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Engineering Change Management in Shipbuilding

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Vår dato 2012-01-16 Vår referanse EAL/LMS

MASTEROPPGAVE

Våren 2012

for

stud. techn. Knut Magnus Gjertsen Norbye

ENDRINGSHÅNDTERING I SKIPSPROSJEKTERING
(Change Order Management in Ship Projects)

"Innovation in Global Maritime Production 2020 (IGLO-MP)" skal lage løsninger for framtidens global skipsprosjektering og fabrikasjon. Prosjektleder er Ulsteingruppen, et norsk industrikonsern innen skipsprosjektering og -fabrikasjon av skip og integrasjon av skipsteknisk utstyr.

Skipsprosjektering involverer usikkerhet og krav til endringer som ofte skaper forsinkelser. Effektive endringsprosesser og innovative planleggingsmetoder kan bidra til raskere behandling og redusere effekten av endringer på den endelige leveringsdatoen. Ulstein Verft bruker PLM-systemet *Nauticus Yard Package* for å styre informasjons- og arbeidsflyt i de fleste av prosjektene sine. Nauticus erstatter egenutviklede systemer med en helhetlig integrert løsning som også er integrert med ERP-systemet *Multi*. Ulstein har derfor et godt utgangspunkt for å skape mere effektive engineering og planleggingsprosesser i sin verdikjede.

Masteroppgaven vil skje i tett samarbeid med SINTEF og prosjektet IGLO-MP (http://www.iglo-mp2020.no/).

Studenten skal arbeide med følgende problemstillinger:

1. Gi en oversikt over relevant teori og best practices innen engineering drawing management og change order management i prosjektbaserte verdikjeder.

2. Kartlegging av Ulsteins engineering change management-prosess og planleggingsfunksjonalitet i eksisterende IKT-systemer hos Ulstein, samt to-tre andre kommersielle IKT-systemer. Benytte prosjektoppgavens resultater til å analysere muligheter og begrensinger, og lage en overordnet kravspesifikasjon for engineering drawing management og change order management ved hjelp av Nauticus.

3. Utvikling av prototype basert på kravspesifikasjonen.

Oppgaveløsningen skal basere seg på eventuelle standarder og praktiske retningslinjer som foreligger og anbefales. Dette skal skje i nært samarbeid med veiledere og fagansvarlig. For øvrig skal det være et aktivt samspill med veiledere.

Innen tre uker etter at oppgaveteksten er utlevert, skal det leveres en forstudierapport som skal inneholde følgende:

- En analyse av oppgavens problemstillinger.
- En beskrivelse av de arbeidsoppgaver som skal gjennomføres for løsning av oppgaven. Denne beskrivelsen skal munne ut i en klar definisjon av arbeidsoppgavenes innhold og omfang.
- En tidsplan for fremdriften av prosjektet. Planen skal utformes som et Gantt-skjema med angivelse av de enkelte arbeidsoppgavenes terminer, samt med angivelse av milepæler i arbeidet.

Forstudierapporten er en del av oppgavebesvarelsen og skal innarbeides i denne. Det samme skal senere fremdrifts- og avviksrapporter. Ved bedømmelsen av arbeidet legges det vekt på at gjennomføringen er godt dokumentert.

Besvarelsen redigeres mest mulig som en forskningsrapport med et sammendrag både på norsk og engelsk, konklusjon, litteraturliste, innholdsfortegnelse etc. Ved utarbeidelsen av teksten skal kandidaten legge vekt på å gjøre teksten oversiktlig og velskrevet. Med henblikk på lesning av besvarelsen er det viktig at de nødvendige henvisninger for korresponderende steder i tekst, tabeller og figurer anføres på begge steder. Ved bedømmelsen legges det stor vekt på at resultatene er grundig bearbeidet, at de oppstilles tabellarisk og/eller grafisk på en oversiktlig måte og diskuteres utførlig.

Materiell som er utviklet i forbindelse med oppgaven, så som programvare eller fysisk utstyr er en del av besvarelsen. Dokumentasjon for korrekt bruk av dette skal så langt som mulig også vedlegges besvarelsen.

Kandidaten skal rette seg etter arbeidsreglementet ved bedriften samt etter eventuelle andre pålegg fra bedriftsledelsen. Det tillates ikke at kandidaten griper inn i betjeningen av produksjons-maskineriet, idet alle ordrer skal formidles på vanlig måte gjennom fabrikkens bedriftsledelse.

Eventuelle reiseutgifter, kopierings- og telefonutgifter må bære av studenten selv med mindre andre avtaler foreligger.

Hvis kandidaten under arbeidet med oppgaven støter på vanskeligheter, som ikke var forutsett ved oppgavens utforming og som eventuelt vil kunne kreve endringer i eller utelatelse av enkelte spørsmål fra oppgaven, skal dette straks tas opp med instituttet.

Oppgaveteksten skal vedlegges besvarelsen og plasseres umiddelbart etter tittelsiden.

Besvarelsen skal innleveres i 1 elektronisk eksemplar (pdf-format) og 2 eksemplar (innbundet).

Innleveringsfrist: 11. juni 2012

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Erlend Alfnes
faglærer

Preface

This report is the result of the master thesis "Engineering Change Management in Shipbuilding". The thesis was developed in collaboration with Ulstein, SINTEF and project IGLO-MP 2020. The master thesis has been written during the spring semester in 2012 at the Norwegian University of Science and Technology (NTNU). The thesis work has been carried out at the Department of Production and Quality Engineering (IPK).

I would like to thank my supervisor at SINTEF Dag Haartveit, and the responsible teacher at IPK Erlend Alfnes, for good and valuable guidance throughout the work on the thesis. A special thanks goes to the case company Ulstein, my supervisor at Ulstein, Runar Toftesund, and Odd-Sverre Volle for making the case study possible.

I would also like to thank Lars Fossum from Summit Systems for the hospitality during my visit to the Oslo headquarters, and for valuable information on Teamcenter. Last but not least I would like to thank the people that have attended meetings and answered my questions, for their contribution to this project:

- Ronny Dagfinn Dimmen, Ulstein
- Gaute Gaudestad, Ulstein
- Vidar Gjerdsbakk, Ulstein

Trondheim, June 11th 2012

Stud.techn

Knut Magnus Norbye

Abstract

In today's global competitive market, it is getting increasingly more important to continuously improve by delivering high quality products at a faster rate and to a lower price, in order to stay competitive. In this context, companies have recently realised the significant advantages a proper engineering change management (ECM) process can yield in terms of time to market and reduced cost. Thus, there is an increased attention towards technology that can better cope with the current ECM problems, and thereby aid a company in getting the competitive edge compared to its competitors. However, since such technology selection is one of the most challenging decisions company management encounters, it is crucial to have a good understanding of the problem ahead and implications of the possible solutions.

The overall purpose of this thesis is to develop a framework that will aid companies with ECM related technology selection. Prior research has already identified ECM as a critical process in new product develop and thereby crucial for a company's competitiveness. Despite the importance, the previous research on ECM appears as scarce. Hence, the technology selection framework is a response to the increased awareness of the significant advantages a proper ECM process can yield, along with the inadequate attention ECM has received in academic research literature.

The research presented in this thesis includes a review of literature on product lifecycle management (PLM) and ECM. The research identifies four core ECM problems, change propagation, knowledge management, collaboration, and information interpretation. Along with these problems, the research also identifies a wide variety of different solutions and approaches to cope with the problems. These findings are then consolidated into a framework providing a concise overview of the key characteristics and relationships among ECM problems and solutions.

A study on Simens' PLM system Teamcenter was also performed. This examination was performed in an ECM context, where the intention was to get a broader understanding of which ECM capabilities that are present in today's information technology (IT) solutions. Through consolidating the findings from the Teamcenter examination and the findings from the literature study, a revised framework was developed.

The last part of the research presents a case study of the Norwegian shipbuilding company Ulstein. The purpose of the case study was to thoroughly analyse Ulstein's current ECM process by adapting the technology selection framework. The case study presents Ulstein's current ECM process, followed by an extensive discussion of possible improvements. Based on this assessment, concluding remarks on how Ulstein should improve their current ECM process were made.

The proposed framework makes it possible for a company to easily classify its own capabilities in relation to the core ECM problems. When adapted, the framework will provide an intuitive overview which enables the company to compare its own capabilities with other solutions available, aiding the process of adapting new technology and assessing its potential impact.

Sammendrag

I dagens globale konkurransemarked, er det et stadig økende press for å kontinuerlig forbedre bedriften ved å levere bedre produkter, raskere og til en lavere pris, for å kunne være konkurransedyktig. I denne sammenheng har bedrifter nylig innsett viktigheten av en god endringshånderingsprosess, og hvilke fordeler det kan gi i forhold til redusert leveringstid og reduserte kostnader. Dette har resultert i en økende interesse for teknologi som kan takle dagens endringshånderingsproblemer på en bedre måte, og dermed bidra til å øke konkurransedyktigheten til bedriften. Det har seg imidlertid slik at det å velge ny teknologi er en av de mest krevende problemstillingene en bedriftsledelse kan stå ovenfor, og det er derfor essensielt å ha en god fortståelse av de foreliggende problemene og konsekvensene av de mulige løsningene.

Det overordnede målet for masteren er å utvikle et rammeverk som vil assistere bedrifter med evaluering av endringshåndterings-relatert teknologi. Tidligere studier har allerede identifisert endringshåndtering som en kritisk prosess ved utvikling av nye produkter og dermed avgjørende for bedriftens konkurransedyktighet. Til tross for dette virker literaturen som omhandler endringshåndtering som utilstrekkelig. Rammeverket er altså en reaksjon til den økende interessen for endringshåndtering i industrien, samt den manglende oppmerksomheten endringshåndtering har mottat i akademisk litteratur.

Det som er presentert i denne masteren inkulderer en litteraturstudie om product lifecycle management (PLM) og endringshåndtering. Fire forskjellige endringshåndteringsproblemer har blitt identifisert, henholdsvis change propagation, knowlege management, collaboration og information intepretation. I tillegg til disse problemene har det blitt identifisert en stor variasjon av forskjellige løsninger på disse problemene. Dette har da blitt sammlet i et rammeverk som viser en kortfattet oversikt over sammenhengen mellom endringshåndteringsproblemene og løsningene.

Det har også blitt gjennomført en undersøkelse av Siemens’ PLM system Teamcenter. Undersøkelsen ble gjennomført med fokus på endringshåndtering, hvor målet var å få en bedre forståelse for hvilke endringshåndteringsfunksjonaliteter som finnes i dagens IT-system. Ved å sammenfatte funnene med det eksisterende rammeverket, ble et nytt og forbedret rammeverk utviklet.

Den siste delen av masteren presenterer en case study om den norske skipsbygger-bedriften Ulstein. Målet med undersøkelsen var å nøye analysere Ulstein’s nåværende endringshåndteringsprosses ved å bruke det utviklede rammeverket. I denne delen blir endringshåndteringsprosessen til Ulstein detaljert beskrevet fulgt av en omfattende diskusjon om mulige forbedringer. Bassert på denne analysen konkluderes det til slutt med hvordan Ulstein skal gå fram for å forbedre endringshåndteringsprossesen.

Det foreslåtte rammeverket gjør det mulig for en bedrift å enkelt identifisere sine egne evner i forhold til de nevnte endringshåndteringsproblemene. Rammeverket gir også en intuitiv oversikt som sammenligner deres nåværende evner med andre mulige løsninger, noe som er til stor hjelp når ny teknologi skal vurderes.

Contents

1. Introduction

This thesis is related to the ongoing research project “Innovation in Global Maritime Production 2020” (IGLO-MP 2011), which is a knowledge-building project executed in collaboration with Norwegian University of Science (NTNU), Marintek, and industrial partners such as Ulstein (IGLO-MP 2011). The main goal of the IGLO-MP project is to enhance the competitiveness of Norwegian maritime industry by strengthening their competitive capabilities (IGLO-MP 2011). The project leader of IGLO-MP is Ulstein Group, a Norwegian shipbuilding company which have gained international recognition due to their high quality, innovative designs and accurate deliveries (UlsteinGroup 2011).

The following sections will present background and motivation for undertaking this project, problem statement, research questions along with an overview of the project structure.

1.1 Background and motivation

In general, shipbuilding today encounters many challenges that are not common for other industries Among them, is the enormous amount of information flowing through a complex network of receivers and senders, which is a result of the complex structure of a ship, the numerous working disciplines involved, and the involvement of other companies. (Mello and Strandhagen 2011)

Engineering changes appears as an additional dimension to this complexity, changes which unfortunately are unavoidable, especially on large and complex projects like ship projects (Wasmer, Staub et al. 2011). Although engineering changes is a source of product improvement, the negative impact of engineering changes is what receives the attention. It has been reported that Engineering Changes can consume as much as one-third to one-half of the engineering capacity, and represent 20% to 50% of the tool cost(Terwiesch and Loch 1999; Kocar and Akgunduz 2010). Such numbers can easily account for over US$ 100 million in large development projects(Terwiesch and Loch 1999). Thus, the importance of proper change handling is crucial for a company’s competitiveness. However, despite its importance to industry, it seems that engineering change management (ECM) has not received adequate attention in academic research literature(Huang, Yee et al. 2001; Joshi, Ameri et al. 2005).

Despite the lack of research on ECM, one can easily argue that the future of proper change handling will most likely depend on the adaption of new and suitable information technology (IT). This is mostly due to the increasing global competition in today’s industry, which have made adapting the right technologies of significant strategic importance (Xiaofeng, Peng et al. 2012). The importance of technology adaption is further supported by Torkkeli and Tuominen (2002), which argues that the right technology can create significant competitive advantages for a company in a complex business environment. There are however many challenges related to technology adaption. In fact, considering the rapid development of technologies, together with their increasing complexity and variety, technology selection is one of the most challenging decision making area company management encounters (Torkkeli and Tuominen 2002).

1.2 Problem statement

Managing engineering changes has always been a challenging task, and it is still a regular source of inefficiency and irritation for manufacturers(AberdeenGroup 2007). However, it's not until recently that companies have realised the significant advantages of a proper change management process. Thus, many companies now seek to improve their engineering change management process in order to reduce time to market. (AberdeenGroup 2007)

The first question asked in this thesis is then, what are the different approaches and IT solutions used in order to improve the efficiency of engineering change management. In light of this question it is necessary to explore the current ECM challenges experienced today, and find different approaches which tries to solve one or more of these challenges. This will be achieved by examining literature on the topic engineering change management and by analysing one existing solution in today's industry. The examined software chosen for this study is Teamcenter, a PLM system developed by Siemens.

Based on the knowledge retrieved from answering the first question and the resulting framework, the second question will focus on how the current ECM process at Ulstein can be improved. This will be done by adapting the maturity framework in order to identify Ulstein's current ECM process along with possible higher maturity opportunities. The opportunities will be discussed in regards to adaptability in an ETO environment and implications that follows new technology adaption, where the result eventually will be a suggestion on how to improve their current process.

The two problem statements for this thesis are:

1. What are the different approaches to solving today's ECM problems and to what degree are these approaches supported by IT solutions?

2. How can the current ECM process at Ulstein be improved?

1.3 Thesis Goals

The overall goal of this project is to develop a framework that will aid companies with ECM related technology selection. The framework will be based on theory about Engineering Change Management and the ECM capabilities that reside within today's IT-systems. The main goals to achieve this are based on the initial set of project goals as presented at the very beginning of this thesis, along with discussions with the supervisors. The goals are presented below.

1. *Develop a theoretical framework that aids companies with technology selection related to ECM*

2. *Analyse the PLM system Teamcenter's ECM functionality*

3. *Develop a revised framework combining the previous framework with knowledge obtained through analysing Teamcenter.*

4. *Analyse Ulstein's current IT-systems in terms of ECM functionality with the aid of the theoretical framework.*

1.4 Research questions

To expand the problem statements, three research questions have been formed. The three research questions will form the background for the literature review. The questions were based on an initial assessment of which topics were required in order to answer the problem statements in a sufficient manner.

The outcome of answering the research questions will be the main contribution towards developing a theoretical ECM maturity framework. The research questions are listed below. The findings regarding the research questions will be presented at the end of the literature review.

RQ1: *What are the challenges experienced in today's ECM process?*

RQ2: *Which approaches and technologies are currently used in order to cope with these ECM challenges?*

RQ3: *How can PLM systems be leveraged in order to better support the engineering change management process?*

1.5 Project structure

This thesis is divided into three parts. The thesis structure is shown in Figure 1 below.

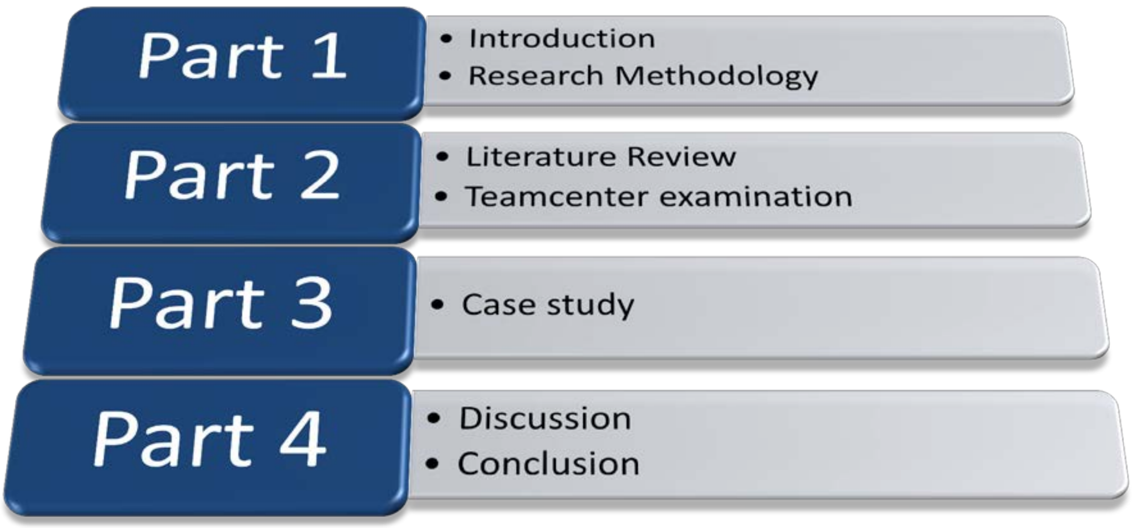

Figure 1: Project Structure

The first part introduces the thesis by presenting the background, problem statement and research questions. Research methodology is also included in this part, which outlines the research methods adapted to answer the problem statement and research questions.

Part two consists of a comprehensive literature review elaborating on important theoretical aspects such as ECM and PLM required in order to find solutions to the problem statements given in section 1.2 Problem statements. In order to arrive at a sounds answer to the problem statement, the three first research questions have been used to guide the literature review process. In order to validate and further extend the findings from the theory, an examination of an existing PLM system was also performed. The examination of the PLM system Teamcenter was a combination of a theoretical and empirical research. The study intended to show the actual limitations and possibilities in today's PLM systems, which again broadens the understanding of possibilities and limitations in terms of ECM, as identified in the literature review. Through combining the findings from the literature review and the Teamcenter examination, an ECM maturity framework has been proposed. The framework links current ECM problems with different approaches and IT solutions, which then have been classified according to how well the approach copes with the problem.

Part three starts off with introducing the case company Ulstein and its current ECM process. Their ECM process is then more thoroughly assed by applying the ECM maturity framework developed from the literature review and Teamcenter examination.

Part four finishes off the thesis by first discussing the findings from the case study and relate the findings to the literature review. This is then used to conclude the thesis and answer the main problem statements.

2. Research methodology

In order to address the project statement and fulfil the goals of the master's thesis, there is a need for an appropriate research methodology along with suitable research methods. Although being used interchangeably there are differences between a methodology and a method. Kaplan (1964) defines methodology as "the study—the description, the explanation, and the justification— of methods, and not the methods themselves", whereas a method is defined as "techniques for gathering evidence". Hence, whereas methodology is an overall understanding of the nature of the research and the research strategies used to answer the research questions, a method refers to the tools used to find the solutions. The following sections will define and present the different research methodologies, along with the chosen approach and methods used for research in this project.

In general, there are two different types of research methods, qualitative and quantitative research. Qualitative research relies on text data and analysing the data in its textual form, or as defined by Strauss and Corbin (1990), "any kind of research that produces findings not arrived at by means of statistical procedures or other means of quantification". Quantitative research on the other hand relies on numerical data, or textual data converted into numbers for analysis (Little 2011). Hoepfl (1997) distinct the two with the following sentence:

"*Where quantitative researchers seek causal determination, prediction, and generalization of findings, qualitative researchers seek instead illumination, understanding, and extrapolation to similar situations. "*

Greener (2008) further identifies two main approaches to theory research, deductive and inductive. A deductive approach starts of by looking at theory, and follows up with hypotheses which relates to the focus of the research, and the proceeds to test that theory. The inductive approach on the other hand starts of by investigating the focus of the research, and through applying different research methods, aims to generate new theory.

2.1 Research Design

As stated by Selnes (1999), research design is an overall plan for how to research should be conducted. Selnes (1999) further identifies the three main categories of research design, *exploratory*, *descriptive*, and *causal* design. Each of the three categories have their own characteristic approaches, thus the choice of research design is dependent upon the characteristics of the problem. Although each of them has their own distinct characteristics, they do however occasionally overlap. The three categories are described below.

An Exploratory design is commonly used when the problem description is vague, and the researcher possesses little or no prior knowledge of the topic. Put otherwise, it is used when you are faced with a phenomenon you want to know more about, but without any idea on how to analyse it. The goal of such research is to explore this phenomenon, where the result is new knowledge and quite possibly a better understanding of the problem ahead. These results could then lead to new research with design classified as descriptive or causal. (Selnes 1999)

A descriptive design is used if the problem is to describe one or more variables and their connection with each other. It defers from the above mentioned exploratory design by the requirement for reliable facts. Already from the initial phase of the research one should have a good understanding of the variables in question. Furthermore, a relatively clear hypothesis on how the variables interact with each other should be present. (Selnes 1999)

A causal design is used in cases where the goal is to measure the effect on a variable from different stimuli. In other words the design intends to identify possible cause and effect relationship, also called causality. The relationship between commercials and actual sale is an example of problem with such causal characteristics. A common problem with causal research is however the interference of other variables, which could be the source of the measured effect. Thus, controlling such independent explanation variables should be emphasised. To prove a causality with 100% certainty is however not possible. (Selnes 1999)

The research conducted in this thesis has been a combination of exploratory and descriptive. The first part, including the literature review and Teamcenter examination, is based on a descriptive design approach. The information gathered are from well know phenomena, ECM and PLM respectively, whereby the connection between the two gets further elaborated based on the different statements and theory from the research. Through consolidating the theory from research literature along with an empirical examination of one of today's PLM solutions, it is possible to develop a framework that presents the different approaches for solving today's ECM problems.

The second part of the thesis, the case study, will on the other hand be more exploratory. The intention is to identify how Ulstein can improve their current ECM process. However, due to the lack of knowledge about Ulstein's current ECM process, a more thorough exploration has to be done. This was achieved by adapting the framework developed from the literature study and the Teamcenter examination, which enabled the identification of Ulstein's current ECM capabilities, while at the same time comparing it with different approaches. This resulted in a much better understanding of Ulstein's current ECM process and ECM capabilities, which again was the source of suggestions for further research and improvements.

Throughout the research, the thesis has always been focused towards the topic "Engineering change management in shipbuilding". The goal of developing a framework that will aid companies with ECM related technology selection has been achieved through adapting several different research methods, as described below in 2.2 Research Methods. Such focus, along with the application of different research methods, aligns very well with the definition of an inductive approach, as described by Greener (2008). Thus, given the exploratory, descriptive and inductive nature of this thesis, it follows from Hoepfl's (1997) definition, that a qualitative approach is most suitable.

2.2 Research Methods

This section will present and elaborate on the qualitative research methods used to gather data for this thesis. The methods presented below will be literature study, examining the PLM system Teamcenter, and finally, the gathering of data from the case company Ulstein.

2.2.1 Literature study

In order for the thesis to qualify as a contribution to the knowledge concerning Engineering Change Management, the knowledge presented shall not have been published in any respected publication. Thus, it is important to do a thorough literature study in order to know what is already published. Another reason to perform a thorough literature study is the inspiration aspect. Reading through what others have written on the subject will most likely contribute with valuable inspiration to research issues and even suggestions for further research. (Karlsson 2008)

L. Rienecker (2011) identifies three basic approaches to literature search; Chain search, systematic search and intended random search. As the topic and core content of this thesis was defined early in the process, the need for intended random search was not present. This is due to the intended results of the method, which is to inspire and provide new ideas. Hence, the two preferred search methods for this thesis are chain and systematic search, which will be presented below.

A chain search is aimed towards finding relevant literature by following a chain of references, one article leads to another. The quality of the originating article should thus be emphasised. The strength of the method is the ability to follow the key arguments by following a trail of good references. On the other hand, its weakness is lack of different perspectives on the given phenomena. Thus, any opposing theories might not be revealed through this search method. (L. Rienecker 2011)

Systematic search is used if the goal is to find literature on a specific topic, a specific author or a theoretical orientation. This search method is usually used in electronic databases, whereby a distinct search profile or search strategy is applied in order to systematically process the extensive amounts of information. The search profile usually consists of specific search words and combinations of these. In contradiction to chain search, this method will most likely reveal different opinions and perspectives on the given topic. The result of the systematic search performed in this thesis can be seen in Appendix E – Literature overview.

Due to the extensive amounts of hits on terms like Engineering change management, the scope of the search was narrowed down to articles dated after year 2000 for ECM articles. This is also due to the fast pace technology evolvement, which implies that anything dated later than year 2000 would most likely be out-dated technology wise, and thus not be relevant for this thesis. In order to further narrow the number of results, the extensive amount of possibly relevant articles was filtered by reading the abstract. The articles with a promising abstract were then read more thoroughly, whereby they were graded according to relevancy, classified according to ECM problem, and given relevant comments as seen in Appendix E – Literature overview.

2.2.2 Case study

As a method for collection of qualitative data, a case study approach has been applied. Yin (2003) defines case study as "*an empirical inquiry that investigates a contemporary phenomenon within its* *real-life context, especially when the boundaries between phenomenon and context are not clearly evident*".

Case study has been identified as one of the most consistent and powerful research methods there is, especially in relation to new theory development. Case research is actually a demanded research method, due to the frequency and magnitude of the changes in technology. Moreover, this research method is highly recognised among practitioners.(Karlsson 2008)

The case study approach has been adapted to this thesis in order to identify current engineering change management problems in shipbuilding, and to what degree IT is used to cope with these problems. The case study has been performed as a single case research, where the case company was Ulstein Yard. The benefit of undertaking a single case research is that it enables the researcher to do a really thorough research(Karlsson 2008). However, as it just represents a single event, it limits the generalizability of the conclusion(Karlsson 2008).

The case study approach was also applied on the PLM system Teamcenter. This was done in order to investigate the ECM capabilities of a PLM system. Similar to the Ulstein case, also this case study was performed as a single case research, which again limits the generalizability of today's PLM systems ECM capabilities(Karlsson 2008). Nonetheless, being able to consolidate theory with actual system capabilities was a strengthening aspect for the final framework.

2.3 Sources of Error, Validation, Reliability and Objectivity

The three possible sources of error in this Master's thesis are:

- The literature: As the literature in this report is heavily based on previous research, it is possible that some of the literature could suffer from inadequate or incorrect information. However, since most of the used literature have been collected from highly recognised research-databases, as presented in Appendix B – Databases, this appears as unlikely. Although it is an unlikely scenario, the importance of using a broad range of research papers and authors has been emphasised.
- Teamcenter examination: As with any sharing of information, whether it is written, verbally or visual, there are room for misinterpretations, which again could lead to errors in my interpretation of Teamcenter. Furthermore, the Teamcenter documentation, which is the core source of information, is written to target potential customers. Thus, what is presented in the documentation might create an inaccurate perception of the actual system. Hence a critical view has been emphasised. Furthermore, I have had Summit Systems, the provider of Teamcenter in Norway, to clarify and elaborate on any uncertainties I had in regards to the documentation.
- The case study: As with any sharing of information, whether it is written, verbally or visual, there are room for misinterpretations, which again could lead to errors in the case study. In order to prevent such errors, I have sought to seek validation from advisors and people from the case company.

3. Literature review

The following chapter will present the key findings of this master thesis. The sections are divided as follows, 3.1 will present a brief introduction to Engineering Change Management (ECM), Product Lifecycle Management (PLM), Engineer-to-order (ETO), and technology selection. Section 3.2 will move on to the actual literature where the current PLM and ECM challenges are identified, along with a variety of different solutions to these problems. Section 3.3 will present the answer to the research questions stated in section 1.4 Research questions. Finally the findings will be consolidated into a maturity classification framework for ECM in section 3.4.

3.1 Definitions

3.1.1 Engineering Change Management

Kocar and Akgunduz (2010) defines Engineering change management as "*The process of organising, controlling and managing the workflow and information flow for Engineering Changes".* Whereas Engineering changes (EC) refers to modifications in shape, function, material or dimension of a product(Huang, Yee et al. 2001). Changes like these are unfortunately unavoidable, especially on large and complex project (Wasmer, Staub et al. 2011). The negative impact of these engineering changes has been reported by numerous authors (Terwiesch and Loch 1999; Kocar and Akgunduz 2010). It has been reported that Engineering Changes can consume as much as one-third to one-half of the engineering capacity, and represent 20% to 50% of the tool cost, which easily can account for over US$ 100 million in large development projects (Terwiesch and Loch 1999). Thus, the importance of proper change handling is crucial for a company's competitiveness.

Although ECs usually have a negative impact and are perceived negatively, something that has been reported in numerous studies, they also contribute with cost savings and performance improvements (Terwiesch and Loch 1999; Eckert, Clarkson et al. 2004). Thus, removing ECs entirely is both unrealistic and undesirable (Clark K. B. 1991). However, even though ECs contributes to product improvement, ECM is a very costly part of a project, with a value-added time as low as 8.5 % (Kocar and Akgunduz 2010). Although 8.5% isn't the reality for every company, it does reflect the fact that the ECM process experiences long ECR processing times. This also correlates with the findings done by the AberdeenGroup (2007), where shortening development lead time has been identified as the top pressure for improving change management performance.

3.1.2 Product Lifecycle Management

As the global competition is an ever-increasing factor, many companies have seen it as a necessity to invest in process improving tools(Vezzetti, Moos et al. 2011). Considering today's knowledge-intensive product development environment, the requirement for a framework which effectively enables capture, representation, retrieval and reuse of product and process knowledge, is evident(Ameri and Dutta 2005). Combining that with the necessity for collaboration across distributed and multidisciplinary design team constitutes the essence of Product Lifecycle Management(Ameri and Dutta 2005). Seeing as knowledge management and collaboration tools are identified as a key factor for competitiveness in today's industry, PLM solutions appears as an essential tool for coping with the challenges ahead(Saaksvuori. and Immonen 2008).

CIMdata (2012) defines PLM as "*A strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise from concept to end of life-integrating people, processes, business systems, and information*." It should be emphasised that PLM is not the definition of a piece of technology. It is a definition of an information strategy which emphasises a coherent data structure through consolidating systems. Some might also define it as an enterprise strategy, because it lets global organisations work as a single team throughout the products lifecycle, while capturing best practices and lessons learned along the way. (Siemens 2012)

Looking back a few decades one can see that today's PLM systems have their roots in computer aided design (CAD) and product data management (PDM) systems. In the 1980s, engineering design entered a new era with the introduction of CAD systems. This was closely followed by the PDM systems as a result of the increasing volume of information created by the Computer-aided Design, Manufacturing and Engineering Systems. Although PDM did evolve over the years, it was still limited to engineering information like geometric models and BOMs, leaving out other aspects of the product's lifecycle. As a result PLM appeared with the intention of extending PDM beyond engineering and manufacturing into more strategic areas like marketing, sales and after sales service, and at the same time addresses all the stakeholders of the product throughout its lifecycle. Clearly an extension like that exceeds the engineering data provided by the PDM systems. In terms of ECM, PDM systems would only be able to notify other engineering applications of any changes. PLM on the other hand, with its extended knowledge base, enables the change to propagate throughout the lifecycle of the product, making its real impact measurable. However, although PLM solutions has been around for almost 20 years, authors still argues that that there are no comprehensive PLM systems existing today that fulfils its tasks satisfactorily. (Ameri and Dutta 2005; Lee, Ma et al. 2008)

3.1.3 Engineer-to-Order

Throughout the manufacturing industry, there are several different manufacturing strategies, usually affected by the market, product and production factors in question. Olhager (2003) identifies four different manufacturing situations; Make to stock (MTS), Assemble to order (ATO), Make to order (MTO) and Engineer to order (ETO). Each of them got their own characteristics that are able to satisfy different customer needs.

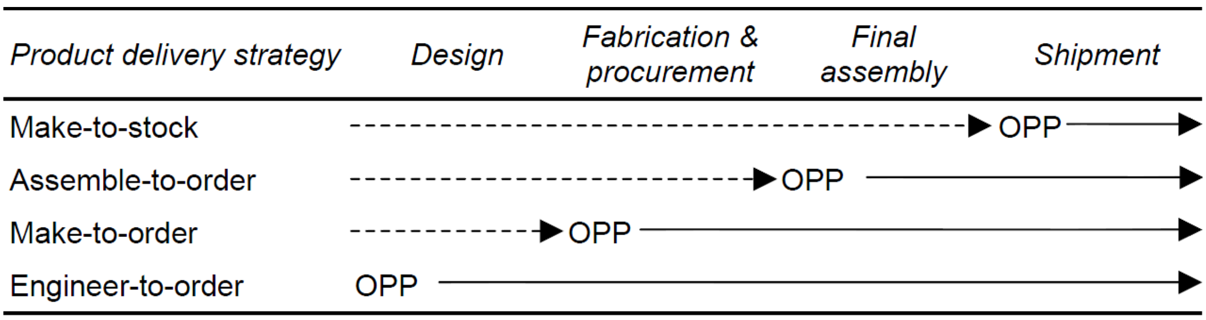

Figure 2: Order penetration point in a manufacturing environment (Olhager 2003)

Each of the manufacturing environments can be easily identified by the order penetration point (OPP), also known as customer order decoupling point (CODP), as seen in Figure 2. The OPP is defined as a specific point in the product value chain, where the product gets linked to an actual customer. A customer that requires a one-of-a-kind customised product will naturally be involved from the design phase, correlating with an ETO environment. Whereas a customer buying standardised mass produced products will buy an already completed product, correlating with an MTS environment. (Olhager 2003)

Due to the early customer involvement in ETO environments, ETO companies can usually be characterised by their high value, customised products, with deep and complex product structure. Due to the products high value and complex product structure, they are also usually supplied in low volumes. Due to the increasing competition, regardless of industry, ETO companies often compete in mature markets where supply exceeds demand. Furthermore, due to the early customer involvement, the delivery lead time is at its highest. Hence, faster and more reliable delivery has been identified as a key competitive factor in ETO markets. (Hicks, McGovern et al. 2000)

3.1.3.1 ETO companies

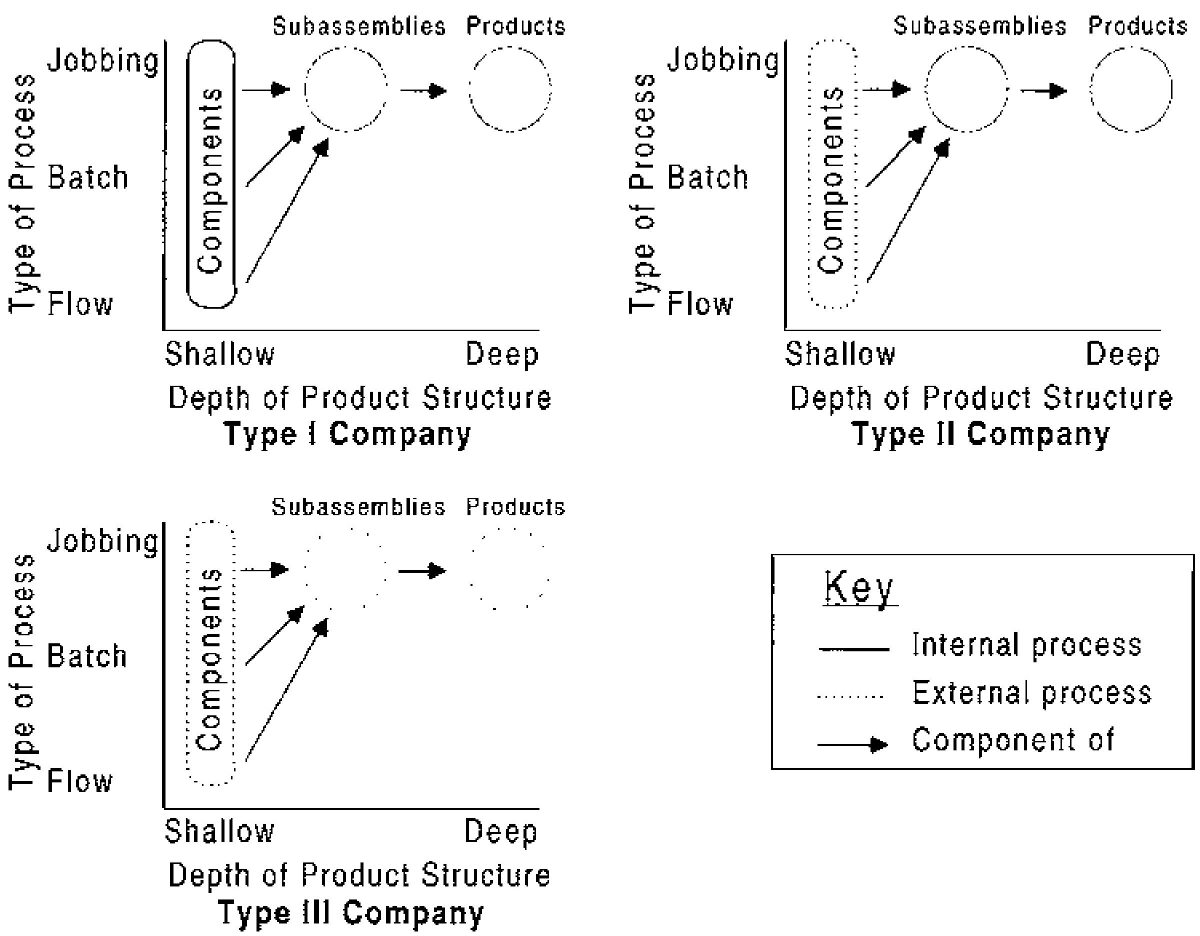

Figure 3: Different ETO Companies(Hicks, McGovern et al. 2001)

The literature has identified four types of ETO companies where the differences in process and company structure are in terms of vertical integration, outsourced supply and internal manufacturing processes(Hicks, McGovern et al. 2000). Among these four types, the company structures range from vertically integrated businesses with significant manufacturing capabilities, to design and contract organisations which have outsourced all physical activities(Hicks, McGovern et al. 2000). The four types are:

1. Vertically Integrated Company: This type of Company will typically have core competencies in design, manufacturing, assembly and project management. This enables the company to manufacture all components and assemblies in-house. Type I Company in Figure 3 illustrates the manufacturing processes performed by such an ETO company. (Hicks, McGovern et al. 2001)

2. Design and Assembly Company: Such a Company will have core competencies in design, assembly and project management. However, in comparison to vertically integrated companies, these companies have lower overheads and are less capital-intensive by outsourcing component manufacturing. This ETO company aligns with Company II as seen in Figure 3 (Hicks, McGovern et al. 2001)

3. Design and Contract Company: This Company will have core competencies in design, project management and logistics. As a result, all physical processes including component manufacturing and assembly are outsourced. This aligns with Company III in Figure 3. (Hicks, McGovern et al. 2001)

4. Project Management Company: This is a consulting company with core competencies in project management, engineering and logistics, managing contracts on behalf of a client. In addition to outsource all physical process as Design and Contract Companies, design is also outsourced. Due to the similarities with a Design and Contract Company, also this ETO Company can be illustrated as Company III in Figure 3. (Hicks, McGovern et al. 2001)

3.1.4 Technology selection

Considering the increasing global competition in today's industry, adapting the right technologies is of strategic importance(Xiaofeng, Peng et al. 2012). This is further supported by Torkkeli and Tuominen (2002) which states that the right technology can create significant competitive advantages for a company in a complex business environment. However, considering the rapid development of technologies, together with their increasing complexity and variety, technology selection is one of the most challenging decision making area company management encounters (Torkkeli and Tuominen 2002).

Although possessing the opportunities for competitive advantage, technology can also be a threat. A company's current competitive advantage can easily be wasted by investing in the wrong alternatives, too much in the right ones, or at the wrong time. Hence a systematic and thorough procedure is often required in order to make good strategic technology decisions. One of the issues is the occurrence of contradictory and complex demands and selection criteria's. This happens since different kind of technology fulfils the main criteria's in divergent ways, whereby the preference internally among departments might vary in just as many ways. It is however important to ensure that the selected technology fits the already existing technology and systems in the company. (Torkkeli and Tuominen 2002)

3.2 Review

3.2.1 PLM Challenges

Although many researchers have proposed more powerful and advanced approaches and functions for PLM, few of these proposals have been adopted and implemented (Wognum and Trappey 2008). This correlates with the statement made by Lee, Ma et al. (2008) which states that there are no comprehensive PLM systems existing today that satisfactorily fulfils the intent of a PLM system. As defined in section 3.1.2 Product Lifecycle Management, this intent is to "support the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise" (CIMdata 2012).

From the statement by Lee, Ma et al. (2008) and the definition from 3.1.2 Product Lifecycle Management, collaboration and knowledge management appears as possible main PLM challenges, which is also backed up by several authors(Wognum and Trappey 2008). These main challenges are however broad terms encompassing several aspects. In order to better highlight the actual issues, knowledge management and collaboration has been broken down to more specific points.

- Collaboration and exchange of data across organisational borders
- Collaboration and exchange of data internally among departments
- Reuse of organisational data and knowledge in order to improve planning and process executions.
- Scattered information among different IT-systems and departments
- None integrated IT solutions

3.2.2 Engineering Change Management and Product Lifecycle Management

Engineering Change Management has already been identified as an important part of product lifecycle management(Joshi, Ameri et al. 2005). Broadly speaking, PLM deals with the management of a company's products throughout the product's lifecycle(Srinivasan 2011). As for ECM,Wasmer, Staub et al. (2011) among others states that engineering changes to a product throughout its lifecycle is unavoidable, and thus making changes a natural part of a product's lifecycle and thereby a natural part of PLM. This further implies that ECM functionality should be a natural part of a PLM solution(Joshi, Ameri et al. 2005).

As the section 3.2.1 PLM Challenges introduced; Collaboration and knowledge management are recognised as important challenges in Product Lifecycle Management. Although the above paragraph already has stated the close relationship between ECM and PLM, the upcoming section will further elaborate on how these PLM problems correlated with the main topic of this project, engineering change management.

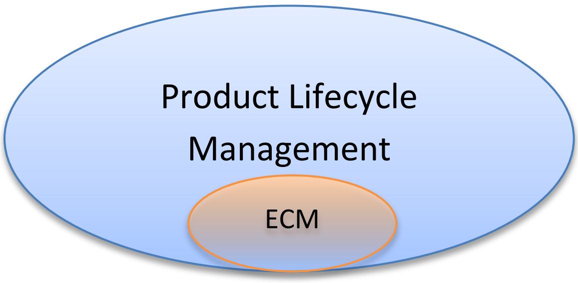

Figure 4: PLM and ECM connection

In section 3.1.2 on ECM, Kocar and Akgunduz (2010) defined ECM as "*The process of organising, controlling and managing the workflow and information flow for Engineering Changes".* Assuming that the information flow is shared with more than one entity, this already correlates with the PLM issue stated in 3.2.1 PLM challenges. Moreover, considering that approximately 60-80 per cent of the ship value is outsourced, the chances are, a supplier will most likely be involved in the various ECs somehow (Mello and Strandhagen 2011). Hence, further extending the collaboration issue in ECM to a multi-enterprise collaboration issue, making it coincides with the PLM issue.

Engineering changes (EC) refers to modifications in shape, function, material or dimension of a product (Huang, Yee et al. 2001). Hence, in order to properly evaluate an EC, the evaluation team requires knowledge about the product and its current state. If this knowledge happens to be resided in dispersed locations and multiple systems, the required information might not be available during the EC evaluation. As a result, wrong and costly decisions can be made, due to limited information. Hence, ECM also has a coinciding issue with PLM in terms of knowledge management.

3.2.3 The ECM Phases

The literature is more or less consensus on what work that is to be done throughout the ECM process, in a general term at least. There are some differences on how many stages the process is divided into, but the content is still the same. Dividing the process into three phases, the request-, the approval-, and the notification phase appears to be the most common one (Terwiesch and Loch 1999; Lee, Ahn et al. 2006; Kocar and Akgunduz 2010). Thus, the three phases will be outlined below to give a brief overview of the ECM process.

- **The Engineering change request phase**, is where the need and request for a change is placed by an initiator. The initiator can be the customer, an engineering team, or anyone else who is involved in the product development. The ECR should contain detailed information on which part to change, the changes in parameters, a reason for the change, and finally a technical engineering drawing or 3D model to represent the change graphically.
- **The Engineering change approval phase**, involves the revision and acceptance or rejection of the change. All the departments/teams that might be involved or affected by the change should be involved in this process. This also includes identifying change propagation and the corresponding departments and teams affected.
- **The Engineering change notification** occur when a change is approved by all the involved parties. The affected departments then get an engineering change notification including parametrical and graphical information regarding the change to be executed.

Although there are some small tasks and some coordination among parties in both the Request and Notification phase, the most comprehensive and time consuming part is the approval process. As the approval phase is the most tedious one, this is also where the problems are most evident, although most of the problems cover the entire ECM process in general. All these problems will be presented in the next section.

3.2.4 Engineering Change Management challenges

From the problems identified in the ECM literature, it is possible to group these into four core problems. The initial problem identification was done in the specialisation project (Norbye 2011). Compared to the specialisation project, the description and content under each problem has however been significantly extended, giving a more thorough introduction to the issue along with the different approaches and IT solutions used to solve the problems. The four core ECM problems are:

3.2.4.1 Unidentified change propagation

Table 1: unidentified change propagation. Adapted from (Terwiesch and Loch 1999; Eckert, Clarkson et al. 2004; Kocar and Akgunduz 2010; Habhouba, Cherkaoui et al. 2011)

Problem 1	Main issues
Unidentified change propagation	• Unable to identify subtle change requirements due to indirect product couplings • All the affected disciplines are not involved in the ECM process

Possessing the capabilities to identify change propagation has been recognised as an important and critical skill in the ECM process (Giffin, De Weck et al. 2009; Tang, Zhu et al. 2010). Change propagation stems from components being coupled with each other, either directly or indirectly (Keller, Eckert et al. 2005). This implies that when there is a coupling between components, there is a chance that changing one component will also require the other component to change, which again can propagate further(Eckert, Clarkson et al. 2004). The stronger these couplings are, the more likely is a change to cause further downstream changes (Cheng and Chu 2010).

Complex products often experiences more change propagation than other products, due to more couplings (Cheng and Chu 2010). Another issue with complex products is that very few people have a good understanding of the entire product, and thus will have problems identifying change propagation throughout the product(Eckert, Clarkson et al. 2004). Hence, it is important to involve several disciplines in order to get different views on the change.

Although change propagation is one of the most discussed ECM issues, the functionalities and procedures provided by present software solutions often appears as inadequate(Joshi, Ameri et al. 2005). This would in most cases imply that change propagation analysis is done mostly based on personal experience, which again leaves more room for errors, errors which could cause large expenses later in the process. Although a very experienced engineer might be able to identify counterintuitive propagation between nonadjacent components, it appears as very difficult to systematically evaluate all potential change options (Keller, Eckert et al. 2005; Tang, Zhu et al. 2010).This can also be seen in correlation with the findings done by Giffin, De Weck et al. (2009) where only 11% of all the questioned companies were able to provide a precise list of items affected by a change.

As briefly mentioned above, components can be coupled with each other either directly or indirectly, which again leads to the terms of direct and indirect change propagation as defined by (Keller, Eckert et al. 2005). Direct change propagation is the more common of the two, and refers to propagation occurring due to a physical connection between the two components in question. Hence, direct propagation is the most intuitive and easiest propagation to identify. However, in complex product structures, even direct propagation might get difficult to follow due to the possible extent of the propagation network.(Keller, Eckert et al. 2005)

Indirect change propagation on the other hand refers to propagation occurring without any physical connection with the two components in question. Hence the connection is not as intuitive as a direct connection. An indirect connection between two components exists, if these components are linked via one or several other components. Such indirect connections are easily forgotten and can be hard to follow, especially on complex product structures.(Keller, Eckert et al. 2005)

As with any problem, there are different approaches to solve it. This is also the case when it comes to change propagation identification, which spans wide both in industry and research papers. The approaches identified in the literature can however be grouped into three main groups, which will be presented below. The approaches/solutions have been grouped based on technological maturity and anticipated results.

- **Personal experience:** This approach is coincides with what is identified as paper based ECM in the literature. The process is not necessarily solely paper based, and might be supported by simplistic IT-systems that keeps track of information like BOMs. The systems do however not provide any propagation analysis tools. Hence, the propagation analysis is solely based on the person’s personal experience and the interpretation of the information at hand. Depending on the person or team assigned to the task, the outcomes can differentiate quite a bit. As stated by Jarratt, Eckert et al. (2006), “Designers have an awareness of the components that they are designing and anything that links in directly into that component. However outside of that area they probably do not have such great understanding”. This implies that if a change propagates outside the team area of expertise, the chance of correct change propagation analysis might drop significantly. Furthermore, as there are no assisting tools, the process time is at its highest. This approach is in the literature presented as the approach that needs to be improved, and has been mentioned by Rouibah and Caskey (2003), Keller, Eckert et al. (2005) and Joshi, Ameri et al. (2005)

- **Manual change prediction model:** At this level there is no “best” visualisation approach for change propagation data, each representation has its “pros” and “cons”. The most common representations are Design Structure Matrix(DSM), Change Risk Plot, Propagation Network and Propagation Tree(Keller, Eckert et al. 2005; Pasqual and de Weck 2010). These four representations forms what Clarkson, Simons et al. (2004) has been defined as the Change prediction Method (CPM). Seen as a whole, their intention is to visualise the propagation paths, highlighting both direct and indirect components couplings, while providing a propagation probability estimate for each component. The CPM should be created right after design release, whereby the product gets broken down into sub-systems, in order to view the collection of parts and their connection to each other. This breakdown allows the interconnectivity within the product design to be presented in a DSM, which allows for the capture and identification of change relationships. This representation gets further extended by a likelihood value reflecting the probability of change propagation between the two components and an impact value representing the severity of the change. The product of the likelihood value and the impact value gives a risk value for the given change propagation. This eventually results in a model highlighting direct and indirect links with a high risk value. Both the product breakdown and risk estimation is done by highly experienced designers with good knowledge of the product. One of the drawbacks is the ability to keep the model up to date when changes has occurred. For a slightly complex product, creating this model is a time consuming process. Thus, if the entire model has to be revised every single time a change has occurred, the resource consumption would get to extensive. This approach has been proposed by Giffin, De Weck et al. (2009), Clarkson, Simons et al. (2004), Tang, Zhu et al. (2010), Eckert, Keller et al. (2006)

- **Automatic decision support:** Refers to the most automated change propagation analysis, a process which is usually supported by an expert agent (Kocar and Akgunduz 2010; Habhouba, Cherkaoui et al. 2011). An expert agent is in this case a software program with an expertise in a given discipline within a mechanical engineering field. The intention of the agent, as with all of the above solutions, is to aid designers and engineers with change propagation analysis. The expert agents are created based on which disciplines are involved with the ECR at hand and its knowledge will be adapted accordingly. All necessary knowledge will automatically be retrieved from an extensive knowledge base. Such automatic information retrieval will necessarily require some advanced data mining tools, in order to locate the relevant data in each case. Whereas the above solution only requires general product information such as location, function, sourcing. This knowledge base would also contain knowledge from previous products and previous change orders. Furthermore, since these are software agents, it enables the system to keep up with how the product evolves throughout the lifecycle, and thereby keeping its dependency analysis up to date. This approach has been proposed by Kocar and Akgunduz (2010) and Habhouba, Cherkaoui et al. (2011)

3.2.4.2 Knowledge Management

Table 2: Knowledge Management. Adapted from (Lee, Ahn et al. 2006; Kocar and Akgunduz 2010)

Problem 2	**Main issues**
Knowledge Management	• ECRs are not properly logged • No systems to interpret knowledge data • Insufficient management of past experiences

Product knowledge has been identified as the most valuable corporate asset, and today's business pressure requires that the company makes the most out of it in order to stay competitive. The difficulties quickly appear when the knowledge is residing in dispersed locations, multiple time zones, localised processes, multiple systems and databases, and diverse cultures.(Siemens 2012)

Along with change propagation are knowledge management the most discussed topic in ECM literature. This stands in strong contradiction to research findings done by Ouertani, Baïna et al. (2011) which states that in a typical organisation, only 4% of organisational knowledge is available in a structured and reusable format and the rest is either unstructured or resides in people's minds. This further implies that information and knowledge is not represented in a shared and easily accessible knowledge base in most companies, something that clearly would have been a major advantage in terms of resource usage(Verhagen, Bermell-Garcia et al. 2011).

As a result, proper knowledge management has been identified as crucial for the success of new product development (Lee, Ahn et al. 2006). However, most of the ECM systems today do not possess the capabilities to easily manage and retrieve knowledge that is generated from the collaboration and decision making process (Lee, Ahn et al. 2006). Hence, the knowledgebase available to decision makers is significantly reduced, and decisions will rely more heavily on personal experience. Considering how fast the costs of a wrong decision rise throughout a products lifecycle, it would be for the best that decision makers has the fullest extent of knowledge available (Verhagen, Bermell-Garcia et al. 2011).

Due to the nature of new product development, which is the existence of incremental modifications to the product structure throughout its lifecycle, similar ECRs will eventually occur(Kocar and Akgunduz 2010). This is a result of similar conditions that may arise throughout the process, possibly triggered by two different customer requests that demand exactly the same modification. The demands will most likely be responded to by different engineering teams in a similar fashion, which will most likely cause the same outcome. Hence, if the first team failed to satisfy the customer request, the chances are the second team will fail for the very same reason. The most common reason for such redundant activities are that the ECM process in many companies relies heavily on personal experience, and does not take advantage of the benefits yielded by today's information technology. Being able to successfully identify such past ECRs, and thereby avoiding them from being processed again, would save valuable engineering capacity. Hence, in order to better cope with this issue, there is a significant requirement for more effective data storage and retrieval systems in regards to ECM. (Kocar and Akgunduz 2010)

Although some companies already might have been able to establish effective data storage and retrieval systems, knowledge management still remains as one of the major challenges within IT (Whitfield, Duffy et al. 2011). The different knowledge management approaches identified in the literature are presented below. The process of knowledge management has been divided in to two sections, information storage and information retrieval. Within each section, there have been identified three main approaches which will be further described.

- Information storage
  - **None-integrated IT-systems:** Refers to the process of storing large variety of information in a just as large number of different IT-systems throughout the enterprise. Each of the different IT-systems got their own database containing their own information. Furthermore, these systems are also usually provided from different vendors, which usually cause compatibility issues if one wanted to combine information from two different sources. As a result, consolidating information from different sources has to be done manually, which is time-consuming. Furthermore, it gets harder to keep track of what information is available, which could lead to decisions errors due to insufficient information. The storing of information in standalone systems has been mentioned by Lee, Ahn et al. (2006), Joshi, Ameri et al. (2005), Huang, Yee et al. (2001) and Gao, Du et al. (2008)
  - **Central storage of ECM related engineering data (**Appendix A – Relevant ECM data**):** Refers to the process of storing the ECM related engineering data in one place, making it easily accessible for the involved departments. One approach is to have a database module that retrieves ECM information and maintains change history. The other option is to integrate the relevant systems, which would be a step in the direction of full systems integration, in addition to making the ECM information more complete and accessible. Either way, although this solution leaves the decision makers with a broader knowledge base at their disposal, there is still information that doesn't get embraced by such a solution. There are however considerations to be made, mostly in terms of cost, since extensive system integration is a very costly affair. Central storage of ECM related data has been proposed by Habhouba, Cherkaoui et al. (2011) and Gao, Du et al. (2008)
  - **Full system integration:** Is the process of storing information in the one unit that constitutes all your IT-systems. Hence, although the information is stored in individual systems, all the information is accessible across systems and throughout the entire enterprise. Compared to the above solution, the information would typically extend the internal engineering data with information from the extended enterprise, making the real impact of an EC more measureable and visible. Given that satisfactory retrieval functionality is in place, this solution would enable the most extensive knowledge base for the decision makers throughout the ECM process. This solution has been proposed by Kocar and Akgunduz (2010), Gerritsen, Gielingh et al. (2011) and Joshi, Ameri et al. (2005)

- Information Retrieval:
    - **Simplistic search functionality:** Enables search for key words and category-based browsing. Often the case when there are limited information availability, as in none-integrated environments. Since there is no integrated information from other systems, the information available is not that extensive, hence simple key word searches is sufficient in order to retrieve the information. The simplistic search capabilities are mentioned by Lee, Ahn et al. (2006)
    - **High-end search engines:** Considers several parameters such as process and component descriptions, when searching for information. Moreover, it provides the user with a larger variety of search features such as file type and domain restrictions. The input volume is however still limited, which makes it difficult to find the "perfect match". In an ECM context, it would be difficult to systematically asses and discover similar ECRs, especially for more complex components. This is because an ECR would contain more information than the search engine can handle, hence limiting the search to certain parameters. As a result, the matching ECR might be of no use. Nonetheless, this solution provides more advanced and comprehensive search functionality, which again eases information retrieval. Such search engines are also usually accompanied by a more comprehensive knowledge base, although this is not a requirement. The approach is adapted from the proposed by solutions by Lee, Ahn et al. (2006) and Joshi, Ameri et al. (2005)
    - **Advanced data mining tools:** In addition to the abilities of the high-end search engines, this solution uses advanced pattern mining algorithms in order retrieve relevant historical data, which in many cases would not have been discovered through traditional search engines. Sequential pattern mining algorithms, as discussed by Kocar and Akgunduz (2010), aims to analyse sequences of data in order to come up with meaningful patterns. Such an algorithm could for instance be utilised to predict change propagation based on patterns from previous ECs. The input would be the actual ECR with the data that follows, as seen in Appendix A – Relevant ECM data. As this information originates from different sources, this solution would require access to CAD tools, EC database and other product related information such as BOM. The approach has been proposed by Habhouba, Cherkaoui et al. (2011) and Kocar and Akgunduz (2010)

3.2.4.3 Collaboration

Table 3: Collaboration. Adapted from (Huang, Yee et al. 2001; Rouibah and Caskey 2003; Gao, Du et al. 2008; Whitfield, Duffy et al. 2011)

Problem 3	**Main issues**
Collaboration	• Distributed members • Cross functional and multi-disciplinary teamwork • Conflict between departments and cultural differences • Several companies involved • Different IT-systems • Poor system integration

Due to the ever increasing competition in the global markets, companies are required to form extended enterprises leveraging each other's core competencies in order to stay competitive (Siemens 2010). In order to successfully form competitive extended enterprises, the companies have to see beyond the limitations of organisational, geographical, cultural and time barriers. The focus should instead be on where the work can be done most effectively. As a result, there will be participants from different continents, companies, time zones and computing platforms. Such networks require a comprehensive set of collaboration services in order to connect individual users with one another, along with the product and process knowledge of their extended enterprise.(Siemens 2010; Siemens 2012)

As stated, the ECM process is a rather complex process, involving different disciplines both from within the company itself and from physically dispersed supply chain partners (Terwiesch and Loch 1999). Although the importance of collaboration and information sharing has been stressed, one can find several examples of companies and even internal departments working in a decentralised and none-collaborative manner(Koçoğlu, İmamoğlu et al. 2011). Whereas they should have been moving towards the efficiency associated with an integrated system and close cross-company collaboration (Koçoğlu, İmamoğlu et al. 2011).

To achieve this unified collaboration network is however not an easy task, and there are several obstacles to overcome(Awad and Nassar 2010). One issue in terms of ECM is as discussed by Huang, Yee et al. (2001), sequential processing of information. This typically occur when the ECM process is either paper based or supported by standalone IT systems that doesn't allow simultaneous user access. As a result, only one user can access the information at once, and hence resulting in sequential information sharing which causes excessive throughput time.

One of the reasons for such sequential information sharing is the lack of system and information integration. Considering how fast the information technology has evolved the past few decades, and the rapidly increase in use of IT in the industry, this issue is not surprising. As new process enhancing technology has entered the market, companies have adopted them accordingly. The "new" technology is however just focused towards a niche issue within the company, which means that other systems from other vendors have to be implemented to solve other issues. Eventually most companies is left with a high number of IT-systems that each solves unique problems within the company, without being able to benefit from other systems information because they were not expected to work together in the first place. As a result, all the information and knowledge the company possesses is spread across several IT-systems making it less accessible for the people who might need it.

By now the complex nature of system integration and collaboration should be a bit clearer; one should however note that the above paragraphs mostly refer to internal integration and collaboration. The collaboration issue also extends throughout the supply chain, which potentially could be even more challenging than the internal process. Considering the internal variety of IT-systems, it is likely to assume that this is also the case for any supply chain partners. Furthermore it is likely to assume that any supply chain partner will have their own company goals, incentives and priorities, something that potentially could add on to the IT problems. On a side note, such differences could also occur internally among departments, but this should in theory be an easier variable to control.

Based on the collaboration theory, it is possible to classify the topic of information sharing into three different groups. The different groups can easily be identified in terms of the pace at which information is shared among the involved users.

- Information sharing
  - **Paper based:** Is the process of sharing information on paper, without interference of any IT solutions. Considering the information technology available today, this approach is considered as a slightly out-dated approach, especially as an enterprise-wide approach. The approach has its characteristics in high throughput time, sequential processing and extensive amounts of paperwork. One of its benefits is however the ability to have the information physically available anywhere, which is why some processes are still paper based. With the increasing availability of portable IT solutions, this appears however as a diminishing advantage. This approach is mentioned by Huang, Yee et al. (2001) and Gao, Du et al. (2008)
  - **Through standalone systems:** Probably the most common way of sharing information. Here information is usually shared through e-mail or similar information sharing tools. The major advantage is the reduction of throughput time and paperwork. However, as this only allows one employee to view the information at the same time, the sequential processing is still a drawback. This solution is mentioned by Huang, Yee et al. (2001) and Gao, Du et al. (2008)
  - **Real time:** Information is updated and shared among all the involved disciplines at the same rate as the information is received by the system. This results in an information throughput time at its minimum and the ability for simultaneous processing of information. Real-time information sharing throughout the company would however require full system integration, since it is based upon full information availability. This solution is proposed by Huang, Yee et al. (2001), Gao, Du et al. (2008), Habhouba, Cherkaoui et al. (2011)

3.2.4.4 Information interpretation

Table 4: Information interpretation. Adapted from (Eckert, Clarkson et al. 2004; Keller, Eckert et al. 2005; Kocar and Akgunduz 2010; Habhouba, Cherkaoui et al. 2011)

Problem 4	Main issues
Information interpretation	• Difficulties in comprehending complicated technical drawings defining the change • Non-technical staff as decision makers • Extensive document management, including both parametrical and graphical information. • Poorly visualised information

The final problem identified in the ECM literature is how the information is interpreted by the receiver. The receiver is thus a very important part of the problem; it is however a variable that cannot be controlled, hence the focus should be towards information representation. As stated by

Kocar and Akgunduz (2010), the review and approval process is both, difficult and time-consuming, even for technical people. Thus, non-technical staff might experience difficulties comprehending complicated parametrical and graphical information correctly, something that could lead to misinterpretations and errors, further delaying the EC process.(Kocar and Akgunduz 2010)

As presented by Stacey and Eckert (2003), many commonly used representations of information are inherently ambiguous and require interpretation by the receiver, who should be conversant with the originating source and their way of representing information. Regardless, the interpretation of information is highly personal and depends on the individuals mind and personal experience (Selnes 1999; Eckert, Clarkson et al. 2004). It is however known that graphical information representation is perceived much more effectively than textual and oral representation (Kocar and Akgunduz 2010). Moreover, 3D representation is supposed to have tremendous advantages over 2D, especially when the receivers are non-technical staff (Kocar and Akgunduz 2010).

Complex product structures further complicates the information representation, and it's basically impossible to display a complex product in detail in one single representation. Hence a good representation of information is not only concerned with what format it is presented in, but also how to display the product effectively. This means that the data presented should be filtered so the receiver is not overwhelmed by the amount of information, irrelevant information in particular. (Keller, Eckert et al. 2005)

The approaches on information representation do differ from process to process and company to company. Below is a description of the three main approaches, which again encompasses several variation of the given approach.

- Information visualisation
  - **Paper based visualisation**: Presenting information through technical drawings. Drawings are in many ways considered as a graphical universal language, which traditionally has been perceived as the clearest way to tell someone what to make and how to make it. Technical drawings intend to provide a means to communicate complexity in a comprehensible and effective manner, which is why engineering drawings still play an essential part in the capture and distribution of information in some industries. Some of the issues are however extensive paperwork and the ease of keeping the drawings up to date. This approach is mentioned by Quintana, Rivest et al. (2010), Quintana, Rivest et al. (2012)
  - **2D and 3D information:** Combining the traditional paper based visualisation with the benefits of representing some information in 3D. The extent of the 3D visualisation is however limited, both in terms of visualisation and accessibility throughout the enterprise. Hence, some of the decision makers that could have benefited from a 3D visualisation do not have that option. Technology wise, this process is usually just supported by simplistic CAD tools. As a result, the 3D models will be responsible for defining and presenting a product's geometry, an area where it easily outperforms engineering drawings. On the other hand, engineering drawings has its strength in representing product related information such as dimensions, tolerances, surface condition and material, in a systematic and formal

way that is well understood. Early stage CAD tools do not have this ability, which is why engineering drawings are still needed at this stage. This approach is adapted from the mentioned solution by Quintana, Rivest et al. (2010)

- **Virtual environment with customised views:** Refers to a virtual information environment that extends throughout the company, making 3D information visible to whoever might benefit from it. The idea is that the 3D model should act as a carrier for all the detailed product information necessary for downstream departments and disciplines to perform their job. Hence, relieving engineering drawings from their advantage of displaying non-geometric data in easily interpretable way. As an additional functionality, there should also be possibilities to customise the information presented through the 3D model in order to best suit the targeted department. Only presenting relevant information would definitely reduce processing time by easing interpretation and thereby lowering the risk of misinterpretation. This approach is adapted from the solutions proposed by Bouikni, Desrochers et al. (2006) and Kocar and Akgunduz (2010),

3.3 Research findings

The theory in this thesis has focused on the current ECM challenges along with the approaches and technologies adapted to cope with these challenges, in order to answer the given research questions in section 1.4 Research questions. The research questions, along with a brief summary of the findings are presented below.

RQ1: *What are the challenges experienced in today's ECM process?*

Today's ECM process is usually a challenging process involving numerous working disciplines and downstream suppliers, possibly affecting the whole value chain. Due to this complex collaboration network, challenges such as knowledge management, collaboration and information visualisation has been identified as three of the four core ECM problems. Considering the increased globalisation in today's industry, a complex collaboration network is obviously not just affecting the ECM process; hence these issues are already well known challenges within other topics such as product lifecycle management. The last ECM challenge is on the other hand ECM specific, and is concerned with how a change propagates throughout the product structure.

RQ2: *Which approaches and technologies are currently used in order to cope with these ECM challenges?*

The variety of approaches and technologies used to cope with the ECM challenges is just as large as the number of ECM research papers, each of them with their own strengths and weaknesses. There were however many similarities among them, which made it possible to group them into larger, more general groups. These groups, along with their respective ECM problem are thoroughly elaborated in section 3.2.4 Engineering Change Management challenges, whereas a shorter a more manageable overview are presented in section 3.4 Maturity classification tool.

RQ3: *How can PLM systems be leveraged in order to better support the engineering change management process?*

The intention of today's PLM systems is to manage the entire lifecycle of a product by providing one single source of information, enabling enterprise wide collaboration and visualising the information in an easy interpretable way. Thus, its intention coincides with three of the four core ECM problems. Hence, a PLM system that manages to satisfy these requirements would most likely be able to provide the backbone capabilities a proper ECM system needs to efficiently manage ECs.

3.4 Maturity classification tool

One of the first steps to adopt new technology is analysing the company's current process along with the IT-systems currently supporting them. The intention of new technology adoption is finding new technology that better fits the company's processes in order to improve the overall competitiveness. It is important to emphasise the fit of the technology, because the state-of-the-art solution might not be the best solution for everyone. Hence it is important to understand the company's current state, and be able to understand where the biggest potential is. In order to better support the technology selection process, a framework which links ECM problems, approaches and IT solutions has been proposed. The framework also tries to rank the solutions among each other based on the degree it responds to the intention stated. It should however be noted that the highest ranked solution is not coincides with the best solution. This is simply because every company is unique; there is no best solution that fits them all.

The framework has been created based on the information gathered from the literature study. The head topics in the framework refers to the problems identified as presented in section 3.2.4 Engineering Change Management challenges. The different approaches along with the IT involvement as presented under each challenge in section 3.2.4.1 to 3.2.4.4, are briefly outlined in each of the rows in the framework.

IT support refers to the internal functionality this approach requires in order to function.

IT requirements refers to external factors that needs to be in place for this approach to function properly

Maturity refers to the rank among the approaches in terms of how satisfactory it solves the problem

<table>
<tr><td colspan="2">

Change propagation

Intention: *Ease the identification of change propagation and aid in decision making*
</td></tr>
<tr><td rowspan="3">Propagation analysis</td><td>**Personal experience:** Propagation analysis solely based on personal experience combined with the paper based information at hand, such as a BOM.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>**Manual change prediction model:** A propagation model visualising component connections and propagation risk through matrix, network or tree models. Developed based on expert assessments.
IT support: None
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>**Automatic decision support:** Automated change propagation analysis with the aid of expert agents, a software program with an expertise in a given discipline. Its knowledge is extracted from a comprehensive knowledge base.
IT support: Advanced data mining tools, software agents
IT requirements: An extensive knowledge base encompassing all product related information, both current and historical.
Maturity: #High#</td></tr>
<tr><td colspan="2">

Knowledge management

Intention: *Provide engineers with easy capture, management and reuse of relevant design and product knowledge throughout the change process.*
</td></tr>
<tr><td rowspan="3">Information storage</td><td>**Non-integrated systems:** The process of storing a large variety of information in a just as large number of different IT-systems throughout the enterprise. Each of the different IT-systems got their own database containing their own non-shareable information.
IT support: Separate IT-systems
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>**Central storage of ECM related engineering data:** Storing the ECM related engineering data (Appendix A – Relevant ECM data) in one place, making it easily accessible for the involved departments.
IT support: A database extraction module or partly integrated systems
IT requirements: Two or more IT-systems
Maturity: #Medium#</td></tr>
<tr><td>**Full system integration:** The process of storing information in the one unit that constitutes all the company's IT-systems. Although the information is stored in individual systems, all the information is accessible across systems and throughout the entire enterprise.
IT support: Full system integration
IT requirements: Two or more IT-systems
Maturity: #High#</td></tr>
</table>

<table>
<tr><td rowspan="3">Information retrieval</td><td>Simplistic search functionality: Key word and category-based browsing.
IT support: Simplistic search-engine
IT requirements: A database
Maturity: #Low#</td></tr>
<tr><td>High-end search engines: Search engines that consider several parameters and provides a larger variety of search features.
IT support: High-end Search engines
IT requirements: A database
Maturity: #Medium#</td></tr>
<tr><td>Advanced data mining tools: The use of advanced algorithms that can process large information inputs in order to retrieve highly relevant data. The algorithms aim to analyse large sequences of data in order to come up with meaningful patters.
IT support: Advanced data mining tools
IT requirements: A database
Maturity: #High#</td></tr>
<tr><td colspan="2">Collaboration
Intention: ensure that the right information is available to the right person at the right time throughout the enterprise</td></tr>
<tr><td rowspan="3">Information sharing</td><td>Paper based: The process of sharing information on paper, without interference of any IT solutions.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>Through standalone systems: The process of sharing knowledge through simplistic information sharing tools such as e-mail.
IT support: Information sharing tools
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>Real time: Information is updated and shared among all the involved disciplines at the same rate as the information is received by the system.
IT support: Real time information sharing tools
IT requirements: Full system integration
Maturity: #High#</td></tr>
<tr><td colspan="2">Information interpretation
Intention: Provide both textual and graphical information in a way that is easy interpreted by anyone involved in the process</td></tr>
</table>

Information visualisation	**Paper based visualisation:** Presenting information through technical drawings. **IT support:** None **IT requirements:** None **Maturity:** #Low#
	2D and 3D information: Combining the traditional paper based visualisation with the benefits of representing some information in 3D. The extent of the 3D visualisation is however limited, both in terms of visualisation and accessibility throughout the enterprise. **IT support:** Early stage CAD tools **IT requirements:** None **Maturity:** #Medium#
	Virtual environment with customised views: Refers to a virtual information environment that extends throughout the company, making 3D information visible to whoever might benefit from it. The 3D model should be the carrier of all detailed product information. There should also be possibilities to customise how and what the information is presented through the 3D model in order to best suit the targeted department. **IT support:** High end CAD and lifecycle visualisation tools **IT requirements:** Full system integration **Maturity:** #High#

4. Teamcenter

This section is based on the Teamcenter documentation available through Siemens web pages, along with meetings with Summit Systems, the distributor of Teamcenter in Norway. As stated in 2.3 Sources of Error, Validation, Reliability and Objectivity, there are room for misinterpretations. Thus, this chapter represents the author's perception of the data collected from Siemens and Summit Systems.

Teamcenter has been used as an example system in order to map existing PLM functionality against theory on engineering change management. This will provide evidence on the current status of a world leading PLM system, and thus provide a good fundament to compare and improve the maturity classification tool developed from the ECM literature. The information presented in the following section is a combination of information retrieved from Siemens Web Pages (Siemens 2010), the Teamcenter resource library (Siemens), and interviews with the Norwegian provider of Teamcenter, Summit Systems.

Teamcenter, a PLM system provided by Siemens PLM software, is the world's most widely used PLM system (Appendix F – Siemens PLM Market Analysis). Teamcenter intends to power innovation and improve productivity by connecting people across global product development and manufacturing organisations with the product and process knowledge they need to succeed. For this master's thesis, the choice of PLM system is based on several aspects, whereby Teamcenter was found as the most appropriate solution. These aspects will be further elaborated below.

Siemens PLM software is currently the leading global provider of product lifecycle management software (Appendix F – Siemens PLM Market Analysis). This makes it reasonable to believe that Siemens and Teamcenter possess capabilities equal, or even ahead of its competitors in terms of PLM functionality.

The case company Ulstein, which will be discussed later in this thesis, is already in possession of Teamcenter. Teamcenter is however not currently used by Ulstein. Since the case study intend to evaluate Ulstein's current ECM processes along with its use of IT systems, this already qualifies as an interesting observation worth noticing.

The following sections will examine the important areas of Teamcenter's functionality related to engineering change management, in order evaluate and propose a revised framework. This will be done by first introducing the different product capabilities which constitutes the backbone of Teamcenter and are in some way related to the ECM challenges in section 3.2.4 Engineering Change Management challenges. This will then be consolidated in an engineering change management section which discusses Teamcenters ECM capabilities. As a result, the maturity classification tool developed in section 3.4 Maturity classification tool will be updated with approaches and functionality that has not yet been discussed by the literature reviewed in this thesis.

4.1 Teamcenter capabilities

Through consolidating the different IT-systems of an organisation, Teamcenter intends to provide a single, organised and secure source of product engineering and process knowledge. That, combined with the ability to seamlessly connect different engineering and design teams, enabling them to work together as a single entity regardless of location, constitutes the essence of what Teamcenter is about.

Based on the four ECM challenges discussed in section 3.2.4 Engineering Change Management challenges, the following Teamcenter capabilities will be presented in this section: Engineering process management, enterprise knowledge foundation, community collaboration, content and document management, lifecycle visualisation, supplier relationship management.

Figure 5: Teamcenter capabilities

4.1.1 Enterprise knowledge foundation

Along with the platform extensibility services and the lifecycle visualisation capabilities, the enterprise knowledge foundation constitutes the foundation of Teamcenter. The enterprise knowledge foundation capabilities are focused towards making the most out of the organisation's most valuable corporate asset, product knowledge. This is achieved by transcending geographical, technological and organisational boundaries through a comprehensive product lifecycle management system. The intention is to bring all stages of the product's lifecycle into one single collaborative knowledge management environment, enabling secure capture and management of product knowledge from all sources worldwide. In order to better understand the foundation capabilities, the management capabilities can be further broken down.

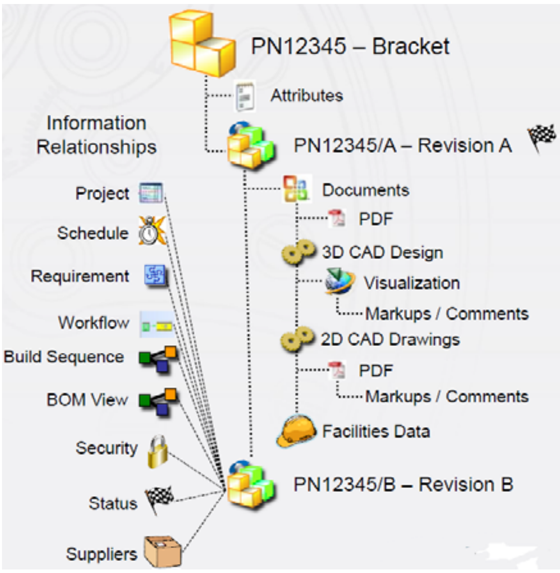

Figure 6: One source of Information

In order to ensure quick information retrieval, Teamcenter provides one source of information combined with a powerful search engine. The search engine enables search for important parameters such as properties, product structure, "where referenced" and classifications, to ensure the retrieval of correct information. Furthermore, the revision control ensures that the information is reliable, since it keeps track of new revisions at all times.

In order to enhance the interpretation of the available information, intuitive 2D and 3D visualisation has also been emphasised. The wide span of information originating from different sources throughout the lifecycle is also consolidated into relationship networks, which connect related information with each other.

The workflow engine enables the ability to capture, automate and deploy processes, best practices and experiences throughout the global enterprise. This ensures that lessons learned anywhere in the enterprise is accessible and are used everywhere. Moreover, it ensures that employees know what to do and when to do it in a real-time manner. It also makes process progress easily indefinable.

4.1.2 Platform extensibility services

The platform extensibility services is as mentioned, one of the core functionalities in Teamcenter. It provides a comprehensive solution to connect Teamcenter with other enterprise applications. This enables the organisation to leverage their existing and future investment in niche system in order to realise enterprise-wide business processes.

This solution already possess connectors to the major ERP and CAD systems, which enables easy integration with systems such as SAP, AX, NX and CATIA. It also inherits the ability to create custom connectors to link Teamcenter with other enterprise applications. This combined with its open and scalable architecture creates the foundation for the integrated environment Teamcenter intends to create.

4.1.3 Lifecycle visualisation

Teamcenter's lifecycle visualisation solution takes the power of today's leading CAD capabilities and puts them into an intuitive tool that enables visualisation of product designs during collaborative design reviews without the use of 3D CAD authoring system. This allows downstream participants in the product lifecycle, which doesn't have CAD authoring systems, to engage earlier in the lifecycle.

The visualisation solution leverages the lightweight JT visualisation format, a CAD neutral format which enables quick loading, navigation through and analysis of complex assemblies. The JT format can also provide more detailed product information such as precise measurement and analysis. This visualisation capability enables team members across the extended enterprise to visualise product data in 2D and 3D formats, even when the data is created using diverse CAD software.

4.1.4 Engineering process management

The engineering process management solution allows an organisation to integrate their global engineering teams by bringing product design and engineering data from multiple sources and sites into a single source of engineering knowledge. This encompasses the capabilities to provide vaulting, global sharing and workflow management needed to capture, manage and leverage geometry and engineering data created in all the major CAD, CAM and CAE systems.

The design validation capability intends to accelerate the design validation process by continuously aggregating design changes. Extended teams are enabled to create and visualise digital mockups of the product, which enables real-time visualisation of design changes.

The automated workflow capabilities enables the ability to accurately plan, incorporate, verify and assess the impact of product changes by providing all product development stakeholders with instant access to necessary data. The solution also provides a change management module, which will be presented in section 4.2 The change management module in Teamcenter.

4.1.5 Community collaboration

The community collaboration solution is a web-based collaboration environment that provides a platform for sharing information and working together throughout the extended enterprise. The solution extends the current collaboration capabilities by reaching out to the product lifecycle participants who does not have direct access to the Teamcenter database. Real-time collaboration and application sharing has been emphasised in order to create an environment for fast and secure communication of product and process information among all the involved participants.

4.1.6 Supplier relationship management

The supplier relationship management solution intends to integrate the extended enterprise and suppliers, along with its associated information, into all stages of the product development process. This is done in order to facilitate early supplier involvement, supplier information visibility, efficient sourcing processes and a better coordination between product development teams.

4.1.7 Bill of Materials Management

The bill of materials (BOM) management solution enables management of the BOM, regardless of structure complexity, in a single environment. The single source of BOM information ensures product accuracy and completeness for all stakeholders throughout the product life cycle. Furthermore, it eliminates the need to maintain, combine and verify all the various pieces of BOM information historically stored in separate systems, databases and spread sheets.

The Bill of Materials Management tool also provides a where-used/where-referenced tool, which provides an overview of all related parts to a given component. In a change management setting, this solution could provide an overview of all the components directly connected to the changed part, thus giving an overview of potentially impacted parts.

4.2 The change management module in Teamcenter

As seen from section 3.2.4 Engineering Change Management challenges, an organisation's capabilities within collaboration, knowledge management and information representation is what constitutes the back-bone of an ECM solution. Thus, not surprisingly, it is the Knowledge management foundation, platform extensibility services and the lifecycle visualisation capabilities that constitute the back-bone of the change management module. The change management module is also supported by some additional capabilities as presented in section 4.1.4-4.1.7, whereby change management is a part of the engineering process management module presented in section 4.1.4. This section will present the change management module and elaborate on how it is connected to the other capabilities.

Teamcenter's Change Management module provides solutions to aid the change process from change request to change execution. In other words, the module enables initiation, administration, reviewal/approval and execution of product changes on an enterprise basis.

The Change Management module leverages a formal process that takes advantage of multiple change objects and predefined workflow change processes. There are three different change objects, problem reports, change requests and change notifications.

- Problem reports (PR) is the first initiation of a change. A PR defines a potential problem or improvement, which again can be populated with additional data such as a link to the actual component and images illustrating the change. A PR might again lead to one or more engineering change requests if the report identifies an actual problem.
- Engineering Change Request (ECR) defines a possible solution to the problem and contains decisions regarding the change. Although the information from the PR is usually propagated to the ECR, the ECR still contains a link to the originating PRs making it easy to identify originating sources. If the ECR gets approved, it is possible to create an engineering change notice.
- Engineering Change Notice (ECN) defines a detailed plan to implement the changes defined in one or more ECRs. An ECN also contains links to all identified parts and documents that are affected by the change. Finally, an ECN authorises the actual implementation of a change.

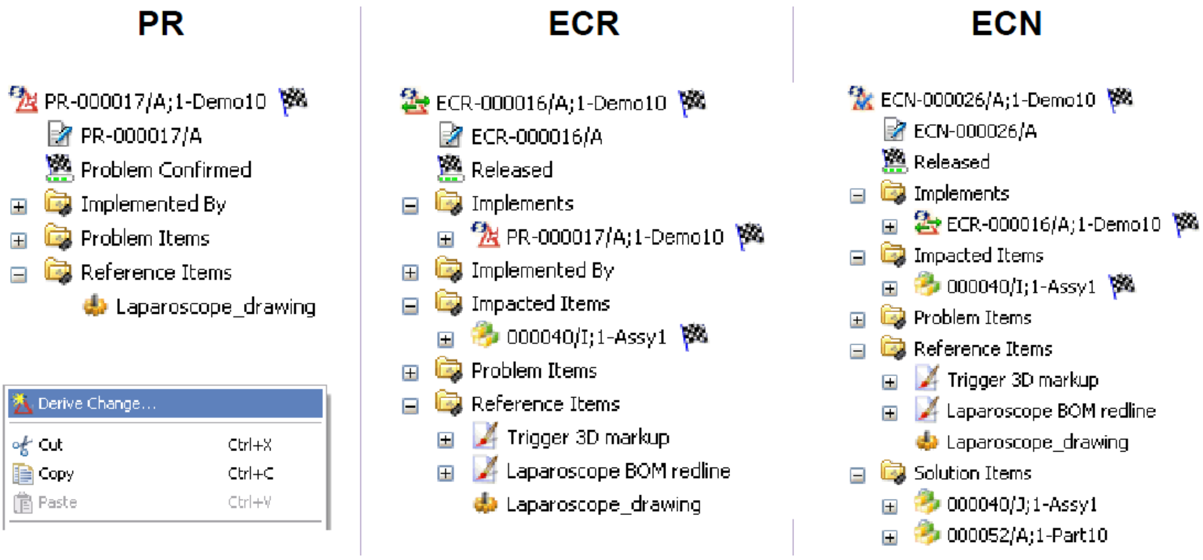

Figure 7: Change objects

As mentioned in 4.1 Teamcenter capabilities, Teamcenter provides one source of information, where all related information can be represented in relationship networks. This also encompasses change information, which means that when a PR, ECR or ECN has been linked to a part, this change information will become a new part of the relationship network for that part. This results in an easy retrieval of change information throughout the product lifecycle.

For each of these change objects, there are predefined change process workflows. These are based on the workflow engine as described in section 4.1.1 Enterprise knowledge foundation. As default the processes are in accordance with the industry-standard CMII closed-loop change model. In case of a submitted change request, this workflow will drive the tasks associated with the ECR such as developing multiple change strategies and performing change propagation analysis. This is achieved through using different workflow tasks, paths, approvals and dynamic user assignments in order to ensure that the right people gets the right information at the right time to complete the task. It also enables the change participants to keep track of the ECM process by providing real-time status of the workflow.

The above functionality is the standardised part of the ECM in Teamcenter. The tasks assigned by the workflow may however vary quite a lot since the different changes are associated with different parts and assemblies, which will impact the extensiveness of the change analysis. Nonetheless, Teamcenter also provides tools that intend to ease these processes. The most noticeable one is the impact analysis tool, also called where-used/where-referenced tool, which intuitively displays the direct links the change part has to other components or assemblies. This enables change evaluators to easily identify components that might be subject to change propagation. Without such support, this is something that would have gotten increasingly more difficult as the product complexity rose. Furthermore, the evaluators have access to all the related product information, including 2D and 3D models, which provide the best basis for correct information interpretation.

4.4 Revised framework

After assessing Teamcenters capabilities in terms of engineering change management, Teamcenter does come out at the upper end of the scale. The reason for undertaking the assessment was however to identify gaps in the theoretical maturity framework. Although Teamcenter could be classified into most of the functionalities, the assessment has resulted in two changes which are highlighted in red in the framework.

- **Propagation analysis support**: This functionality refers to the where-used/where-referenced functionality, which intuitively identifies directly linked components and assemblies to the component in question. This is especially beneficial for complex products where there might be large amounts of connections. Such functionality does however require a complete and up to date Bill of Materials in order to provide accurate results.
- **Workflow support:** This is an additional feature which was essential to achieve real-time collaboration in Teamcenter. This functionality was also identified as one of the key enablers for best-in-class change performance by the AberdeenGroup (2007). Thus this functionality has been added under the topic Real-time collaboration.

<table>
<tr><td colspan="2">Change propagation
Intention: Ease the identification of change propagation and aid in decision making</td></tr>
<tr><td rowspan="4">Propagation analysis</td><td>Personal experience: Propagation analysis solely based on personal experience combined with the paper based information at hand, such as a BOM.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>Manual change prediction model: A propagation model visualising component connections and propagation risk through matrix, network or tree models. Developed based on expert assessments.
IT support: None
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>Propagation analysis support: Through elaborating the product information available in the system such as BOMs, the system presents a set of directly linked components.
IT support: BOM analysis tool
IT requirements: A knowledge base containing the complete product BOM
Maturity: #Medium/High#</td></tr>
<tr><td>Automatic decision support: Automated change propagation analysis with the aid of expert agents, a software program with an expertise in a given discipline. Its knowledge is extracted from a comprehensive knowledge base.
IT support: Advanced data mining tools, software agents
IT requirements: An extensive knowledge base encompassing all product related information, both current and historical.
Maturity: #High#</td></tr>
<tr><td colspan="2">Collaboration
Intention: ensure that the right information is available to the right person at the right time throughout the enterprise</td></tr>
<tr><td rowspan="3">Information sharing</td><td>Paper based: The process of sharing information on paper, without interference of any IT solutions.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>Through standalone systems: The process of sharing knowledge through simplistic information sharing tools such as e-mail.
IT support: Information sharing tools
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>Real time: Information is updated and shared among all the involved disciplines at the same rate as the information is received by the system.
IT support: Real time information sharing tools, workflow solution
IT requirements: Full system integration
Maturity: #High#</td></tr>
</table>

5. Case study – Ulstein

The information in this chapter is solely based on the interviews and observations done at Ulstein. As stated in 2.3 Sources of Error, Validation, Reliability and Objectivity, there are room for misinterpretations. Thus, this chapter represents the author's perception of the data collected at Ulstein.

The chapter contains a presentation and evaluation of all the data collected during the case study of Ulstein yard. In the first three sections, Ulstein will be briefly introduced, along with a thorough description of their ECM process. The chapter will act as a foundation for section 6 where the ECM data retrieved from the case study will be further evaluated.

5.1 Ulstein Group

The Ulstein Group is a Norwegian company in the shipbuilding industry, providing sophisticated vessels for demanding marine operations. From the beginning in 1917, Ulstein has grown from a small family owned workshop engaged in repairing ships, to an innovative, internationally renowned company in the maritime industry, employing approximately 800 people. (UlsteinGroup 2011)

Ulstein yard, as a part of the Ulstein Group, is the company in charge of the actual shipbuilding, and are currently producing a wide range of sophisticated vessels including offshore support, offshore construction, seismic and research vessels.

5.2 Engineering changes at Ulstein

In the competitive market of shipbuilding, it is important to focus on the core competencies, while benefiting from others core competencies through outsourcing(Koçoğlu, İmamoğlu et al. 2011). Currently, Ulstein operates with an ETO approach, which is characterized by being highly flexible, producing "one-of-a-kind" or small batches of products. In order to reduce operational cost, Ulstein is focusing on their core competencies in design and assembly, while outsourcing most of the parts manufacturing leveraging others core competencies. Thus making Ulstein identical to the Design and Assembly Company described in 3.1.4.1 ETO companies.

The manufacturing process starts off with a request from a customer, were the request gets possessed by the design department in close relation with the customer, to ensure that the customer requirements are satisfied. However, as the drawing are sent to the project leader at the site, and gets further discussed with the departments, there are often details that are not realisable. Hence a miss-match change occurs.

Ulstein identifies two different Engineering Changes:

1. Miss-match changes: Changes that occur because the initial idea cannot be done, in other words a construction error. These kinds of changes are often discovered early in the process. However, since this is a change that doesn't occur on the request from the customer, the entire cost falls on Ulstein.

2. Customer requested changes: Changes which are requested from the customer. These changes often appears later in the process, and thus might cause greater harm to the initial production plan. However, in this case, the change request will be analysed in terms of cost, propagation, and plan consequences. The customer will then be presented with a new offer that possibly states an increased price and delivery time. The customer then has to evaluate whether he still wants the change or not. Although the customer is supposed to takes the extra cost, miscalculations do happen, and Ulstein do sometime inquire a loss on the added change. This is often due to undetected change propagation.

How each change is handled varies according to potential impact on the production plan and ship details. Large changes, potentially impacting dead weight, stability and speed, will require Ulstein Design and Solutions (UDS) to assist in the change evaluation. For medium sized changes UDS will not be contacted, instead the technical and the production department will analyse impact to see if it is doable. If the change can be done, the technical department creates a new engineering drawing version that includes the change, and present it together with cost and impact data to the customer. Very small changes might be concluded by the project leader without including the different departments in the decision making. The next part will outline the ECM process in further detail.

5.3 The ECM process

In order to easier discuss and explain the ECM process at Ulstein, a brief overview of the different stages of the ECM process is presented. Although the source of the change request can potentially be anyone related to the project it is the customer requests that usually are the one that can induce the largest EC cost, and thus also involve the most participants. The overview will be mapped for customer requested ECs. The only difference is that the initiator is the owner instead of an engineer at Ulstein. The model is adapted from the specialisation project(Norbye 2011) which again based the model on the ECM process overview provided by Ulstein, as seen in Appendix C – ECM process Ulstein, and the information gained through interviews at Ulstein.

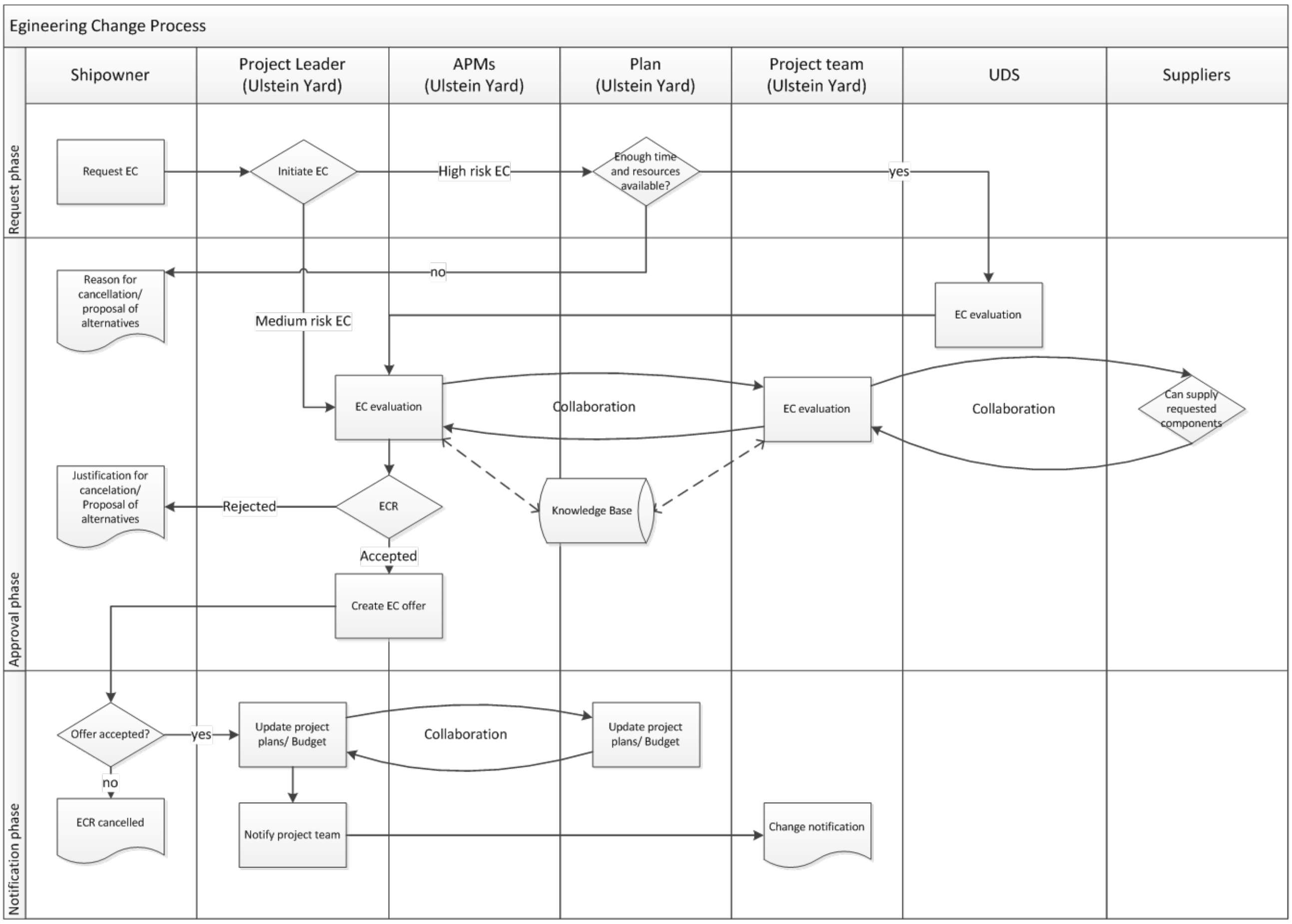

Figure 8: Ulstein's ECM process

As an Engineering change request is initiated from the customer or due to a miss-match, the Project leader, along with the Assisting Project Managers (APMs) from the different departments, discusses the potential impact of the change. Based on that assessment, the correct people will be notified. If the change has a chance of altering performance and balance, UDS will be involved. On the other hand, if the change is minor enough, the project leader might choose to approve the change without involving the different departments at all. Normally however, the change request gets passed on to project team consisting of staff from the technical, production and procurement departments for further analysis.

The engineering change evaluation done by the three departments will eventually end up as calculations and estimates of hours, costs, materials, change propagation. Based on this evaluation the project leader will determine whether or not the change is feasible. Considering that 60-80 per cent of a ship is outsourced(Mello and Strandhagen 2011), the project team also have to consider whether the suppliers are able to deliver the requested parts before the change is approved. Thus making the supplier an important part of the EC evaluation phase. If the change is approved by Ulstein, the project leader will present a new offer to the customer, stating possible increases in cost and schedule, along with an updated Engineering drawing. After customer approval, the plans will be updated whereas the change request will be sent back to the departments for implementation.

6. Applying the Maturity framework on Ulstein

The information in this chapter is solely based on the interviews and observations done at Ulstein. As stated in 2.3 Sources of Error, Validation, Reliability and Objectivity, there are room for misinterpretations. Thus, this chapter represents the author's perception of the data collected at Ulstein.

In the framework below, Ulstein's ECM processes have been positioned according to their perceived maturity. The background for the positioning will be presented and discussed in more detail in section 6.1 Current ECM processes at Ulstein.

<table>
<tr><td colspan="2">Change propagation
Intention: Ease the identification of change propagation and aid in decision making</td></tr>
<tr><td rowspan="4">Propagation analysis</td><td>Personal experience: Propagation analysis solely based on personal experience combined with the paper based information at hand, such as a BOM.
IT support: Limited or none
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>Manual change prediction model: A propagation model visualising component connections and propagation risk through matrix, network or tree models. Developed based on expert assessments.
IT support: Limited or none
IT requirements:
Maturity: #Medium#</td></tr>
<tr><td>Propagation analysis support: Through elaborating the product information available in the system such as BOMs, the system presents a set of directly linked components.
IT support: BOM analysis tool
IT requirements: A knowledge base containing the complete product BOM
Maturity: #Medium/High#</td></tr>
<tr><td>Automatic decision support: Automated change propagation analysis with the aid of expert agents, a software program with an expertise in a given discipline. Its knowledge is extracted from a comprehensive knowledge base.
IT support: Advanced data mining tools, software agents
IT requirements: An extensive knowledge base encompassing all product related information, both current and historical.
Maturity: #High#</td></tr>
<tr><td colspan="2">Knowledge management
Intention: Provide engineers with easy capture, management and reuse of relevant design and product knowledge throughout the change process.</td></tr>
</table>

Information storage	**Non-integrated systems:** The process of storing a large variety of information in a just as large number of different IT-systems throughout the enterprise. Each of the different IT-systems got their own database containing their own none-shareable information. **IT support:** Separate IT-systems **IT requirements:** None **Maturity:** #Low#
	Central storage of ECM related engineering data: Storing the ECM related engineering data (ref Appendix X) in one place, making it easily accessible for the involved departments. **IT support:** A database extraction module or partly integrated systems **IT requirements:** Two or more IT-systems **Maturity:** #Medium#
	Full system integration: The process of storing information in the one unit that constitutes all the company's IT-systems. Although the information is stored in individual systems, all the information is accessible across systems and throughout the entire enterprise. **IT support:** Full system integration **IT requirements:** Two or more IT-systems **Maturity:** #High#
Information retrieval	**Simplistic search functionality:** Key word and category-based browsing. **IT support:** Simplistic search-engine **IT requirements:** A database **Maturity:** #Low#
	High-end search engines: Search engines that consider several parameters and provides a larger variety of search features. **IT support:** High-end Search engines **IT requirements:** A database **Maturity:** #Medium#
	Advanced data mining tools: The use of advanced algorithms that can process large information inputs in order to retrieve highly relevant data. The algorithms aim to analyse large sequences of data in order to come up with meaningful patters. **IT support:** Advanced data mining tools **IT requirements:** A database **Maturity:** #High#

Collaboration

Intention: *ensure that the right information is available to the right person at the right time throughout the enterprise*

<table>
<tr><td rowspan="3">Information sharing</td><td>Paper based: The process of sharing information on paper, without interference of any IT solutions.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>Through standalone systems: The process of sharing knowledge through simplistic information sharing tools such as e-mail.
IT support: Information sharing tools
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>Real time: Information is updated and shared among all the involved disciplines at the same rate as the information is received by the system.
IT support: Real time information sharing tools, workflow solution
IT requirements: Full system integration
Maturity: #High#</td></tr>
<tr><td colspan="2">Information interpretation
Intention: Provide both textual and graphical information in a way that is easy interpreted by anyone involved in the process</td></tr>
<tr><td rowspan="3">Information visualisation</td><td>Paper based visualisation: Presenting information through technical drawings.
IT support: None
IT requirements: None
Maturity: #Low#</td></tr>
<tr><td>2D and 3D information: Combining the traditional paper based visualisation with the benefits of representing some information in 3D. The extent of the 3D visualisation is however limited, both in terms of visualisation and accessibility throughout the enterprise.
IT support: Early stage CAD tools
IT requirements: None
Maturity: #Medium#</td></tr>
<tr><td>Virtual environment with customised views: Refers to a virtual information environment that extends throughout the company, making 3D information visible to whoever might benefit from it. The 3D model should be the carrier of all detailed product information. There should also be possibilities to customise how and what the information is presented through the 3D model in order to best suit the targeted department.
IT support: High end CAD tools
IT requirements: Full system integration
Maturity: #High#</td></tr>
</table>

6.1 Current ECM processes at Ulstein

This section will elaborate on the marked maturity stage along with their respective core problem.

6.1.1 Propagation Analysis

This topic refers to the process of identifying change propagation throughout the product structure. In the case of Ulstein, this analysing process is performed by the Project leader, APMs and project team during the EC evaluation in the Approval phase as seen in Figure 9: Ulstein's ECM process. As for now, there are currently no systems at Ulstein which can identify or aid in identification of change propagation. Due to the possession of highly experienced employees, all change propagation analysis is based on personal experience, and a thorough discussion of the engineering drawing among the different departments.

Due to Ulstein's lack of IT support for change propagation analysis combined with heavy reliance on personal experience, makes the process coincide with the **Personal experience** process in the framework. The process can be characterised by the non-existing IT involvement, where no measures are taken in order to ease identification of change propagation. As a result Ulstein's change propagation analysis process is classified as a low maturity approach.

6.1.2 Knowledge Management

The knowledge management process is divided into two sub processes, information storage and information retrieval.

6.1.2.1 Information storage

Information storage refers to the process of storing and managing information in a way that makes it easily accessible to the involved participants. An essential part of this is where the information is stored, where having one single source of information would be the goal to strive for.

Although Ulstein to some degree has realised that having an integrated system environment is beneficial, information are still to some degree, dispersed throughout the different systems. One of the main reasons for this is the difficulties of integrating systems that by default are not intended to interact with each other. Moreover, Ulstein does not currently possess a solution that stores product data in an easily accessible way.

Due to the lack of product data storage systems, Ulstein does not manage satisfy the requirements for the **Central storage of ECM related engineering data** approach, where product data is an essential part. However, as they do to some degree have some integration between their systems, they do not fit within the **non-integrated** systems approach either. Hence, both the low and medium maturity approach has been marked red, whereas Ulstein's approach has been classified as a low/medium approach.

6.1.2.2 Information retrieval

The information retrieval functionality should aid in easy retrieval of product and process knowledge and thus facilitate efficient reuse of knowledge. The necessary extent of this functionality will naturally depend on the extent of the database in question. The ideal and most demanding situation would however be a fully integrated system acting as a single source of knowledge.

Due to the lack of an integrated environment at Ulstein, extensive search functionality has not been emphasised. As a result, one might experience that information can be very difficult to find if you don't know where to look. To cope with this Ulstein have a project coordinator which at all times should have control of the information flow, what information is available and the most current revisions.

Based on the lack of integration, reliance of project coordinator and difficulties in locating and retrieving information, the information retrieval process possess similar characteristics to a **simplistic search functionality** environment. Thus, Ulstein's information retrieval abilities have been classified as a low maturity approach.

6.1.3 Collaboration

The collaboration process should ideally ensure that the right information is available to the right person at the right time throughout the enterprise. This does to some extent refer to the degree of system integration and whereby information gets automatically updated throughout the different systems. It also refers to the direct communication among different employees and departments.

Ulstein's approach to ECM collaboration is mainly through e-mail and meetings. Meetings are commonly used when the same information has to be discussed and passed on to everyone, which is the case when a new change has been requested. These meetings are usually a weekly event, in order to ensure that the process stays on schedule and to collaboratively resolve potential problems. Information is usually received through e-mail or retrieved from one of the different IT-systems.

Based on the lack of system integration, and sharing of information through meetings and e-mail, the collaboration process seems to be done mostly **through standalone systems**. Hence, Ulstein's collaboration process has been classified as a medium maturity approach according to the maturity framework.

6.1.4 Information interpretation

Information interpretation refers to the process of representing both textual and graphical information in a way that is easy interpreted by anyone involved in the process. How information is interpreted by an individual and how that information is best presented varies from person to person. However, the benefits of representing information in 3D in terms of interpretation has been stated and supported by several authors, as discussed in 3.2.4.4 Information interpretation.

Ulstein currently possess and use a web interface called eBrowser. The purpose of eBrowser is to make the drawing archive and 3D models of the products available throughout the company. This solution is integrated with their CAD systems Nupas and Cadmatic which again enables eBrowser to automatically update drawings and 3D models according to changes being made in the CAD systems.

Although eBrowser does not possess the ability to customise product views according to department and employee preferences, this solution possess the ability to share 2D and 3D information throughout the company. This aspect is coherent with the High Maturity **Virtual environment** solution from the maturity framework. One of the issues however, is the lack of integration and availability towards product information. Although eBrowser can display basic product information along with the 3D model, this information is manually inserted by a designer from the technical department. Thus, eBrowser does not fulfil the requirements of a **virtual environment** where all related product information can be seen in a linked network with its representative 3D model and 2D drawings. On the other hand it provides functionality that is perceived as better than the **2D and 3D information** process from the framework. Hence, both the Medium and High Maturity approach has been marked red, whereas Ulstein's solution has been classified as a medium/high maturity approach.

7. Discussion

After assessing Ulstein's ECM process by using the maturity framework on information gathered from interviews and documents, the average maturity is set to low/medium. As stated earlier, a high maturity solution is not necessarily coincides with the best solution. Considering how Ulstein operates in a complex environment involving numerous of working disciplines and companies while creating complex and sophisticated ships, their current ECM approach might indeed be a good fit to their current processes. The low/medium maturity does however indicate the possible existence of unexploited potential in terms of IT solutions.

It is however important to note that, despite how promising new technology may appear, it is also very important to understand the implications of adapting new technology. Because as stated in 3.1.5 Technology selection, adapting new technology can either be a source to competitive advantage or a threat. It is important to note that when an adaption decision have been made, it can often be very difficult to reverse the process. Thus, timing of new technology acquisition is one of the key strategic decisions a company has to make. In order to ensure these sound technology decisions, it is important to emphasis a thorough assessment and good understanding of their current processes and the possible effects the new technology will bring.

The following section will elaborate further on the different aspects concerning Ulstein's current solutions and the possibilities ahead. This will be done through analysing the current situation against the possibilities while at the same time considering the implications of new technology adaption and the dynamic ETO environment.

7.1 Change propagation analysis

Let's consider the change propagation analysis, which currently is solely based on personal experience, possibly aligned with a Bill of Materials and 2D drawings. Today, this might not appear as a significant weakness. However, personal experience does not stay in the company forever, although some of it will possibly be passed on.

There are two aspects to this problem, where the first one is storage and retrieval of previous ECs. Ideally one would want one single source of information with easy retrieval abilities. Such a solution would enable everyone on the project to have the same "personal experience", since it enables everyone to retrieve similar ECs from different projects and thus contributing to a good sustainable EC propagation evaluation. In Ulstein's case, this information currently reside within each employees mind, making it inaccessible to others. Hence, employees at Ulstein without the prior experience are unable to learn from previous EC mistakes or success, which is a source of double work and waste of resources.

The second issue is the ability to efficiently process the EC history and current product data in order to make better decisions regarding possible change propagation. Currently there are no information retrieval and representation solutions available at Ulstein that tries to make sense of the EC data, in order to present possible propagation links. Thus, the employees at Ulstein are required to identify all possible propagation linkages manually, which leaves room for links being overlooked.

Now let's consider the optional approaches. The high maturity approach, as presented in 3.2.4.1 Unidentified change propagation, is aiming towards using advanced data mining tools and expert agents. This is done in order to efficiently fetch previous similar ECs from the database and the suggest decisions based on the outcome from the old ECs. Although such a solution would be able to provide links difficult or maybe impossible to identify manually, there are some uncertainties regarding whether an ETO company like Ulstein produces enough ships to sufficiently populate such a database. Moreover, since this solution still is at the idea stage, there are several uncertainties regarding a possible implementation.

The medium maturity approach on the other hand is already present in some of today's PLM systems. This solution does however only display direct linkages, which are identified through the BOM available in the system. Thus it is not able to take advantage of the history residing in old EC reports. In order for this solution to function properly there is a requirement for a knowledge base containing the complete product BOM and a tool that are able to display the links in a clear way. Considering the enormous amounts of parts in a ship, such a solution could be a good way to keep track of all the direct linkages, reducing the risk of overlooking important connections.

7.2 Knowledge management

Now let's consider the second problem, knowledge management. Also in this case, the reliance in personal experience is evident, whereas reuse of knowledge gathered is non-existing. In addition to aligning with the argument of experience sustainability stated above, one would also believe that being able to easily access the experienced acquired by the company would significantly broaden the decision basis. Considering how fast costs can increase on wrong decisions, one should emphasis having an as broad knowledge base as possible. This topic slightly overlaps with the above one, where one of the remarks was similar, learn from the experience others have made.

This topic consists of two sub-topics, where the first one is information storage. As mentioned above in 7.1 Change propagation analysis, information storage is concerned with making information easily available, facilitating reuse of knowledge. Although there are some integrated systems at Ulstein, the important ECM information such as EC reports and product information along with CAD models and drawings are dispersed throughout different databases. This causes valuable links between engineering changes and related components, products, and solutions to not be preserved in an easy identifiable way. Furthermore, it requires exact knowledge on the whereabouts of the information in order to find it. Regardless of how familiar the current employees at Ulstein might be with this process, the excessive time spent looking for information significantly increases process time. Moreover, if prior knowledge remains undiscovered, double work, waste of resources and decision errors are typical results.

The second topic is information retrieval, which is somewhat related to the storage aspect. Large and complex storage systems usually requires more advanced search abilities to even have chance to find relevant search results. Since Ulstein lack proper PDM systems and integration towards CAD systems, such advanced search functionality is not required. Hence, their current information retrieval process was classified as low maturity. Considering their storage situation, this might in fact be sufficient. However, any improvements in the storage abilities will also require improvements in the retrieval functionality.

Now let's consider the optional approaches, where the high maturity storage approach will be discussed first. Full system integration focuses on providing one single source of information throughout the enterprise, which sounds ideal. Full system integration is however a comprehensive process to achieve, and should be done stepwise, and is typically a long term goal. Considering how one of the most common mistakes in technology adaption is trying to grasp more than you can handle, Ulstein might benefit from building a good foundation first.

Considering the current lack of a PDM system and thus the lack of integration between product information, EC information and CAD models, the medium maturity approach might be a better fit. Emphasising a central storage of ECM related engineering data, would bring necessary benefits in terms of information availability along with a reduced implementation risk compared to full system integration.

The information retrieval abilities should naturally follow the evolution of the storage capabilities. As discussed in 7.1 Change propagation analysis, it is however not certain that advanced data mining tools would have access to enough data in order to come up with meaningful patterns. This is mostly due to the low volume ETO environment Ulstein operates in, which probably would not generate enough similar data. Thus expanding the search functionality from simple keyword and category-based browsing to the medium maturity approach would be the obvious choice. However, such search functionality is usually already present in more advanced PDM/PLM systems.

7.3 Collaboration

The third problem collaboration is a difficult topic, which probably never will be mastered perfectly. Continuous improvements is however possible and highly recommended. Considering that the current communication form during the ECM process is e-mail and meetings, moving towards a more integrated real-time system that easily interacts with the different departments' sounds ideal. However, since collaboration is not a standalone issue solely affecting ECM, the benefits from a system implementation would have to span wider than ECM. In other words, such a turnover will have to be a part of a larger implementation for the whole company.

The intention of proper collaboration is to ensure that the right information is available to the right person at the right time throughout the enterprise. When considering the non-integrated environment at Ulstein, along with the process of sharing information through e-mail and meetings, the current process appears as inadequate in comparison with the intention. The non-integrated environment and lack of PDM systems makes it difficult to locate and find "the right information". While, a meeting, whether it is weekly or daily, represents a collection of batched information. Although the batched information was available prior to the meeting, it was not distributed, possibly causing information to not be received at the "right time".

When considering the high maturity real time approach, the comprehensiveness gets evident. This is mostly due to the requirements of full system integration in order to always have access to updated information from one source. The collaboration topic is also concerned with the information sharing tools, which currently are e-mail and meetings at Ulstein. Adapting real time information sharing solutions such as advanced workflow engines as described in 4.1.4 Engineering process management, would not require a fully integrated environment, but still be able to provide a better flow of information throughout the ECM process.

7.4 Information interpretation

The final problem, information interpretation, is focused towards how information is presented to the receiver. It does not really matter how large the knowledge base is, or whether the information got to the right person at the right time, if the employee fails to understand the implications of the information. Ulstein's current use of the eBrowser, which enables 3D models along with basic product information to be visualised throughout the company, is already a very good solution in terms of information visualisation. The drawback is however the lack of integration towards some kind of PDM system, which would enable employees to see every aspects of the product in a linked way. There is basic product information available in the eBrowser; this information is however inserted manually, thus making it vulnerable in a changing environment in terms of information consistency.

When comparing to the high maturity virtual environment approach, Ulstein's approach is only missing the integrated environment which connects 3D models with actual product and EC information. Thus, whether this will be improved will depend on choices made in terms of the information storage approach as discussed in section 7.2 Knowledge management.

7.5 Technology providers

Ulstein is currently using many different IT-systems provided by just as many providers. Due to the increased importance of system integration, the possibilities for integration appear as an important criterion. As a result PLM providers are already providing PLM software with customised connectors for integration to the most popular ERP systems such as AX and SAP, and the most popular CAD system such as NX and CATIA. However, due to the wide variety of support solutions, it is impossible to have customised connectors for them all, thus the marked leaders are prioritised. Hence it appears as if the marked leader solutions will distinguish themselves even more by facilitating system integration, leaving the smaller providers behind.

Smaller providers are usually companies that have focused on a niche market, which could be shipbuilding. Since one customer represents a larger part of their total income compared to large multinational companies, small providers usually have a closer connection to their customer. This enables the customer, such as Ulstein, to make request on functionality which usually will be followed up on, if it is achievable. On the other hand, the issue for smaller companies is the lack of resources in order to stay ahead of the market in terms of functionality. Instead they might have to settle on creating functionality on demand. Considering that customer sometimes have difficulties in realising their needs, this is indeed a drawback.

On the other hand, larger companies usually have a broader customer group. They will not necessarily be specialised in one field, thus the large customer base. They do however have the resources to stay ahead of the market in terms of functionality. Although not being industry specific, functionality that has solved problems in one industry might also be applicable in another, such as shipbuilding. This is a link specialised companies will not benefit from.

8. Conclusion

In the global competitive market, it is getting increasingly more important to continuously improve in order to stay competitive (AberdeenGroup 2007). Needless to say, this also goes for ECM, however it's not until recently companies have realised the significant advantages of a good ECM process. This is now causing an increased attention towards reducing time to market by improving the company's ECM capabilities. Considering the ever increasing importance of technology in today's industry, it is likely to believe that these improved ECM capabilities will require IT-solutions of some sort. However, since such technology selection is one of the most challenging decisions management encounters, it is crucial to have a good understanding of the problems ahead and implications of the possible solutions.

The literature review on ECM identifies four core ECM problems, change propagation, knowledge management, collaboration, and information interpretation. By using these four problems as a basis, several approaches to cope with each of the problems were identified. By consolidating the approaches with similar characteristics, it was possible to classify them into three main groups. The main groups, along with its characteristics were then linked to its respective ECM problem. This resulted in a framework giving a concise overview of the key characteristics and relationships among ECM problems and solutions.

The proposed framework makes it possible for a company to easily classify its own capabilities in relation to the core ECM problems. When adapted, the framework will provide an intuitive overview which enables the company to compare its own capabilities with other solutions available, aiding the process of adapting new technology and assessing its potential impact. The model is a response to the increased awareness of the significant advantages a proper change management process can yield (AberdeenGroup 2007). The framework is believed to assist in improving a company's ECM process by easing the analysis of their current ECM process and identifying possible improvements in terms of IT solutions.

8.1 Project Goals

To achieve the thesis goal of developing a framework that aids companies with ECM related technology selection, and answer the two problem statements, a series of project goals where defined in order to guide the overall process. These goals are discussed in the following section.

1. *Develop a theoretical framework that aids companies with technology selection related to ECM*

A theoretical framework is presented in section 3.4 Maturity classification tool. The framework intends to aid technology selection by classifying the ECM process in question and simultaneously comparing its capabilities with other solutions and approaches. This results in a better overview of which solutions might be promising to adapt, while at the same time listing the possible implications such a solution might cause. The framework is a result of the thorough literature review on the current ECM problems today and the wide diversity of possible solutions to these problems.

2. *Analyse the PLM system Teamcenter's ECM functionality*

This analysis can be found in section 4. Teamcenter. The analysis was performed in order to get a broader understanding of which ECM capabilities that were currently present in today's industry.

3. *Develop a revised framework combining the previous framework with knowledge obtained through analysing Teamcenter.*

Through consolidating the current theoretical framework with the findings from the Teamcenter analysis, the revised framework got expanded under the topics change propagation analysis and collaboration. The revised parts of the framework can be found in section 4.4 Revised framework .

4. *Analyse Ulstein's current IT-systems in terms of ECM functionality with the aid of the theoretical framework.*

By adapting the revised framework to the information retrieved from Ulstein, Ulstein's current ECM capabilities gets highlighted in red, as seen in section 6. The average maturity of Ulstein's ECM capabilities ended up as low/medium, which gives an impression of unexploited opportunities. The highlighted capabilities gets further elaborated on in section 6.1, whereby the result from this assessment gets thoroughly discussed in section 7.

8.2 Thesis results

The answer to the two problem statements resulting for this research is presented below.

1. What are the different approaches to solving today's ECM problems and to what degree are these approaches supported by IT solutions?

The variety of approaches and technologies used to cope with the ECM challenges is just as large as the number of ECM research papers, each of them with their own strengths and weaknesses. There were however many similarities among them, which made it possible to group them into larger, more general groups. These groups, along with their respective ECM problem can be found in the Framework presented in section 3.4 Maturity classification tool, whereas the more thorough elaboration on each of the approaches can be found in section 3.2.4 Engineering Change Management challenges.

Almost all the suggested solutions described in this thesis, was in some way supported by IT. The comprehensiveness of the IT solutions did however differ quite a bit, which again was related to how well the solution intends to fulfil its purpose. Based on this differentiation, the approaches were classified according to ECM maturity, which can be seen in the maturity framework in section 3.4. Although ECM maturity is supposed to give an idea of which approach copes with the problem in the best way, it should be emphasised that there is no "best" way that fits every company.

2. How can the current ECM process at Ulstein be improved?

The current ECM process at Ulstein can be characterised by the lack of integrated IT solutions, sequential information sharing and the lack of propagation analysis solutions. Their information visualisation capabilities through eBrowser are however quite satisfying as a standalone solution. However, also this solution has its drawbacks due to the lack of integrated product information, something that could have been achieved through integration with a PDM or PLM system.

Based on the ECM process analysis performed in section 6 and the discussion in section 7, Ulstein needs to emphasis establishing a solid system framework which facilitates the future requirements for collaboration, system integration and information visualisation. Whether this foundation can best be achieved through improving and expanding their current IT systems in the direction of PLM, or adapting a new and complete PLM system, is difficult to conclude on due to the many aspects that need to be considered. That being said, a system network which continuously gets expanded in order to fit the needs of the customer, would most likely result in a good fit between processes and IT systems. On the other hand, a well-established PLM system already got a PLM framework that is extensively tested and approved in the industry, thus making it more reliable. Although it's not specialised towards shipbuilding it provides collaboration, integration and visualisation capabilities that are beneficial regardless of industry. Furthermore, a well-established PLM system with a large customer base will also usually coincide with leading-edge capabilities, putting its user ahead of its competitors in terms of functionality.

Regardless, Ulstein is eventually in need of a PLM system that provides one single source of information and facilitates real-time collaboration throughout the company through workflow tools and integration. Furthermore, this PLM system also needs powerful visualisation capabilities enabling the employees to see every aspect of the information. However, as discussed regarding technology selection, it is important to take moderate implementation steps. Thus the first goal should be to expand their current systems towards PLM or adapt a new PLM system. However, in the short term this PLM solution will basically act as a PDM system, due to the lack of integration. Nonetheless, this will enable Ulstein to better incorporate product and EC information into the ECM process. More importantly it will also create the necessary foundation to evolve into a fully integrated PLM system when the time is right.

8.3 Further research

The work done in this thesis has resulted in a better overview of the current challenges in ECM and which solutions are currently provided to cope with these challenges. As today's PLM systems are already making good progress towards coping with collaboration, knowledge management and visualisation issues, the remaining problem is propagation analysis. Although current solutions are using BOMs in order to visualise direct linkages, there are still unexploited EC information in terms of previous ECs which possibly contain valuable experiences.

As already discussed in regards to propagation analysis, analysis based on previous ECs might have limitations when it comes to ETO due to the limited amount of similar data. Regardless, previous ECs is a currently unexploited source of knowledge, which could significantly lower processing time by easing decision making and avoiding similar mistakes being made again. Thus, how to exploit the knowledge residing in old EC reports in a better way is a topic for further research.

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10. Appendices

Appendix A – Relevant ECM data

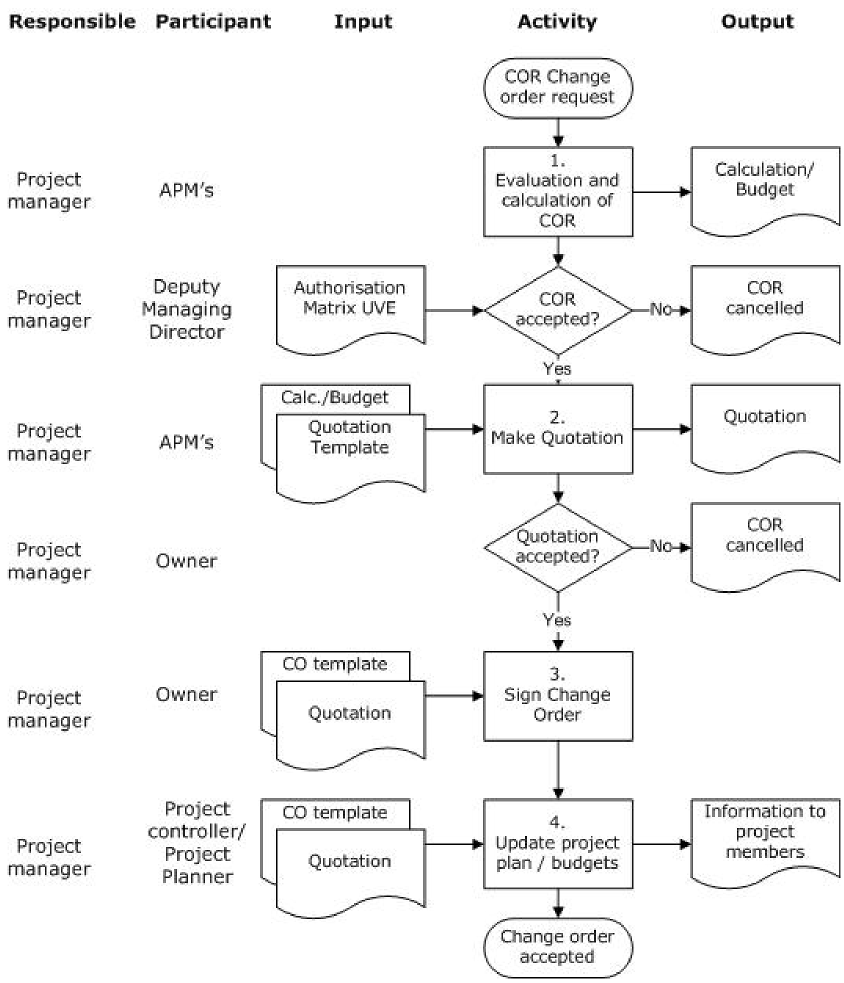
Adapted from Kocar and Akgunduz (2010)

EC Data
EC Number
Initiator
Time of ECR
Attribute changed
Previous value of the attribute
New value of the attribute
Reason code
Reason explanation
Reason comments Priority
Current status
Product data
Component number
Component description
Product family
Level on BOM
Quantity per assembly
Technical drawings
CAD model

Appendix B – Databases

Databases	Description
ScienceDirect	The world's leading full-text scientific database
BIBSYS Ask	The catalogue of NTNU library
Compendex	The most comprehensive interdisciplinary engineering database in the world
Scopus	The largest abstract and citation database of research literature and quality web sources

Appendix C – ECM process Ulstein



Appendix D – Abbreviations

- ECM – Engineering Change Management
- EC – Engineering Change
- PLM – Product Lifecycle Management
- CAD – Computer Aided Design
- PDM – Product Data Management
- IT – Information Technology
- ETO – Engineer To Order
- OPP – Order Penetration Point
- DSM – Design Structure Matrix
- CPM – Change prediction Method
- BOM – Bill Of Materials
- PR – Problem Report
- ECR – Engineering Change Request
- ECN – Engineering Change Notice
- UDS – Ulstein Design and Solutions
- APM – Assisting Project Manager

Appendix E – Literature overview

Letter description
A=Change propagation
B= Knowledge Management
C=Collaboration
D=Information Visualisation

Grading
1= Poorly written/nothing relevant
2= A few citations/ might be relevant
3= Ok written/ relevant
4=Well written/ some parts are very relevant
5=Well written/ very relevant

ECM papers

Name	Grade	A	B	C	D	Notes/comments
A Benefit Measurement Framework for an Online Contract Change Management System	2					Maturity model for contract change management.
A critical review of Knowledge-based engineering: An identification of research challenges	2		x			KBE in design Some quotes
A network-based assessment approach for change impacts on complex product	1	x				Weighted networks Nothing new
A product Feature Evolution Validation Model for Engineering Change Management	3				x	Different views according to information needs
ADVICE: A virtual environment for Engineering Change Management	4	x	x		x	ECM issues
Agent-Based Assistance for Engineering Change Management: An Implementation Prototype						Older version of Decision-Making Assistance in Engineering-Change Management Process
An approach to predict impact of proposed engineering change effect	2		x			Predicting EC effect to determine whether the EC should undergo a fast track or detailed evaluation. Using previous knowledge. Requires a large number of ECs.
An information-theoretic approach to determine important attributes for engineering change evaluation	2		x			The challenge of determining similarity of ECs. Similar to the paper above.
An integrated system for change management in construction	2	x				Change prediction in construction projects.
Analysis on Engineering Change Management Based on Information Systems	3			x		Integration, a sharing database. Nice Introduction
Capturing and reusing knowledge	3+		x			Ch 3.3,

in engineering change management: A case of automobile development						4.4 information retrieval
Challenges for Handling flexibility in the change management process of manufacturing systems	1					Organisational change
Change and customisation in complex engineering domains	2+	x				Check Eckert reference Change propagation parameters
Change decisions in product development projects	2					Change decision criteria's
Change Management in concurrent engineering from a parameter perspective	2	x		x		3.4 current ECM systems SIMNET
Change Propagation Analysis in Complex Technical Systems	2	x				Didn't get much out of the data presented
Construction Project Change Management in Singapore: Status, importance and impact	1					
Current practice of engineering change management in Hong Kong Manufacturing industries	2					A survey, no interesting findings
Decision Making Assistance in Engineering Change Management	3+	x	x	x		Expert agents, decision making assistance. Ch 1,2 and 4
Developing a multi-layer reference design retrieval technology for knowledge management in engineering design	3		x			Ok knowledge introduction. Knowledge retrieval #Note# Re-read if in-depth knowledge retrieval methods are needed.
Development of a web-based system for engineering change management	3-			x		Referring to paper based a lot. The actual system is not that relevant, the pre-discussion might be however
Enabling collaborative product design through distributed engineering knowledge management	3		x			Methodology for engineering knowledge management. Page 4-8 relevant
Engineering Change Management in individual and mass production	1					Nothing new
Engineering Change Management 2.0: Better Business decisions from intelligent change management	5	x	x	x	x	Best-in-class vs laggards A lot of number and tables Spot on paper
Framework for change notification and view synchronization in distributed model management systems	3	x			x	Ok introduction. Some of the functionalities might be relevant for the framework.
Frameworks and technologies for exchanging and sharing product life cycle knowledge	2		x			Product lifecycle knowledge. good, but slightly off-topic

From theory to practice: Challenges in operationalizing a technology selection framework	2					Technology selection. Might get relevant in the discussion chapter
Implementation and Application of a CMII-based System for Engineering Change Management	1					Nothing new
IT-based approach for effective management of project changes: A change management system	1		x			Nothing of interest
Knowledge-based decision support system for management of variation orders for institutional building projects	1		x			Nothing of interest
Lean Information Management Model for engineering changes	4		x	x		-Waste categories in LIM -ECM challenges -The tool boxes
Managing the exchange of engineering product data to support through life ship design	1					Dense and not that relevant
Managing the process of Engineering Change Orders: The Case of the Climate Control System in Automobile Development	3					Good ECM intro Considers ECM problems, but probably a bit out-dated
Modelling and managing engineering changes in a complex product development process	2					NPD and ECM comparison and resource allocation between the two, not that relevant
Multilayer network model for analysis and management of change propagation	2/3	x				States what data is required for propagation analysis. Also got some interesting findings, as mentioned in the abstract. Might need a re-read on results
Multiple View to Support Engineering Change Management for Complex Products	4-	x			x	Information representation Good change propagation text
Pitfalls of Engineering Change	1	x				Nothing new
Product design knowledge management based on design structure matrix	3	x	x			Interesting user interface/functionality for a knowledge management system
Re-engineering the Engineering Change Management process for a drawing-less environment	3+	x				Lists required CAD functionality Lightweight distribution files
Study of ICT adoption for building project management in the Indian construction industry	1					
Supply chain management in the shipbuilding industry: Challenges and perspectives						Re-read for the shipbuilding part

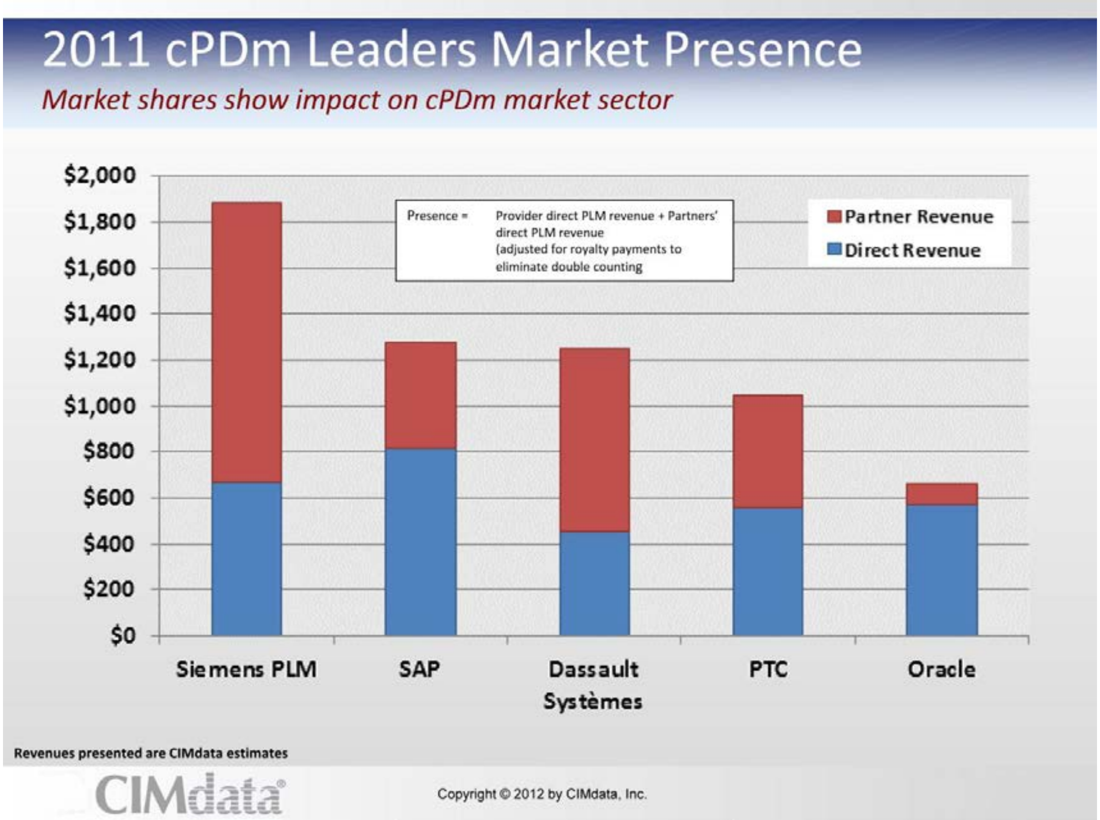
Supporting change processes in design: Complexity, prediction and reliability	2	x				Section 5.1
Supporting conflict management in collaborative design: An approach to assess engineering change impacts	2	x				Change dependency network Might get relevant
System dynamics modelling of engineering change management in a collaborative environment	1+					Links ECM and NPD Nothing new
Systematic Decision Support for Engineering Change Management in PLM	4	x	x			ECM and PLM functionality
The Configuration Management Benchmark Report	2					
Towards Intelligent Change Management in Product Modelling	1					Didn't get much out of this
Traceability and management of dispersed product knowledge during design and manufacturing	2	x	x			
Tracking product specification dependencies in collaborative design for conflict management						DEPNET2 Same as a previous paper Change dependency network
Will Model-based definition replace engineering drawings throughout the product lifecycle? A global perspective from aerospace industry	3				x	Drawings vs visual representation

PLM papers

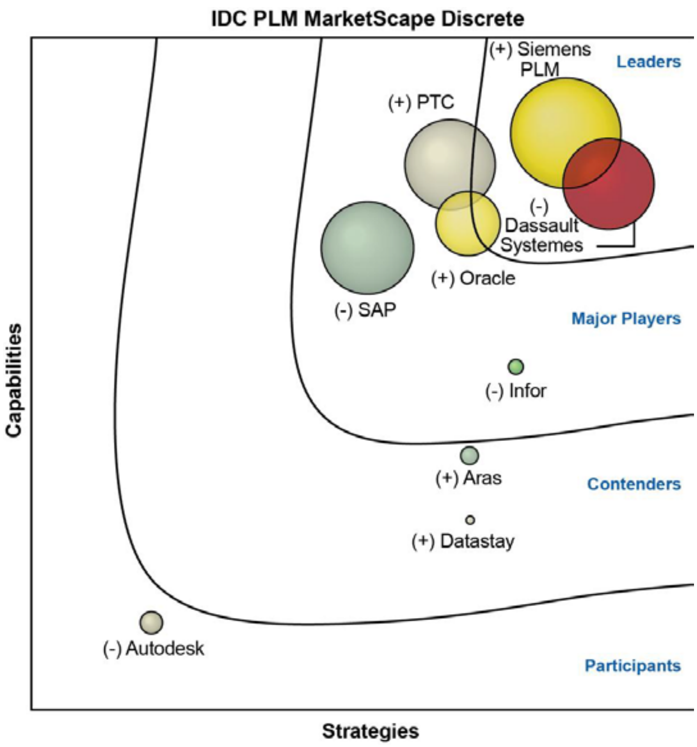
Name	Grade	A	B	C	D	Notes/Comments
A product lifecycle management methodology for supporting knowledge reuse in the consumer packaged goods domain	2		x			Knowledge reuse
A reference framework following a proactive approach for product Lifecycle management	3	x		x		Check ref 32,33,34 Expert agents and collaboration
An empirical analysis of the PLM implementation effects in the aerospace industry	3+					Nice intro. Table 1 and 2 for reference overview, check ref 4. Functionality table fig 2 and 3
An integration framework for product lifecycle management	2					intro
Integration of evolutional BOMs for design of ship outfitting equipment	2+					PLM, Shipbuilding and BOM Didn't make much sense of it, might have to look more into it though
Modeling framework for product	1					

lifecycle information						
Product Lifecycle Management Empowering the Future of Business	3+					Business challenges, can be used in intro? PLM as a strategic approach rather than a piece of technology Some of it might be out-dated Enterprise system relationships
Product lifecycle management in aviation maintenance, repair and overhaul	4					Ch 1 and 2, the rest is not of interest The evolution of PLM
Product Lifecycle Management: Closing the Knowledge Loops	4					Ch 1,2,3 and possibly 8
Product Lifecycle Management through innovative and competitive business environment	1					

Appendix F – Siemens PLM Market Analysis



Source: CIMdata 2011 Market Analysis Results, PLM Market & Industry Forum



Source: IDC MarketScape: Worldwide Product Lifecycle Management (PLM) Applications 2011 Vendor Assessment: CAx, Discrete, and Process PLM

Appendix G – Preliminary Report

Engineering Change Management in Ship Projects

Stud.techn. Knut Magnus Gjertsen Norbye

Preliminary Report

ULSTEIN

NTNU

Innovation and Creativity

Background

This report is a preliminary report for the Master thesis “Engineering Change Management in Ship Projects” in the course TPK4900 Production and quality engineering. TPK4900 is a 30 credit course, which approximately equals a workload of 40 hours a week. The preliminary report will give a brief overview of thesis objectives and scope. It will also contain a project plan describing tasks and schedule for the thesis.

The master thesis is executed in collaboration with Ulstein, SINTEF and project IGLO-MP 2020. Both IGLO-MP and Ulstein will be briefly introduced in the introduction.

Main topic for this master thesis is “Change Order Management in Ship Projects”.

……………………………………..

Knut Magnus Gjertsen Norbye

Contents

Introduction

The main goal for the master thesis is to get a detailed understanding of the “state-of-the-art” ECM functionality from a set of IT-systems picked on the basis of availability and relevance. Furthermore, the thesis is focused towards identifying potential gaps in the ECM functionality and then propose a prototype that closes the identified gaps. The project is related to the ongoing research project “Innovation in Global Maritime Production 2020 (IGLO-MP 2020)”, which is a knowledge-building project executed in collaboration with Norwegian University of Science (NTNU), Marintek, and industrial partners such as Ulstein (IGLO-MP 2011). The main goal of the IGLO-MP project is to enhance the competitiveness of Norwegian maritime industry by strengthening their competitive capabilities(IGLO-MP 2011).The project leader of IGLO-MP is Ulstein Group, a Norwegian shipbuilding company which have gained international recognition due to their high quality, innovative designs and accurate deliveries(UlsteinGroup 2011).

In general, shipbuilding today encounters many challenges that are not common for other industries Among them, is the enormous amount of information flowing through a complex network of receivers and senders, which is a result of the complex structure of a ship, the numerous working disciplines involved, and the involvement of other companies.(Mello and Strandhagen 2011)

Engineering changes appears as an additional dimension to this complexity, changes which unfortunately are unavoidable, especially on large and complex projects like ship projects(Wasmer, Staub et al. 2011). Thus, the importance of proper change handling is crucial for a company’s competitiveness. However, despite the impact ECs got on manufacturing companies, it appears that it is not getting the attention it deserves (Huang, Yee et al. 2001; Rouibah and Caskey 2003). Looking at popular topics like supply chain management, the research done on Engineering Change Management appears as inadequate. Combining the complex nature of ECM in ship projects, with previous inadequate research, makes this an appealing topic.

The upcoming sections will present a project description consisting of the main objectives and goals for the project. This will be followed by a description of progress, methods and project breakdown.

Project description

The points listed below outlines the main tasks from the project description, which will form the basis for this master thesis.

1. Give an overview of relevant theory and best practices in engineering change management in project-based Supply Chains.

2. Map Ulstein's engineering change management process and present the engineering change management functionality in their current IT-Systems. Use the results from the specialization project in order to analyse possibilities and limitations. Based on the analysis, develop a general requirements specification for engineering change management in Nauticus.

3. Develop a prototype based on the requirements specification.

Based on the given tasks above and a phone meeting with Ulstein, the objectives and my interpretation of the assignments are as follows:

- Present an overview of relevant theory and best practice within engineering change management in project based supply chains using the research performed in the specialisation project "Engineering change management in ship projects" as a foundation.
- Present an overview of "state-of-the-art" IT-systems with ECM functionality available in the industry today.
- Present the engineering change management functionality in Ulstein's current IT-systems.
- Based on the results from the specialisation project along with the information collected from the above tasks, analyse possibilities and limitations of Ulstein's current IT-systems and two other commercial IT-systems.
- Develop a general requirements specification of engineering change management in Nauticus.
- Develop a prototype based on the requirements specification.

Goal

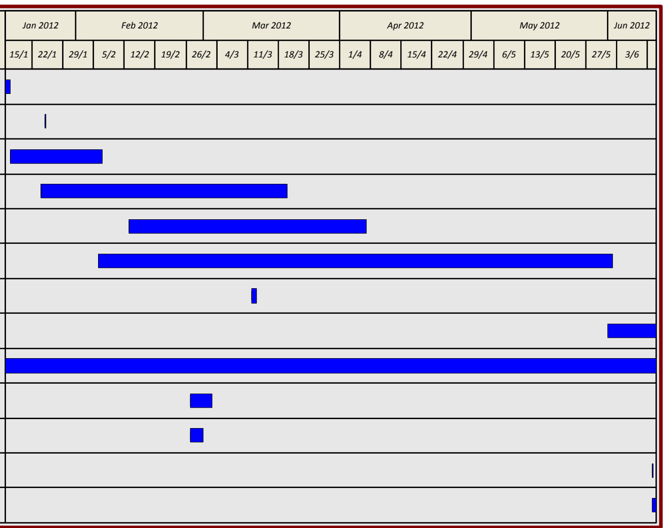
The goals for the Master thesis are to:

- Further investigate the aspects of good engineering change management
- Identify and bring attention to the ECM gaps in the current IT-systems available today
- Propose and identify innovative solutions to solve the current ECM problems

Progress

The planned progress throughout the lifetime of the Master thesis is outlined in the Gantt chart below.

ID	Task Name	Start	Finish	Duration
1	Project hand-out	16/01/2012	16/01/2012	1d
2	Meeting with supervisors	25/01/2012	25/01/2012	2h
3	Write Pre-study report	17/01/2012	6/02/2012	15d
4	Perform literature study	24/01/2012	19/03/2012	40d
5	Empirical study of IT-systems	13/02/2012	6/04/2012	40d
6	Write main report	6/02/2012	1/06/2012	85d
7	Write progress report	12/03/2012	12/03/2012	1d
8	Final adjustments of report	1/06/2012	11/06/2012	7d
9	Project planning and control	16/01/2012	11/06/2012	106d
10	Trip to Ulstein	27/02/2012	2/03/2012	5d
11	Introduction to Nauticus	27/02/2012	29/02/2012	3d
12	Presentation of report	11/06/2012	11/06/2012	2h
13	Project hand-in	11/06/2012	11/06/2012	1d



Methods

The foundation of the thesis will be the literature study performed in the specialisation project along with a more thorough elaboration on key aspects of these findings. The project will however be focused towards hands-on research of the current IT-systems at Ulstein along with two commercial IT-systems with functionality related towards ECM. In order to analyse the IT-systems at Ulstein, there will be conducted at least one field trip to Ulstein with an introductory and educational approach towards their IT-systems as the main focus. Furthermore, software vendors such as Summit Systems will be contacted in order to get an overview of “state-of-the-art” functionality in the IT-systems available in industry today.

Major milestones

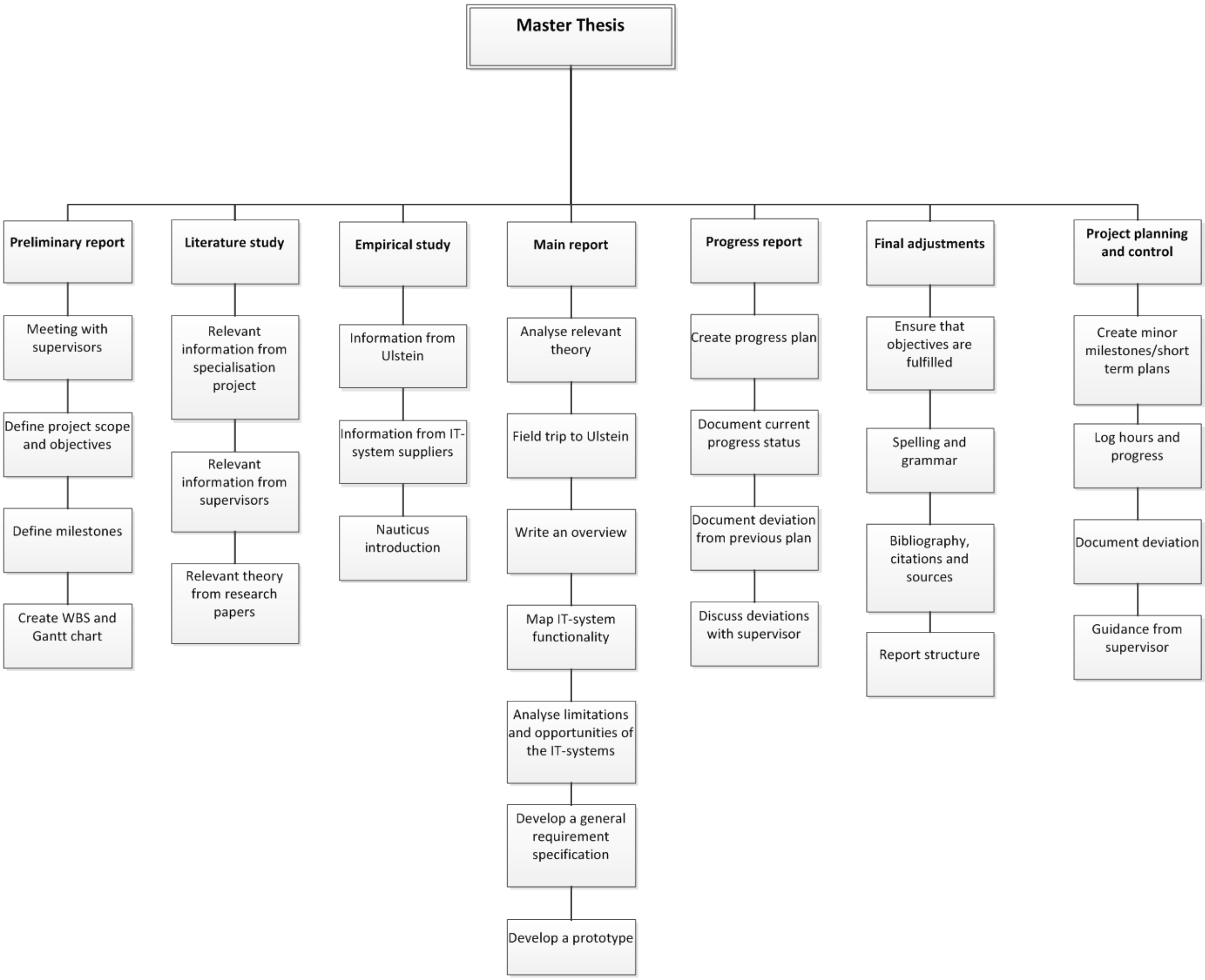
- Project start 16th January
- Preliminary report completed 6th February
- Report progress 12th March
- Hand in the thesis 11th June

Project Overview Statement

Project name : Engineering Change Management in Ship Projects	**Duration:** 16/01/2012-11/06/2012
Problem	In general, shipbuilding today encounters many challenges that are not common for other industries. Among them, is the enormous amount of information flowing through a complex network of receivers and senders, which is a result of the complex structure of a ship, the numerous working disciplines involved, and the involvement of other companies.(Mello and Strandhagen 2011) The major challenge occurs when engineering changes are added to the equation, changes which also could induce further downstream changes. In the end the processing of a change can consume up to half of the current engineering capacity, with a value-adding time as low as 8,5%(Kocar and Akgunduz 2010). A part of the problem seems to be the lack of ECM functionality in today's IT-systems, which can also be seen in relation to the inadequate amount of research done on ECM. Hence, the challenge is to develop a prototype that identifies and tries to close the ECM gap in the IT-systems analysed.
Goal	Get a detailed understanding of the "state-of-the-art" ECM functionality from a set of IT-systems picked on the basis of availability and relevance. Identify the current ECM gap in these systems. Successfully develop a prototype that covers the gaps identified.
Objectives	• Present an overview of relevant theory and best practice within engineering change management in project based supply chains. • Present an overview of "state-of-the-art" IT-systems with ECM functionality available in the industry today. • Thoroughly map the engineering change management process at Ulstein. • Present the engineering change management functionality in Ulstein's current IT-systems. • Based on the results from the specialisation project along with the information collected from the above tasks, analyse possibilities and limitations of Ulstein's current IT-systems and two other commercial IT-systems. • Develop a general requirements specification of engineering change management in Nauticus. • Develop a prototype based on the requirements specification.
Success criteria	• Grade A • Positive feedback • In depth knowledge of ECM functionality in IT-systems today • Successfully develop a prototype for engineering change management in Nauticus
Risks	• Poor planning • Too wide scope
Deliverables	A well written and well documented scientific report.

Work Breakdown Structure

The project consists of 7 main work packages, Preliminary report, Literature study, Empirical study, Main report, Progress report, Final adjustments, and Project planning and control.



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