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Benefits of Simulation Models in Product Data Management Systems

A pilot study with cooling system simulation models

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Product and process development

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ABSTRACT

The product development today handles increasingly complex products and to be able to compete on the current market companies need an effective PLM/PDM system to manage the lifecycle, models, and data connected to their products. Three of the factors for success in product development are time, cost, and quality. Which need to be supported by the processes and tool used in a project. Product development often uses both physical and analytical prototypes. The analytical method of simulation is an important element in product development that has started to shift from being a validation and verification tool at the last stages in the development process to be more included in the early stages. Simulation models often generate a big amount of data and because of this, the storing and management of them can be troublesome. Therefore, there is a need to have closer integration between design and simulation. The purpose of the thesis is to do an inquiry about what a PLM system contributes to in a company regarding their product development and why and how simulation models can be connected to the company's PDM system.

The methods used during the study were literature reviews, interviews, workshops, and a survey. The results show that in the literature the benefits of using a PLM and PDM system are connected to the factors for a successful product development which are time, quality and cost. While the employees think traceability, reuse of data and storing is the most important benefits. Simulation models are beneficial to the product development process and should, therefore, be stored in a way that there is a connection between the simulation model and the design model. For the employees, the highest-ranking benefits with adding simulation models to the system are traceability, reuse of simulation models and control over simulation models. A manual for how the simulation engineer can utilize the system and add simulation models to it are presented.

Keywords: *Product lifecycle management, Product data management, Product development, Simulation*

SAMMANFATTNING

Företag som arbetar med produktutveckling hanterar alltmer komplicerade produkter och för att kunna konkurrera på den nuvarande marknaden behöver företag ett effektivt PLM / PDM-system för att hantera produktens livscykel, modeller och data som är kopplade till den. Tre av faktorerna för framgång i produktutveckling är tid, kostnad och kvalitet. Vilket behöver stödjas av de processer och verktyg som används i ett projekt. Produktutveckling använder ofta både fysiska och analytiska prototyper. Analysmetoden för simulering är ett viktigt inslag i produktutveckling som har börjat skifta från att vara ett validerings- och verifieringsverktyg i de sista stadierna i utvecklingsprocessen för att inkluderas i de tidiga stadierna. Simuleringsmodeller genererar ofta en stor mängd data och på grund av detta kan lagring och hantering av dem vara besvärliga. Därför finns det behov av en närmare integration mellan design och simulering. Syftet med avhandlingen är att göra en förfrågan om vad ett PLM-system bidrar till i ett företag vad gäller produktutveckling och varför de bör kopplas samt hur simuleringsmodeller kan kopplas till företagets PDM-system.

De metoder som användes under studien var litteraturrecensioner, intervjuer, workshops och en enkätundersökning. Resultaten visar att i litteraturen är fördelarna med att använda ett PLM- och PDM-system kopplade till faktorerna för en framgångsrik produktutveckling som är tid, kvalitet och kostnad. Medan anställda tror att spårbarhet är återanvändning av data och lagring är de viktigaste fördelarna. Simuleringsmodeller är fördelaktiga för organisationens produktutvecklingsprocess och bör därför lagras så att det finns en koppling mellan simuleringsmodellen och designmodellen. För de anställda är de högsta fördelarna med att lägga till simuleringsmodeller till systemet spårbarhet, återanvändning av simuleringsmodeller och kontroll över simuleringsmodeller. En manual för hur simuleringsingenjören kan använda systemet och lägga till simuleringsmodeller till det presenteras.

Nyckelord: *Livscykelhantering, Produktdatahantering, Produktutveckling, Simulering*

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ABBREVIATIONS

CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAx	Computer Aided x (CAD/CAE)
MDD	Model Driven Development
NPD	New Product Development
PDM	Product Data Management
PLM	Product Lifecycle Management
SDD	Simulation Driven Design
SDM	Simulation Data Management
SLM	Simulation Lifecycle Management
Windchill	PLM/PDM software that the company is implementing
GT-Suite	Simulation software

Context: In this context when referring to a PLM system it regards the use of a software system.

1 INTRODUCTION

This chapter introduces the problem occurring at the company and presents background information about the research subject of Product life cycle management (PLM) and Product Data management (PDM). This chapter also presents the aim and limitations of the study.

Product lifecycle management (PLM) has increased in popularity due to its efficiency in improving manufacturing processes and management of the data generated in the lifecycle of a product (Enríquez, Sánchez-Begines, Domínguez-Mayo, García-García, & Escalona, 2019). According to Batenburg, Helms, and Versendal (2005), the publications about PLM are mostly from software sellers and business analysis and there is a need for more scientific literature. PLM has the ability to improve the operational effectiveness of a company and will, therefore, become more of an important benefit for companies in the current market (Constantin & Staretu, 2016). The PLM system is also considered to be a need in the current market as it aids product development while it reduces cost (Liu, Maletz, Zeng, & Brisson, 2009). PLM connects different information systems from the various phases of a product's lifecycle and mirrors the physical product (Grieves & Tanniru, 2008). The information systems consist of computer-aided design (CAD) applications, text applications, visualization applications, product data management (PDM) and simulation applications (Stark, 2016). PLM is based upon PDM, process management and engineering project management (Gmelin & Seuring, 2014). PDM has emerged as a necessity due to the increased size of complex data handled by manufacturing companies (Obank, Leany, & Roberts, 1995). The competitiveness of a company improves with effective data and knowledge sharing (Feng, Cui, Wang, & Yu, 2009).

More companies have started to use simulation in product development in general, it is no longer reserved for certain areas (Karlberg, Löfstrand, Sandberg, & Lundin, 2013) Simulation is used to help design complex systems and it has commonly been used to eliminate design choices as early in the development process as possible to decrease the design cost (Mefteh, 2018). The possibilities of simulation have been somewhat underestimated, and more and more companies must invest in simulation because of competitive pressure (Thomke, 1998). Simulation is also becoming a bigger part of the development process of the case company. Because of this, a need for saving simulation models in the company's PLM system is an important factor to consider. This enables them to track models, share information in a global world, speed up the development process and ensure quality. The company is at the beginning of changing their PLM system supplier and wants to be able to connect their simulation models to the system. This will further enable the shift to using CAD/computer-aided engineering (CAE) driven development in the company. The company is moving from an old PLM/PDM software to Windchill (Lindmark, 2019). The focus of the report is what a PLM system contributes to a company regarding their product development and simulation models in connection to the company's PDM system.

1.1 Problem formulation

The company is implementing a new PLM/PDM system to replace an old system. In the system used before, the simulation models were not saved to the shared system; they were handled by the simulation engineer only and saved locally. With the new system implementation, the simulation engineer wants to be able to save simulation models connected to each product and to share other simulation documents that are relevant for the product. The company wants to know if there are any benefit with using a PLM system for the product development and if when implementing it, there is any reason to try to connect their simulation models to the system for the benefit of the simulation engineers and the storage of the simulation models so they are easier to access. Also, what factors are important to consider from the employees' perspective when using the system and adding simulation models to it.

1.2 Aim and Research questions

The purpose of the thesis is to identify what a PLM system contributes to a company regarding their product development and why simulation models should be connected to the company's PDM system. How the engineer can work in the system and which factors that are important to consider when adding simulation models to a PLM/PDM system. The goals of the study are to identify the six most important benefits with using a PLM/PDM system and the six most important benefits with adding simulation models to the system. The factors will be considered from both a literature perspective and an employee perspective. Six has been chosen to be able to choose three factors from each perspective and give a hint at what are important when using these systems. The employee perspective is important to consider because to be able to investigate if the need for adding simulation models to the system is a need for the employees in the company. Then an investigation will be done to see if it is possible to add simulation models to the system. The goal with the investigation is to do a manual that introduces a way of adding simulation models to the system, this will be based on the investigation done during the workshop. The manual will also consider the benefit factors gathered from the simulation engineers as they are the end users of the manual. The research questions this thesis is trying to answer are:

1. What are the benefits of using a PLM and PDM system for a company's product development?

2. Why should simulation models be connected to the PDM system?

3. Can simulation models be added to the PDM system and what factors are important to consider?

1.3 Project limitations

The study will only consider PLM and the subcategory PDM, not process management and engineering project management. The employees are mostly accustomed to the PDM feature in the old system. The limitations for the project will be that the only simulation models considered in the workshops are of the cooling system, the connection between the simulation tool GT-Suite and the PDM tool in the Windchill software are the focus. GT-Suite is used by the company to do multi physics system simulation. But the literature and interviews will consider simulation in a more general product development aspect. The empirical part will be done within the company. The factors for the first two questions have been limited to six as to make it easier for the company to discover what are the most important to focus on from both company and employee perspective. The third question will do a manual that consider the three most important factors when implementing simulation models in the new system. The manual is only an introduction to how the company can add the models to the system. The manual is a practical verification of the last question. The study will not consider how big these benefits are to the company only that there may be benefits, since the new system is not implemented in the company yet and the time for this thesis will come to an end before the implementation.

2 RESEARCH METHOD

This chapter presents the research methods used during the thesis. Research is the search for knowledge to develop the already existing knowledge base through objective and systematic methods. The purpose of the research is to explore research questions and locate the answers to them, to reach new insight (Kothari, 2004).

Methods used for collecting data have been literature reviews, interviews, survey and participation in workshops. The research had been made to gain a deeper understanding of the problem by using secondary data from research publications and primary data through interviews, observations, and workshops. The data collection has been both qualitative and quantitative in order to gain a better understanding of a not yet established system, as qualitative methods give depth and quantitative give breadth (Mujis, 2004). A research design supports the gathering of data that is needed to solve the formulated problem and should suit the purpose of the study (Blomkvist & Hallin, 2015). The research design has been used to try to answer the research questions with the appropriate methods. The research design includes a literature review to get information about methods and the research aim and problem. The workshops were attended to be able to learn the new software that the company is implementing. To obtain answers and background for the research questions, qualitative interviews were done within the company. Then a quantitative survey was done to consolidate the answers from the interviews and to get a more quantitative approach of the answers from the employees. To reach the goals of the study, literature review has been used to answer research question 1 and 2 from a general company view then interviews were conducted at the company considers these questions from a simulation engineer/employee view. These answers were then applied to a survey to quantify the results from the interviews and to easier pick out the top three most important factors for each question from the employee viewpoint. The workshops were done to answer the third research question together with the other collected data. The workshop will then end in a manual, that will be done last with all the collected data in mind.

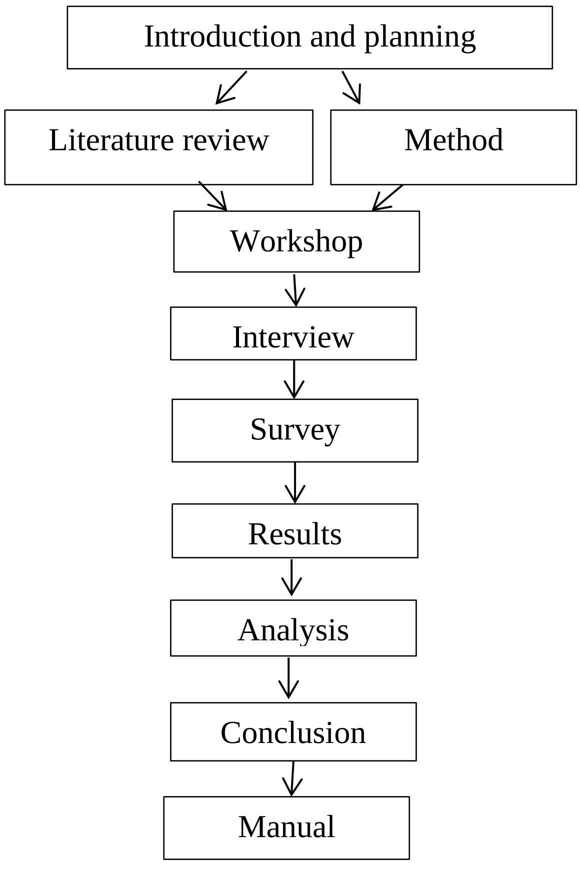

Figure 1 - Project process over activities for the report (own produced).

2.1 Literature

The literature review has been conducted to get the theoretical position of the literature regarding the case that is being studied (Allen, 2017). The literature review examines the prior research and detects contradictions and similarities to answer the research question (Mathison, 2005) and to gather arguments for the research question and to establish that the report is valid in regards to the topic (Allen, 2017).

Secondary sources are based on a research article, conference proceedings, books and review articles. The literature was found in databases and through search engines that forwarded to databases. Some material was also found through ResearchGate, where scientist and researchers publish their work. References were also found by looking through the reference list of the articles. Books were found in databases, in the library, and through web search. An assortment of usable material was made by first reading the articles heading and abstract then the introduction and conclusion were read to see if the material were relevant.

The literature has been limited to only include sources written in Swedish and English. Some literature was known from other courses. The databases used for the literature review are IEEE Xplore, ScienceDirect and Scopus and by using the search engine Google Scholar. Other websites used for searching literature have been ResearchGate and Primo. The different words used for literature search are: PLM, product lifecycle management, product, development, simulation in product development, product data management of simulation models, PDM in manufacturing companies, PDM systems in product development, CAE in PDM systems, early decisions in the PDP(product development process), PDM in product development, PLM in product development, product simulation models in PLM, , early decisions in product development, product development and PLM, product development simulation, simulation-driven design, virtual prototyping, simulation data PDM systems and simulation data management.

2.2 Case Study

Case studies are often rich in empirical data and often used for researching, explaining and describing and often aid to answer research questions that start with why and how. Case studies are often applied to inductive studies that let the theory emerge from the data. Unlike inductive research a deductive approach aim at testing the theory (Blomkvist & Hallin, 2015). The inductive parts in the study are the interviews and the workshops, the deductive part that was derived from the interviews and the workshops are the survey.

2.2.1 Workshops

To learn the new PLM/PDM system the company provided test cases and the ability to participate in workshops to try the system. The test cases are made by developers at the company and used to test the system and its different functions to support this Windchill have their own support that can be used to understand the system better (PTC, n.d). This laid a foundation for the interview questions and helped with the understanding of the system and its possibilities and limitations. During the workshops, experimentation with Windchill and GT-Suite were done to see if the two software work together and to see how the work process for engineers should be structured and how the models should be managed in a structured way. The testing was based on the knowledge gained from the workshops. A total of 9 workshops were attended.

2.2.2 Interviews

The interviews are qualitative, open-ended and semi-structured. A qualitative approach was used to ensure that the focus was on the participants' position and the format makes it possible to let the interview participant decide what is important and relevant. And there is a possibility to ask supplementary questions (Bryman, 2011). The open-ended interview results in more extensive and richer data (Yin, 2009).

The interview questions were based on the research questions and aim to get a background of information to be able to answer the research questions. Before the questions were created a couple of articles about PDM/PLM, simulation and product development were read to gain understanding about the area. This is called a problem-oriented way of handling different sources, which means that first the secondary sources are utilized to get an understanding of the area and then develop questions relevant for the primary sources. This way knowledge about the area and other appropriate sources deepen (Bell, 2006). The total amount of interviews conducted is 5. For the interview guide, see A – Interview questions.

The assortment of interviewees has been made through purposive sampling, this means the participants are strategically chosen to ensure the depth and relevance of the research questions. They are chosen based on their connection to the research goal and the interviewees have been used to direct to other persons that may be relevant for the study (Bryman, 2011). The selected interviewees work as simulation engineers, product owner, designer, and system support.

2.2.3 Survey

A survey was sent out to employees who work with simulations and other employees that were relevant for the survey. The survey was done to verify the results from the interviews, in regard to the benefits in adding models to the system and benefits in using a PLM/PDM system. The survey was also done to see the difference between the employees working directly and indirectly with simulation. Also, to ensure that benefits mentioned in the interviews were considered important by a wider range of employees. The survey had close-ended answers and was structured to ensure that there could be a comparison between different subgroups (Bryman, 2011). Some questions were one selection only and some were multiple selections. To sort out the most important factors a maximum of three could be chosen in the multiple selection answers. There was an option to write an answer if the sample were not representative to the respondent. The survey was an electronic survey that was sent out through email and the answers were collected automatically by the program. The answers were presented in cluster bars and a table. The table contained the answer, the number of times that answer had been chosen and the corresponding percentage.

The use of surveys as a compliment to the interviews has been used to increase the credibility and confirm the results (Bryman, 2011). The total number of respondents to the survey is 29. For survey questions see Appendix B – Survey questions. Question number 3,7 and 8 had maximum multiple selections of three as to narrow down the three most important benefits and the most frequently used way of collecting input data. See Appendix B – Survey questions for full survey layout.

2.3 Data analysis

Transcription of the interviews will be done to ensure easier analysis of the interviews by making it possible to check the answers multiple times and it will be easier to exclude that the analysis has been colored by the interviewers own values (Bryman, 2011). The method used for transcription is unfocused transcription; this means the basic meaning of the interviews will be presented. This method does not consider nuances, gestures or other contextual data. The focus is on what was said (Brown, 2011). Interview parts that do not contain relevant data for the study will be sorted out for easier further analysis (Bryman, 2011). The transcription will distinguish be between participant and interviewer.

Analysis of the empirical data from the interviews has been made with a content analysis which searches for correlations in the transcription of the interviews and noting similarities and differences the themes found in the text has not been decided beforehand but emerged during the analysis (Given, 2008). The analysis of the survey was made by using column charts to statistically see the results from the survey and then be able to compile results from it.

2.4 Validity

In qualitative research trustworthiness and authenticity is used instead of validity and reliability, since the interviews are qualitative. Their validation and reliability will be judged by these standards instead. Validity for the databases is that they are all listed by the university library collection for databases. The validity of the journal articles is that the content is often reviewed by other researchers (Gunnarsson, 2014). The validity for the empirical data has been made by using triangulation, which is when more than one method for data collection or several data sources has been used to strengthen the results from each method used (Bryman, 2011).

2.5 Manual

The results from the literature workshops, interviews, and the surveys will end in a manual for the company with a suggestion about how the simulation engineer should add the models to the system. The manual consists of steps provided as to how to work in the system. The steps involve adding a simulation model to the PDM system, searching for a model, and some information about the system in general. The manual only considers handling cooling system simulation models in the PDM system. The manual is based on the knowledge gained from the workshops, interviews and the survey

3 THEORETIC FRAMEWORK

This chapter presents the theoretic knowledge gained from books, articles and academic papers that were researched during this study.

PLM has become more important in the current economic market (Constantin & Staretu, 2016). The need for a PLM system can be seen on both the internal and external level. The internal drivers are product innovation, operations excellence, and customer satisfaction. While some of the external drivers for the use of PLM are globalization, mass customization, environment issues, and product complexity. PLM is swiftly shifting from an advantage to a competitive necessity for companies (Ameri & Dutta, 2005). There is a need for more efficient product development and simulation is a way of supporting that. The pressure of more efficient product development comes from customers, authorities, and government as a result of the sustainability problem. Because the sustainability of the product is often determined during the early development phases, simulation is a way to aid this (Wall, 2007).

3.1 Product Development

According to Ulrich and Eppinger (2014), there are five factors that should be considered for successful product development: product quality, product cost, development time, development cost and development capacity. The authors mean that when considered, these factors should lead to financial success. This is also supported by Heim and Mallick (2011) who state that for new product development (NPD) time to market, cost control and product performance quality have the strongest link with market success. The work by Stanko, Molina-Castillo, and Manuera-Aleman (2012) suggest that speed to market is an important factor that leads to higher quality and lower cost. This is based on the fact that increased speed leads to fewer working hours, decreased cost, and faster cycle times by including the newest components from suppliers in their products, which positively affects the quality (Stanko, Molina-Castillo, & Manuera-Aleman, 2012). The innovation speed in a project is a success factor more than cost and quality but is more applicable for predictable products and stable context, not entirely new products and markets. In this context, the cost factor gives a bigger reward if the company invests in speed for PD and quality, rather than just cutting costs for a more efficient PD. They should invest in the speed for PD and not lower the costs for it as a way to cut corners (Kessler & Bierly, 2002). If a development project involves large quantities of data, the project team should be encouraged to use software tools to aid the communication and facilitate the coordination and avoid pointless group meetings. The use of software tools for design and validation (CAD and simulation) are important for an NPD projects market success. The software tools used in a project should be chosen based on the project characteristics, for products with high uncertainty tools and practices that make communication and coordination easier are necessary to be able to solve problems (Heim & Mallick, 2011).

A prototype is defined by Ulrich and Eppinger (2014) as “an approximation of a product within one or more area of interest” (p. 375). It can be classified into two groups: physical and analytical. Physical prototypes are material products and used for testing and validation the functionality. Analytical prototypes are non-material and represent the product in a visual or mathematical form, often simulations, 3D-models, and calculations. Analytical prototypes are often used to change parameters and evaluate different alternatives. The physical prototype then confirms if the construction works and to discover unforeseen conflicts. In product development prototypes are used as a way of communication, learning, integration, and milestones. Prototypes strengthen the communication between management, suppliers and different departments in the company.

By answering two questions: will this work? And does this satisfy the customer needs? A company can use the prototype as a way of learning. Prototypes are also used as a way to check if the different components and systems work correctly together, the integration is most effective with physical testing to see if there is any interference on the overall function of the product. Using prototypes in product development are a way to check that the products meet the requirements of each milestone. This is a base used by the management to make decisions about the continuation of the project (Ulrich & Eppinger, 2014).

By using a prototype in the product development there may be a reduction in expensive changes made at a later stage, but the building of a prototype needs to be weighed against the time and money invested. The building of physical prototypes is more in question for products with high risk and uncertainty. Other benefits include the speed up of other processes as the prototype may help finish other process activities faster and change the connection between the sequences of the activities (Ulrich & Eppinger, 2014). In large companies, the development of a complex product involves a lot of different departments and suppliers. Because of that, there is a need for higher cooperation between designers and engineers in the product development process. The human factor is the most important knowledge resources and the collaboration between them an essential aspect of the effectiveness of processes (Constantin & Staretu, 2016).

3.2 Product Lifecycle Management

A PLM system offers the company a full overview of a products life cycle, from the idea stage to development, manufacturing process, sale and dispose of. Gmelin and Seuring (2014) suggest that PLM is based on product data management, process management, and engineering project management. PLM and PDM are often used synonymously but PLM covers a bigger area. PLM is a management system to integrate technical data from different stages of the products lifecycle and from varying departments of the company (Cantamessa, Montagna, & Neirotto, 2012; Jetchev & Todorov, 2017). An example of steps in a products lifecycle is product and manufacturing planning, 3D design models, analysis, marketing and service (Cho, Kim, Park, Yang, & Choi, 2011) A PLM system is a way for the company to shift to virtual engineering, where both 3D CAD systems and simulation is an important part. 3D models are used to specify critical relationships and handle collisions. Simulation is used as experimentation models to test the dynamics and to apply the results to real products (Jetchev & Todorov, 2017). PLM is a way for companies to improve the quality and lower the costs connected to their products (Xin & Ojanen, 2017). The use of PLM is a huge asset when developing complex products, because of the increased productivity of the development process the projects often stay within reasonable time and cost (Mas, et al., 2015).

According to Cantamessa, Montagna & Neirotto (2012), PLM helps users retrieve data, which lowers the time spent managing, searching or reinventing. But even when more time was available the productivity of the user was not increased (Cantamessa, Montagna, & Neirotto, 2012). Product lifecycle management is important for product development processes efficiency (Cho, Kim, Park, Yang, & Choi, 2011). The PLM system does not support the creative activities for a development project, but more supports the different development tasks (Merimond & Rowe, 2012).

PLM supports the product development process by coordinating the information connected to the workflows and product information (Tai, 2017). Using PLM systems helps the design team communicate with manufacturers about the products design and visual representation of the 3D model will help eliminate finding errors in the product at a later stage and misinformation between the teams. This will ensure decisions are made based on common knowledge. Visual representation helps create a common understanding of the design of the product between different departments involved in the project e.g. marketing and styling in NPD (Merimond & Rowe, 2012).

If suppliers are involved in the product development process earlier, through the use of a PLM system, it may lead to an increase in customer satisfaction and reduce the technical errors in a product. The PLM system makes it easier to share information with stakeholders and the system enables knowledge storing which can take on a role as an important competitive factor. It also makes it easier for different departments varying from purchasing, manufacturing, research and development (R&D) to communicate and collaborate on a project (Kunga, Ho, Hung, & Wu, 2015). The synchronizing of the system minimizes the complications when design changes are made to the product. The system also solves the issue for the project manager of collecting data from different systems or departments and makes sure the information is accurate and up to date which also enables the managers to make decisions based on accurate data. Knowledge sharing improves product development (Kunga, Ho, Hung, & Wu, 2015). According to Ameri and Dutta (2005), one significant determinant for success in today's market is the use and care of the company's intellectual assets.

Utilizing a digital form of a PLM system has a positive impact on the NPD performance of the company. This is because the use of digital PLM has a positive effect on the collaboration in the company and thus increases the NPD performance, especially in complex companies (Schweitzer, Handrich, & Heidenreich, 2019).

According to Vila, Abellán-Nebot, Albiñana, and Hernández (2015), a sustainable PLM approach are a crucial matter for the next generation of manufacturing companies. The authors present a sustainable product lifecycle framework that involves the stages: design and development, manufacturing and service. The framework describes the methods, tools, and knowledge that will help achieve sustainability throughout the products lifecycle. They consider the design stage to be one of the main factors in the sustainability impact and that in the future more connection should be made towards the end of the product lifecycle to be able to get a wider perspective of the sustainability impact.

A drawback of PLM is that the data can be hacked or stolen by competitors. Access and confidentiality are important parts to consider when implementing the system (Xin & Ojanen, 2017). Merimond and Rowe (2012) also suggests that the implementation of a PLM system as a form of communication about the product design between a company and its supplier may not have had the exact same positive outcome if the system had not been supported by an outsourcing engineer that could handle the organizational and cultural gaps between the companies. Since the system is complex different types of employees needs different support when handling the system (Cantamessa, Montagna, & Neirotto, 2012). Another drawback is that PLM systems requires a lot of resources and time for implementation, as it changes the way of working in a company (Alemanni, Alessia, Tornincasa, & Vezzetti, 2008). When designing complex products, the functionality of the system needs to increase but since this makes the system more complex the usability decreases. Sometimes the functionality included some unnecessary utilities that weren't used and the cost for this increased more than the functionality (Mas, et al., 2015).

According to Batenburg et al. (2005), the information technology and people and culture are the business areas that often stay behind on PLM maturity, the authors refer to maturity as in which progress stage the companies are in their PLM implementation from none or ad-hoc level to inter-organizational level with the supplier involved. The reason these two areas are left behind is that some activities relating to them are not organized, like including PLM in the job description, involve employees in the implementation, or the integration of PLM software in the company. Investing in PLM software can gain the company a competitive advantage. The alignment for PLM-system describes how well different areas of the implementation such as IT and business are balanced. When investing in a PLM-system there should be a plan that describes and controls the activities in the implementation to bring the PLM maturity and alignment in the company to the next level (Batenburg, Helms, & Versendal, 2005).

3.3 Product Data Management

PLM emerges from PDM which links the product components and their information (Merimond & Rowe, 2012). PDM technology supports the management of both process information and engineering data through the product development phase (Chang, 2016). The PDM contains all the product definition data and helps handle the data relating to the design, building of products and the support and service of them (Philpotts, 1996). PDM systems are a vital part for an efficient NPD as the system allows for structured and descriptive data storage (Scheidel, Mozgova, & Lachmayer, 2018)

PDM supports the use of PLM by making data more accessible and manageable (Peltokoski, Lohtander, & Varis, 2014). The use of PDM systems enables design changes to be made earlier in the project by distributing data between project members, which declines the cost of having to change the product in a later stage. Other benefits with PDM are that relationships between the different sets of data can be preserved, a reduced manufacturing cost and design time and increase in quality. If the PDM system is used with classification to enable finding standard parts, this will lead to less reinventing and more reusing. This will save time, reduce purchasing costs and inventory (Philpotts, 1996). Collecting data is often time-consuming and using a PDM system decreases the time spent searching in different data storages and the data presented in the system will be more up-to-date (Gmelin & Seuring, 2014).

PDM system is an essential tool in handling the high volume of complex data for a manufacturing company. The benefits of having a PDM system include reduced time to market, which is a result of better control of the introduction process of products. Better control over data and changes in data, the information will be more accessible and time spent searching for it will be reduced, more efficient data use which reduces duplication and errors, better communication within the organization with shared information and improved traceability of information (Obank, Leany, & Roberts, 1995). Because of the amount of data, the revision during a product development process and the globally scattered design teams the management and access of product data is complex. To support the product development a company needs to have an efficient organization and management of product data (Chang, 2016). PDM is an efficient storing tool for product development and information management (Huang, Liu, Zhou, & Wang, 2009)

3.4 Simulation Models

Simulation models are used to represent a real system that you can experiment on to try to understand what will happen in reality (Robinson, Nance, Paul, Pidd, & Taylor, 2004). It is hard to create a virtual product that is representative of the physical product regarding various dimensions and the different physical laws. But it is important to be able to evaluate how the components of the product interfere with each in different circumstances (Grieves & Tanniru, 2008). Simulation is often used as a way to verify design in product development, but a shift is starting to happen to simulation-driven design (SDD) where the focus is on aiding the development process as early as possible to enable evaluation of concepts and designs in a more continuously development process (Karlberg, Löfstrand, Sandberg, & Lundin, 2013). The shift to SDD should also support the dialogue with customers and enable to be more competitive in the market (Wall, 2007). The significance of the simulation process for the product design development process is growing (Blondet, Duigou, Boudaoud, & Eynard, 2015).

Simulation can help the designers increase the design changes made, but at a lower cost, while at the same time speeding up the process compared to building physical prototypes. By using simulations, errors can be fixed much earlier in the development process and thus reduces the cost and time spent of having to make changes at a much later stage in the process. Substituting the simplest physical prototype with a simulation can in some cases save a lot of time and reduce cost. This affects other activities as well since they can proceed at a much earlier stage and with lower uncertainty. Sometimes the value of using simulation is limited. This may be because the models the simulations are based on are not exact or the technology for the product is changing too fast. A combination of simulation and prototype testing is the best way to experiment on products, as the technology for prototype testing is evolving as well (Thomke, 1998). The simulation models aids in choosing the right design by eliminating others early in the development process. This is especially important with complex design systems (Mefteh, 2018).

Simulation models should be used during the whole product development process as it contributes to the efficiency of the process and the end quality of the product (Saavedra, et al., 2016). Becker et al. (2005) consider that simulation offers better control over design processes. Companies have a better chance of more innovative design by using simulation tools if the possibilities are supported by organizational and management structures. Simulation shifts the way companies solve problems and redefine the options considered. Simulation makes companies extend the search space by allowing testing of alternative design variations (Becker, Salvatore, & Zirpoli, 2005). The simulation models aids in choosing the right design by eliminating others early in the development process. This is especially important with complex design systems (Mefteh, 2018). Thomke (1998) suggest that by using simulation the company gains higher development flexibility and the company can better handle changes in the market.

For the virtual model to be able to describe the physical part the PLM system needs some characteristics according to Grieves and Tanniru (2008) "The informational characteristics required by PLM are singularity, correspondence, cohesion, traceability reflectiveness, and cued availability" (p.42). Singularity means that there exists a version of product information that is the base for everyone, the reliability for singularity can be strengthened by supporting information about in which context, for what purpose and by who the information was created. Correspondence is the link between the virtual product and the physical product. Cohesion means that the information connected to the virtual product is broad and covers different views like mechanical and electrical. Traceability means that there should be a historic line over the versions of the products available. Reflectiveness is the way the virtual product mirrors the changes that a product encounters over its lifecycle. Cued availability means that the information about a product should be available in its context and not only when that information is requested (Grieves & Tanniru, 2008).

Grieves and Tanniru (2008) suggest that start parts should be used as a way for the employee to save time and avoid common mistakes that may accompany simple designs. The start part only covers the parameters for the basic functioning of the part and can be used as a starting point for variations of the product. Smart parts are based on start parts but modified for other uses, smart parts are meant to have rules so that the function will be the same. This is so the employees can focus on the design task at hand, while the model still follows standardizations and important parameters. The benefit with connecting start and smart parts to a PLM system is that there will become more standard parts available and the employee cannot make changes without consideration for the functionality (Grieves & Tanniru, 2008). But when considering reuse for the simulation models it is important to consider if the whole simulation model, a component or an even smaller part should be reused. The benefits in time or cost for reuse of the model might become obsolete because it becomes more complex and harder to become familiarized with depending on if a complete models or a small component are reused and the validity for using a model obtained from another context (Robinson, Nance, Paul, Pidd, & Taylor, 2004).

3.5 Simulation Data Management

Charles and Eynard (2005) recommend that there is a distinction between the design and simulation data management (SDM). This is because often the PLM/PDM system is complex as it is and they are often not designed to store the simulation data, which may impact the connection and integration of the simulation software in the system. There should instead be an interface that can communicate with the PLM/PDM system to ensure communication between the softwares. The benefits with simulation data management are the access to model and data, sharing of models and data, traceability of models, changes and decisions, organization of data and better operability between simulation and design activities. To be able to reuse models to improve the product development process a simulation data management system is a necessity (Ottino, et al., 2015). The size of the simulation data is increasing more and more because of the improvement of computers and networks (Blondet, Duigou, Boudaoud, & Eynard, 2015).

A lot of PLM/PDM systems handles CAD models since the simulation files contain a large amount of data and are often complex, the simulation models are often hard for the system to handle. CAE/simulation systems also often have their own way of managing data which adds to the problem of sharing data with other systems and applications (Cho, Kim, Park, Yang, & Choi, 2011). But according to Buda et al. (2011) generally, PDM-systems are enough to store the big amount of data that simulation results in.

According to Liu, Maletz, Zeng, and Brisson (2009), a future trend is simulation lifecycle management (SLM), a vendor developed an SLM interface that handles simulation data and processes, stakeholders and management this enables activities in later stages of the product development process to occur earlier. According to Lefévre, Charles, Bosch-Mauchand, Eynard, and Padiolleau (2014) there is a need for better management of complex products to ensure their quality and shorten the development time. This can be done by improving the data backbone between modeling and simulation.

4 IMPLEMENTATION

This chapter presents the implementation of the workshop, interview and the survey.

According to Sokolowski (2019) there is no integration of the simulation software GT-Suite with Windchill today but there has been integration of other PLM software with GT-Suite. This is supported by Enríquez, Sánchez-Begines, Domínguez-Mayo, García-García and Escalon (2019) who states that for simulation and validation, the PLM/PDM system incorporated by the company (Windchill) uses another of the company’s software. There are no plans for using the PDM-system as storage for simulation models with this implementation in the company.

4.1 Workshop

During the workshop some basic training in Windchill was provided, the training was a necessity to understand the program and its possibilities and drawbacks. During the workshops, the simulation models were added to the system in different ways.

4.2 Interview

4.2.1 PLM/PDM Systems

The advantage with using Windchill is the traceability of the model, which allows better control over who creates, releases and changes parts in the system, partly to ease the employee's personal work process and for other employees as well. Traceability is also important to see how and in what order the components are put together and in what machine configuration they are present. This is important when considering a change to see that the change does not affect the machine too much or the cost. The traceability is necessary to find where a located problem occurs and in which machine. The systems also allow for a historical overview to see what a product has been replaced by and to see older versions of the product.

The exchange from the old to the new system will collect/integrate data from different systems into one; data that has been scattered in different systems will be in the new system where employees can collect it and see the different connections between data sets. It should also become more uniform and easier to work with. Having one system with accessible data should reduce the exchange of data between two employees through for example email, which reduces the data loss that may occur because of sickness or if an employee quits, to be able to find it in a system will save time. The system also stores data from products that did not go all the way to production, which enables the data to be saved for future use. To have all the data in the same place is important because there are so many different persons involved in the process. In reference to that, one advantage of working with the new PLM/PDM-system is that the data and the employees may become more organized. The system allows employees to collect documentation of product data which covers everything from the first sketch to production in the product life cycle.

By collecting data from the PDM system it should reduce double work, creating the same model or data twice, and the difficulty of finding data or get access. An advantage with the new system would be to integrate more requirement management; every project handles the requirements differently and it should be standardized where the information is to be stored and that it contains the right information. Another important factor is the repeatability; this is connected to both context and requirements. If both the context and the requirements are stated it will be easier to repeat a simulation without it being dependent on who makes it. The new system will be easier for new employees to learn because there is one system to use, since designers need two software's to search in the current PDM-system and with the new system there is only need to learn one. One system will also allow for easier system maintenance.

Drawbacks are that there may be time-consuming to learn the new system. There are a lot of opportunities in the system to work in different ways, but a standardized way may be easier for new employees to understand. Based on which program that is used to create the simulation models they may be out-dated and may not give the support needed and you are not able to trace the history of the simulation model. Another drawback is if other employees cannot find where the models are saved, and they disappear in the system. The drawbacks are that sometimes models are based on assumption and works in a special way, if this is not stated there is a possibility that the user thinks it works in this way, but it doesn't. There needs to be a statement in which context and what the simulation model can do. Sometimes some calculations are based on static data and not simulated as if two media meet.

The risks are that employees may not be able to do stuff as fast in the learning period, the communication between different software's and Windchill may not work. To ease the implementation more work time should be given to early adopters to adapt the system before everything are set. A drawback is that the system feels space demanding. It is also important to be selective in who has access to the system and thin about the security. Some drawbacks are that the system may be complex, hard to navigate and find the correct data, which will make employees hesitant to use the system. There are also some risks with having only one system, and what should be done if it does not work.

4.2.2 Simulation

The company uses simulation models for development, control, testing of product dimensions and performance and for testing the different systems included in the product. The company uses a lot of different kinds of simulations for the cooling system, engine simulation, whole machine simulation, fuel simulation, different flux simulations and vibrations, and sound simulations.

The old system is not used by simulation engineers to save their models, it's used to find CAD models to base their work on or gather information from. Simulations can be based on input data from CAD models or on data that the employee gathers themselves by contacting the right persons, searching for data or assumptions. The data can come from suppliers, colleagues, measurements, machine results, test rig results, servers, and reports. There is a lot of time spent searching for data which makes things ineffective and leads to frustration. To be able to build a physically correct model there need to be a lot of input data, but in reality, the data is often incomplete or insufficient. Often there are a lot of variations of a model rather than one perfectly correct one. The models are based on the available data and what kind of info they want out of it. The simulation varies a lot depending on which question you want it to answer. So when new employees want a model to start with, it can be hard because of the variation of the models.

The cooling system simulations are often changed a lot in the beginning but when they have reached a state of maturity and the engineer trusts the simulation they are not changed. The calculation is only redone if something in the product changes or if another parameter needs to be tested. But the old model still needs to be connected to its specific product model, not the new version. Total vehicle simulation models are more prone to changes than cooling systems because it's a more used simulation method and more changes are done because more errors occur. Some simulation models are stored on a shared server when they are used by a lot of employees, this is often the case with simulations done on the whole machine, when changes are made to a simulation model on a shared server, comments are made in the code or when the simulation model is checked in or out of the system there should be a comment about the change.

From the interviews it was gathered that most of the simulations have been saved locally, sometimes on a shared server where the simulation engineers have access but not in a very systematic way. The results from them have been presented in a report, mail, power point or answering questions. The report/power point is often shared with others on a shared project space.

The usability of adding simulation models to the system is in traceability to see different variations and the small changes that have been made between each variation and that the information is documented and not only stored in someone’s head or local folder. The components could be standardized but it is important to document how the whole system has been built. Other employees that do not work with simulation first-hand may want to run the model, to see that the model gives the performance needed and to double check for mistakes. To be able to see the performance early in a project helps reduce the cost. There are always advantages with all the information that you can add to the system.

The simulation models should follow the product and not the individual simulation engineer. It should be accessible for all and easy to follow the history if there is an error it should be easy to track the model to see where the error occurs first and evaluate why. If there are changes to be made to a product or a new product is created there may be some savings in reusing an old model. To be able to add the simulation model to the system in a way that works there need to be documentation about the context. This will make the creators more active in documenting the simulation models and the system will ensure that data doesn’t disappear, as it sometimes does if a computer is malfunctioning.

The files that should be included in the system are simulation models that other employees can run and use. It is easier to save how a model should be run rather than saving all the results. The result files from the simulation models contain a lot of data so it could be summarized in a report instead and connected to the simulation to show the context of the model. The system should be used as a base for CAD data, component data, data from testing, and simulation models. All this information should be connected to a product. Some of the simulations are done on a whole system so it should be connected to a part that represents that system. In projects there are often several concepts, when choosing one it is mostly stated why it was chosen, but the ones that were not selected are not documented. A project can end up in a dead end and one of the other concepts might be better but if they are not documented in a correct way it is hard to go back. And the process might have to be redone.

There should be an easy and organized way to search for models connected to different projects, so employees can use the system instead of their personal network to find data. A possibility with the system regarding reuse is to add simulation models’ components to pick and choose from so the employee can build the product system themselves instead of trying to find a system simulation that matches exactly. Sometimes some components in a system may be valid for one simulation context but not the other. In a simulation, there is no 3D model so you have folders with measurements that characterize the component these could be connected to the individual components in the system. The product system for example cooling system will behave differently depending on size, which affects the simulation input and output.

One of the interviewees expressed a wish that the systems would be a little more integrated so that persons who do not have access to the simulation software still would be able to run some features of the simulation models.

4.3 Survey

There were a total of 29 respondents to the survey, of this a total of 11 identified as simulation engineers, 7 as designers, 4 as product owners/project managers and 7 as the category other. The results from the survey are presented in column charts. The charts presented are based on question 2, 3, 6 and 7 in the survey, for a complete survey questions see Appendix B – Survey questions. These three questions and their results were deemed to be the most important to answer the research questions. Prior to the chart in Figure 3 and Figure 6 there is a table that explains the different benefits that could be selected.

Figure 2 - Distribution of answers regarding work in the system Figure 2 presents the question *"Do you work in the current PLM/PDM system?"* and the distribution of answers.

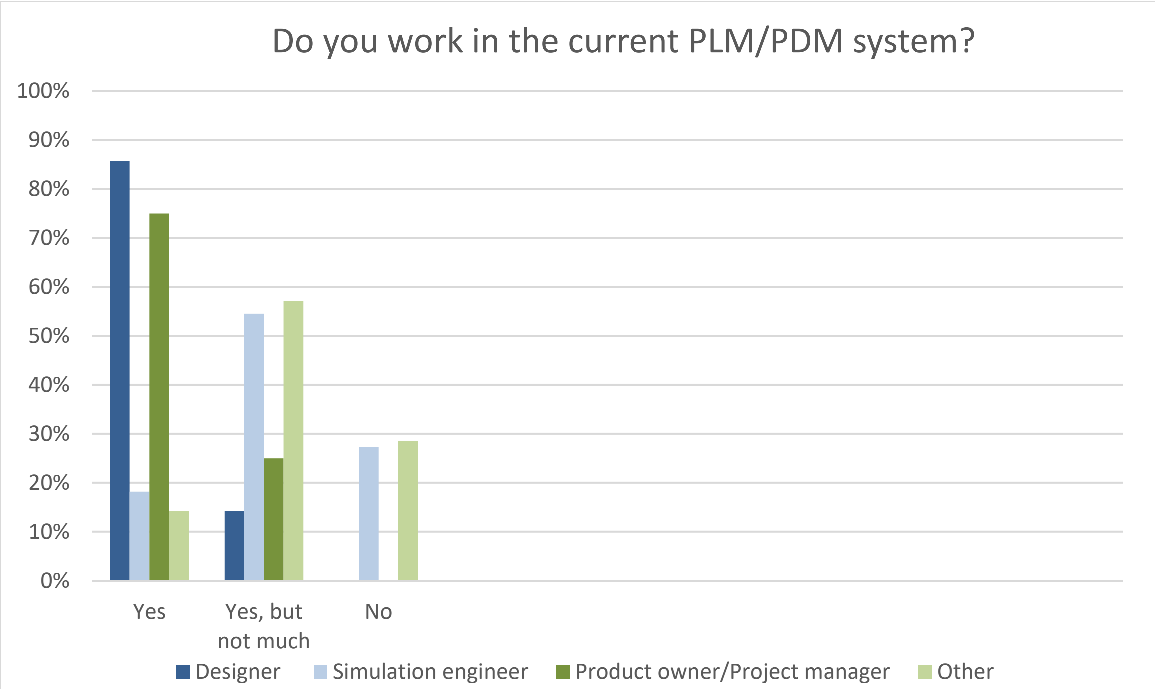

Figure 2 - Distribution of answers regarding work in the system (own produced figure).

The designer and the owners/managers have answered yes to the question at a rate of 86 respectively 75%. The simulation engineers and other have answered the highest to yes, but not much with a rate of 55 and 57%. There are no designers or owners/managers who have selected no in the survey, while some of the simulation engineers and other has selected that alternative.

Figure 3 and Table 1 represents the question *"What are the most important benefits in using a PLM/PDM system for your work?"* and the distribution of answers between different work titles.

Table 1 - Explanation of the axis titles in Figure 3

1. Reduced data loss	Reduce the risk of losing data

2. Traceability	Easy to trace the model and where it is used and its different connections. It is also used to see the small changes from each variation.
3. History overview	Easy to see an overview of the different historic variations.
4. Easier collection	Easier data collection by using the PDM system.
5. Control	Better control over product data.
6. Reduced double work	Reduce the risk of double work (creating the same data/model twice).
7. Errors	Tracking errors in the system.
8. Reuse data	Reuse of data.
9. Storing	Storing data in the system
10. Other	Other benefits that were filled in by the respondent. Designer: Efficient to use (responsiveness/Batch processing) Simulation Engineer: Collect CAD models and CAD models for building FE models. Other: The system needs to be easy to use for sporadic users.

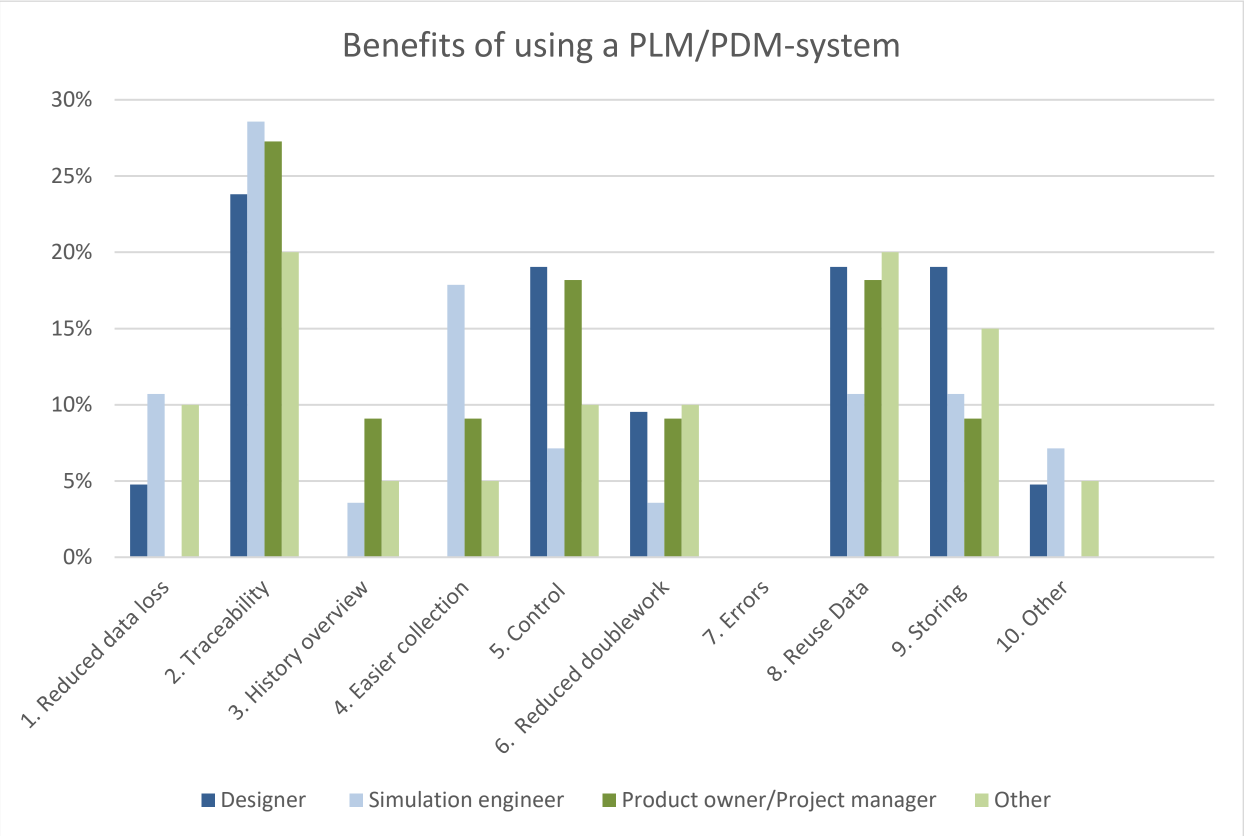

Figure 3 - Column chart presenting the distribution of benefits in using a PLM/PDM-system (own produced figure).

To the research question "*What are the most important* benefits in using a PLM/PDM system *for your work"* the highest selected answer for designers, simulation engineers and product owners/project managers are traceability at 24-27% (Figure 3). In the work title category other both traceability and reuse of data were a priority at a 20% answering rate each. Then there are some differences between the employees. For designers' better control over product data, reuse of data and storing data are equally distributed at 19% as the second highest. Reduced risk of double work at 10% in third place. For the simulation engineers' easier data collection are at second place at 18%, then in third place an equal distribution between reuse of data, storing data and reduced risk of data loss. For the product owners/project managers the second most important benefit is better control over product data and reuse of data at 18%. Then the third most important is history overview, easier data collection, reduced risk of double work and storing data at 9%. For others the second most important benefits are storing data at 15% then at third place is reduced data loss, better control over product data and reduced risk of double work at 10%. For an easy overview of the most important benefits, a chart with all the respondents compiled together can be seen in Appendix C – Chart with respondents' answers compiled together., chart 1.

Figure 4 presents a ranking of the different important factors for the different work titles from Figure 3.

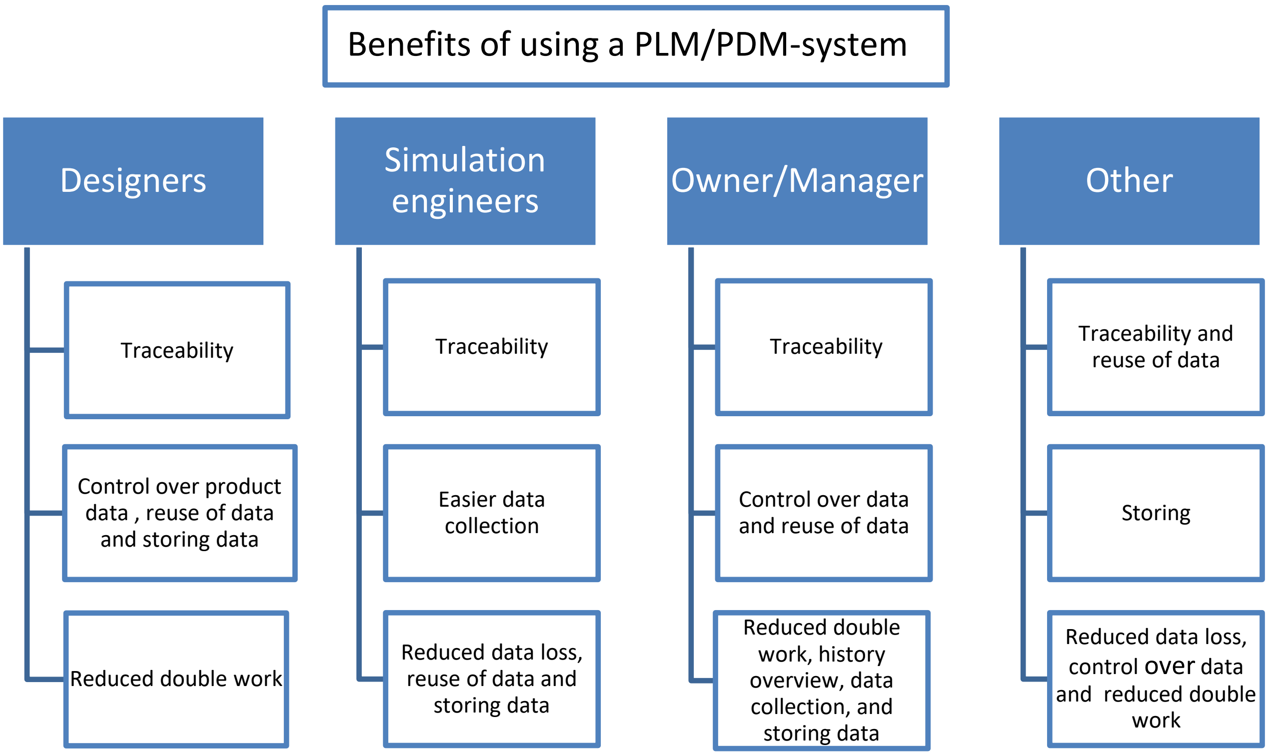

Figure 4 - Ranking of important factors from figure 1 according to different employees (own produced figure).

Figure 5 presents a column chart and the distribution of answers from different work titles connected to "*Would there be any benefit to your work to add simulation models to a PLM/PDM system?"*

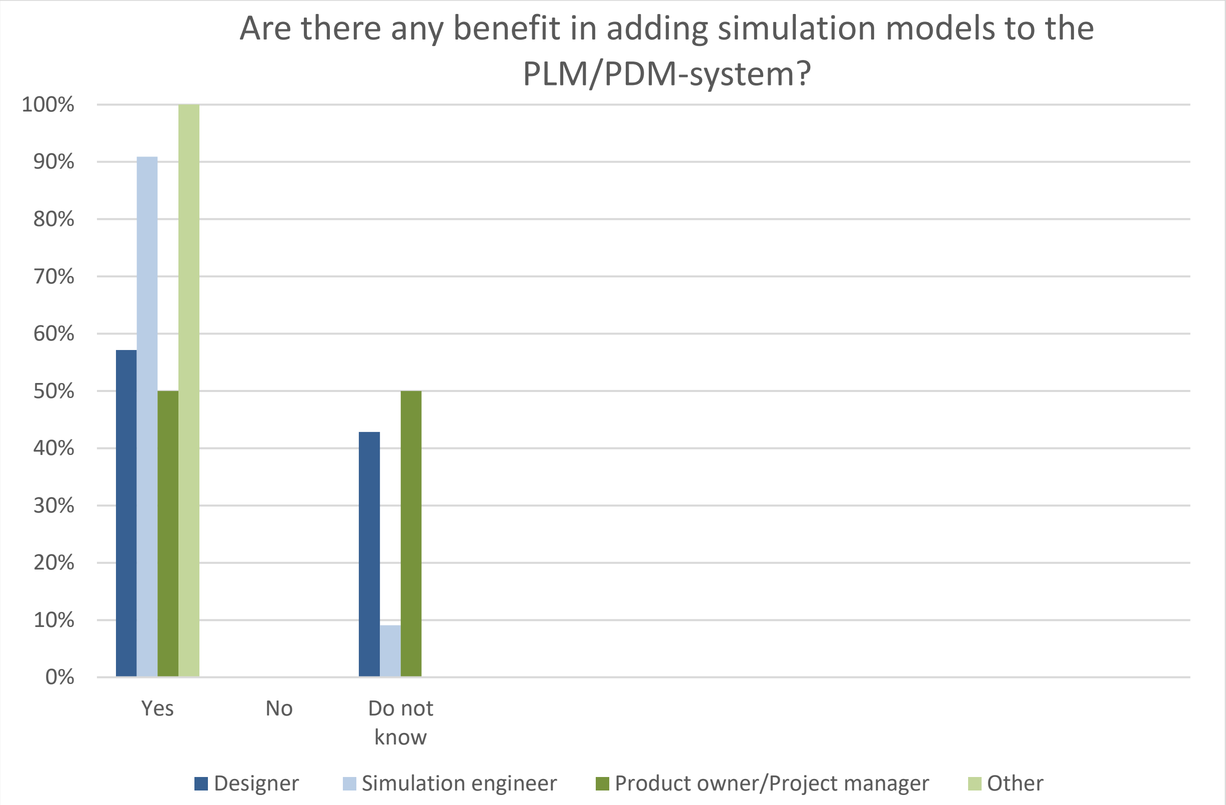

Figure 5 - Distribution of answers regarding if there is any benefit in adding simulation models to the PLM/PDM-system (own produced figure).

In Figure 5 both simulation engineers and others have a high answer percentage of yes with 91% versus 100% to benefit with adding simulation models to the PLM/PDM-system with both having answered. The designer and the owner/managers have a more equally distributed column in both yes and do not know around 50% each.

Figure 6 and Table 2 presents the distribution of answers for *"What benefits do you think adding simulation models to the PLM/PDM system will create?"*

Table 2 - Explanation of the axis titles in Figure 6

1. One system	More data available in one system instead of several.
2. Traceability	Easy to trace the model and where it is used and its different connections. Is also used to see the small changes from each variation.
3. History overview	Easy overview of the different historic variations.
4. Easier access	Easier to access the simulation models for the creator and other employees.
5. Control	Better control over simulation models
6. Access to data	Easier access to simulation data. (results and inputs)
7. Reuse	Reuse of simulation models
8. Other	Other benefits that were filled in by respondents. Simulation engineer. Connecting models to requirement specifications.
9. Not applicable	Storing data in the system

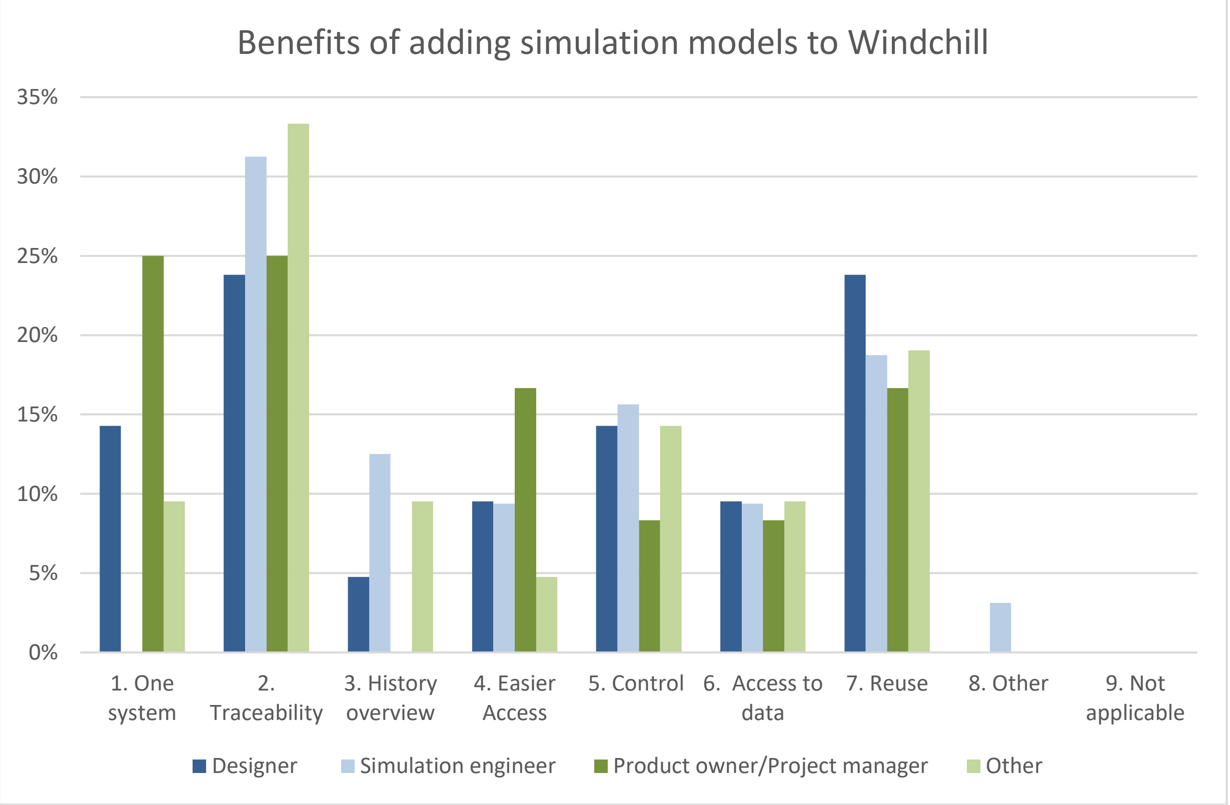

Figure 6 - Column chart over benefits adding simulation models to PLM/PDM-system (own produced figure).

The chart in the above (Figure 6) displays the answers to the question *"What benefits do you think adding simulation models to the PLM/PDM system will create?"*. The designers view traceability and reuse of simulation models as the most important benefits at 24% each. At the second place the one system and control over simulation models at 14%. Then in third place access to simulation models and access to data at 10 %. For simulation engineers, the most important factor is traceability at a 31% rate. Then in second place reuse of simulation models at 19%. Then at third place control over simulation models at 16%. The owners/managers view one system and traceability as equally important at 25% each. In second place is both access to simulation models and reuse of simulation models at 17%. As the third place is control over simulation models and access to data ranked at 8%. For others, traceability is the highest ranked factor at 33%. Then reuse of simulation models at 19% and after that control over simulation models in third place with 14%. For an easy overview of the most important benefits, a chart with all the respondents compiled together can be seen in Appendix C – Chart with respondents' answers compiled together., chart 2.

Figure 7 ranks the answers from Figure 6 to get an easier overview.

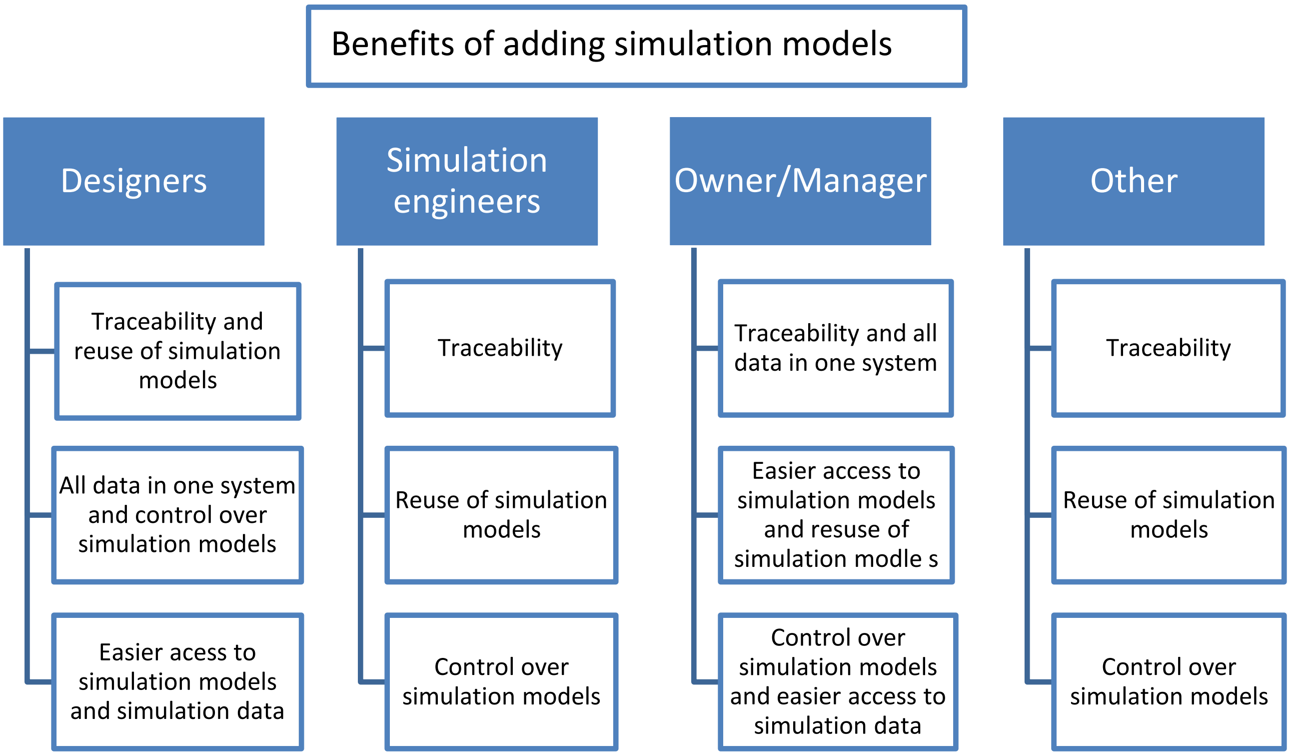

Figure 7 - Ranking of factors from Figure 6 (own produced figure).

5 RESULTS

This chapter shortly presents the results from the different methods.

5.1 Workshop

There is a classification tree in Windchill. That can be used for classification of the different parts/document/simulation models. It is possible to connect a simulation model to a part in the system. But there is no integration between the two programs so the simulation file shows up as an unknown document. The integration is not the same as with the CAD software. The new version of a simulation models needs to be uploaded manually and therefore stored locally first. The system is not in its early phases adapted to simulation storage. The file should be connected to a part and not a CAD document, this will be most logical and easier to find. Based especially on the knowledge gained during the workshops, a manual was created about how the simulation models can be added to the PDM system. The manual takes into consideration the input from the employees which were collected during the interviews and the survey. For manual see Appendix E – Manual

5.2 Interview

From the interviews it was gathered that the benefits with a PLM/PDM system is reduced data loss, traceability, history, easier data collection, control, reduced double work, reduced errors, reuse of data and storing capabilities. Regarding the simulation models in the system the most important factors to consider are traceability, easier collecting of the simulation models, the system should store different simulation data, that there are some problems with control over the models, the access are limited, there should be more reuse, all data connected to simulation models should be in one system, the models should be able to be reused or run again.

5.3 Survey

The results from the survey suggests that a lot of the employees are working with the old PLM/PDM system in some way, see Figure 2. The employees further think that the top three benefits factors of using a PLM/PDM system is traceability, reuse of data and storing. The top three benefits of adding simulation models to Windchill are traceability, reuse of simulation models and better control over the models. See Appendix C – Chart with respondents' answers compiled together.

5.4 Summary

The following table presents a summary of the advantages and the drawbacks with using a PLM and PDM system and connecting the simulation models to it. The results are drawn from both literature and interviews and survey. The benefits and drawbacks are not presented in a specific order.

Advantages	**Drawbacks**
Traceability	Complex
One system instead of several	Not useful if the context for simulation models are not stated
Able to see history over the model	Learning period

Easier data collection	Risk of data being lost due to a complex system
Reduces data loss	Model needs a clear context description
Better control over product data/simulation models	The simulation varies a lot and the reuse might be limited
Easier access to simulation models/data	Communication between PLM and simulation software's can be inadequate.
Storing data	There is a risk with using one system if it fails.
Easier reuse of simulation models/data	The system can be hacked by competitors
Reduced double work	Different employees need different support when handling the system
May be possible to integrate more requirement management.	Takes time and resources when implementing
Save products in the development stage for future use.	The system can be hard to navigate
Able to create connections between different data sets	If the system is hard to understand fewer will utilize it if they don't have to
Employees become more organized	Cost overrides the functionality and usability
Easier collaboration on projects	Simulations takes up a lot of storing material

Table 3 - Presentation of advantages and drawbacks

6 ANALYSIS

This chapter presents the analysis of the theoretic framework and the result from the other methods used during the study. The analysis is divided after the research question for an easier overview.

- What are the benefits of using a PLM and PDM system for a company's product development?

According to Ulrich and Eppinger (2014), there are five factors to consider for successful product development: quality, product, and development cost, capacity and time. The three factors most mentioned by the PLM/PDM literature are quality, time and cost. So a lot of the advantages mentioned in both literature and interviews about PLM and PDM systems connect with three of the factors for a successful product development project. The manufacturing companies of the future needs to have a sustainable PLM, most of the products sustainability impact is decided in the design stage (Vila, Abellán-Nebot, Albiñana, & Hernández, 2015) and by having a sustainable PLM it will be easier to manage it over the whole lifecycle and follow up the decisions about sustainability made in the design stage.

PLM can be a way to increase the development process efficiency (Cho, Kim, Park, Yang, & Choi, 2011) and since the system can lower the time searching and managing data (Cantamessa, Montagna, & Neirotto, 2012) it can influence the development time. The company will when implementing the system, go from using two systems to one. This should further reduce the time it takes for searching and for managing data. But according to Alemanni et al. (2008), the system takes time to implement, and from the interviews, it was gathered that a drawback is the new learning period for a complex system. Therefore, benefits of using it regarding time may not be visible directly.

Xin and Ojanen (2017) suggest that PLM is a way for companies to lower the cost for their product and improve the quality. Both of these factors are important to the successful development of products (Ulrich & Eppinger, 2014). PLM can reduce the cost an improving the quality because the system helps the designers communicate the design of the product to manufacturers and with the help of visual representation it helps create a common understanding of the design which will reduce the misinformation between teams and thus errors can be eliminated (Merimond & Rowe, 2012). This is supported by Kunga et al. (2015) also who suggest that the involvement of suppliers reduces technical errors and by involving the supplier early the customer satisfaction of the product may increase. The need for expensive late design changes should decrease if a common understanding of the design exists and are supported by the manufacturer.

Even if the creative activities in a project are not supported by PLM the different development tasks are (Merimond & Rowe, 2012) and by making it easier for different department to collaborate on a project through PLM (Kunga, Ho, Hung, & Wu, 2015), the project should meet the predetermined development time easier.

When considering a PLM system for a complex product the use of new technologies for more functionality needs to be weighed against the usability and cost of the system (Mas, et al., 2015). They should be balanced, and the PLM system must provide the necessary applications without increasing the cost and lowering the usability too much. If the company pays for extra functions they should be utilized.

From the interviews, it was established that traceability is an important factor for using PLM/PDM systems. To see who has managed the model, where the model is used, what the associated parts are and to see older variations of the model and history. The results from the survey suggest that traceability is one of the most important factors for all the different employees, see Figure 3.

The designer views traceability, control over data, reuse and storing as the most important benefits, while the simulation engineer values traceability, easier collection, reduced data loss, storing and reuse of data the highest (Figure 2). This distinction may be because of the different ways of working. The simulation engineers spend a lot of time looking for input data and would like an easier collection. And reduced data loss is due to the unstandardized way some simulation models are stored and there have been problems with some data disappearing. The benefit of storing data is due to that the simulation models are stored in different ways and sometimes only the simulation engineer knows where. And there should be one system where most simulation models are stored for easier access for those with authorization. This pattern can also be seen in Figure 6 and Figure 7 regarding benefits with adding simulation models to the system. Where the benefits are traceability, reuse of simulation models and control over them is the highest ranking for simulation engineers. Both designers and owners have ranked all data in one system and easier access as a benefit, this may be because the simulation models are often stored where they cannot access.

Both the designers and owner/manager have a similar priority order with traceability, control over data and reuse of data and reduced risk of double work (see Figure 3 and Figure 4). This may be because they view the system in the same way and are more accustomed to the system, see Figure 2. They, therefore, may have a better understanding of the system and its possibilities and limitations. When the answers are compiled together the ranking of benefits are traceability, reuse of data and storing of data, see Appendix C – Chart with respondents' answers compiled together., chart 1. The difference between the literature and the empirical part is that literature mentions a lot of saving time and cost but the employees have values that relate and which have a more direct affect to their daily work as the benefits.

- Why should simulation models be connected to the PLM/PDM system?

Simulation models should be added to the PLM/PDM system because the system is a way for the company to engage in virtual engineering where both CAD and CAE/simulation are important parts (Jetchev & Todorov, 2017). Analytical prototypes where simulation is a part are often are used to change parameters and evaluate design alternatives. Prototypes can reduce the need for making changes at a later design stage, and therefore avoid expensive changes. The prototype may also speed up the development process since it can help finish other process steps faster (Ulrich & Eppinger, 2014). Simulation allows the testing of different design variations (Becker, Salvatore, & Zirpoli, 2005) and therefore offers better control over the design process. Since various designs can be evaluated and stored in the PDM system.

According to Chang (2016), a PDM system supports the use of the engineering data throughout the product development. By adding simulation models to the system more engineering data will be available to support the employees in the different development phases and since the system also supports the traceability of information (Obank, Leany, & Roberts, 1995) it meets the need of the employees that want traceability for their models. According to Wall (2007) simulation is a way to aid the sustainability of the products in the design stage, which is supported by Vila et al. (2015) who recommends the use of CAx tools to aid the calculation of the sustainability impact of the product. To achieve a sustainable product the use of these tools to predict the impact and connecting them in PLM will make the sustainability reach most of the corners in the lifecycle and would be an important necessity for the sustainable companies of the future.

A PDM-system helps with managing the data and reduces the time spent searching for data and the data should be the newest data presented (Gmelin & Seuring, 2014). In the survey result, easier data collection was an important benefit in using a PDM/PLM system especially for simulation engineers who ranked it the second highest, see Figure 3. The simulation engineers spend a lot of time looking for input data for the simulation and it is sometimes collected by contacting colleagues. The PDM system should manage both simulation and the needed input data to make it easier for the employees. By collecting data from a PDM system the risk of double work should reduce. The results from the simulation are not shared that much often in short presentations or text format, if there were more reuse of models it could reduce the time spent looking for data and make the results more usable for future references as well. The system also solves the issue for the project manager of collecting data from different systems or departments (Kunga, Ho, Hung, & Wu, 2015). The system should store more of the data that are needed for input such as measure results and other data as this would greatly benefit the simulation engineers who spend a lot of time searching for data . Another way of reducing double work is by adding simulation start models or components to build the system that is going to be simulated, to the PDM system. In the interview, there were mentioned that simulation models can be reused and altered to fit the development of old or completely new products. This connects to the work by Grieves and Tanniru (2008) who suggests the use of start and smart parts. The models are built according to what they want out of it and this varies a lot. If using start parts there need to be a context description and some simplicity to the model so it does not take a lot of time to get familiar with. The company needs to have a strategic organization and management of the data to be able to support the product development (Chang, 2016).

The use of physical prototypes is still important for products with high risk and uncertainty (Ulrich & Eppinger, 2014) but evaluating the product with simulation first will narrow the choices for which physical prototypes to build. This should be even more important in the future as the company will meet new market demands with new technology and solutions that may not be established knowledge in the company.

Kunga et al. (2015) suggest that suppliers can take part in the early phases of product development to reduce errors and increase customer satisfaction. But according to the interviewees on the company, there should be limited access to the system, so the supplier cannot reach sensitive information or increase the purchase price of their products/services if they are the only ones that can deliver. This is also supported by Xin and Ojanen (2017) who also suggest limited access to reduce the risk of getting hacked and have data stolen by competitors.

Both simulation engineers and other have a higher frequency of answering yes to if there is any benefit in adding simulation models to the PDM system (Figure 5). This may be because they are the ones who would benefit the most. They may also feel the most need since there work can be scattered and not very standardized or prioritized. Between designers and owner/managers, the answer is more evenly distributed between yes and do not know which may be because the simulation result is easily obtainable for them in the form of reports in shared project spaces. One of the interviewees said that the simulation models should be stored in the system so it could be run again as a way to ensure that no mistakes were made. The reason why nobody has answered no can be because the simulation models are related to the work of the designers and there no direct concerns with adding them.

There are some differences between the employees as to what is important when considering adding simulation models to the system. The question about benefits of adding simulation models to the system shows (Figure 6) that both simulation engineers and other views the traceability as the most important benefit then reuse of simulation models and then better control over the models. The simulation engineers may have answered this way because they are used to collecting data from various sources, storing models in different ways and reporting the result in various form so a more controlled way of handling the models might be welcome. To be able to easily trace the models and to be able to reuse models will save them some time and give a better overview of the model's connections and history. Another reason for wanting better control and traceability might be because if someone in the company quits and the simulation models are left without context, they are harder for the company to reuse or know what value they hold. No simulation engineers view the use of one system for data as a benefit (Figure 6) as because of their way of working and using various sources, one system may feel impossible.

The owner/managers view the traceability and data collected in one system as a benefit them easier access and reuse (Figure 6 and Figure 7). This may also be a result for them to have better control and access to data regarding the product/project. While designer view traceability and reuse as the equally most important this might be a benefit for them in time if the simulation engineer does not have to start over with each new simulation. When the answers are compiled together the ranking of benefits with adding simulation models to the system are traceability, reuse of simulation models and control of simulation models, see Appendix C – Chart with respondents' answers compiled together., chart 2.

In the interviews it was gathered that simulation models are saved locally. But in the survey the simulation engineers answered that the simulation models are saved on a shared, some wrote that it is saved on a shared space that and that only the ones who works on the model has access. While the designers for the most part stated that the models are stored in a way that they can only be accessed by the creator, see Appendix D – Storing of simulation models for chart over answers. This divides the simulation engineers and the designers in their experience of the accessibility of the simulation models and it may also be important to notice that even when they are shared the simulation models are not easily available to other employees.

- Can simulation models be added to the PDM system and what factors are important to consider?

Because the system and the simulation software are not integrated the simulation engineer will not have the same functions and possibilities as the designer who uses CAD and may lose some of the core values with having a PDM system if they are not connected in a good and easy to use way. Some functions may not be as easy to do and will give the simulation engineer a new way of working, in how they share and store their work. Grieves and Tanniru (2008) suggest smart parts but this can only be used to some extent because often the functionality of the cooling system will vary because it adapts to other values from the transmission and the engine. The function may be the same that the values may not be able to go over a certain value because then it will lead to an overheated engine. From the interviews, there was mention of simulation models disappearing both when saving locally and on servers and concern that models may disappear in this new complex system. To avoid this, the simulation models need to be connected to the part is represents this is also a logical way to work and ensures models are easy to find if the structure of the product's components is good.

To be able to use the system a manual will be presented that presents how a simulation engineer can work in the system. This is a recommendation and summarizes the knowledge gained from the workshops, interviews, and survey. This might change in the future as the system is in the first phase of adaption and implementation. When considering adding simulation models to the system it is vital to look at the most important factors when adding simulation models and how these can be translated into the implementing of simulation models to the PDM system. The factors chosen to guide the focus of the implementation is traceability, reuse, and control. These factors are gathered from Figure 7 as the benefits most important to simulation engineers this ranking can also be seen in the chart for all the respondent compiled together in Appendix C – Chart with respondents’ answers compiled together. chart 2.

Traceability – To make the simulation models easy to trace there needs to be a connection to a product in the system and it should be easy to follow the history and see other connections. The sim

Reuse – Make the models easy to reuse by having a context report and making use of classification the simulation should be easy to find even and this should make it easier to reuse simulation models.

Control – For better control over simulation models should be placed by the product in a standardized way, to ensure that the simulation engineers know where to find simulation models and result reports and make it easier for other employees to access the report as well.

7 CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusion, recommendations and future research of the study. When doing a shift to a new PLM and PDM software the company wanted to investigate if it was possible to add the simulation models to the new software and if it would be beneficial. The scope was also to investigate if there are any benefits in using a PLM system regarding their product development. The company had not stored simulation models in the previous PDM system.

There are several benefits that can come from using a PLM system, these were connected to product development by researching the factors for successful product development and then looking for a connection with PLM by searching for benefits that correspond with these words. The top three benefits of using a PLM system according to the literature are reduced time, higher quality and lower cost. For the employees, the most important benefits are traceability, reuse of data and storing of data. Simulation models should be connected to the PDM system because they are beneficial for the product development process by evaluating and narrowing the choice of design, the more data that is available to employees in the development project the more support they get. Adding simulation models will make it possible to reuse models and data and therefore reduce double work. For the employees, the highest-ranking benefits with adding simulation models are traceability, reuse of simulation models and control over simulation models. These are also the factors that should be considered when adding simulation models in a more structured way to a PLM/PDM system or when considering other management options. Most of the simulation engineers and others do think there are benefits with adding simulation models to a PDM system, so considering this, the company should invest some thought in the management of their simulation models.

The study did not connect the parts considered important in the literature with the survey since this might be hard for the employees to relate to. Those factors might be more considered and important in a management a business perspective. The empirical part is based on a small sample and should if taken further perhaps be bigger to include more varied and inclusive results since the owner/managers were a very small sample group. In the survey, there was not a 100% answer rate on some questions from some groups and therefore the distribution rate may be somewhat of in some instances. Worth to note that the structure for the context in which the simulation models are most likely to be stored is not decided when the project was ongoing so which made it harder to do a proper suggestion on how the structure should be as there is no base to make assumptions from. A drawback of utilizing qualitative interview formats is that it is troublesome to replicate and the results from these interviews are not always applicable to other situations. Because the interviews were done with a small group of people from the same company there is possible that interviews at another site may give different results (Bryman, 2011).

7.1 Recommendations

The company should start to manage their simulation models, as a PLM and PDM system is a need for the company to be competitive, the correct management of simulation models are needed since the future possible holds more advanced and better simulation. The simulation will possibly be integrated more in product development and used as a way of improving the design earlier in the design process. If the company already has a structured and stable way of handling this type of data, it will be a benefit. Even though there it is possible to store the simulations a balance and standardization need to be set so the system is not flooded with different simulation models that answer different questions.

Another recommendation for the company is to investigate which other simulation software that the company own and see which are already integrated with the new PDM system or can be added without a problem, then let the simulation engineers test the manual to see if this works. As a first step in to collectively store the simulation models in a more collected way. For a manual in how the simulation models can be added to the new system under implementation see Appendix E – Manual. Further recommendations are to again test the adding of simulation models when the system has been implemented and evaluate how the simulation models function in the system when it is stable and in use. If it is decided that the simulation models should not be included, the result reports should at least be connected to the PDM system as they have value for the other employees as well. Then other solutions should be considered, to be able to store and manage the simulation models.

7.2 Future research

For future research, the company should look into how to manage input data to the simulations to ease the collection for the simulation engineers. There could be an evaluation for the use of other file formats that can store and transport the data between different applications with smaller file sizes or store the simulations in another space with links to the system. The context reports contents must be decided by the company themselves since that is out of the scope of this report. There should be a comparison between the SDM software and PLM/PDM to see what would work best for the company. The software should still need to be connected to the PLM/PDM system in some way so there is some form of communication between the different systems. The employees working in the PLM/PDM system should see that there is a simulation model connected to the product and either be able to see it themselves or see a person to contact for models. An important future research topic is the measurement of potential cost reduction when using a PLM system in connection to product development and potential cost reductions when adding simulation models to a data management system. Also, if when the new system is implemented there is a reduction in time. Another topic for future research is to measure what benefits the employees experience when the new PLM/PDM system is in use in connection to both product development and simulation models. The benefits could be measured in how big of a benefit they are, by measuring for example cost and time. The manual should be further developed if the company decides to make use of it.

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Appendix A – Interview questions

1. What is your work role?
2. What are simulation models used for? Why does the company need simulation models?
3. Which simulation models do you use?
4. What software does your company use for simulation models?
5. Are the simulation models based on any other file format?
6. Are you picking up data from Cad?
7. What kinds of simulation file formats are there?
8. How is the simulation models stored today?
9. How standardized is your work on simulation models?
10. Do you share results from the simulation with others (managers, project managers, colleagues)? How? And in what format?
11. What information can others access?
12. Are there any standardized results report from the simulation models?
13. Do you often make changes to the simulation models? How often do you change them?
14. Do you need to report that changes have been made to the model? And how is this done?

15. What do you know about PLM systems?
16. Do you work with the current PLM / PDM system?
17. What kind of info do you get from the system?
18. What do you want to do in the new system?
19. How would you like to work in the system
20. What kind of files would you like to add to the system?
21. How would you connect simulation files to a Volvo part or a CADpart?
22. How do you see that the simulation models are structured in the system?
23. Do you think the structure of how models are handled in the system is important?
24. Do you see any benefits of downloading input data (for projects or simulations) from the PDM system?
25. How do you maintain data that may be reused from projects today?
26. Do you think someone should be able to access the system externally?

Appendix B – Survey questions

1. What do you work with?

- ◯ Designer (Uses result from simulation)
- ◯ Simulation Engineer (Creates simulation models)
- ◯ Product owner/Project management
- ◉ Other

2. Do you work in the current PLM/PDM-system? (SmarTeam)

- ◯ Yes
- ◯ Yes, but not much
- ◉ No

3. What are the most important benefits of using a PLM/PDM system for your work? (Can choose a maximum of three answers)

- ☐ Better traceability
- ☐ History overview
- ☐ Easier data collection
- ☐ Reduced risk of data loss
- ☐ Better control of product data
- ☐ Reduced risk of double work (creating the same data/model twice)
- ☐ Tracking errors
- ☐ Reuse of data
- ☐ Storing data
- ☐ Other ______

4. What is simulation models used for in your work?

- ☐ Evaluation of product
- ☐ Testing of product design dimensions
- ☐ Testing of a system (cooling system/fuel simulation/engine simulation)
- ☐ Testing of performance
- ☐ Other ______
- ☐ Not applicable

5. Where are the simulation models stored?

- ☐ Saved locally on a computer or server (Can be accessed by the creator only)
- ☐ Easy access for other employees (server or another platform)
- ☐ Other ______
- ☐ Not applicable

6. Would there be any benefit to your work to add simulation models to a PLM/PDM system?

- ◯ Yes
- ◯ No

- Do not know

7. What benefits do you think adding simulation models to the PLM/PDM system will create? (Choose the three most important)

- More data available in one system
- Traceability
- Easier history overview
- Easier access to simulation models
- More control over simulation models
- Easier access to simulation data
- Reuse of simulation models
- Other ____________
- Not applicable

8. How do you collect input data today? (Choose the three most frequently used)

- Mail/skype
- Reports
- Servers
- PDM-system
- Face to face communication
- Estimation of data
- Other ____________
- Not applicable

Appendix C – Chart with respondents' answers compiled together.

Chart 1

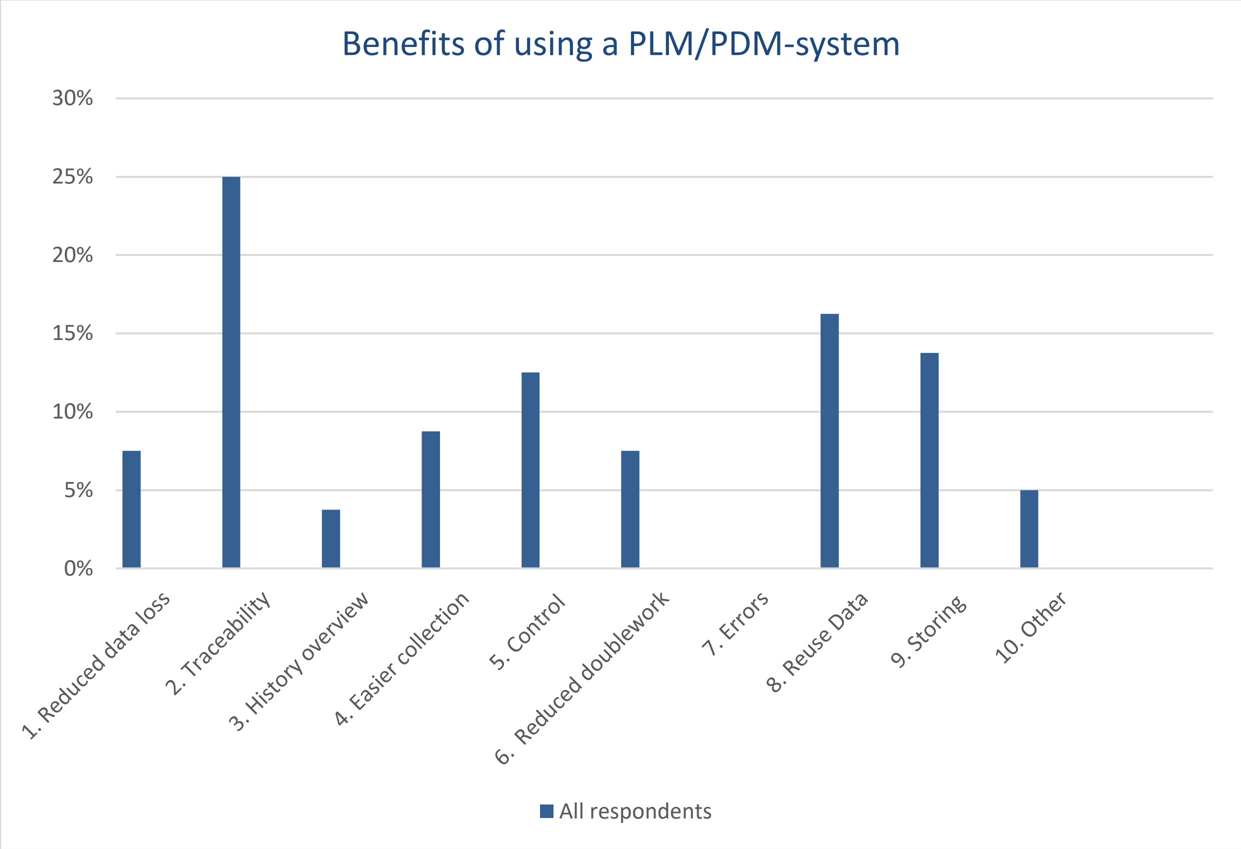


Figure 8 - Combined result of answers from survey question 3 (own produced)

Chart 2

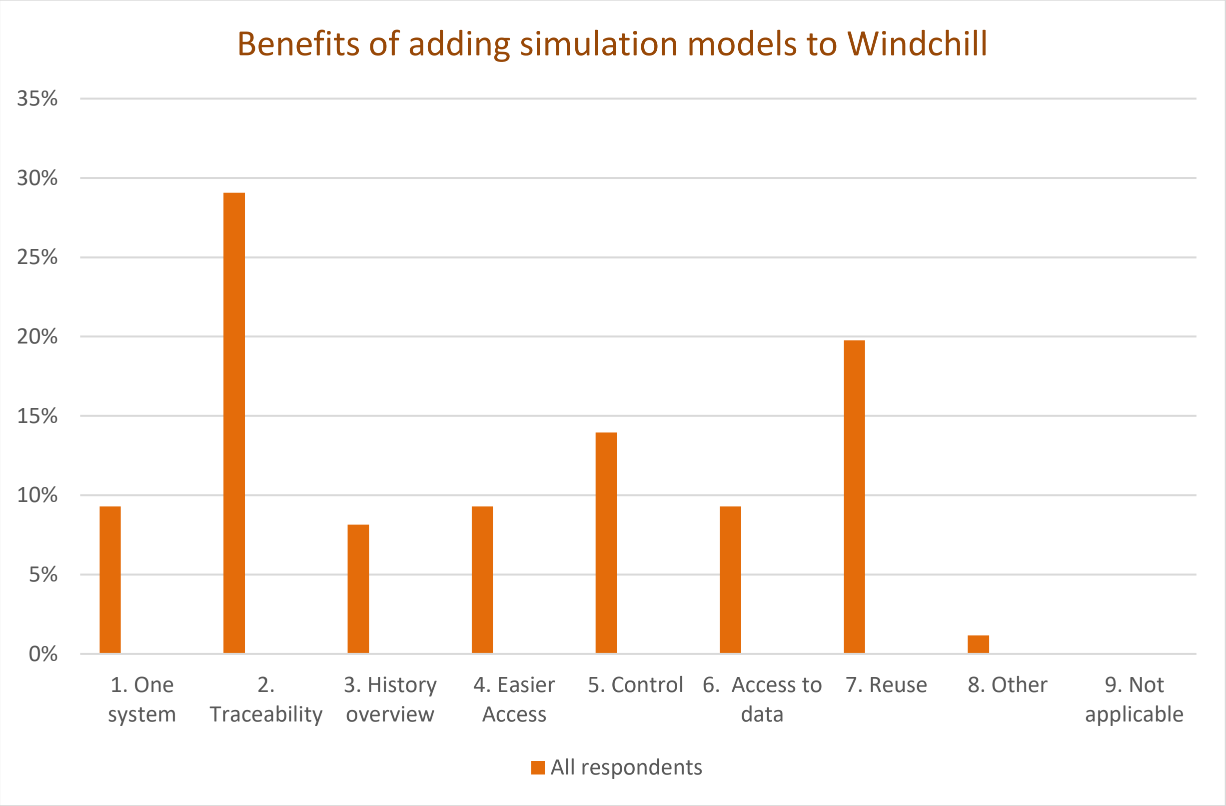


Figure 9 - Combined result from survey question 7 (own produced)

Appendix D – Storing of simulation models

This chart is based on the answers to question 5 from the survey, see Appendix B – Survey questions for full survey layout.

Chart 3

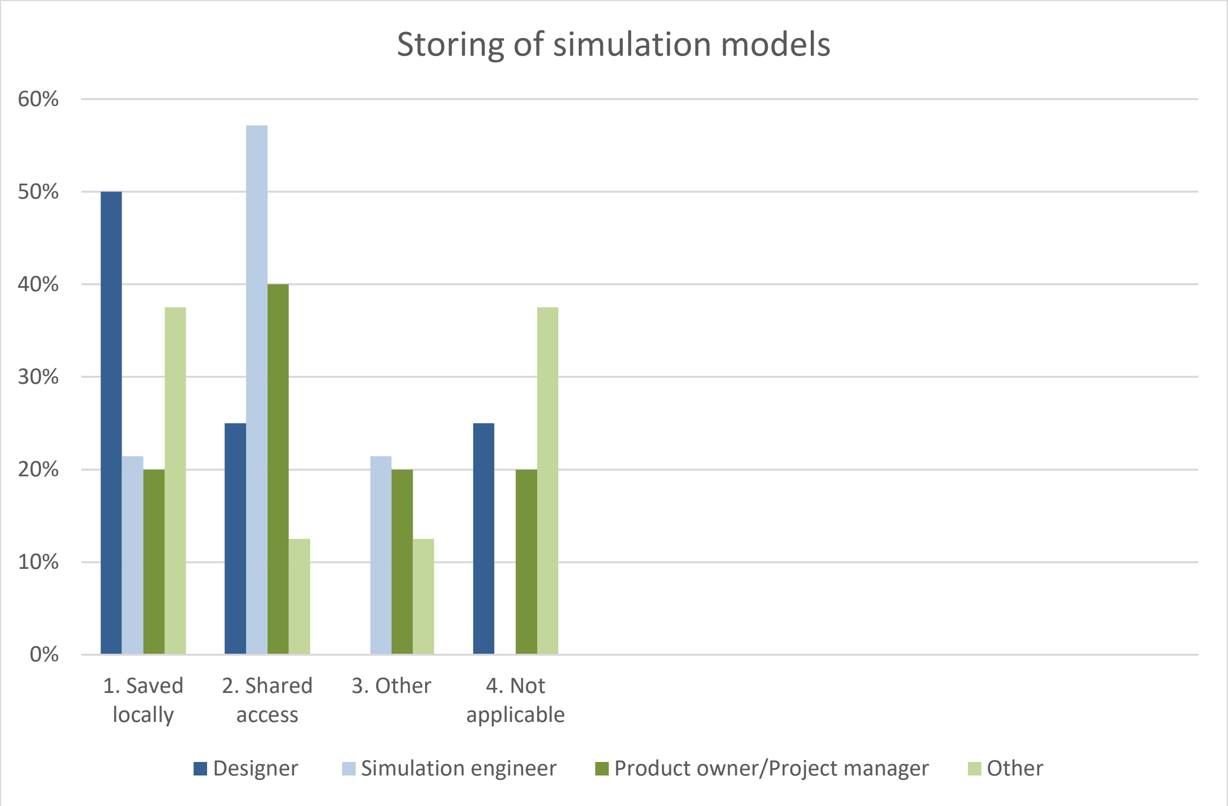


Figure 10 - result from survey question 5 (own produced)

MANUAL

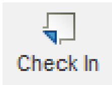
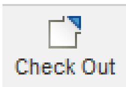
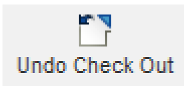
Introduction

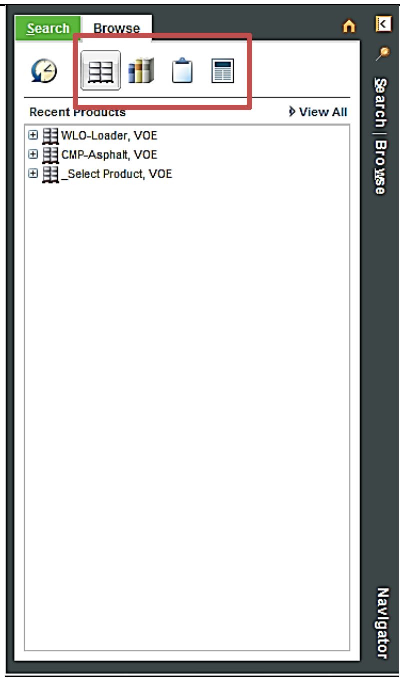
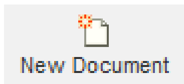
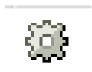
This is a short manual for adding GT-SUITE simulation models in Windchill. The manual will present some basic setup information like searching in the system, creating a workspace and then continue to show how simulation models can be added to the system. Manual is made for Windchill PDMLink release: 11.0 M030. The manual has been made with simulation models of cooling system files and not tested on other simulation files. This is made with how a simulation engineer may work in the system and does not cover everything. This manual was done 2019 in May when Windchill is starting to be implemented in the company, and therefore the system may look different from what is described in text and pictures. This manual is based on using Windchill in a web browser.

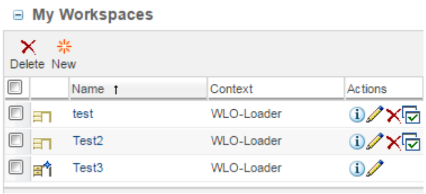
Explanations

A short explanation of words and actions for Windchill combined with pictures for easier understanding.

Table 4 - Description of different commands in Windchill

Name and description	**Picture/Icon**
<u>CAD document</u> Cad documents are CAD parts and drawings.	
<u>Check-In</u> A check-in releases the model back into the system. Are often done after alterations are done and finished. Or a new object has been created.	
<u>Check Out</u> Check out picks the model out of the system, and the model will have a checked out other employees and done when the part needs alteration and to prevent double copies. **<u>Undo Check Out</u>** Checks in the object without ant regards to the changes that have been made. Undo what has been done.	 

<u>Context</u> Are a collection of people, data and processes that organizes the database, these three factors are what defines a context. The context can be set to products, libraries, projects, and changes, see the red box in the picture to the right. Can be found by clicking on browse on the navigator pane to the left on the screen	
<u>Described by documents</u> This is found under the related objects tab on when viewing information about the Volvo part.	 
<u>Home</u> Home is where you can create a workspace, see your tasks, see your updates and checked out work.	
<u>New Document</u> Creates a new document in the system. This is how the simulation models are added. Can be found under Product Context -> Folders -> grey pane over the products in the context.	
<u>New Part</u> Creates a new part in the system. Can be found in a workspace. Or in on the folder in the product context.	
<u>Volvo part</u> A Volvo part represents the physical product with a part number and structure of the product. CAD documents and other files that	

represent or have a connection with the product are attached to this part.	
Workspace Is where you can manage your data without access from others. You can perform different actions and create new parts and CAD documents.	
View information Will open object and to the objects "home" page where details, structure, related objects, changes, history, where used, traceability and superseded can be viewed.	
Search Searching can be done in two ways, either by using the navigator pane or the quick search box in the upper right corner.	
Navigator The navigator can be found to the left on the screen, it's a black panel that has navigator written on it in the lower left corner. The navigator pane contains both search and browse functions. Is used when a more advanced search is done with different parameters and	
Related Objects Here you store your object that relates to the Volvo part. This is where the related documents, CAD documents, and others can be found.	

Basics

Home

Open Windchill and click on the orange house in the upper left corner. This is the home icon and will take you to your tasks, workspaces, updates and checked out work.

Workspace

To do a workspace, go to home and under *my workspace* click on new. Add a name, description and select context. Name and context are required.

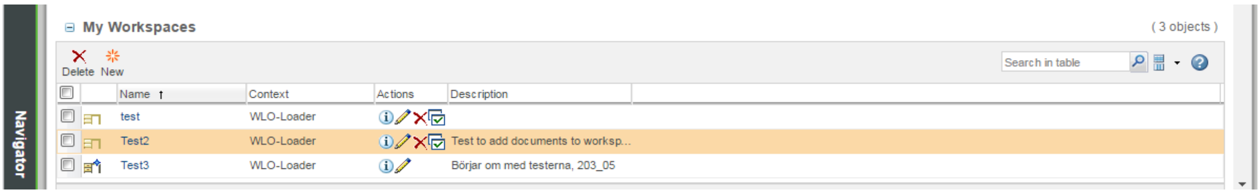


Figure 11 - Screen print of windchill and how to access workspace

To enter workspace click on the name or the view information icon. This the picture under is how the workspace should look when you enter.

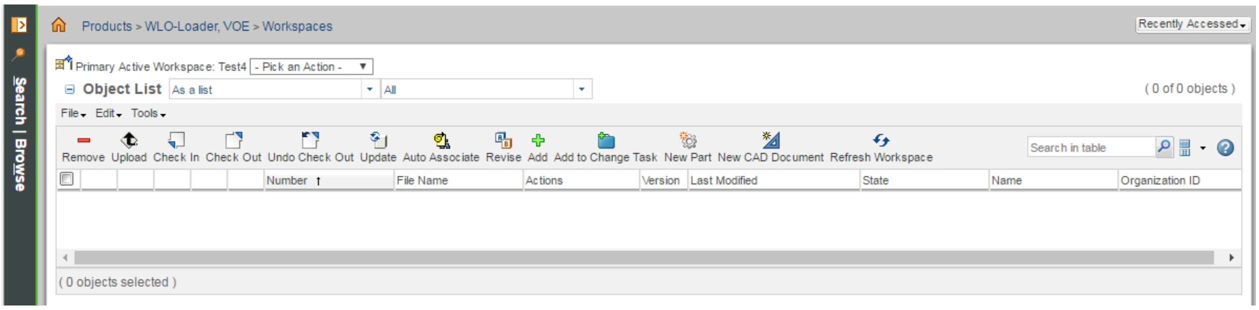


Figure 12 - Print screen of windchill workspace layout

Search

Alt 1: To do a search in windchill open the program and click on the search in the upper right corner. To the left of the search bar, in de drop-down menu, you can choose a specific type of file to search for or click all types. Fill in the part number and do the search.

Alt 2: To the left, you will find a navigator panel, click the word search or the orange arrow to extend the panel go to advanced search and fill in the search criteria, context, and type. Fill in the part number and do the search.

Models

Save a simulation model to an existing Volvo part

To add a simulation model to a Volvo part click on the view information page on the Volvo part, go to related objects (Volvo part must be checked in) click on the new document icon under described by documents. Fill in the correct data and used an appropriate document type e.g engineering document Browse for your local file and add the appropriate attachments. Using described by documents makes sure the file are always connected to the correct version of the product.

Create Volvo part (if the part doesn't exist)

To create a Volvo part, go to a workspace and select a new part from the overhead panel. Select context and click next. Set attributes and if needed, click create CAD document to auto-assign a CAD part.

Create a simulation model (not connected to a part)

Open the navigator bar and go to browse. Open the correct container (WHO-loader) and then click the folder. In the left corner on the overhead grey panel click the new document. Choose the correct type of document, engineering document, in primary content server fill in a local file. Upload the correct file and fill in the rest of the needed information. Then if there are any attachment files to the model, like context description or test result, then it can be uploaded in the next step otherwise click finish. To connect the model to a part go to the right part and

Check-in

Find the model by searching or looking in the workspace or go to home and lock under checked out work. To check in the simulation model, click on view information and the in the left corner click on actions and then check in.

Check out

To check out the simulation model follow the steps above to locate the model. Then click actions and choose to *check out*, *check out and download* if you need the file and, *check out and edit* to choose a new version of the model from a local file.

For further help see:

https://support.ptc.com/apps/help_center/brand=Windchill?redirect=no

To see which release of Windchill is in use, see the right corner of the screen:
Quick links -> Help -> About Windchill
The release version will be stated at the top to the right.