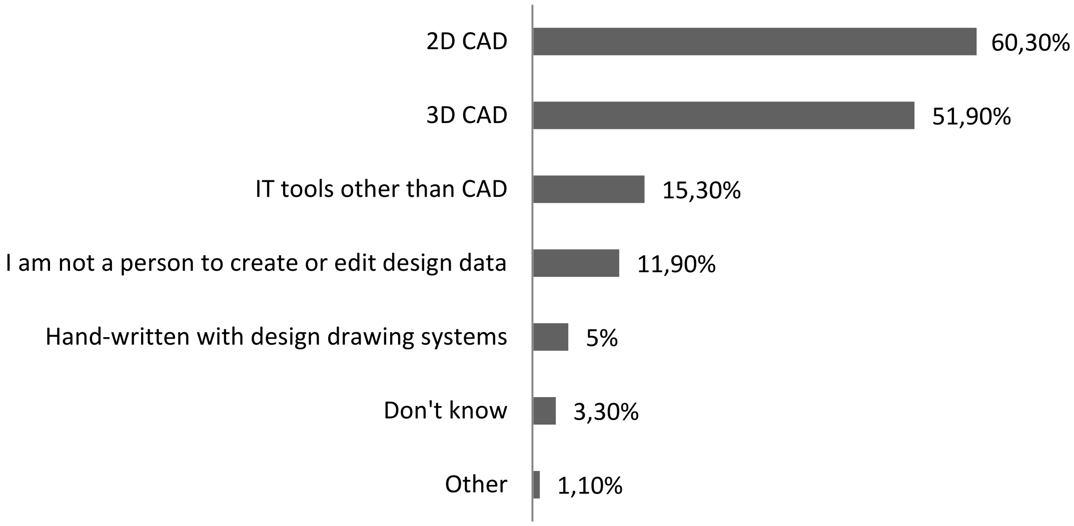


Figure 3-5. Design information created/edited in industries. Source: Toriya (2008)

Traditional tendencies are however noticeable when considering figure 3-5. The figure depicts 2D data as the primary design information created/edited. This can be interpreted as odd seeing as most cases would prove that 2D data (drawings) is created from 3D data. However, this inconsistency can be held in conjunction to figure 3-6, which implies that 3D models are not used as much as 2D drawings in terms of information conveyance. The reason being that 3D models are unable to include all design information and can contain inaccuracies in terms of file format inconsistencies. Many of the barriers detected can be said to stem from the nature of design and production processes, lack of development processes based on 3D models and inability to view 3D models for instance. Lightweight formats are in this sense held in great regard for being able to mitigate some of the barriers present. Toriya emphasize the importance of being able to effectively use the accumulated 3D data to enhance work performance.

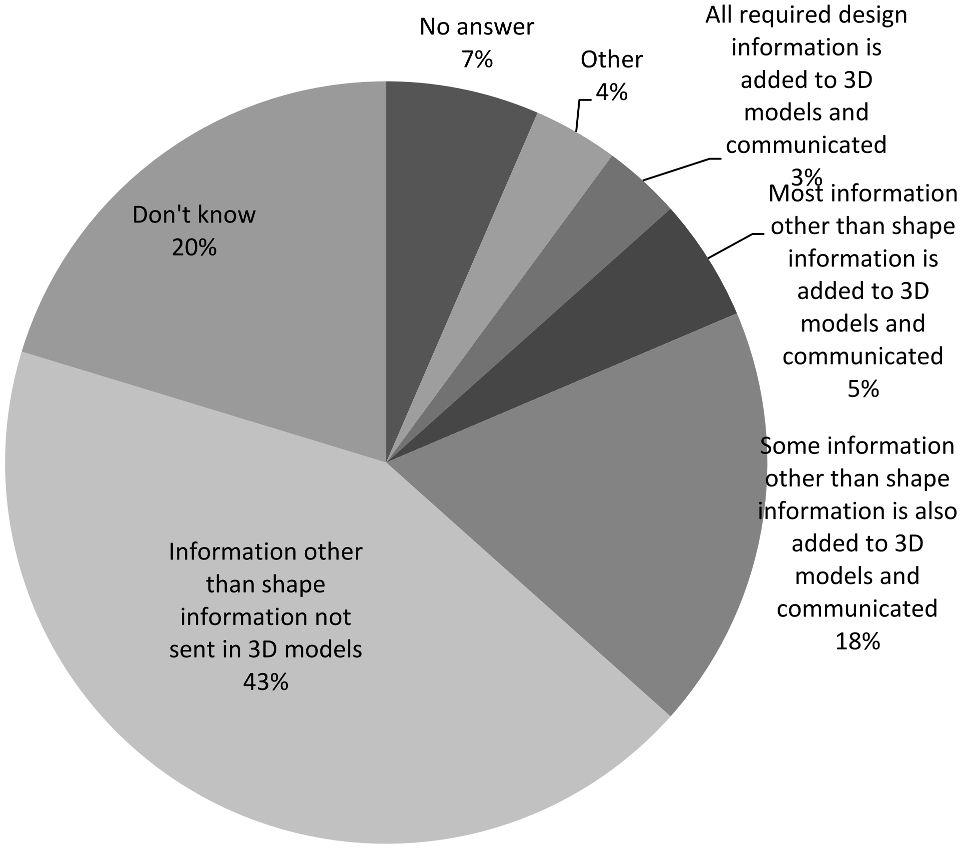


Figure 3-6. Depicted proportions of answer to the question: Is information such as annotation communicated along with 3D shape? Source: Toriya (2008)

Toriya argues that with the help of 3D lightweight formats one can amongst other things improve reductions in cost and at the same time achieve differentiation. Cost reductions are said to be achieved by the thorough reuse of 3D data and differentiation is achieved by the motivation of new rules and strategies implying an enhanced collaboration between engineers. In a sense, elimination of simple intellectual work in design and manufacturing is achieved.

In the following paragraphs, some of the case studies of the book are presented briefly. One must however underline the partial skepticism in the facets presented in this book. This because the author Hiroshi Toriya, at the time of writing the book, was president and CEO of Lattice Technology, CO., Ltd, the company who in fact licensed the XVL format, a predecessor to the Dassault owned 3D XML format. Caution has been/is taken when considering the described effects and circumstances surrounding the implemented strategies. Objectivity is of vital importance and even though very positive effects are described in the book, the outmost priority is to be enlightened of the several areas in which Toriya has found use for the lightweight format.

SONY – SONY is one of the leading manufacturers of a diverse range of digital equipment. The company started to use lightweight 3D formats in trial production processes in 2003. The company quickly learned that people in downstream processes found it hard to obtain 3D data during the design process, at the same time, it was hard to identify which was the correct 3D data. To resolve the issue, SONY built an information system with the possibility to exchange and distribute a lightweight 3D format to all employees. Any department could use the 3D data freely when they wanted. To help increase awareness, the company initiated projects promoting the use of 3D data. Noticeable improvements (according to the book) include spontaneous efforts aimed at converting even more models to the lightweight format, enabling the manufacturing department to refer to the data at any time.

Toyota Motor Corporation – Toyota one of the world's leading manufacturer of automobiles uses lightweight 3D format in design reviews, prominent reasons being:

- CAD systems cannot display very large assemblies. Instead of systematically dividing CAD models up into sections, lightweight formats are used since they enable display of entire vehicles at once.
- Interference checks are easier allowing for a higher degree of automation.

Nikon – NIKON precision Inc. is a manufacturer of semiconductor fabrication exposure devices. The company uses lightweight format as a communication pipeline. The format has allegedly reduced the work required to prepare documents and has enabled customer manuals to be created immediately after the design is completed and 3D data is available. The lightweight format has become a tool to convey information inside the company but has also proven a useful tool when considering communication with affiliated partners.

ALPINE PRECISION – ALPINE PRECISION**,** a manufacturer of car audio and navigation systems, started (in 2003) to move to a completely drawing- and report- less information exchange using a lightweight 3D format. Short delivery times mean compressed deadlines for die and mold making. Shared lightweight 3D information and related attribute information saw reductions in information loss and enhanced the productivity.

MAN Nutzfahrzeuge AG - MAN Nutzfahrzeuge AG, a truck and bus manufacturer, are especially encouraging the use of light weight formats for 3D drawings. Reasons include (excerpt from Hiroshi Toriya, 2008) 3D Manufacturing Innovation, p 116):

1. 3D data can be visualized in the whole process chain because it is less abstract than a 2D conventional drawing.

2. Because design is already done in 3D, the design departments will see a reduction in time by avoiding the 2D drawing production step.

3. Non-CAD-trained staff will be able to visualize and interrogate design models thereby enabling easier cooperation on a common data basis and including refinements such as 3D animations of assembly and disassembly and “exploded”.

These cases are but a few of the occurrences listed in the book. The aim is to actively search for common aspects in the study of SCANIA, hopefully making new observations allowing for further interpretations.

3.10 Visualization

The saying *a picture is worth a thousand words* is often put forward as an advantage of using visualizations of some kind. But are all variants of visualizations good or is there a spectrum of better and worse ones? According to Ware (2012, pp.345) *a good visualization is not just a static picture or a three-dimensional (3D) virtual environment that we can walk through and inspect like a museum full of statues. A good visualization is something that allows us to drill down and find more data about anything that seems important.* Furthermore a mantra for developing user interfaces that support good visualization has been expressed as: *Overview first, zoom and filter, then details on demand* (Shneiderman, 1998 cited in Ware, 2012, p.345). Ware explains this mantra as three different tasks that a user interface should offer, but the order that the tasks are conducted is not important as long as all tasks are supported (2012). He continues and says that the visualization tool should be able to present more information if the user needs it but also hide information that is not useful at the moment. Ware further explores what he calls *the Cognitive System* where an interactive visualization is said to be the interface between humans and computers in a system for solving problems. Neither humans nor computers can achieve problem-solving by itself, but must be considered together as a system. This interaction is be based on what Wares calls *visual queries* that is a part of humans working memory. Such a query should be based on solving a specific problem and in order to solve that problem a visual query is combined with a visual pattern that could be searched for. For example could such a visual pattern be red circles indicating interferences between geometrical shapes in a CAD model. In the process of finding these interferences an iterative workflow is used that is triggered by human interacting with the computer, for example by zooming in on some part of the 3D model. Ware conclude that interactive visualization should provide help for humans in a way that users do not need to keep a lot of information in their working memory. The author gives an example that using two windows showing the same object from different angles could heavily decrease the time it takes for humans to process information, instead of having to zoom out and rotate the object and zoom in again.

When a tool is designed for interactive visualization it is important to be aware of two properties that are in contradiction. The first being the wish for having a specialized and customized tool that can handle exact what the organization demands and the second is the goal of complying to industry standards (Ware, 2012). Ware (2012, pp.423) states that *standardization is the enemy of innovation and innovation is the enemy of standardization*.

3.11 Manipulation tasks in 3D

When a user interface for displaying 3D models is developed, it is trying to imitate different human tasks for manipulating the 3D view (Bowman et al., 2005). The authors describe three basic tasks for manipulation being; selection, positioning and rotation. With each of the basic tasks comes specific parameters that defines how the user can accomplish a task. For example when selecting an object, the object size-parameter is interesting for deciding if more than one object is selected.

The input device used for manipulating a 3D view plays a main part in how usable the interface is. According to Bowman et al., (2005) there are two properties of the input device that influence how the user can manipulate a 3D model. First it is the *number of control dimensions,* which describes the number of planes that can be changed by the device. Secondly it is the *integration,* which describes how many of these dimensions that can be changed simultaneously. Even though there exists input devices with more than two control dimensions, the most common input device for 3D manipulation, the mouse, is limited to only two.

Furthermore the design of an input device is also important for how the user experiences the interface. The input device can either measure the position of the user's hand or measure the force put on the device by the user. A device measuring the position is preferable when manipulating 3D and a device that determines the force might be better when controlling rates, for example speed.

The form of an input design also counts when measuring how usable an interface is. Two common devices for controlling 3D interfaces are the sensor glove and the *precision grasp* (see figure 3-7). Which device type to choose depends on what degree of precision you need the interface to use. Using a glove involves larger muscle groups within the whole arm and a precision grasp device, for example a ball, use smaller muscle groups in the fingers.

Figure 3-7. Haptic Issues for Virtual Manipulation. Source: Hinckley, (1996)

In most CAD software, usually a normal mouse is enough for manipulating the 3D view. Even though a mouse only has two control dimensions there are techniques when creating the user interface in order for a mouse to control it (Bowman et al., 2005). A common method is to separate the control of planes and let the user first decide which two dimensions he or she wants to control and then let the mouse control the selected planes. Another technique is the use of 3D widgets where the controls are displayed directly in the 3D model. For example small boxes around an object which the user can select and drag using them mouse in order to manipulate the object.

3.12 Evaluating 3D user interfaces (UI)

On the topic of defining the purpose of evaluating Bowman, et al. (2005, p.350) writes that *evaluation is the analysis, assessment, and testing of an artifact. In UI evaluation, the artifact is the entire UI or part of it, such as a particular input device or interaction technique.* Furthermore the authors claim that evaluation should be conducted iteratively throughout the design process in order for improvements to be made based on the evaluation results.

When it comes to defining the evaluation process, a central term is usability. Usability is described as anything about an artifact or a user that influence the person’s ability to use the artifact (Bowman, et al., 2005).

3.12.1 Evaluation tools

According to Bowman, et al. there are four different tools for evaluating design and implementation of 3D user interfaces. The four tools are: User task analysis, Scenarios, Taxonomy and Prototyping.

3.12.1.1 User task analysis

With this evaluation tool, the needs of the user are traced and explained. The tool aims for thoroughly describing the tasks that users need to conduct together with information flows and work sequences. This kind of analysis is usually done by a team of developers responsible for providing the interface which is supposed to fulfill the user’s needs.

3.12.1.2 Scenarios

User task analysis can be used to define user task scenarios, which are the ordering and ranking of user tasks and task flow. When using scenarios to evaluate an interface it is important to make sure that the right scenarios are included, that is to say only include tasks that are really conducted by the user. Furthermore the scenario should not only include simple mechanical tasks, but also include higher levels of cognitive tasks that are common within 3D user interfaces.

3.12.1.3 Taxonomy

Here the tool is about classifying tasks into different categories that can be analyzed more easily. Each task can also have subtasks which in turn have one or more Technique Components (TC). The most useful aspect of this evaluation tool is the possibility to add several TC's together and evaluate them all at once.

3.12.1.4 Prototyping

Very early in a process of developing a 3D user interface, there is not so much to evaluate (or sometimes nothing at all). It might be a problem to start develop something before you know what you want and in order to find out what you want an evaluation might be needed. Especially if several options are considered, it could be very complex and expensive to develop a fully operational software only to make an evaluation of it. Instead a prototype could be developed, which might be only a sketch of how it should look and the functionality is explained in words or done by hand by the evaluator.

4 Method model of study

This master thesis is based on a case study. The main part of the work has been carried out at Scania in Södertälje. Three reference visits at Volvo PV, White Architects and SAAB Aeronautics have been done to compare findings and to enhance analysis. The reasons for choosing a case study are that it is suitable when conducting research at a specific company and with a specific group of people (Patel & Davidsson, 2011). Furthermore Patel & Davidsson emphasize that a case study is often used when studying a process or a change, which is what implementing a 3D-viewer into product development could be characterized as. Another advantage that comes from using a case study is that several types of data gathering can be used, for example interviews, observations and surveys (Patel & Davidsson, 2011). In figure 4-1, the systematic method approach is presented.

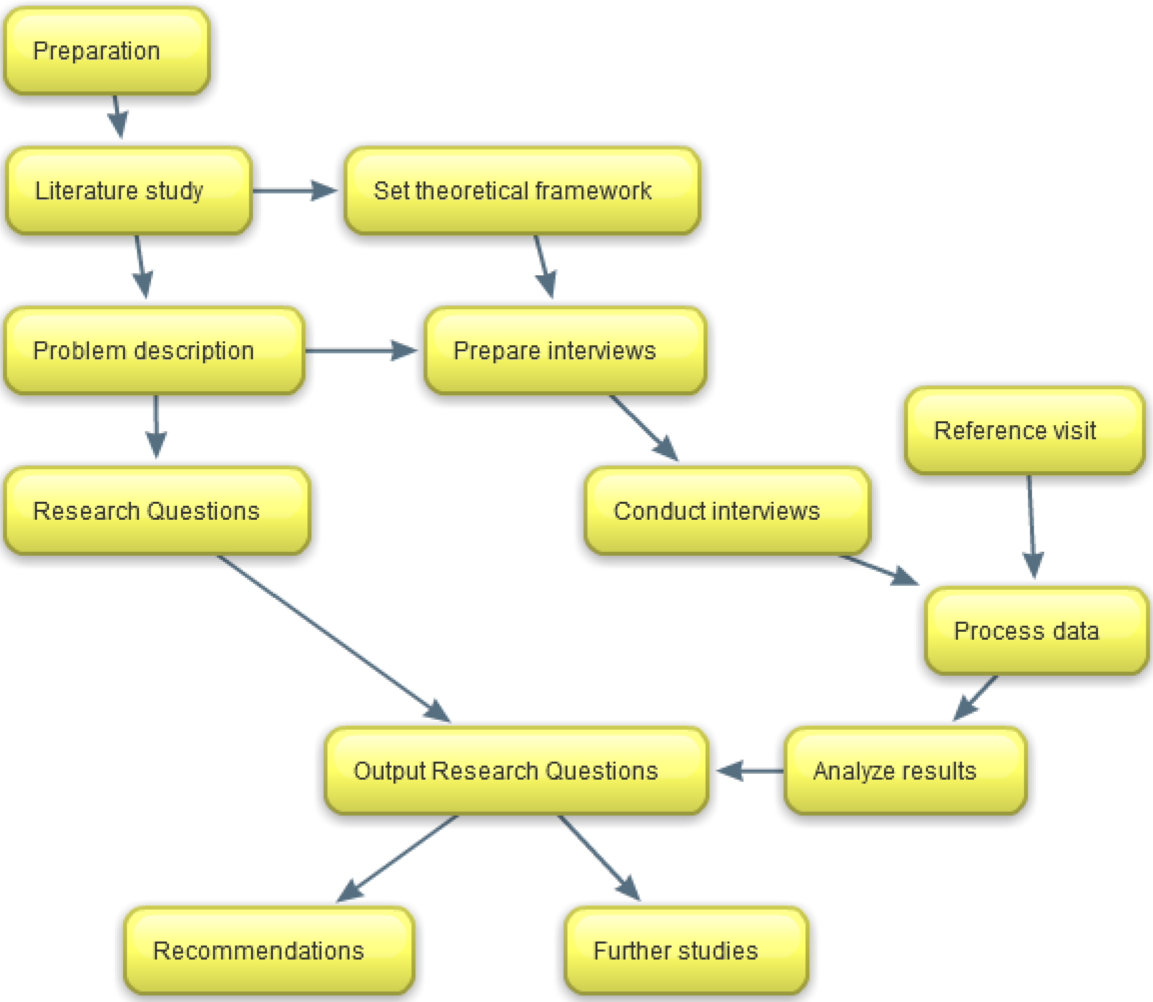


Figure 4-1 - Model of method

4.1 Methods to find output to Research Questions

This segment aims at providing a general guideline for establishing methods to find output to the presented research questions. The research questions are:

- RQ1: In what way does the flow of information improve with the use of a 3D-viewer?
- RQ2: In what ways would an implementation of a 3D-viewer imply that potential problems in product development were discovered earlier? How does it affect work processes, for example preparation work?
- RQ3: What needs must be satisfied by the 3D-viewer software? Are there changes to the product development process that needs to be made in order for an implementation of a 3D-viewer to be possible?

The following paragraphs present methods to individual questions.

4.1.1 Method to find output to RQ1:

To find output to research question 1 it is important to investigate how the information flows currently and then add possibilities, advantages and disadvantages from the use of a 3D-viewer to the flow of information. To acquire information about the flow, but also about implication of an implementation of a 3D-viewer, interviews and observation have been conducted. RQ1 should be looked upon as a company specific issue, because it could be depending on workflows, ways of communication and policies, which are company specific. In order to find output that is compatible with Scania, interviews conducted with people who are department heads have been taken into account.

4.1.2 Method to find output to RQ2:

In order to find work operations that could be done more efficient with the help of a 3D-viewer, similar work operations that are done “manually” today have been studied. Such work operations have been investigated during interviews with coworkers at Scania. Internal documents at Scania have been studied and compared to observations which have allowed a deeper interpretation and broaden the search for work operations that could be streamlined.

4.1.3 Method to find output to RQ3:

For research question 3 the key aspect is to find elements that depend on viewing, whether it is in 3D or 2D on a paper. Interviewing staff that use the work operation viewing is an important step to find measures that needs changing before implementing 3D-viewing. To expand the perspective on 3D-viewing in product development and in an attempt to include issues that are hard to foresee, three reference visits to companies that already have implemented 3D-viewing in the product development process have been undertaken.

4.2 Data Collection

According to Andersen (1994) data collection can mainly be conducted in three different ways; document studies, observations and/or interviews. In this master thesis all three methods have been used to some extent.

4.2.1 Document studies

Using document studies is an indirect way of collecting data, because the lack of direct connection with the people concerned with the study (Andersen, 1994). Furthermore it will make the data more fixed when you do not have the opportunity to ask follow-up questions, which is pointed out as a weakness by Andersen.

When choosing what literature to study, Andersen proposes that you start with the most recent and most general documents and then work your way towards older and more specialized literature as you go along.

In this master thesis we (the authors) have used books and articles on the subject, but also previous master thesis's and webpages on the subject. Internal Scania documents have also been used in order to clarify today's situation and for understanding current methods in product development.

4.2.2 Qualitative interviews

In regard for the research topic the use of qualitative interviews has been chosen. The challenge is to encourage people to evaluate their work process and thereby find areas that can be improved. In this case a more informal dialogue in a qualitative respect is seen as the most appropriate way of investigating the possible use of 3D-viewing in certain work flows.

It is common to use an interview guide when preparing and conducting a qualitative interview (Ryen, 2004). According to Ryen there are no guides ready-to-use immediately, but instead it should make the researcher think about the degree of formalization and what techniques to use during the process. Ryen puts forward that the degree of structuring depends on the research questions, the focus of the research and on the selection criteria. Furthermore the researcher should be aware that too much preparation work could result in that the researcher neglect important aspects of the respondents answer. On the other hand if the researcher has a specified are of research it is often an advantage to prepare the interview beforehand. It also prevents the researcher from collecting lots of unnecessary data which could blur the analysis (Ryen, 2004). Another parameter for deciding to a structured or unstructured interview is if the study is explorative or verifying art. In an explorative study it is preferable to have a low degree of structure simply because it is difficult to formalize something that you know little about.

For a qualitative interview in a case study it could be important to recognize how many cases you are about to study when deciding on the degree of formalization. If the study is about a single company or organization it is not as important to have a structured interview as it is when studying and comparing several companies or organizations. The reason comes from how generalizable the results should be (Ryen, 2004).

In the spectra for degree of formalization is also the semi-structured interview. It involves some formalization by the researcher, for example that a few themes or broad questions are prepared but during the interview the researcher can ask follow-up questions. Ryen emphasizes that the interview has been called a conversation with a purpose and that the semi-structured interview combines the usual conversation with the scientific study.

We (the authors) have set up interview groups with a span from a single person up to four people depending on their current job but also from their past experience at Scania. The interviews have been recorded and notes have been taken. Our approach has been a semi-structured interview with some generizable questions prepared but with the freedom of putting follow-up questions forward during the interview.

4.2.3 Observations

The method of observation can be used in different contexts and for different purposes (Patel & Davidsson, 2011). One purpose could be as a start for a study using explorative research, and another could be as a complement to other tools for collecting data. An advantage with observations is that it reflects information from “real” situations and not a narrated memory from an interview. The most common shortcoming with observations that is put forward is that it takes a long time and is usually expensive.

Observations, like interviews, can be divided into structured and non-structured ones (Patel & Davidsson, 2011). A structured observation is when the studied behaviors and events are clearly stated from the beginning. It also involves creating an observation schema with presumed actions stated. On the other hand is a non-structured observation when the researcher tries to observe “everything”.

In the work with the master thesis we (the authors) have attended group meetings where 3D-visualizations have been used, this, in order to understand the different communication paths used at Scania.

5 Results

Needs and requirements revealed from interviewing Scania employees are presented here. Participants are grouped by their working roles. Results from the three reference visits are also presented here and the chapter is concluded by a section on 3D-viewing at Scania.

5.1 Interviews

Most interviews were held at the research and development department and only a few at purchase, production and aftermarket departments. Since the scope of this thesis is mainly R&D, this section will be split in two parts: one for R&D and one for other departments at Scania. An interview guide and a table containing respondent quantity and belonging are presented in appendix b. In addition to listed categories, employees with system and process specific knowledge have been interviewed with the intent to enlighten and educate the authors (of this thesis), these are in the table of the appendix listed in the category *other*. Even though they can’t necessarily be linked to a specific function discussed, many of the subjects interviewed provided a level of insight that could have gone unnoticed and unexplored. All insights received are presented in the following segments.

5.1.1 Research & Development

Groups of employees with different roles have been interviewed. Those groups are: managers, physical testing, design engineers, mechanic personnel and product coordinators.

Every project entails a changing amount of effort from the categories interviewed. It is therefore hard to pinpoint project process entry of every category. In accordance by the guiding criteria set by R&D factory however, it is always the outmost intent to include every concerned actor as early as possible.

5.1.1.1 Manager role

At Scania it is hard to distinguish managers as a homogenous group when it comes to tasks and work situation. In this master thesis, when dealing with visualization, we will broaden the group of managers even further to include project managers, object managers and group managers. Within this group we will also place employees that are appointed to carry out a managers assignments, for example reviewing a design drawing. Consistent efforts maintained within this category include coordination strategies for effectively achieving group or project goals.

After interviewing managers we could draw an early conclusion that different managers conduct their work in different manners when it comes to interacting with 3D-models. One reason for this comes from earlier experience from CAD-data and the use of Catia. A manager that is experienced in, and know how to use Catia, saw less need for one additional tool only for visualizing the 3D model. While the big majority of managers experienced a lack of such a tool and saw great need for a simple and fast way to visualize geometries. That a visualizing tool is needed was presented by one manager with the words:

> *If we had a visualizing tool we would be able to first share our previous experience regarding the design but also prepare our testing at an earlier stage. We are not part of the digital flow of information today and are not able to do those things.*
>
> (Manager at Scania, 2012)

Most of the managers that were interviewed explained that their work with a future visualizing tool would probably not occur every day and maybe not every week. For that reason several managers stressed the point to make the tool intuitive and easy to use. Examples on what would make it easy to use were given; an easy way to find what you want to view, either by searching with part number or the ability to open a 3D visualization through a link received by email. Moreover one manager explained a need by employees working with testing to be able to view specific test trucks that all have their own identity and are customized to carry out a series of tests.

A few of the respondents put forward the need for a secure logon in order to control the level of access to different employees. Furthermore the option of letting external companies acting as a supplier to Scania receive access to a limited part of the 3D-models.

Managers are often preparing visual presentations, which in some cases holds 3D-models explaining the product development. A property that is asked for by managers is the possibility to export from the viewer into any Microsoft Office format.

Managers for design engineer teams are responsible for approval of design drawings. In many cases the manager needs to visualize the 3D-model to check if the design is correct. Today the approval process is conducted with the help of Catia, but as the manager never makes any changes to the design a viewing tool would be sufficient.

5.1.1.2 Physical testing

In the category physical testing we include employees working with ordering, preparation and follow up of tests conducted on trucks. We have excluded testing mechanics and given them a group of their own. Moreover managers of physical testing groups are also included here as well as in the manager role group.

The category maintains a variety of tests adhering to durability of specific parts or whole vehicle systems. Establishing specific tests to be carried out is an activity that entails close collaboration with concerned design engineer. Various tests are necessary for establishing and making sure the developed article fulfills stated laws, quality and/or performance. Dependent on project definition, a physical test might or might not be necessary.

A point that was made during several of the interviews was about understanding what was supposed to be tested. In order for a testing engineer to prepare a physical test, he or she has to understand what is going to be tested and what the surroundings look like around the object. Such an understanding was thought to be retrieved more easily and faster if a 3D visualization tool were to be implemented. To enhance understanding even further, a function for measuring length, area and volumes were expressed as a need in a viewer software.

To prepare for physical field testing of a part it is crucial to know what the surroundings of that particular part looks like. If it is a prototype part the employee preparing the test needs to make sure the part will fit together with the other parts on the truck. To make this practical in a viewing tool the user must be able to find the part he or she is going to test and from that part load the surrounding geometries placed correctly in space. When the geometries are checked for interferences and it seems to be working, the parts included in the physical testing is ordered. Today the ordering process takes place with pen and paper where an employee ticks of part numbers from a drawing and puts them on two different lists. One list for parts that are already in production for current vehicles and one list for prototype parts that needs to be produced separately. If a viewing tool could put together these two lists from what is currently viewed, a lot of time would be saved and mistakes from doing it by hand could be avoided.

For some physical tests, sensors are placed at certain places on the truck. These sensors measure for example movements of that particular part and saves all these measurements in a table. To be able to use these measurements in a meaningful way you need to know somewhat exactly where the sensor was placed. Today this is either done by measuring by hand on the physical truck itself or by measuring on the drawing to a known position on the truck, for example a hole in the frame that you already know the coordinates for. In order to speed up this process and to make it more accurate, the future viewing software should be able to give the exact coordinates in space and thereby show where the sensors were positioned.

5.1.1.3 Design engineer

The characteristics of a function that is in this context denominated design engineers, include a common responsibility of amongst other things realizing product development goals in terms of specifically achieving predetermined product properties and objectives manifested in project deliverables. Other responsibilities include establishing necessary contact with internal partners or customers that affect or can affect circumstances connected to the product that is to be delivered. Further responsibilities adhere to properly documenting deliverables (e.g. CAD models, drawings, engineering change orders etc.) and reacting to inconsistencies in development work.

This category employs CAD tools in terms of Catia licenses. A relevant aspect can thus be contemplated by asking why this category has been interviewed. The respondents all have access to visual aids and they are very well understood with the functionality the tool possess. The intent is thus not specifically to be well understood of how such a category can utilize a viewer, instead the many facets of their work that is contingent to creating basic visual data for instances other than their own is investigated.

Respondents were to a high degree concurrent with the notion that some effort was in fact guided towards providing relevant visualizations to aid understanding to group managers and other relevant parties. In regards to the group manager, the general idea was conceived to be that the managers own experience to CAD software and whether the manager had access to a CAD license played an important role in how visual information was distributed. If the manager had access to a license and were well understood with the functionality, a lesser amount of visual aids needed to be prepared. One respondent also answered that a high amount of effort (40-50 hours per test) was needed in order to provide physical test groups with relevant data. This data could to some extent be descriptions/visualizations of environmental/structure based factors of the specific item tested.

Other relevant visualizations that according to design engineers would be relevant to convey was article movement. This adheres to articles where circumstances imply different positioning, for example springs bottoming, implying a shift in overall positioning connected items.

Aspects of problematic occurrences connected to the implementation of CAD software were also discussed in an effort to highlight possible factors in context to a viewing platform. The respondents did in these instances concur to the fact that knowing what to incorporate in addition to what was being developed was not always clear. This means that environmental variation was not always clear and did in some cases prove to be somewhat time consuming in cases where specifics needed to be established. However, noted was as well, that in cases where the environmental circumstances or variations where known, the task was considerably less troublesome. In these instances the case was rather that the article data being launched could be very large and thus needed extensive loading time, creating ineffective time disturbances.

Another raised issue was the inconsistency in updated positions of developed articles. The problem was not conceived as being of vital proportions but did to a certain extent exist. It meant that knowing positions of surrounding articles (from the perspective of the article being developed) to a certain extent became circumstantial. That is, if a close collaboration between affected departments existed, the problem was not as likely to occur as when the collaboration was less tangible. At Scania there is a predetermined way of documenting and updating changes while designing, the issue must thus be held as a consequence of not following standardized rules.

5.1.1.4 Mechanic personnel, Research and Development

This function builds and makes sure early designs or prototypes fits and fulfills intended test objectives. Dependent on project, the prototypes are fully functional or just a representation of design features intended for fitting purposes. Work efforts in this area is amongst others contingent to rigging, scheduling, setting up/adjusting connected instruments, assembling, rebuilding, and following predetermined methods for intended purposes.

The respondents in this category emphasized a situation where circumstances of one project in many instances differed from the other. In some projects, respondents engaged in a close collaboration with design engineers, in other instances, the collaboration was less tangible and the work more independent. In terms of communication, the matter could be said to have been an effect of location. If design engineers were located in close proximity to the mechanic, communication patterns were mostly face to face whereas if the location to the design engineer was far off, communication technologies were emphasized. In conjunction, the respondents did underline the importance of having visual aids (such as 2D images of 3D geometry, or rapid prototype models) or basic drawings in order to convey and understand properties in a bigger context. Some of the respondents did have minute experience from using Catia and made the reflection that the software was far too hard for them to use as a complement to daily undertakings.

In terms of basic article design data, different project did as well mean different information data. Some projects entailed very in depth information in terms of specific article surroundings and design. Other projects were very sparse in terms of design data and implied a higher level of freedom when building and assembling. In context, one respondent also stated that the level of information didn’t necessarily imply a better design, it could in fact give false indications to the level of completion. Making an elaborate design could result in a solution so closed off to other unseen criteria that a complete redesign was necessary when the specific criteria were noted. The respondent thus underlined the notion that the design engineer placing too much effort on initial information and design data (to a certain extent) was unnecessary, stating:

The lesser amount of design data, the better.

(Mechanic respondent on basic design data, 2012)

Being able to judge and commit to work task based on experience was a prerequisite of daily undertakings, a viewer could aid the conveyance of this experience. Effectively reviewing early designs circumstantial to environmental elements in 3D design data was a notion raised, this could to a certain extent mitigate a few of the inconsistencies noted today. It could free the design engineer from extensive information design data gathering allowing the mechanic to single handedly contemplate surroundings.

Further indications adhering to design data was the level of accuracy employed. One respondent found it hard to know the level of detail one should employ when basic data was sparse. According to the respondent there existed instances where, not knowing what emphasis to put on specific details led to excessive machining on articles that had very little impact on tested/implemented design. Knowing article environment and overall context was highlighted in this instance.

In terms of viewer functionality, respondents were adamant in pointing towards the need of being able to measure various lengths in the model. Another aspect was speed in loading the models. One respondent did in fact have access to a viewer tool but dismissed it, seeing as it took too long to load the data that was to be viewed. Other functions included being able to print various design data on paper and specifically making irrelevant articles disappear, as well as producing cross sectional views. In relation to the discussed subject, one respondent stated:

Functions just like in Catia but easier.

(Mechanic respondent on viewer functions, 2012)

5.1.1.5 Product coordinator

Product coordinators are responsible for maintaining and updating product structures (TCR/VCR/KS, see segment 2.7) in accordance with basic mechanical design data and engineering change orders. Other responsibilities include updating text based product specifications along with reviewing and updating engineering change orders. Acting on product abnormalities and faults both from internal and external sources is highly motivated. At Scania there exist four groups of product coordinators, each group being connected to specific sub systems. This means that every product coordinator instance have well established contact with several engineering departments.

A prominent feature of a product coordinator is the link to product structures. This is updated and maintained with the aid of AROS, an in house based data system for keeping track of product information, such as article number and coordinate positioning. AROS also keeps track of conditional product variations, vital to the modular system employed by Scania.

The groups of product coordinators have a minimal amount of CAD licenses, making any visual reflection linked to a set of predefined product/variant conditions a somewhat tedious task. Availability of licenses is one aspect that contributes to this feeling of tedium and the fact that the visual aspect is linked to a different system is another constituent. When asked if a direct visual linkage between the conditions set in the AROS environment and the CAD instance of the corresponding articles would be of any use, respondents answered affirmatively. Directly drawing on a visual representation of the conditional product information data produced, would help detect inconsistencies or misconceptions.

Not being a design engineer at Scania means not having the ability to directly publish geometry positions while in a CAD (Catia) environment. A product coordinator often detects problems in terms of positioning and must in accordance notify responsible design engineer or update incorrect position to correct position manually through the manipulation of coordinate specific data in AROS, a viewer prerequisite is thus the ability to measure accurately. Further viewer properties described was the ability to manipulate view (viewing from different angles) and being able to produce cross-sectional views.

5.1.2 Production, purchase & aftermarket

A few employees from production, purchase and aftermarket respectively have been interviewed.

5.1.2.1 Production

In order to coordinate needs that lay with research and development with instances of production, two interviews were held with eight people in total. It must be highlighted that the emphasis of this thesis does not lie with production, the intent of the interviews was to detect common tendencies that would allow production needs to be matched with needs of research and development. Possibly, this would allow similar solutions for both instances.

Being a part of production related units means being involved in several circumstances of development work. Some instances of production maintain close relation to initial project steps other are more likely to be involved in later stages. In relation to instances of research and development, common problematic occurrences were related to out dated drawings creating unnecessary misconceptions and time delays. Other occurrences related to format and ability to view files created for different purposes, in essence some data was closed off for specific file storage or PLM solutions/software. In context, respondents stated that in some cases, a complete CAD (Catia) license was used just in order to facilitate viewing of specific product or assembly data.

In terms of functionality, the belief is that as in research and development, the needs and specific functionality of a viewer is highly dependent on department responsibilities. Therefore drawing specific conclusions on specific needs is left out in this thesis. However, adhering to above stated illuminations of outdated product data, a clear indication of product/project status was by many respondents believed to be a need throughout production instances.

5.1.2.2 Purchase department

The purchase department acts as a link between R&D and supplying companies to Scania. When the design engineers are done with the design of a part that Scania is not able to produce by itself, the purchase department use the CAD drawing to ask suppliers for offers on that part. Some of the people working in the purchase department already use a lot of 3D models in their current work but all of that work relies on that somebody, mostly a design engineer, has prepared one or several files for the purchaser to view.

During the interview with employees working with purchases, the basic understanding of the surroundings of the part was emphasized as important. The reason for wanting to view the surroundings was put forward as further on understand the specific demands that were set on the part.

Other needs on a viewer software that were put forward was the ability to go immediately from the textual based structure program AROS and directly viewing the choices you have made to the configuration. Also basic tools for measuring length, area and volume was given as needed functions of a viewing tool. Furthermore a tool to calculate the unfolded area of a curved part, in order to see of big rectangular raw material is needed to produce the part.

5.1.2.3 Aftermarket

In this section we have included employees working with creating service manuals and internal instructions to service mechanics. When these manuals and instructions are made today, photos are taken on a real physical part to illustrate something. According to an employee working at aftermarket, this might be the best way in some very specific cases, for example when illustrating how the turbo works which might not be described in a CAD model and thereby the illustrator could not use a 3D model to describe the turbo in the manual.

If a viewing software was to be implemented which had direct access to the same database as the design engineers, it was pointed out that some sort of status or maturity level of the parts has to be in place in order for the after-market to know if a part or system of parts is in the process of updating.

For an illustration in a service manual to be clear and easily understood, the possibility to put colors on specific parts is a needed property.

5.2 Reference visits

Three reference visits have been carried out in order to search for advantages and disadvantages in already implemented solutions in the area of 3D visualizations. Two visits to companies in the manufacturing and one in the architectural industry were conducted.

5.2.1 Volvo Car Corporation (From now on called Volvo)

All information in the background section was found in (Volvo, 2012). The information in the remaining sections is based on an interview with Mikael Rosenqvist (Business Application Manager) conducted at Volvo's facilities in Gothenburg on September 11 2012.

5.2.1.1 Background

Volvo is a car manufacturing company that was founded in Sweden back in 1927. Last year, 2011, they sold more than 449,000 cars in more than 100 countries. The main manufacturing sites are located in Gothenburg, Sweden, and in Ghent, Belgium. Headquarter, R&D and design departments are also located in Gothenburg. In May 2012 around 21,500 people were employed at Volvo.

5.2.1.2 CAD and PLM software

Volvo uses Catia V5 from Dassault Systems as CAD software together with Teamcenter from Siemens as PLM software. In order to keep license cost at a minimum a strategic decision to only let design engineers use Catia V5 has been taken. The licenses for Catia V5 is offered on a monthly basis to make the license costs more dynamic even further. According to Rosenqvist (2012) it was not an easy task to merge a CAD software from one supplier with a PLM software from another supplier and making them work together. An example of a problem area is that Dassault Systems and Siemens use different formats for lightweight representation of a 3D-model. At Volvo they have chosen to convert all CAD-data into JT files, which is the lightweight format that Siemens use. The conversion is done by an automatic script that runs immediately after a design engineer has saved his or hers work into Teamcenter. Depending on the workload of the IT system the conversion takes between 30 seconds up to one hour to complete. Even though Volvo encountered problems during the early phases of implementing the IT system from two suppliers, Rosenqvist points out that it runs very smoothly at present time.

At the beginning of the process of implementing Teamcenter, different IT workshops and test groups were working on how the implementation would take place. The time from starting the process to having a fully implemented system took around 4-5 years.

5.2.1.3 Lightweight viewer

Since Volvo mainly allows design engineers to use Catia, a solution to spread information from CAD-data to others involved in the product development had to be implemented. The solution was to use Teamcenter visualization by Siemens, which is included in a free standard package of software for all computers at Volvo. But in order for the staff to use it they need to take a course in how to use it to be allowed access. Rosenqvist believes that almost all staff at Volvo have taken the course and are thereby entitled to use the viewer.

The lightweight viewer is not only used at the research & development department, but also at manufacturing, preparation etc. To use the same viewer at all levels and departments at Volvo has been a strength according to Rosenqvist. Furthermore an overall goal for the IT department has been to reduce the number of different applications running on the company system. This strategy leads to a reduction in need for different educations and the number of possible support cases might be lower.

Security levels in the lightweight viewer does not exist, and Rosenqvist points out that it is not a needed property since everyone who is entitled to login to Teamcenter is supposed to be a part of the product development process and thereby give feedback on design. Concepts and very early projects are stored in a separate place in the PLM system, why they are not accessible for every employee through Teamcenter visualization:

[cars] *that are supposed to become real vehicles are accessible from the viewer.*

(Rosenqvist, 2012)

When it comes to efficiency in running the lightweight viewer, it is perceived as much faster than Catia V5. But it cannot run on any hardware since it demands more than a “standard” computer. For example is a graphic card with separate memory a requirement for the program to run smoothly enough. This requirement is important to keep in mind at Volvo since their IT strategy states that laptops should be used to a great extent. On the contrary there are no plans for integrating tablets into the product development process.

Available functions in Teamcenter Visualization that Volvo use are measurements, sectioning, move parts and make them transparent. It might even be possible to make text annotations but Volvo does not use that function.

If an employee at Volvo wants to give feedback to the design engineer responsible for that particular product, he or she can take snapshots from the viewer and insert it into a mail or a Powerpoint presentation and send it to the designer:

It is a viewer with one-way communication.

(Rosenqvist, 2012)

To filter out what you want to view, the user picks for example a car model from the “garage” in Teamcenter. Then makes a few choices such as model year, engine and number of doors. When clicking open, the 3D-model of that specific car appears in Teamcenter Visualization. Of course it is possible to only view separate components if you do not want to view a whole car. This way of configuring is perceived as very simple and user-friendly since the user does not need to know which components go into specific car models.

For Volvo it was important to have the ability for exact measurements, which was fulfilled by the use of JT-files that are numerical exact. It is just as exact as the Catia-models says Rosenqvist. The viewer does not handle kinematics or “soft” components such as cables that act in a natural way.

It is not possible for external suppliers to access 3D-models through Teamcenter Visualization, but some of the big suppliers have so called resident engineers at Volvo. Resident engineers work on site at Volvo and get the same access to the viewer as normal employees. If external suppliers needs CAD-data they can order it and get it sent to them.

The method of always using the lightweight viewer has been well accepted since all non-designer staff at Volvo can view the same models as the design engineers are able to view. Earlier employees went to meet the design engineer in person and asked him or her to visualize the 3D-model. Rosenqvist says that it is a big difference in today’s working methods.

Furthermore the viewer is used during conference meetings as an easy and relatively fast way of visualizing the problem at hand. A big advantage from having Teamcenter visualization installed on every employees computer is that everyone at a conference meeting can take the wheel and explain an idea by running the computer him- or herself. There is no need for someone with special training in running the visualization tool.

5.2.1.4 Advice

Rosenqvist points out three areas that needs extra attention when implementing a visualization tool like Teamcenter Visualization.

First of all, it might be preferable to choose CAD software and PLM software from the same vendor. If a decision to use two different suppliers you should be aware of that problems with integration will probably occur.

Secondly, the performance of the system should be researched and tested before new tools are introduced. Rosenqvist emphasizes not only is the performance of each workstation important, but also the capacity of the network needs to be taken into account. When all users are given the opportunity to look at 3D-models, that are sent through the network, there will be an increase in network traffic. When Volvo first introduced Teamcenter Visualization the time for loading a whole car would take a very long time.

As a final word of advice, Rosenqvist says that giving access only to those who had taken the introductory course in how to use the software, was a positive thing. It made the number of support cases fewer, but also worked as an eye-opener for employees that did not know what they could do with the viewer.

5.2.2 WHITE Architects

5.2.2.1 Background

White is an architectural firm founded in Gothenburg year 1951. Today White employs 678 individuals with 8 offices in Sweden, 3 offices in Denmark and project offices in London and Oslo (White, 2012). Areas coherent with environment, sustainable urban developments and health care are specialties recognized in the firm. Prominent constructions created by White are amongst others connected to the urban housings of Hammarby Sjöstad in Stockholm and a co-creation (White and Tengbom) of a new hospital in Solna (Nya Karolinska Solna, projected completion in 2017) (White, 2012).

The architectural processes of White is contingent to the notion of establishing needs that exist in conjunction to the project or building. By confirming or speculating on various ideas formulated or raised by any individual concerned or connected to the project, a high degree of involvement or commitment is established, creating viable and effective grounds for good architecture. The White innovation process (hereafter referred to as WIP) entails tools that help capture insight and creativity from people with different competence, the purpose being to as soon as possible establish direction and unite different instances accordingly. Working visually with models and ideas maintains a tangible realization. With this effort, coordination in the pursuit of valid solutions is easier. The WIP is also used in later stages of the project for detailed planning and design. (White, 2012)

Often, you need more than words, figures and blueprints to illustrate an idea. Visualizing can effectively and powerfully communicate a project before it is in place, thereby improving communication paths and aiding decision processes (White, 2012).

The focus of the interview held with environmental specialist Erik Eriksson and construction engineer Ola Lindblad lay with visual planning aspects of the company.

5.2.2.2 Coordination through a visual management tool

Visualizations are guided towards customers but are also a vital part in coordination efforts internally. Involved project partners are not all located in the same building, the projects are to a high extent a collaboration between several companies, providing different services (e.g. various construction engineering functions, electrical engineering functions etc.):

> *A big part* [of the visual aspects] *is coordination*.
>
> (Ola Lindblad, 2012)

Seeing if the project/building contains any inconsistencies before actual building is highly motivated in terms of cost and time efficiencies. Inconsistencies are in this case mainly coherent with different piping and electrical wiring interfering and clashing with other wiring, piping or structural entities (inconsistencies can moreover adhere to inadequate esthetics, e.g.

rough piping effecting room atmosphere in a negative way). Also, by visual coordination, separate construction elements can be put together in an effort to detect further structure based indecisions (or clashes) in an overall view.

Large projects entail vast amounts of building data. A visual and easy way of coordinating the different instances has according to the respondents enabled a deeper insight to building properties. Going back a few years, the case was another, reviews were to a large extent based on 2D drawings with the result being somewhat misguiding. Despite thorough evaluations, the real life constructions often contained clashes or other mismatches. Expertise and experience of the persons aiding the coordination could be said to have had a viable impact on end results.

The coordination efforts are today aided by a software (Autodesk Navisworks) that can integrate data from multiple sources (be it piping from one engineering instance, electrics from another and design features from a third), facilitating project review in 3D environments. The separate elements are uploaded to a portal from which a coordinator can assemble the entire building/project. This is useful for initial reviews but also for stages of production. By reviewing current state of project or construction works, checks adhering to schedule and specifics can be confirmed, or inconsistencies noted and changed:

Changes happen all the time.

(Erik Eriksson, 2012)

If a problem is noted in the integrated model, the software (Autodesk Navisworks) allows for demarcations in the form of shapes and text notations, a view or action point can then be saved in conjunction to this marking. A copy of the entire model and connected action points can be saved in a common industry format (.dwg), a free viewer can then be used by other connected parties in order to facilitate conveyance (The partner in this case, must however receive a pre-edited file of the object viewed). In this way, a continues feedback loop is possible between all internal/external partners and customers. Further possible functions of the Autodesk application/applications allows for color coding of different elements (also hide/show), adding of several entity properties (e.g. material, volume, etc.) and simple measurements.

The conceived idea of this approach to visualization in the specific business segment was that the tools provided an easy and effective recognition of possible problems and maintained an effective communication:

Everybody wants this [the tools discussed], *because it makes things easier.*

(Erik Eriksson, 2012)

5.2.3 SAAB

All information in this section is based on an interview with Michael Karlsson and Magnus Manke (both System Architects at SAAB Aeronautics) together with background facts about the company Saab found on their web page (www.saabgroup.com).

5.2.3.1 Background

Saab was founded in 1937 in order to deliver military aircrafts to the Swedish air force. The main part of the company works within the defense industry, but Saab also acts as a supplier of parts for civilian aircrafts. Furthermore Saab takes part in cooperative development programs, for example developing a new driver-less aircraft which is an international cooperation. When Saab started to supply parts for the Boeing 787 project the development switched from drawing designs on paper to using Model Based Design (MBD), which basically means designing without paper drawings.

5.2.3.2 CAD and PLM system

Saab is running Catia as CAD software and Enovia/VPM as PLM system, both from Dassault Systems. Many employees working in R&D at Saab are using either Catia to draw designs or use the tool DMU-navigator within Catia if they only need to view CAD models. Since Saab introduced MBD they have aimed for letting all part of the development process work with the same source of data. They also needed to broaden access including those using the paper drawings earlier.

As soon as CAD models are checked in to Enovia it will trigger a translation to a lightweight format. The translation is conducted every night and the models are ready to view the next day in the ERP system.

5.2.3.3 Lightweight 3D-models

In order to spread information about product data to all employees relying on paper drawings before, Saab developed a web interface which show lightweight models together with relevant information about the part or system of parts. Michael Karlsson is of the opinion that the user should not need to navigate through a tree structure in order to find notes or a captured view of the viewed product. Instead that information is easily accessible through different lists placed next to the visualization window. The web interface is mainly used in the production process since it supports preparation of assembly steps that are easily visualized together with a short describing text. One reason for using a web interface instead of the software itself is to prevent users from saving design drawings locally that might become obsolete if the design is changed.

The current visualization tool behind the web interface has been dismissed by the software provider and a new lightweight format is about to be introduced at Saab. But even though the software tool is changed, the web interface will still look the same.

When the implementation of a lightweight format started, Saab did set a goal that any relevant data should take no more than 10 seconds to load. This goal was set after the use of CAD software in production had been tested and loading times were perceived as too long.

5.2.3.4 Model Based Design

Switching from traditional product development with a paper based design drawing to a MBD approach without paper drawings is a major task. According to Karlsson it might work as an eye-opener when it comes to the need for visualization, because all staff that came in contact with paper drawings before now need to visualize the digital drawing. The introduction of MBD is also a big task for the IT department since the visualization tool needs to be easy enough to use. Karlsson explains that a good measurement for how good the implementation of lightweight visualization is, is to measure the time for a specific task using paper design drawings and comparing it to the same task using a visualized model of the same drawing. He continues to explain what he would do differently if he were to implement MBD again:

> *I would have […] created more demonstrations to show and give examples of how ones workday will change. […] I, as an employee, know what I am doing today, but I do not understand what I am supposed to do tomorrow.*
>
> (Karlsson, 2012)

When asked about how future system should work, both Karlsson and Manke said that all software (both lightweight viewers and CAD tools) should access the same database and use the same data. In that way no integrations or translations need to be in place and maintained. Furthermore a dynamic flow of information would be appreciated, which means for example that the user can decide at what level of exactness different geometries should be displayed. Also different modules of information could be selected by the user, for example he or she could choose to view CAD-data together with demands for production, demands for maintenance and so forth.

5.3 Findings/Recommendations for visualization requirements

This section aims at providing the reader with guiding criteria for a successful implementation of visualization functionality at Scania. General viewer requirements are presented in an effort to highlight common functionality that would aid most instances interviewed, specific needs are then mentioned in relation to specific roles.

5.3.1 General requirements

Paragraphs connected to this headline lists conceived functions that most instances of research and development would benefit from. It must be noted that the stated requirements entails a viewer being able to access and make use of all relevant databases used by Scania. Following requirements can be discussed and noted:

- **Status**, a clear indication of article status. Many respondents, regardless of responsibilities found it hard to conceive current status of articles connected to departments to which no regular interactions would occur. Having the ability to view an article with a clear indication of current status could mitigate one of the most frequent inconsistencies found in the conveyance of information. An easy way of conceiving this status would adhere to color coding schemes.

- **Conveyance of article design engineer**. This means the ability to conceive which function and design engineer the article has been produced by.
- **Article context**. Being able to effectively conceive investigated article in context to surrounding circumstances or assembly structure was held in great respect by virtually all participants. This means that even though some instances highlighted the need to view on a level coherent with single article studies, the majority saw the need for being able to produce views that incorporated system break down structures. The requirement is thus contingent to being able to view systems of articles, not just being able to view single articles. An aspect of it being easy to produce such a view was almost always a prerequisite mentioned however.
- **Measurement**. Almost every respondent indicated the need to relate to article size. Investigating single articles could in some instances create misconceptions in relative size. An easy way to solve such an issue would be the ability to measure article features.
- **Cross sectional views**. Being able to produce a cross sectional view was in many interviews noted as highly motivated. This could adhere to aspects of review and understanding.
- **Performance**. Providing a view of intended view object in a matter of reasonable time was motivated by everybody. Varying answers was however noted when deliberating what would suffice as quick loading time. *It has to be quick* or *not more than a few seconds* were some answers given. This must however be put in context to how large and intricate the loaded model is. When discussing the matter of performance with Michael Karlsson at SAAB Aeronautics, he stated that they measured the time for work being done with 3D visualization and compared it to previous work done with 2D paper drawings. According to Karlsson the time needs to be equal or less for 3D visualization work in order for it to be classified as good performance.
- **Being able to hide irrelevant articles**. This links to the notion of viewing the article in context. If a large assembly is viewed, the ability to hide articles not relevant for intended purposes is a must. This need was portrayed by many of the interviewed respondents.
- **Simplicity**. Many respondents concurred to a notion of simplicity. That is, retrieving the object must be easy. In reference, when asked to describe this sense of simplicity many respondents stated an ability to search for article number or receiving a predefined link to a larger decomposition of an assembly structure. In cases that meant knowing product structures (for example product coordinator), being able to simply click a button for alleged conditions set in SPECTRA was termed simple.

5.3.2 Specific function needs in relation to a viewer platform

In this section, specific needs adhering to role entailment follows. The needs are presented with potential tasks that each group expects from a viewer tool together with requirements that must be fulfilled by the viewer in order for the employee to conduct the expected task.

5.3.2.1 Manager role

Potentials:

- Review basic 3D data and give feedback to design engineers.
- Review simulation results.
- Collect and prepare basic 3D data in conveyance purposes, such as Powerpoint presentations.

Requirements:

- Ability for “redlining”, which is essentially a function that lets you draw on and mark elements represented.
- Ability to play film sequence of kinematics or view of other simulation results.
- Ability to export visualizations to various file formats.

5.3.2.2 Physical testing & Mechanic personnel R&D

Potentials:

- Early preparation for testing sessions.
- Rationalize the process of ordering parts for tests.
- Make it easier to collect mounting drawings.

Requirements:

- Ability to make text annotations connected to marked segments.
- Ability to produce article lists of elements represented in the viewer, separating prototype articles from manufactured ones.
- Ability to visualize mounting drawings, that is, a 3D or 2D representation of the assembly of complete or sub-systems solutions that is currently viewed.
- Ability to print specific element features in terms of drawings, assembly drawings or other useful visualizations of article features.

5.3.2.3 Design engineer

Potentials:

- Visualize large 3D models faster than Catia.

Requirements:

- Good performance.
- A need to specifically resemble functions and visual layout of Catia.

5.3.2.4 Product coordinator

Potential:

- Easily discover potential inconsistencies in product structures.

Requirements:

- Automatically display the corresponding 3D visualization from the selected product structure.

5.3.2.5 Production, purchase & aftermarket

Potential:

- Increased support for working methods.

Requirements:

- Access to relevant basic 3D data.

5.4 3D-viewing

This segment presents exemplified concept solutions to 3D-viewing. In addition, viewing software compatible with Catia is presented.

5.4.1 Dassault Systems

Since Scania has a close company relationship with Dassault Systems when it comes to CAD and PLM software, it has been natural for us to look into their products within the area of 3D viewing as well. We have studied three different applications, developed by Dassault Systems, which is used to display 3D-models of CAD data, 3DLive, 3DXML Player and 3DVIA Composer. The purpose of the latter one is to *create and update high quality product deliverables including documentation, technical illustrations, animations, and interactive 3D experiences* (Dassault Systems, 2012). This means that this software is mainly subject to use by aftermarket and especially in the creating of technical documentation of the vehicle. For this reason 3DVIA Composer acts in the areas of delimitations for this master thesis.

The “lightest” and simplest viewer software supplied by Dassault Systems is 3DXML Player, which only reads 3DXML-files and has no possibility to access a database like Enovia PLM. It is supplied free of charge and can be downloaded from Dassault Systems webpage. Moreover it has no capabilities to make exact measurements or sectioning of the 3D-model. Because of the lack of functionality and the fact that no database can be accessed, this application will not be analyzed further and will not be put forward as a possible solution for Scania.

The 3DLive application (see figure 5-1) is supposed mainly to be used during the development process. For example, it does have possibilities to access the Enovia PLM system directly and it is also possible to make measurements and sectioning with 3DLive. Furthermore the tool is capable of reading stand-alone 3D-models in Dassault’s own lightweight format, 3DXML. The software has a built in web interface, which makes it possible for the user to open 3D models through a web browser.

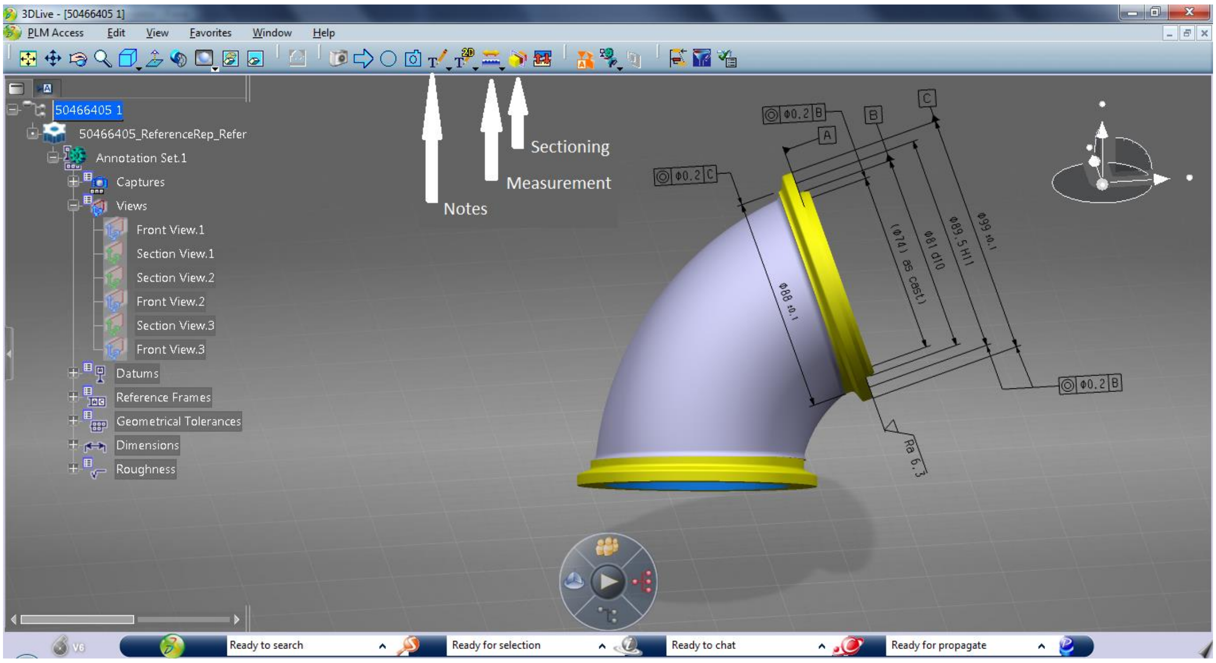


Figure 5-1 - Screenshot of 3DLive

5.4.2 Web interface

From our reference visit at Saab Aeronautics we got a clear view on how a viewer could be implemented in a web interface. Saab did put a viewer software as a visualization motor on a webpage several years ago and made the webpage accessible within the company instead of installing and maintaining a separate software on every employees computer. A similar implementation might be feasible at Scania. Such an interface could be highly customized to Scania's needs as a whole in general and to specific needs by different employees and in that way keep the same foundation of data but visualize it in the most efficient way. Moreover the web interface viewer which is connected to the PLM system directly will prohibit users from viewing old and outdated 3D models, since it can only visualize what is currently in the database. A consequence of only being able to view what is currently in the PLM system will require a network connection at all times.

A web interface could be created with different levels of functionality which would fit different employee groups' need of a 3D visualization tool. At the bottom level, with the least functionality, there might be an interface that only lets the user view single parts or prepared captured views of a system of parts. A basic toolbox with measurements and sectioning is implemented. On the next level the user also has the opportunity to add several parts together, with the use of a so called configurator (see section below), and view a system of parts. The toolbox would be extended by tools for adding notes and simple drawings of arrows and boxes.

5.4.3 Configurator

A configuration tool plays a central role in a more advanced viewer software, since it presents a way to decide what the visualization should display. This can be implemented in several different ways, for example if a whole truck is to be visualized, then a few global choices might be selected first to set the base of the truck. With these global selections set the remaining choices should only include available options. As the user goes along and makes choices, the 3D visualization should change accordingly. In order for a visualizing software to have a good configurator it needs to know the structure and rules of the product. For example what parts are not allowed to exist together on the same truck and if one feature has been chosen, what consequences does that choice have on the remaining part selection.

The configurator could also be implemented on a more basic level of viewing capabilities and let the user choose from predefined systems of parts together with predefined viewpoints and notes. A result would be an easy-to-use viewer suitable for infrequent use and with low thresholds for learning. An example of such a configurator is Tacton (see figure 5-2), which is used within Scania's sales department. When a customer is about to order a truck it is configured and specified with this tool.

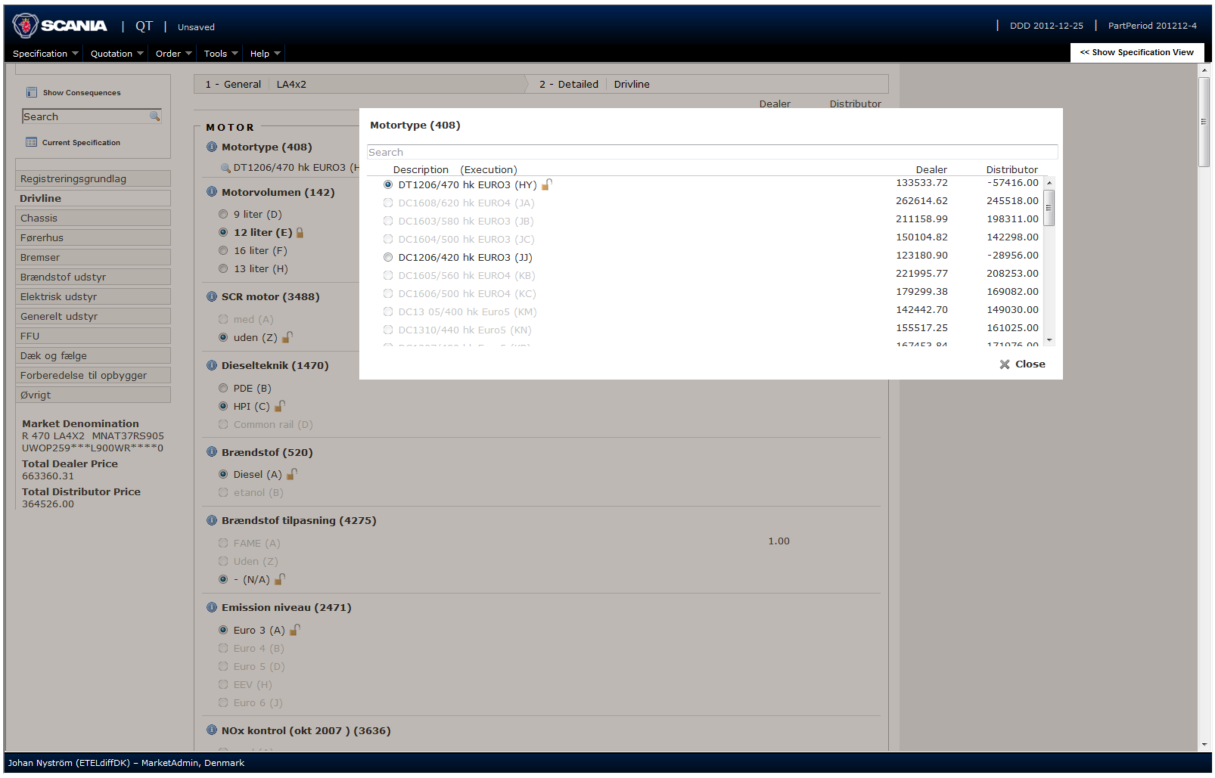


Figure 5-2 - Screenshot of Tacton used at Scania sales

5.4.4 OAS

Scania has an Object and Structure tool called OAS, which stores information about the product description and conditions for in what context specific parts can be used. The geometric position of the parts is also stored in OAS. This tool is used for filtering out what combination of parts is approved and where in space are they positioned. The output from such a filtering can be used to collect the corresponding 3D geometries and display them as a decomposition. Unfortunately is this not an automatic process, but needs to be done by hand. If an automated flow of collecting the corresponding 3D geometries to the filter at hand would be implemented, a quite advanced configurator together with visualization would be in place (see figure 5-3). This application that is exemplified in the figure is a future product and is not available today, but merely shows the potential areas of usage.

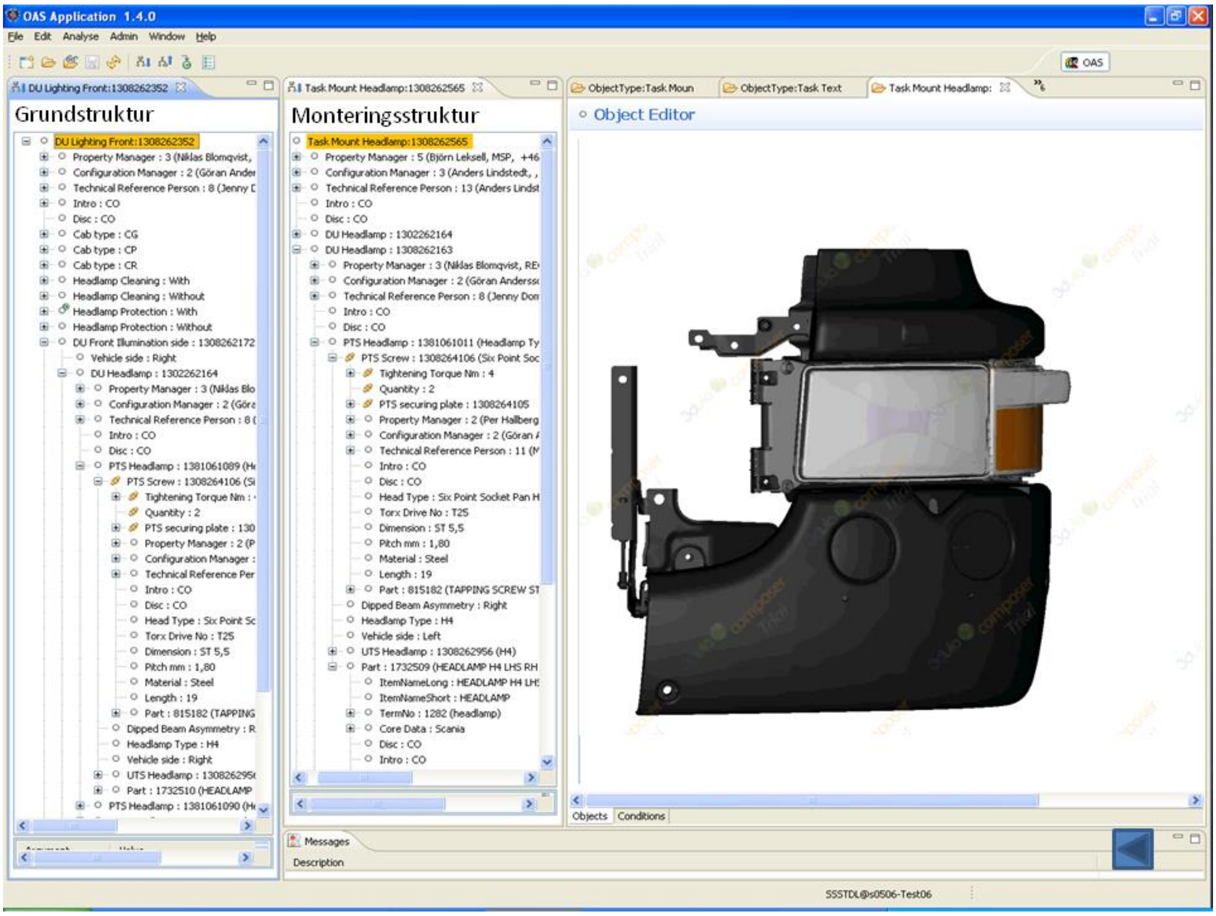


Figure 5-3 - Screenshot of the concept OAS with 3D visualization

6 Analysis & Discussion

Results are analyzed and discussed with respect to the theoretical framework. Possible solutions is examined and presented with advantages and disadvantages. The chapter also put the findings relative to the lean concepts, R&D factory incentives and further theoretical studies in order to make them more generalizable. The chapter is concluded with a segment on sustainability correlating to an increased use of 3D visualizations and a segment discussing the method approach utilized in this thesis.

6.1 3D-viewing at Scania

The needs for 3D visualization described in the result section can be arranged at three different levels; 1. Basic level with prepared breakdown structures, 2. Advanced level with configurator, 3. Advanced level with "Catia-like" design. The reason for having more than one visualization capability comes from the fundamental need of having an easy-to-use software for some groups of users that use the application infrequent and only have basic need of functionality.

6.1.1 Basic level with prepared breakdown structures

This level should be easy and intuitive to use with a simple interface (see figure 6-1) together with the most basic functionality such as measurements and cross sectioning. It should be implemented within a web interface for maximal customization. If a stand-alone software were to be used, either the functions of measurements would be lacking or there would be too many functions displayed with too many icons, making the user interface inefficient. With a customized web interface the number of functions and their placement can be specialized to fit the task at hand. Furthermore the web interface is easy to deploy and maintain, because the application is stored in a central place and not on each workstation. In the long run it could be preferable to have a web interface since the visualization motor could be replaced and the interface would still look the same.

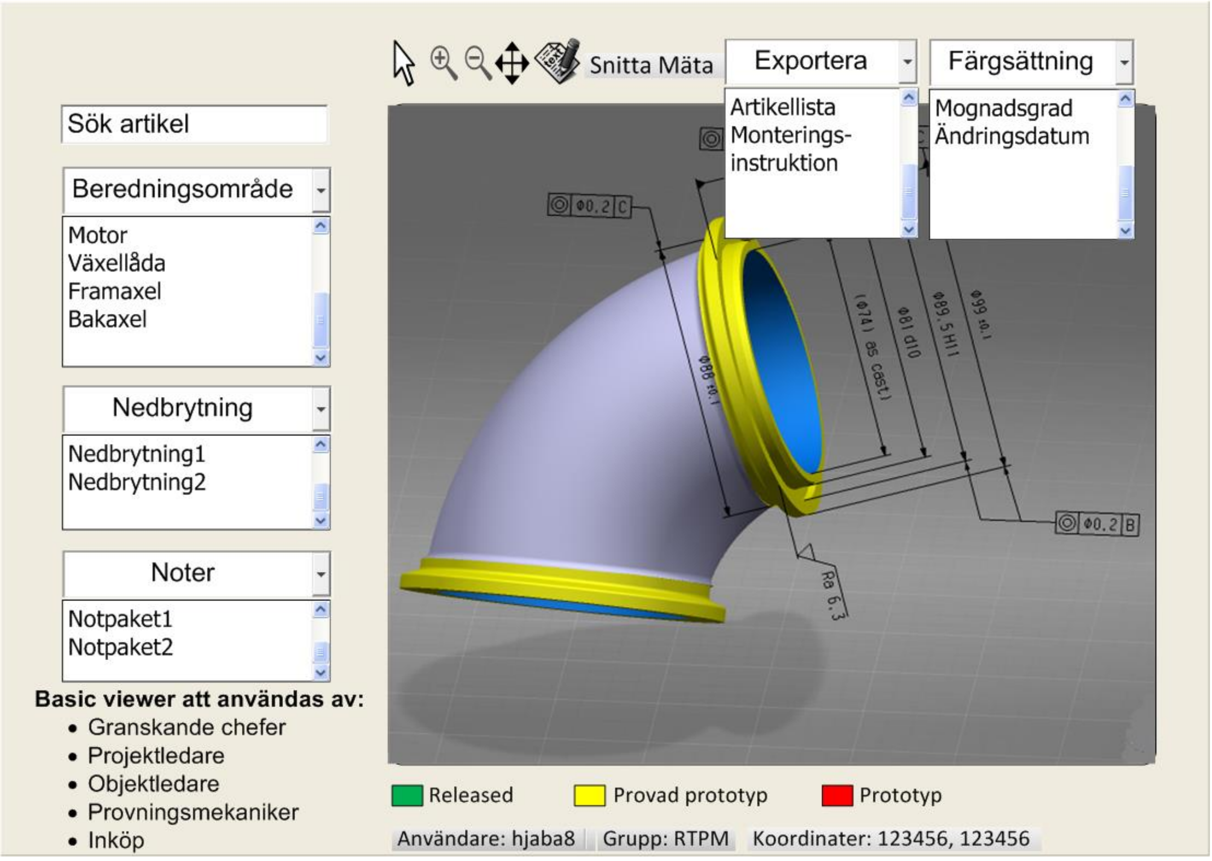


Figure 6-1 - Concept drawing of a basic level viewing tool (designed by the authors)

Within this level of visualization the process of finding relevant 3D models is made through linking directly to it in a email or on a webpage. When the link is opened the view can be altered either by dragging the model by the mouse or with predefined captured views. An option with predefined notes and labels can also be selected together with 3D tolerances and requirements. To refine the visualization, there should be an option to display the tree structure for the product in order for the user to hide unwanted parts or details.

At this level the requirements for different kinds of managers (project managers, design engineer managers, object managers) will be met. The need for simplicity is a crucial component for these groups since their work with a 3D viewer will not be frequent. Most of their need for visualization would be based on prepared 3D models which makes it suitable for the basic level. Furthermore the requirements of mechanic personnel and some parts of physical testing, within R&D, will also be fulfilled by this level and the respondents expressed that the visualization tool would not be used in the everyday work flow and therefore the tool had to be easy to use.

6.1.2 Advanced level with configurator

In the advanced level of visualization, unlike the basic level, a configurator should be in place. This level is more advanced since it demands from the user that he or she has knowledge about product structure and variants, but it is also more powerful with capabilities to customize the configuration and get the corresponding visualization immediately (see figure 6-2).

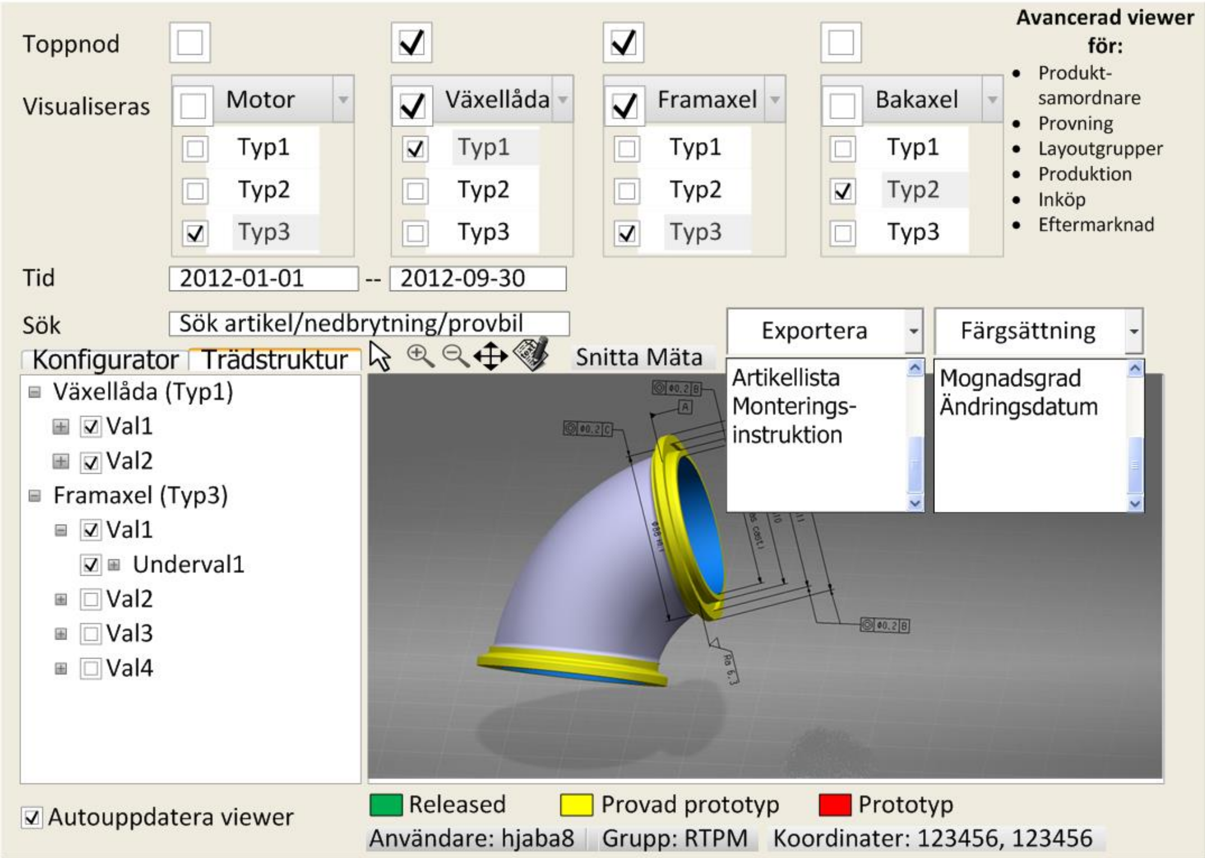


Figure 6-2 - Concept drawing of an advanced level viewing tool with configurator (designed by the authors)

The implementation of this advanced level 3D-viewer tool might be done in different ways. For example could Scania's current system for structure and variant control, OAS, be used as a configurator in order to filter what is to be viewed (see figure 6-3). This way would be desirable for employees already working within OAS, since their working situation would be the same but with an extra feature where the 3D visualization would be displayed.

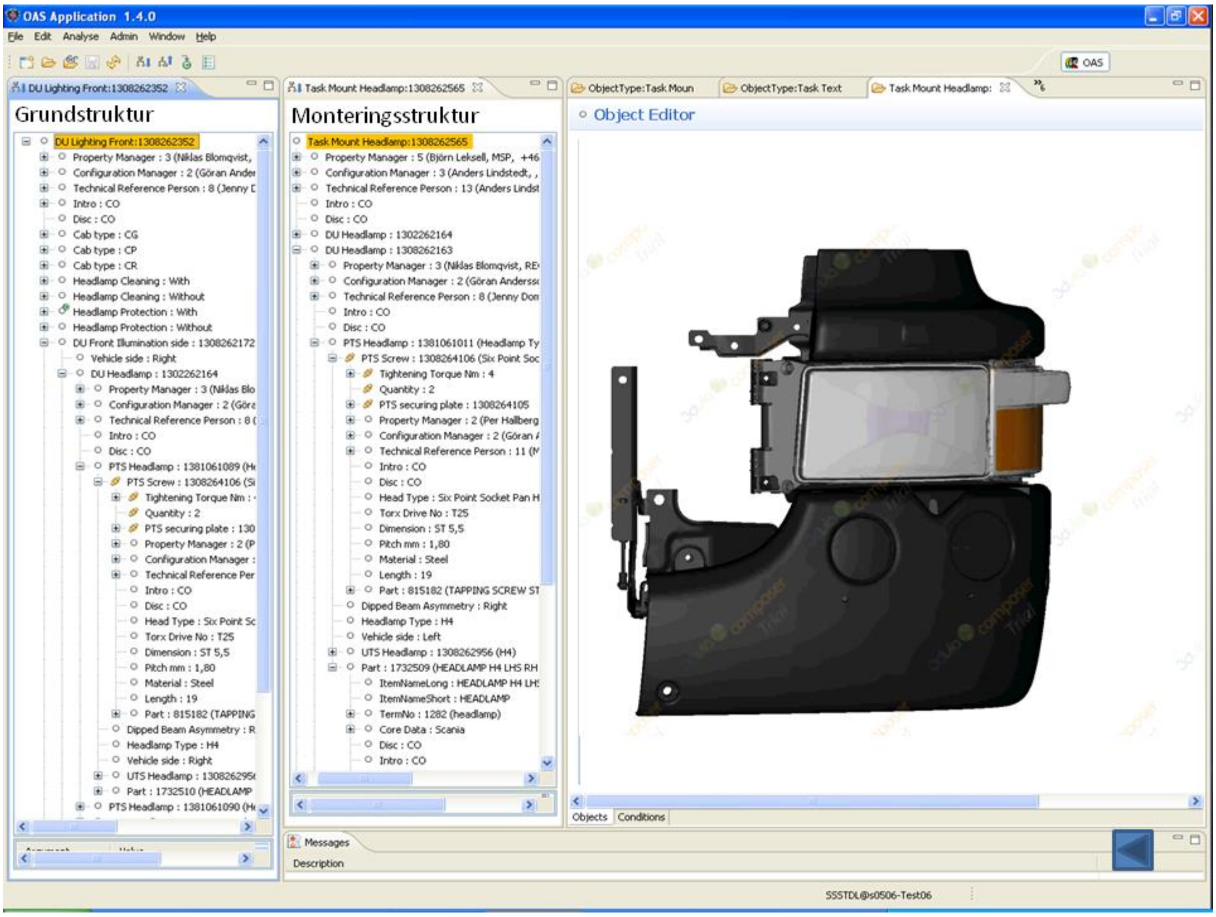


Figure 6-3 - Screenshot of the concept OAS with a 3D visualization

Another way could be to use a separate configurator, for example Tacton, to create an interface that is easier to use without knowledge about the product variants or structure. This solution demands for a connection between the configurator (Tacton) and the product structure (called KS at R&D Scania), which would then be connected to the CAD database for visualization possibilities. An example of Tacton together with a visualization is presented below (see figure 6-4).

Figure 6-4 - Screenshot of Tacton configurator with 3D visualization

At the R&D department, product coordinator and some physical testing groups have requirements that would fit into this level of visualization. Their work already require knowledge about product structure and variants, which will be user defined at this level. Since product coordinators are working with the OAS software today, the implementation of viewer capabilities within that application could be seen as a natural path ahead. For the three user groups at the borderline of our master thesis, production, purchase and aftermarket, this level of visualization would fulfill most of their requirements.

6.1.3 Advanced level with “Catia-like” design

From interviews with design engineers, it can be concluded that the current CAD software, Catia, is demanding when it comes to performance and loading times. As design engineers have meetings to discuss different designs, interfaces or problems, it would be appropriate to have a faster visualization tool with less functionality than Catia.

Within the delimitations for this master thesis we have tested a visualizations tool supplied by Dassault Systems, called 3DLive (see figure 6-5). Since the software has capability of reading both stand-alone 3DXML files and access an Enovia database directly, it is versatile and suitable for this advanced level of 3D visualization. One could argue that 3DLive is situated close to the Catia software in terms of functionality and visualization. The tree structure looks the same as in Catia and the overall design is very much similar to the new version of Catia (V6). These similarities and the rich flavor of functionality in the CAD field makes this level of visualization suitable for design engineers to use during group meetings, when visualization of the 3D model is the central part and not modifying it.

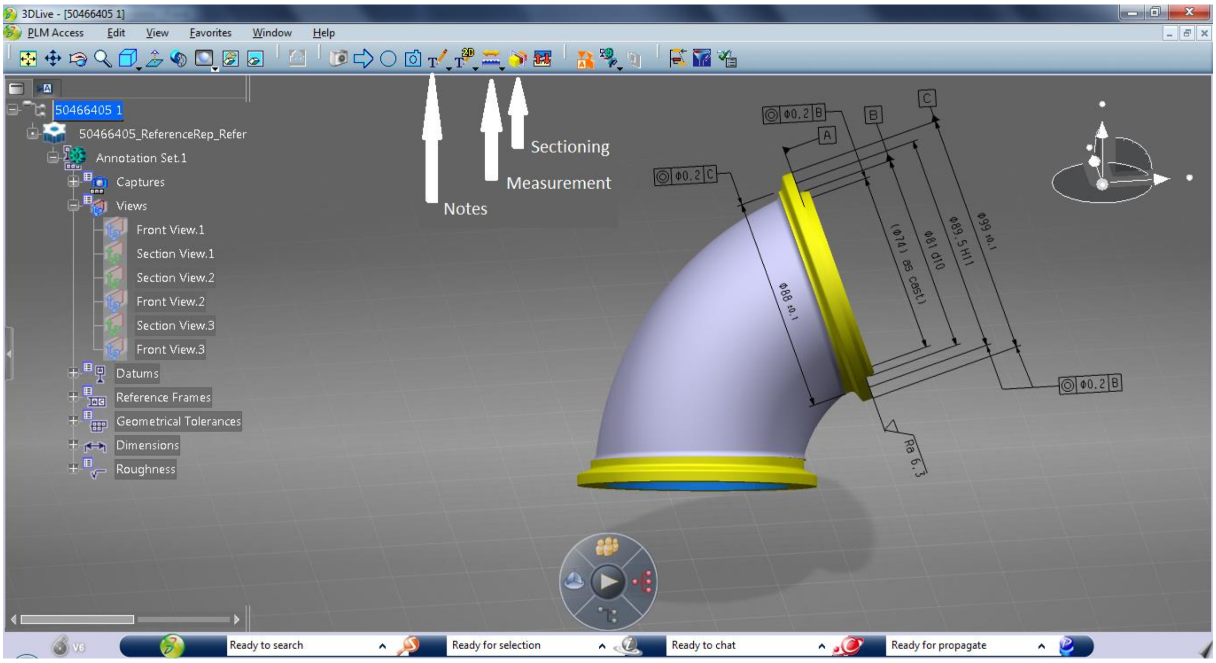


Figure 6-5 - Screenshot of 3DLive

At the moment Scania uses Enovia/VPM V5 R19, which has only limited support for 3DLive when it comes to functionality such as measurements and cross sectioning. If one of the next revisions, R20 or R21, is implemented that functionality would be enabled. Another advantage that comes along with using 3DLive together with a higher revision of Enovia/VPM is the performance of visualization. Since 3DLive is designed to visualize 3D models saved in later versions of Enovia/VPM, it will take less time to load models that users want to visualize if 3Dlive is matched up with R20 or later.

6.2 Possibilities, Advantages and Disadvantages with using visualization at different levels

The structure of presenting requirements at different levels has the possibility to adapt solutions for unique working flows and to benefit from employees unique competence. Together with carefully thinking about adapting the visualization tool to the development process, the solution will comply to Morgan and Liker's *principles for choosing tools and technology* (2006).

For being called the basic level of visualization, the proposed concept might be perceived as quite advanced if you are familiar to other lightweight products on the market, such as 3DXML Player. The reason products like that are not presented as a possible solution it because their lack of basic functionality (measurements, cross sectioning) which is needed at Scania. Furthermore are the really basic products totally dependent on stand-alone files which ought to be created by someone, and thereby the user cannot find a visualization through Enovia.

At the second level of visualization, either a customized web interface could be developed or a visualization feature in OAS could be pursued. The two different paths are not quite equivalent to each other, since the OAS software demands a lot from the user in terms of structure and variants but a web interface is supposed to be more generalized and easier to use without knowledge about product structures.

The advantages of having viewing solutions at different requirement levels are:

- It will give the user a more customized overview together with tools to zoom and filter in order to dig deeper into the visualization which is suited to the work at hand. This is part of the criteria for good visualization according to Shneiderman (1998).
- Each level will be flexible with the ability to change accordingly when requirements and needs change.
- The start-up threshold for using 3D visualization tool should be smaller if the levels are designed according to the work flow and does not contain unnecessary tools and graphics.

The disadvantages of having viewing solutions at different requirement levels are:

- If the requirements are not fully investigated, the risk of users need to use several levels in their work might appear.
- More resources for education and support might be needed if employees switch between levels of visualization often. On the other hand the total amount of support errands might decrease if the levels are adjusted correctly to the different tasks.
- The levels that contain a web interface must be created in-house and cannot be bought off the shelf. This might be more expensive than rolling out a stand-alone visualization software by itself.

In our (the authors) opinion, the advantages outweighs the disadvantages. By employing levels of visualization the increase in value adding activity enhancement will be the greatest.

6.3 Findings from interviews and reference visits in relation to presented theory

The idea of the Lean product development domain adheres of how the general idea of Lean thinking can be applied to the field of product development. The findings of the investigative studies of Scania reveal a dynamic very similar to Lean philosophies. As noted in earlier sections, a Lean philosophy seems to include the notion of technology being primarily a function that needs to be adapted to fit process, enabling support rather than drive. Being a source for enhancement is another notation emphasized. In conjunction, Scania highlights technology as being a source for assuring quality and securing ‘right from me’. Dynamics of allowing additional employees other than design engineers the ability to gain access to visualized 3D product properties will in this section be held in regards to findings from both the internal interviews and the reference visits.

Reflecting on perceived annotations conceived during interviews revealed function dynamics very dependent on each other. In relation to the texts provided by Browning (1998) and Robertson and Allen (1993), findings of the interviews include an overall consensus of 3D-visualizations providing deeper insight in integration issues. As statistical findings presented by Toriya (2008) indicate, Scania does as well show signs of an increased use of computer aided engineering software. In accordance, several instances without specific linkages (that is, no software being able to use such visualizations) of Scania would benefit from the increased integration such a viewer tool would provide.

One aspect of viewer rationalizations at Volvo was depicted as a higher tendency for well founded basic data. By effectively distributing design properties, making them assessable to everybody, conversations could to a high degree be based on relevant features, creating better grounds for an effective information conveyance. One additional described effect at Volvo was the notion of design engineers being less interrupted with request of supplying relevant design data to functions in need.

Aspects of visualizations adhering to the construction of buildings were in focus in the interview with White architects. The picture portrayed an architectural industry heavily involved with visual aids. One aspect of this depended on intrinsic and visually pleasing representations of desired project outcome for marketing purposes, another depended on upholding effective grounds for development and management efforts. A highlighted aspect at White was thus the level of coordination the visual management tool provided. The interview revealed project circumstances that involved several functions associated with several different areas of expertise.

At SAAB Aeronautics, MBD allowed enhancements in the sense that the focus could be allocated to one format instead of two. A viewer format was in this sense a natural response to the methods and systems employed.

In industrial circumstances that imply intrinsic and effect full CAD renderings during initial design engineering stages, best in class performers are 55% more likely to employ downstream capabilities (Aberdeen Group, 2006). In accordance, part of this thesis has been focused on how viewer formats aid process and method, possibly mitigating inconsistencies in R&D functions specifically not coherent with CAD tools. The findings at Scania showed very positive response. Many of the functions interviewed found themselves unable to effectively make use of visualization that would in fact enhance daily undertakings. Managers reflected on the knowledge and experience share that would be made more tangible as a common point of reference existed and were made accessible. Physical testing groups and R&D mechanics reflected on the early undertakings that could be achieved as specific environmental factors were known. People from purchasing saw potential in increasing overall understanding and possibly being able to produce their own basic data from sources already existing. Aftermarket saw the need to effectively commit to design at earlier stages than currently and did as physical testing groups see potential for providing better grounds for earlier undertakings. Design engineers reflected on the enhanced level of communication the tool could deliver. Product coordinators saw a possible tool as an easier way of committing to daily undertakings and to a higher extent mitigating inconsistencies in product structure. Functions coherent with production saw the need to more effectively conceive basic data from various databases and R&D units.

In reference to Lean and Scania process philosophies, the tool could provide a platform that would aid process imperatives. Specifically pointing towards a few of these aspects:

- Project frontloading schemes in terms of:
  - Possibly allowing further insight in project and design properties.
- Leveled flow schemes in terms of:
  - Possibly providing a means to decrease momentum loss.
- Competence increase in terms of:
  - Possibly providing a more manageable way of interpreting design elements.
- Waste elimination in terms of:
  - Possibly providing a communication platform suited for enhancing knowledge conveyance, possibly mitigating loss of knowledge.
- Securing right from me:
  - Possibly allowing functions with the ability to allocate inconsistencies to a higher degree than before.

6.4 Aspects of sustainability in conjunction to an increased use of 3D visualizations

Iterative development processes of Scania today are consistent with multifaceted work formats. Effectively conceiving findings and knowledge allocated within different functions is vital when securing a successful product or service. Providing sufficient insight to front loading schemes is key in order to mitigate cost in development processes (Johanneson et al., 2004). In conjunction, relevant findings points to the notion that 3D data can be visualized in the whole process chain, being less abstract than a conventional 2D based drawing. This allows further untrained CAD staff with the possibility to interrogate design, while being able to refine cooperation. In terms of sustainability, economic set-backs can be mitigated by highlighting this notion. As design in initial stages is enriched with knowledge, probable retakes are decreased and late design changes diminished. In terms of specific environmental impact, a decrease in prototypes built (due to rework) could be said to be less likely to occur. In conjunction, investigated aspects of employing simulation driven product development can be mentioned. Johansson and Sätterman (2012) presents findings that highlights environmental aspects as one incentive to using virtual methods and mention Jaguar Land Rover as a company that actively employs computers to diminish the effects that the product development process has on the environment. The reduction of hardware prototypes are one of the key elements listed.

6.5 Drawbacks and strengths of utilized research method

Exactly knowing what factors the undertaken thesis entails, have been hard to foresee. The belief however, is that utilized methods have proven fruitful in revealing information dynamics and possible effects of implementing 3D viewing software.

The qualitative semi-structured interviews revealed needs and exposed conceivable improvements. One noted drawback however, was the fact that interviewed subjects' knowledge and experience with 3D formats varied significantly. This meant it was sometimes hard to effectively draw conclusions of what the gain of an increased use of 3D renderings would imply. On the other hand, the approach employed was well suited for illustrating and highlighting the lack of such a tool in current work formats and illuminating new ways to use already existing 3D data. The belief is thus that the method utilized in the interviews was the best suited.

Seeing as every individual company maintains different dynamics, specifically applying theory conceived through literature has at times been hard. In combination with reference visits and observations however, applicable patterns have been noted and general conclusions taken. It is also important to note that this thesis presents an extensive study of visualization techniques and connected review techniques as well as presenting notions of information dependencies and process improvement ideas. The intent has been to leave no stone unturned. In retrospect however, it can be said aspects of the thesis has suffered from this. The extensive commitment to underlining every conceivable aspects of the discussed subject means that some aspects inevitably has suffered. This includes a thorough consideration of what functions would gain the most from a more comprehensive use of 3D-visualisations. Elaborating, a probable pilot project entailing an extensive use of a 3D-viewing software could have been preferable. This could have been done by documenting normal circumstances of a certain function (e.g. physical testing), and then comparing these circumstances to a pilot project were a 3D-viewer (e.g. Dassault's 3DLive) were used. This would have pinpointed rationalizations. A drawback of such an approach however would have been the vast amount of time that would have been allocated accordingly. The strength of the employed method is the above mentioned criteria, that is, it has allowed a vast consideration of many facets surrounding digital design data.

7 Conclusions & Future work

This chapter will include outputs to the research questions followed by general conclusions. In the end recommendations and future work will be presented.

7.1 Result of the research questions

RQ1: In what way does the flow of information improve with the use of a 3D-viewer?

RQ2: In what ways would an implementation of a 3D-viewer imply that potential problems in product development were discovered earlier? How does it affect work processes, for example preparation work?

RQ3: What needs must be satisfied by the 3D-viewer software? Are there changes to the product development process that needs to be made in order for an implementation of a 3D-viewer to be possible?

7.1.1 Output to research question 1

From the result section of the thesis it is clear that certain groups of employees perceives their work as more difficult than necessary. They express a feeling of not being part in the flow of information. The reason for being excluded from the information flow is not lack of information to spread, but lack of the tools for spreading it. All information that is needed exists, even though sometimes in different places, and could be accessible with the right kind of tools. A smart 3D-viewer that is designed to fit the needs and requirements at different user levels at Scania would definitely extend the flow of information to include more employees, increasing the ability for cross-functional integration. The tool would in this case enhance several work efforts.

7.1.2 Output to research question 2

Together with the output of research question 1, one could argue that when the flow of information is extended to include more employees, that would lead to earlier discoveries in the product development process. When more eyes are looking at the same 3D model and taking their personal experience and knowledge into account, that would further enhance the feedback and thus make the process more efficient.

Work processes are influenced by the implementation of a 3D visualization tool in terms of an easier knowledge conveyance. This adheres to the front loading schemes of Scania and Lean philosophies, which could possibly provide cost and rework mitigation.

7.1.3 Output to research question 3

From the interviews conducted a list of common needs and requirements has been compiled (see section 5, *Viewer requirements*).

No changes to the product development process, that is required in order for a visualization tool to be implemented, have been identified. On the contrary, all databases needed for visualizing 3D models are already in place. It is a matter of connecting different data sources and make them work together.

7.2 General conclusions

The main conclusions are discussed and presented. Since the master thesis has a strong company connection the conclusions will be given from a Scania perspective although most of them could be applicable to a more general viewpoint as well.

7.2.1 Flow of information

If the flow of information is disrupted or not working well it will have other consequences than just lack of data at the recipient part. When discussing Research and Development at Scania, key principles as *right from me*, *elimination of waste* and *normal situation – flow orientation* often comes up. The combination of these principles and respondents answers, gives the picture of problems with the flow of information at Scania. Employees are supposed to impose their knowledge and experience on information and send feedback on to other employees are not able to do so when 3D visualization arrive too late or not at all. The result is that the employee cannot deliver *right from me* and cannot live up to the standards set for a *normal situation – flow control*, which leads to an increase in waste.

One solution to the information flow problem could be an implementation of 3D visualizations that should reach virtually anyone needing it at Scania. Since the needs and requirements of 3D visualizations are different from different groups at Scania, it would be desirable to implement a solution with several levels of visualizations. This would imply that only the information needed by the user would be displayed, but also that the complexity of the tool would be held at a minimum and it would probably be seen as easy to use.

7.2.2 Small and early instead of big and late

In order for the product development process to function with a parallel flow where several employees contributes with their knowledge to one single product, small iterations that spread information for reviewing is necessary. These iterations need to come early and be relatively small. Small iteration time is created by working methods, but the ability to spread information needs software tools as well. It is important to note that iterations and spreading information is related in a way that making iterations with the objective to review and receive feedback on current status is only possible if the flow of information work correctly.

7.2.3 Single data source

In product development process that involves several different groups of people working with separate parts that go together in a system, it is important to have clear interfaces and rules for how the design process is to take place. If, for some reason, the data being produced would be stored in several places, it could easily lead to misconceptions because the information is outdated or missing. In order to avoid such problems, a single data source should be used and kept up to date.

7.3 Recommendations to Scania

Here, recommendations guided towards Scania is listed.

7.3.1 Highlight enhancement of key activity

As product development include several functions, with several areas of expertise, means that different functions are contingent to key activities of expertise. Tools that aid efficiency should provide the level of sophistication intended function needs. Effects of a viewer tool should include a rationalization of work efforts not an increase in tasks conditional to new methods applied in utilizing the tool. In accordance, this thesis present findings that indicate three levels present at Scania. The belief is thus that an implementation of aiding visualizations must consider levels of implementation. This being said, there is no reason to believe that one single solution (created for right purposes) can't suffice all three levels.

7.3.2 Investigate all requirements and needs of 3D visualizations from all departments at Scania

In this thesis the needs allocated within R&D have been studied. To fully comprehend needs and potential enhancement effects of an implemented viewer, we (the authors) suggest a complete study of the entire organization of Scania.

7.3.3 Follow up methods for publishing 3D CAD data

If there is no 3D CAD data stored in the database, no visualization of the data can be produced. This is why it is important to ensure that design engineers among others always tries to publish all their work as soon as possible. No matter how early in the product development process, it is still important to let others in on your work and give others a chance to contribute for a better design. In an early stage of implementing 3D visualization on a broad level this might be a problem, since not everything will be visualized. On the other hand, giving more people the opportunity to "consume" 3D models would probably lead to a great demand for correct and early published 3D CAD data. Design engineers will become more aware of the advantage of publishing early.

7.3.4 Strive for single data source

Since Scania is working a lot with shortening lead times and making the product development process more efficient, it would be a great drawback if employees worked with outdated information. It would be an even bigger problem if work was conducted at several different levels in parallel, since the chain of information would be even more complex. If a change was to be made at one end of the chain it would then take time and effort to make sure the updated information spread to all parts of the chain. To reduce the risk of working with outdated material and to make the process run smoothly it is recommended to strive for the use of a single data source.

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Appendix A – Interview outline

Since the interviews were conducted with employees working with very different things, it would have been difficult to follow a strict scheme posing the same questions to every person interviewed. Instead more open questions were asked and discussion about the topic was encouraged. The outline of an interview was to first understand what the employee was working with and try to put that work into a 3D visualization context. An important part was to clarify which people the interviewed person was cooperating with and what information was shared between them. Furthermore examples of how a 3D visualization tool could become useful were put forward and discussed. Interviews often ended with a brainstorming session where possible requirements that needed to be met by the tool were analyzed.

Appendix B – Interviewed subjects

The table below presents the amount of respondents and respondent belonging. In addition to listed categories, employees with system and process specific knowledge have been interviewed with the intent to enlighten and educate the authors (of this thesis), these are in the table listed in the category *other*.

Category	**Number of individuals interviewed**
Research and Development	
Physical testing:	
Manager role	4
Mechanic personnel	2
Test engineer	4
Design engineer	4
Product coordinator	2
Manager role	11
Other	15
Production	8
Purchase department	2
Afermarket	2