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A System Engineering Approach to evaluate PLM during Upstream Ship Design Processes

10018 / Elisabeth Masdal Hovden

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A System Engineering Approach to evaluate PLM during Upstream Ship Design Processes

Introduction

PLM is short for Product Lifecycle Management, related to store system information together with main components throughout the lifecycle of a engineering project. Ulstein Group will be a partner in the thesis. The target is to apply PLM from the initial conceptual ship design phase, and continue to supplement on the process in the detailed engineering phase and also to be used during assembly and construction. Generally speaking this is a new method for tackling the design challenges, so many designers are skeptical and concerned on the limitation of the new approach.

System Engineering (SE) approach will be applied to investigate the upstream PLM process more in detail. In general terms, SE methods will be used to understand the problem properly and define it. Later, bottlenecks in the process can be identified and investigated more thoroughly. With SE it is important to look at the problem from different stakeholders perspectives, with a holistic mindset.

Motivation

The motivation is to contribute in the process of implementing PLM in the company. Since they have open questions when implementing it, the process needs to be looked at from different stakeholders perspectives. When/if PLM is the new working method, many advantages will probably come with it, like reuse of systems and 3D models, continuing the work from different phases, better communication between departments and with customer. PLM foundations facilitates the communication with customers and envision the final product with a more practical mindset. By reusing some of the systems and automatically updating and changing parts of the model, the designer would ideally have more time and freedom to come up with innovative solution with all main components, since the work between the iterations is automatically done.

Scope

The scope of the project is the PLM during the upstream ship design processes, mainly from concept to construction). System Engineering methods will be applied to understand the PLM process, discover the bottlenecks of today's solution, evaluate the current PLM processes as well as suggesting improvements to make the PLM processes work in practice. Figure 1 present the scope

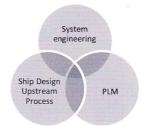


Figure 1 – Scope of the thesis on the intersection between the three circles.

Objectives

In order to investigate the PLM applied during the upstream ship design processes, different stakeholder's perception needs to be taken into account. First the PLM processes needs to be



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thoroughly mapped holistically. Each stakeholder has different expectations for each of the process and different perspectives generally. Top-down and bottom-up appraoches needs to be taken into consideration when decomposing the systems, identifying bottlenecks and evaluating the current upstream phases. Following research questions (RQ) are proposed:

- RQ 1: How can System Engineering methods be applied to evaluate the PLM during upstream ship design processes?
- RQ 2: What are the bottlenecks of the PLM system now and how to evaluate them?
- RQ 3: What improvements needs to be done to make the process work in order to maximize stakeholder's satisfaction?

Methodology:

Use of System Engineering methodology to investigate PLM during upstream ship design processes. Apply system engineering method to investigate stakeholders opinions and perspectives, identify bottlenecks, evaluate processes and proposes solutions that maximizes stakeholder's satisfaction.

Milestones and schedule:

Tasks:

- 1. Identification of research questions, scope, objective
- 2. Literature review on System engineering method nad PLM processes (Siemens NX, Teamcenter)
- 3. Choose System Engineering methods to map PLM during upstream ship design process
- 4. Analysis of PLM process, Bottleneckes, Stakeholders' perspectives, PLM tool usage
- 5. Suggest changes, improvements to maxime stakeholder's satisfaction
- 6. Implement changes
- 7. Results
- 8. Discussion
- 9. Conclusion

Objectives	Jan			Jan Feb				Mar				Apr				May			June		
Week	1	2 3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
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Task 1																					
Task 2																					
Problem spec.																					
Task 3																					
Task 4																					
Concept appl.:																					
Task 5																					
Task 6																					
Results:																					
Task 7																					
Task 8																					
Conclusion:																					
Task 9					e																

Deliveries:

Preliminary Thesis (30th March) Final Thesis + Article (3rd June)

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Preface

This report concludes the work done during the final semester of my Master of Science degree in Ship Design at Norwegian University of Science and Technology (NTNU) in Ålesund. Objective of the thesis is to evaluate PLM in the conceptual phase of ship design. The thesis is written in cooperation with Ulstein Design & Solutions.

Topic was chosen to get a deeper understanding of PLM and the work done in the conceptual phase. The thesis is performed by collecting information about the current practices through internal documentation, observations and interviews. With a better insight in the stakeholders daily work and the ship design process itself, the PLM process is evaluated.

Elisabeth M. Houden

Elisabeth Masdal Hovden Ulsteinvik, 02.06.17

Abstract

Ship design is a complex and iterative process to design the best possible vessel for a customer. Inside the conceptualization phase a lot of requirement information, calculations and documents is created and collected. Product Lifecycle Management (PLM) is a process to manage these documents and the process itself. An ongoing implementation process is facing resistance in the company currently regarding the tools chosen and what it will be like for the employs when the process and tools is implemented. The software selected consists of a 3D drawing tool with a database of searchable components. Documents and information is intended to be stored together with this 3D model for the specific vessel. Re-use of components, assemblies and vessels, and reduced time across design and engineering phase is the main goal with this new implementation, and to get better control of the specific projects. The step of shifting from 2D to 3D drawing tool is a big leap for the company.

The aim of the thesis is to evaluate the PLM process during upstream ship design process with the stakeholders perspectives conserved. Upstream ship design is the all the phases from conceptualization and until the vessel is ready for delivery. The scope of this thesis is limited to the conceptual design phase, were the layout of the vessel is designed. Systems Engineering approach is applied to investigate the case and collect information from different perspectives. The PLM process is evaluated based on the findings of the investigation.

Evaluation shows many good aspects with the use of PLM in the conceptual phase, but some issues needs to be resolved before making this approach the current state of the art. One challenge is the assumed time to make the first revision of the ship design. Based on experience from other companies, the assumed time to design the vessel will increase by approximately 6 - 9%, dependent on the project type. However, when this master model of the vessel is created, it is assumed a shorter time than before to come up with the second revision of the General Arrangement. Many positive ripple effect will come from this 3D model, like Bill of Material, revision control, a 3D model which can be exported to stability software, rendered illustrations of the vessel, and less export between softwares than now.

Acknowledgements

I would like to show my gratitude to my supervisor Henriquie Murilo Gaspar for guidance and help through the whole process of the thesis writing. Your knowledge in Systems Engineering and ship design has been a great support.

I would also like to express appreciation for my supervisors at Ulstein Design & Solutions, Frode Sollid and Bernt-Aage Ulstein for good directions and ideas along the way. During the study, valuable information about the practical aspects of ship design was shared by Bjornar Hatloy, which I am grateful of. I would also like to thank Berit Cecilie Skeide for including me in the ongoing work with 3D and PLM in the pilot project.

Finally, I would thank Per Olaf Brett for good feedback during the process.

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Abbreviations

2D	=	Two dimensional
3D	=	Three dimensional
4GD	=	4 th Generation Design
GA	=	General Arrangement
KPI	=	Key Performance Indicator
NPV	=	Net Present Value
PBS	=	Product Breakdown Structure
PDM	=	Product Data Management
PDT	=	Parametric Design Tool
PLM	=	Product Lifecycle Management
R & D	=	Research & Development
SE	=	Systems Engineering
SLD	=	Single Line Diagram
SoI	=	Systems of Interest
UDS	=	Ulstein Design & Solutions
WBS	=	Work Breakdown Structure

Chapter 1

Introduction

1.1 Evaluating PLM in ship design

PLM is short for Product Lifecycle Management, which is a tool to manage product related information throughout the lifecycle of components and systems. PLM is mostly used in production companies, who mass produces items. Ship design is often customized design of one-of-a-kind vessels designed for specific operations and for specific customers. Currently PLM processes are being implemented at Ulstein Design & Solutions, here after referred to as UDS, in the conceptual design in a pilot project. An issue with this implementation is the stakeholders opinions and mistrust to the PLM processes. The stakeholders opinions is important for making the processes work and implementing it to their daily work. Ship design is complex and iterative, so the working method needs to be flexible and efficient for it to work. According to Terje Vaage, Naval Architect at UDS "no ship design process is executed the same way so to make generalized processes which will be applied for all projects is very challenging"

Many experts are working together in UDS towards a mutual goal of designing the best possible vessel for the customer, so everyone needs to cooperate to meet these expectations and requirements. By forcing everyone to work with the same PLM processes in the conceptual phase, and for the engineers in the detailed design phase to continue this work can lead to problems. Different stakeholders in different phases has different area of focus when planning and engineering the vessel, which can lead to conflicts of interest.

Figure 1.1 illustrates the challenge of incorporating all the different components with separate properties regarding life cycle and system interfaces into the vessel. The main components of vessel are in most cases very big and the systems connected complex. The

vessel needs to house these components and support all their sub systems, for both ship systems and payload systems. This leads to a huge amount of piping and space allocation in general on the vessel. The hull of the vessel is also limiting the space available; restrictions regarding main dimensions, stability issues and performances is controlling the hull shape.

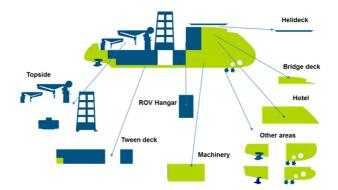


Figure 1.1: Illustration of Complexity, Ulstein and Brett (2015)

To evaluate the PLM process for UDS, Systems Engineering methodology is applied to collect information about the current ship design process, documentation, stakeholders and circumstances around the ship design process. Both qualitative and quantitative methods is applied to compare and evaluate the current state of the art with the assumed situation were PLM and the 3D modeling tool is implemented.

1.2 Implementation of PLM

The motivation of this thesis is to get a better understanding of PLM in general and a deeper knowledge about each step of the conceptual design process. With a better understanding of the situation, the thesis may contribute in the process of implementing PLM in the company. Since they have open questions when implementing it, the process needs to be looked at from different stakeholder's point of view and from different perspectives.

When/if PLM approach is the new working method, many advantages is envisaged to come with it, like reuse of systems and 3D models, continuing the work from different phases, better communication between departments and customers and less time spent looking for existing solutions in the market. PLM foundation facilitates the communication with customers and envision the final product with a more practical mindset in the 3D domain. By reusing some of the systems and automatically updating and changing parts

of the model, the designer would ideally have more time and freedom to come up with innovative solution.

Ulstein currently have license to Siemens for the PLM software, which include tools for 3D modelling, common library, project management and documentation control. One special feature with this software is the parametrized modeling possibilities and the collaboration possibilities. Designers can work in the same model and cooperate in finalizing the vessel design, approving each other and giving feedback. Rendered pictures is also possible to create with the software.

The 3D implementation at UDS is a project in collaboration with DNV GL where sources from The Research Council of Norway is partly funding the project. The objective with the collaboration is to eliminate the need for 2D drawings in the design verification by class, by developing, testing and evaluating technology and work process. This financial aspect is important to remember when evaluating the situation. Rules are constraining the vessel design, but the process of making the actual GA is not affected by these rules.

1.3 Scope

The scope of the thesis is shown in Figure 1.2 as the intersection between these subjects. Systems Engineering is logical and holistic approach to state what the problem is, to investigate the circumstances around. Evaluation methods will be investigated and applied to the PLM process. Through this investigation and evaluations the goal is to collect enough information to do a proper evaluation of the current state of the art, and the PLM process.

Product Lifecycle Management is a process to manage system related information throughout the lifecycle of projects.

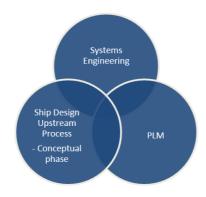


Figure 1.2: Scope is the intersection between the three subjects

In the conceptual ship design the overall architecture of the vessel and main systems is designed. Contract is signed based on the decisions made in this phase, so the technical feasibility of the design should be well examined before offering the design for the customer.

The main research question is - How can System Engineering methods be applied to evaluate the PLM process during upstream ship design processes?

1.4 Structure of the report

The report is structured with a introduction, literature review, methodology, analysis of PLM, discussion and concluding remarks.

The literature review covers subject about systems engineering, ship design methodology and an introduction to PLM and the relevant software. Methodology chapter consists of the approach to evaluate PLM in the upstream ship design process. The methodology is tested on a simplified case study of only the drawing process.

Analysis of PLM is performed in Chapter 4 with the methodology described in Chapter 3. A critical evaluation and published experience from others is also presented here.

Discussion of the results and the methodology is presented in Chapter 5. Conclusion and further work is in Chapter 6. Attached in the Appendices ten different documents are listed. Appendix 10 gives a research paper created based on this thesis.

Chapter 2

Literature Review

2.1 System Engineering

2.1.1 Systems Engineering Fundamentals

A System is defined as "a set of different elements so connected or related as to perform a unique function not performable by the elements alone" and "complexity is defined as being composed of interconnected or interwoven parts", Rechtin (2000).

"A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected", Rechtin (2000), INCOSE (2017).

"System Engineering (SE) is the bridge between the identification of needs or market opportunities and the acquisition of systems that fulfill them effectively and efficiently. SE is the glue that binds the pieces together in a project, by combining and integrating different pieces into a full system. The holistic view is a key concept in Systems Engineering and makes the approach applicable in complex systems with interdisciplinary properties. SE is both handling the complexity of products/processes and the lifecycle of the object by investigating inside the different phases and balancing between different criteria in a logical and organized manner. There are many definitions of systems engineering although all have in common the transformation of the analysis of a need or opportunity into requirements, the holistic view, the consideration of the entire life cycle and the need for the system to effectively and efficiently fulfill its goals throughout the complete life cycle", Sols (2016).

Systems Engineering Framework

Systems Engineering methodology focus on to clearly separate the "AS IS" from the "TO BE" situation. With this approach it is very important to separate the problem from the solution and also to keep the domains separated. In the problem domain, the stakeholders requirements is converted into high-level requirements. The solution domain handles the system requirements in more detail. Figure 2.1 shows SE framework.

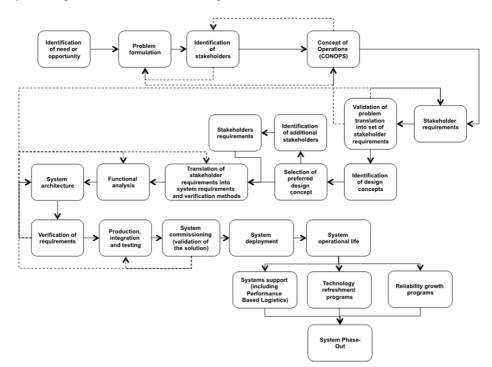


Figure 2.1: Systems Engineering Framework, Sols (2016)

From this figure, one can see the first stages of discovering a need or opportunity for something new. These needs must be converted into a clear problem formulation. Based on the problem, the stakeholders are identified. The last two steps with problem formulation and stakeholder identification runs an extra loop before continuing to the ConOps. Also here, the process is not followed sequentially, but rather in extra loops collecting as much input as possible before determining the concept. In general this framework runs in loops in some steps and sequential for others, collecting as much information as possible without spending more efforts than necessary.

When investigating a need, this does not necessary have to be a whole system or a product, but rather a Systems of Interest (SoI). This SoI is the part interesting for the decision maker, either the final product or parts of it. This versatile approach makes the method interesting for many cases of both complex systems with sub-systems and for simple changes to a product.

The Concept of Operations is a document meant to plan for the actual operation as an user-oriented document. Relationship, dependencies and interfaces between the new and the old system is identified through this document. Characteristics of the system from the user perspective and operational profile is shown. With this document the stakeholders and their needs is easier identified and the focus when designing the system is centered to the operations. Further the steps in Figure 2.1 is followed, with verification and validation steps frequent.

Stakeholders

Classical definition of a stakeholder is "any group or individual who can affect or is affected by the achievement of the organization's objectives", Friedman and Miles (2006). Stakeholders come with different level of involvement, different level of decision-making power, different perspectives and generally different agendas. Figure 2.2 gives an illustration of the stakeholders influence on the activity.

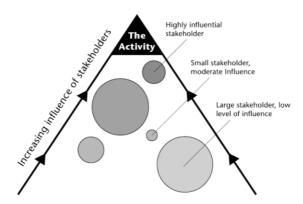


Figure 2.2: Stakeholder influence map, Bourne (2016)

In Figure 2.1 two blocks are concerning stakeholders, first Identification of stakehold-

ers and after the requirements are identified, validated and a concept agreed on the next step is *Identification of additional stakeholders*. Some stakeholders are pretty obvious and others are more hidden or on the periphery, maybe not even thought of considerate before the process is started.

Requirements

"There are two types of general requirements: Stakeholders Requirements and System Requirements. The Stakeholder requirements is connected to the high-level requirements, or the requirements for the system to satisfy the identified need. This type of requirements is not connected to a specific solution, but what the system should accomplish. The System requirements is the detailed requirements for the specific solution", Sols (2016).

One large challenge is to translate the stakeholders needs correctly into requirements. Seeing the problem from multiple stakeholders perspectives is essential for increasing the understanding of the need. The needs leads to work of collecting information from for example Big Data and interviews to better define the stakeholders requirements. "The stakeholders requirements should be in the form "*What has to be done*", not "*how to do it*" to keep the requirements concrete and complete to avoid misunderstandings and conflicts", Sols (2016).

For system requirements use-case-scenarios and interviews are performed to harvest information, which later is turned into the system requirements. Use case scenarios are descriptions of steps/actions between the user and a system. To discover both stakeholdersand system requirements input/output matrices can be used to see what the input causes and what input is needed.

The number of requirements is different for the different cases. "Unnecessary requirements may inhibit the development by adding more constraints than needed, limiting the solution space and possibly increase the cost. Each requirements should be assessed to weed out incomplete, incoherent, confusing, non-designable, non-verifiable and nonvalidatable requirements", Sols (2016).

2.1.2 Five aspect taxonomy

In Rhodes and Ross (2010) the five aspect taxonomy is introduced as an approach to investigate a system from different perspectives. Figure 2.3 shows these taxonomies.

The current model-based systems engineering (MBSE) approach only includes the two first taxonomies - the *Structural* and the *Behavioural* taxonomy of the system, but Ross and Rhodes added three new taxonomies: *contextual, temporal and perceptual* taxonomy. The two authors does not take credit for inventing these aspects, but only "to give them

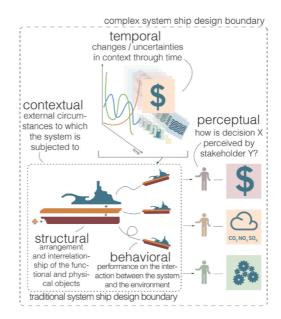


Figure 2.3: Five aspects taxonomy, Gaspar et al. (2012)

adequate focus to their importance in engineering of value robust systems, which delivers value to the stakeholder of the entire lifespan of the system", Rhodes and Ross (2010). These new aspects come with more advanced analyses and modelling possibilities, like Epoch Modelling, Multi-Epoch Analysis, Epoch-Era Analysis, Multi-Stakeholder Negotiations, and Visualization of Complex Data Sets.

During each of the taxonomies different aspects of the case will be enlightened, but when combining them other aspects can come up which can be a source for innovation. One challenge of combining several taxonomies is the human ability to take in and process this knowledge. "With appropriate mechanisms to compute and display the information, the decision makers can make a better informed decision with multiple considerations accounted for. With this multi-perspective approach more robust and complex methods for design can evolve from it. Tradeoffs, compromizes and risks are also better accounted for with this approach, along with identifying better combinations of systems which are able to achieve synergies", Rhodes and Ross (2010).

Structural Taxonomy

The Structural taxonomy is applied to dig deeper into the structure of a system, or the form of the system. By starting at the top and breaking down the product in smaller pieces, the

PBS, or Product Breakdown Structure is created. By investigating the product in this way the relevant properties or functions for each part is made visible. The breakdown can also reveal alternative options to solve a need or a function in the system. With the structural taxonomy the interrelationships also is identified. Work can also be broken down in Work Breakdown Structure (WBS) to investigate the activities in a process.

Behavioural Taxonomy

The behavioral taxonomy is related to performance, operations, and reactions to stimuli. The system shall be able to perform the emergent behaviours resulting from the complex interconnections. The specifications of the product or system is quantefied in the behavioural taxonomy.

Contextual Taxonomy

The contextual taxonomy is concerning the circumstances in which the system exists in. The outer boundaries of the system can include finances, deadlines, politics, cultural aspects, rules and regulation to mention a few. This taxonomy is useful for investigating in which context the system will be within. External complexity and uncertainty in which the system is operating in is affecting the system and must therefore be identified and concidered. The contextual taxonomy will change over the lifecycle of the system, so the Stakeholders needs based on the outer environment is changing.

With a System context diagram the system boundaries, external entities, and external interfaces is illustrated. The Operational concept documents, Capability description and System context diagram is descriptive rather than analytical. Methods for modelling the system context is used in order to generate context specific design concepts and model their value (utility) for cost within a full tradespace of possibilities. Epoch analyses can be used to understand the effects of changes, by setting the requirements/needs fixed and changing context assumptions. This method is called a Multi-epoc Analysis, where the context assumptions is referred to as an epoch.

Temporal Taxonomy

Temporal means how the system will change over time. "For systems with long lifespan, the system will encounter several transitions and shifts in context and needs. The timebased properties needs to be thought of to ensure survivability, evolvability, flexibility and adaptability over the systems lifespan", Rhodes and Ross (2010). "The temporal aspect is not given sufficient treatment with regards to time and level of detail generally", Rhodes and Ross (2010). Scenario development is an Systems Engineering method to include the temporal aspects of the lifetime of a system by envisioning the system and its intended use in its environment. Different approaches exists to include these scenarios, like Boardman's systemigrams, Monte-Carlo Simulation and Richtey. Epoc- Era analysis is the most recent contribution to this field to analyse systems in a dynamic context regarding the delivery of value to stakeholders.

In decision making the analysis will provide insight in what option will perform well for multiple contexts. In the Epoc-Era analysis the systems lifespan is decomposed into series of epochs, which is time periods with a defined context. These epoch are again linked together to form an Era, or a scenario. For each Epoch, evaluations are performed in each of the contexts and also path analyses are performed to secure generally high performance for all the scenarios. Utility/cost plots are generated to evaluate the different eras.

Perceptual Taxonomy

The last taxonomy is related to the stakeholders preferences, perceptions and cognitive biases. Stereotypes/stakeholders can be formed based on interviews with different stakeholders in how they interpret the system. "The human considerations have not been emphasised in previous approaches, causing a lack of knowledge about how the stakeholders preferences changes over time. Available technology and financial situation will affect what the stakeholders value at the time", Rhodes and Ross (2010).

Different stakeholders come with individual requirements which are very important for them. The decisionmakers seldom are the same persons which are using the systems, so to interpret what requirements is improtant for each phase is a key to success. Diversity in the system can make individual stakeholders satisfied with the same system. Negotioation of compromizes with different stakeholders in the decision making will enhance the complexity and balancing of the final system.

2.1.3 International Council on System Engineering(INCOSE)

"Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem ", INCOSE (2017). The acronym for the system engineering approach decribed at INCOSE is "SIM-ILAR" and the steps are: *State the problem, Investigate alternatives, Model the system,* *Integrate, Launch the system, Assess performance, Re-evaluate*, shown in Figure 2.4. The phases of the product is followed sequentially with clear deliveries between the phases, but the SIMILAR process is executed in parallel or what suits the process best in the defined phases.

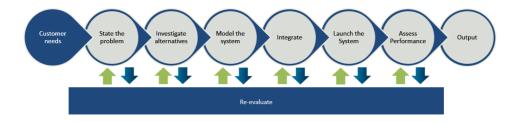


Figure 2.4: SIMILAR process, based on INCOSE (2017)

"In the System Engineering community there is consensus that before the problem is solved, one must understand the whole problem... This should be translated into measurable requirements before alternative solutions are created... When the solution concept is chosen, the whole system should be tested", INCOSE (2017).

2.1.4 System Engineering at NASA

National Aeronautics and Space Administration (NASA) have been working with Systems Engineering since 1995 when the first 6105 - Systems Engineering Handbook was written at NASA, NASA (2010). This handbook is still in use, only with updated information and improved best practices. "The intention with the handbook is to communicate principals of good best practices and alternative approaches, rather than describing particular ways of accomplishing a task", NASA (2010). Ships and Space vehicles have in common a high level of complexity in a limited physical shell, making the theories and methods used in aviation industry applicable for ships also.

"With SE the awareness and consistency across agency is increased in addition to a more advance SE practice", NASA (2010). Systems Engineering Fundamentals, Project Lifecycle, System Design, Product Realization, Crosscutting Technical Management and Special topics relative to SE is the main chapters of the book. For this thesis, the most valuable chapter is number 1, 4 and 6, describing SE Fundamentals, System Design and Crosscutting Technical Management.

NASA defines Systems Engineering approach to be logical since the method is disciplined and methodical for tackling for example engineering processes and product design. For NASA (and everyone else) it is important to design a product that satisfies stakeholder functionality, physical performance, operational performance and the requirements of intended use and environment in mind. In addition, the planned lifecycle of the products with all parts included needs to be controlled. "The engineering of NASA systems requires a systematic and disciplined set of processes that are applied recursively and iteratively for the design, development, operation, maintenance, and closeout of systems throughout the life cycle of the programs and projects... Systems Engineering is a method for balancing the contributions from the different disciplines into a holistic, safe and balanced product. By seeing the whole picture, the systems engineer is *not only ensuring that they get the design right (meet requirements) but that they get the right design*. The Systems Engineer is skilled in the art and science of balancing organizational and technical interactions in complex systems", NASA (2010).

Systems Engineering Engine

Systems Engineering Engine is defined in NASA (2010) as a tool to shows all the processes needed to develop and realize the end product. Tasks in the process is shown in Figure 2.5. In the **System Design Process** the stakeholders expectations and requirements are first being settled and converted into technical design requirements. As the figure shows, the product should further be decomposed to identify product functions and technical solutions needed. Further, the **Product Realization Process** is applied to all products in the system to tie the project together. The lowest level parts are structured in bigger assemblies and integrated into the final product. In this process, the parts are verified and validated for each hierarchy level, assuring compliance with the final product requirements along with correct lifecycle properties. **Technical Management Process** establishes and is used to evolve the technical plans for the product. Communication across interfaces is managed along with assessments of progress according to plans. This part of the engine is active for all phases.

NASA uses their SE Engine for extracting as much information in each project phase as possible. Different parts of the SE Engine are active for different stages in the lifecycle of the product. Figure 2.6 shows the project phases in NASA.

In the **conceptual phase** the System Design Process is first active (left side in Engine) to familiarize with the stakeholders and their requirements. These requirements are further converted into technical solutions starting from the highest level, Tier 0, and decomposing the product as much as possible. This holistic starting point ensures the stakeholders interests and that the technical requirements are preserved. In this initial phase, multiple solutions and ideas should ideally be discussed and a concept created. This organized and structured working method is typical for Systems Engineering. For phase A the Concept

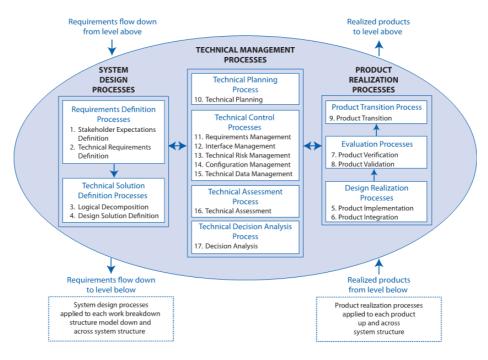


Figure 2.5: System Engineering Engine, NASA (2010)

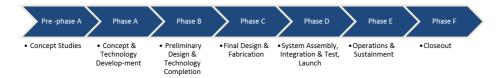


Figure 2.6: From Concept to Closeout at NASA, based on NASA (2010)

of Operations (ConOps) is settled. This means the key requirements put in numbers and the technology needed to solve the problem identified. The feasibility of the concept is checked before entering the phase of realizing the product. For realizing the product, the right side of the engine is in use. From the highest detail level the parts are realized. Each part is verified and validated before integrating the components into bigger assemblies. Recursively and iteratively the product concept is designed. For each integration step, verification and validation should be done to lead the concept towards the stakeholders requirements. Depending on the case, this can be done using simulations, models, analysis etc. These steps aid in the process of defining a verification and validation method for the final product. Verification and validation is two important terms in Systems Engineering. The term verification is used to confirm that the product is in compliance with requirements. Validation is a control if the end product accomplishes the intended purpose.

When the concept is agreed upon and validated, the **preliminary design** can begin. NASA suggest making a prototype or model of the product to go through the process from the smallest parts and integrating into bigger components (right side of engine). This aids the planning process for the final build and can discover mistakes or issues with the design, giving far better opportunities to make corrections without large consequences economically and structurally. With a completed base line, the design is verified and validated before entering the next phase.

Final design and **fabrication** is the next phase, where the knowledge gained from the preliminary design is used for judging stakeholder requirements and the technical solutions. Now the work for the next phase is shifted to the right side of the SE engine, where realization of the final product can begin; the **System assembly, Integrations and test phase**. Here small parts are integrated into larger and verified and validated for each pass. With the final product being build, the testing and launching is executed. Also for this phase, validation and verification is important to secure a good end result. Now that the product is being built, the **operational** phase starts and eventually **close out**.

2.1.5 NASAs System Design Process

The system design process for developing air crafts is described in NASA (2010). This approach starts with the *Stakeholder Expectation Definition* and description on how they intend to use the product. Next step is the *Technical Requirement Definition*, where the stakeholder requirements are transferred into a set of validated "shall" statements for the final product. In the *Logical Decomposition* the product is broken down in a Product Breakdown Structure (PBD). The last phase with this methodology is the *Design Solution Definition* where the chosen concept is finalized. Each of these phases will be elaborated on in the following paragraphs.

Stakeholder Expectation Definition

The stakeholder and their requirements is the input to the *Stakeholder Expectation Definition*. The activities inside this process is to identify all the stakeholders and their requirements and expectations to the final product. These expectations and requirements needs to be analyzed for measures of effectiveness before the requirements are validated and made bidirectional traceable. Further these requirements need to be committed upon by the customer to have a base line for the system. The output of this process is validated stakeholders requirements, ConOps, enabling product support strategies, and measure of

effectiveness. ConOps is capturing how the system will be operated and the system characteristics from an operational perspective together with capturing expectations, requirements and the architecture.

Technical Requirement Definition

The output from the previous phase is the input for the Technical Requirements Definition. Different types if technical requirement is in this phase validated as requirements, and the measures of performance is determined. The technical performance measures described in NASA (2010) is Measure of Effectiveness (MOE), Measure of Performance (MOP), and Technical Performance Measures (TPM).

The different types of requirements in the same handbook is *Functional-, Performance-*, *Interface-, Environmental-, Reliability-, and Safety requirements*. By going through the ConOps document, the Design Reference Missions (DRMs), and the different scenarios, these requirements can more easily be detected. To dig deeper into the requirements, they can be put in an hierarchical structure of decomposed requirements, where both allocated requirements and derived requirements is shown. This breakdown of the requirements starts from top-down and is broken down one tier. For each tier, the new requirements needs to be validated towards the top requirements, securing both traceability of the requirements and that no new restrictions is invented or assumed in the process.

In this requirement definition process, human factors are also included with human capacity and capability included as any other physical part to the system. These human factors introduce requirements, standards and guidelines which make the system able to accommodate human factors. NASA also emphasize the importance of the traceability of the technical requirements.

Logical Decomposition

With the Logical Decomposition process from NASA (2010), the goal is to find out what must be achieved by the system at each level to enable a successful project. The requirements can be broken down in functional requirements from the top-level and allocate down to the lowest desired level. With this breakdown, the top-level requirements are well understood and brought down in the hierarchy making sure important requirements is fulfilled with physical parts or processes in the system. Also, the relationships between the requirements can be found and organized during this process.

With the architecture of the system/process being identified, the different parts can be designed individually and they will fit in the system the intended way, and deliver the function needed to fulfil the system requirements. In this investigation, different concepts to solve the same problem can be found. By allowing the engineers to work creatively in the process, and come up with several options to choose from, the end result can be of better quality and more innovative than if the design work was more directed towards the final product/system.

NASA describes some tools in the logical decomposition process: *Product Breakdown Structure (PBS), Work Breakdown Structure (WBS), Functional Flow Block Diagram (FFBD), N2, Timeline Analysis (TLA).* PBS is a hierarchical display of the parts in the system and how they are connected. WBS shows the steps to complete the project or steps during operation to discover lifecycle properties of the system. FFBD is a breakdown of task sequences and the relationships of them, to fulfil the function of the system. This diagram is function oriented and does not include the duration of each action, only the actions steps. Also, here the top-down approach is used to fist investigate top level actions, and further break it down level by level. N2 diagram is used for identifying the interfaces or interactions inside the system. In this process, potential conflicts of interfaces can be pinpointed and dependencies, assumptions and requirements for the interfaces can be highlighted. TLA is used for functions which are time critical. Through mathematical models and computer simulations the duration can be estimated and collected in a Time Line Sheet (TLS).

Design Solution Definition

Design Solution Definition is the last step in determining which concept to be finalized. With the information from the stakeholder requirements and logical decomposition of the system, the different design options have been formed and verified. In this step, the different alternatives are analyzed before one is selected. For this solution, the full description is made, with system specifications, end product specified requirements, enabling product requirements, product verification plan, product validation plan, and logistics and operate-to procedures. With all these properties determined, the systems engineer can make a good informed decision in the most cost-efficient alternative.

To dig deeper in the space of possible designs, NASA suggest going through the process of identifying goals and create concepts, before performing trade studies to the concept. Next, the design concept is selected and the resolution is increased. This process is done in loops, circling in to a better understanding of the situation.

2.1.6 Technical Management at NASA

Technical Management is referring to the middle column in the Systems Engineering Engine (Figure 2.5). In this process the technical planning, requirements management, interface management, technical risk management, configuration management, technical data management, technical assessment, and decision analysis is described in NASA (2010). Only the relevant topics is commented in the following paragraphs.

Interface Management

To succeed in implementing a new software in UDS, the interfaces between existing software and personnel need to be investigated. "Interface management is a process to assist in controlling product development when efforts are divided among parties", NASA (2010). Interfaces can be both logical and physical.

Risk Management

Risk matrix is a qualitative approach to visualize and manage risk for different scenarios (Figure 2.7). "Risk matrices combine qualitative and semi-quantitative measures of likelihood with similar measures of consequence. The risk matrix is not an assessment tool, but can facilitate risk discussions", NASA (2010). As mentioned the risk matrix is not a valid assessment tool, because "interactions between risks is not considered, it has inability to deal with aggregated risks, and inability to represent uncertainties", NASA (2010). Formula for risk is shown in Equation 2.1.

$$Risk = Probability \cdot Consequence \tag{2.1}$$

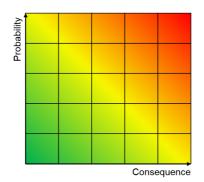


Figure 2.7: Risk matrix, based on NASA (2010)

Red areas in the figure represent areas of high risk, were the given scenario is "likely to cause significant increase in cost, disruption of schedule, or degradation of performance", NASA (2010). Yellow areas in the matrix is area with moderate risk, were it "may cause

some increase in cost, disruption of schedule, or degradation of performance", NASA (2010). The green area is low-risk areas.

Technical Data Management

"The Technical Data Management Process is used to plan for, acquire, access, manage, protect, and use data of a technical nature to support the total life cycle of a system. Data Management includes the development, deployment, operations and support, eventual retirement, and retention of appropriate technical, to include mission and science, data beyond system retirement", NASA (2010). "Data management plan is created to identify and define the data requirement for all requirements for all aspects of the product life cycle, to control procedures, as guidance on how to access/search for data for users, which data exchange formats to use to promote data reuse and help to ensure that data can be used consistently throughout the system, about data rights and distribution limitations, and storage and maintenance of data", NASA (2010).

Decision Analysis

In the Decision Analysis Process chapter, tools and methods to make decisions is described in NASA (2010). Figure 2.13 shows this process.

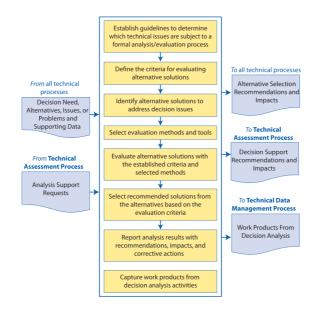


Figure 2.8: Decision analysis methodology, NASA (2010)

What to analyze, and which criteria to evaluate from is first determined here. When this is done, alternative solutions are identified. Next, the evaluation method is selected and applied. Based on the evaluation, the recommended solution is selected and documented.

Decision matrices can be used to compare different options. Each category is assigned with weighting. Figure 2.9 shows how NASA does this.

Decision Matrix Example for Battery				Extend Old Battery Life	Buy New Batteries	Collect Experient Data With Alternative Experiment	Cancelled Experiment
CRITERIA	Mandatory (Y=1/N=0)?	Weight	SCALE				
Mission Success (Get Experiment Data)	1	30	3 = Most Supportive 1 = Least Supportive	2	3	3	0
Cost per Option	0	10	3 = Least Expensive 1 = Most Expensive	1	2	3	1
Risk (Overall Option Risk)	0	15	3 = Least Risk 1 = Most Risk	2	1	2	3
Schedule	0	10	3 = Shortest Schedule 1 = Longest Schedule	3	2	1	3
Safety	1	15	3 = Most Safe 1 = Least Safe	2	1	2	3
Uninterrupted Data Collection	0	20	3 = Most Supportive 1 = Least Supportive	3	1	2	1
WEIGHTED TOTALS in %		100%	3	73%	60%	77%	0%
			SCALE 1-3				

Figure 2.9: Decision matrix, NASA (2010)

"Evaluation criteria typically are in the rows on the left side of the matrix. Alternatives are typically the column headings on the top of the matrix (and to the right top). Criteria weights are typically assigned to each criterion.", NASA (2010).

2.2 Product Lifecycle Management (PLM)

2.2.1 Theory

The term *Product* is now connected with a greater meaning than earlier, when the object had to be physical and tangible to define it as a product. In recent years, this definition has enlarged to include also "something very intangible such as a piece of software, a piece of knowledge or an algorithm or a formula", Saaksvuori (2008).

Product Lifecycle Management is the foundation for managing product related information for components throughout their lifecycle. Product Data Management (PDM) was the precursor to PLM. "PDM emerged in the late 1980s as engineers in the manufacturing industries recognized a need to keep track of the growing volumes of design files generated by CAD (Computer Aided Design) systems ", Saaksvuori (2008). With many drawings with multiple revisions, the number of files to keep track of increased rapidly. PLM does not only consists of management of documents and Bill of Material, but also of many other aspects, shown in Figure 2.10. This management continues for the whole lifecycle of the product, from an idea and until retirement and disposal.



Figure 2.10: Product Lifecycle Management elements, Andrade et al. (2016)

One of the key features with the PLM system is the defined relationship between parts and assemblies. For large assemblies, the information can be split in pieces to gain control of the overall product. In the system of standardized parts with information about the lifecycles and other properties, the risk with the processes are reduced. All the choices the designer can pick from is existing products with known properties and possibilities in combinations with other components. "The benefits of operational PLM go far beyond incremental savings, yielding greater bottom line savings and top-line revenue growth not only by implementing tools and technologies, but also by making necessary, and often tough, changes in processes, practices and methods and gaining control over product lifecycles and lifecycle processes", Saaksvuori (2008).

"Complex and changing situations typically have two characteristics, danger and opportunity. Companies that understand the situation can adapt and benefit from the opportunities", Stark (2011).

2.2.2 Siemens NX PLM

Siemens offers a large variety of application possibilities in their software packages with integrated functionality for 3D modelling and PLM. Figure 2.11 shows some applications in the Teamcenter PLM platform. This platform gives the involved among other good insight in properties of parts, time aspects, structural aspect and so on. Teamcenter also consists of System Engineering & Requirements Management, Portfolio, Program & Project

Management, Engineering Process Management, BOM management, Compliance Management, Content & Document Management, Supplier Relationship Management, Mechatronics Processes Management, Manufacturing Process Management, Simulation Process Management, Maintenance, Repair & Overhaul and Reporting & Analytics tools, according to Teamcenter (2011). This software comes with cloud based application to share the drawing with others and work in a collaborative environment.

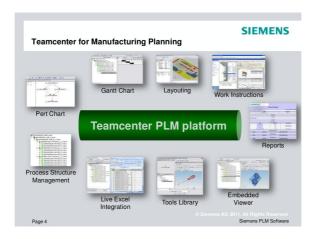


Figure 2.11: Teamcenter Platform from Siemens NX, Teamcenter (2011)

Modelling tool for 3D comes with opportunity to make parametrized items, which makes it a Parametrized Design Tool (PDT). Siemens has recently developed their knowledge connected to shipbuilding, so this platform will reduce cost to develop ship designs, Siemens (2017).

2.3 Ship Design

2.3.1 Upstream Value Chain Activities

Upstream Ship Design is described as all the phases from conceptualization and until the ship ready for delivery, shown in Figure 2.12. Downstream activities are defined as the activities after the vessel is delivered, like guaranties insurance, operation and maintenance, commercial operation, and demolishing and recirculation.



Figure 2.12: Upstream Ship Design Process, based on Ulstein and Brett (2012)

Concept development phase at UDS

"The main task of engineers is to apply their scientific and engineering knowledge to the solution of technical problems, and then to optimize those solutions within the requirements and constraints set by the material, technological, economic, legal, environmental and human-related considerations", Pahl et al. (2007). Conceptualization phase is very important to be able to reduce the risk in the project and being able to deliver a good product. Figure 2.13 gives an illustration of the level of impact the decisions made in this phase has on the final product. So by using more efforts in this phase, the further process will require less work and resources.

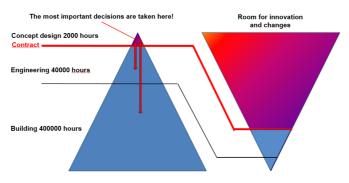


Figure 2.13: Impact of the concept design, Sollid (2016b)

In the conceptual phase the hull lines, main components and vessel arrangement is determined. 2D drawing of the General Arrangement (GA) of the vessel along with written specification of the vessel and relevant systems drawings is developed in this phase. Here the ship size, hull form, arrangement of main components, Single Line Diagram (SLD), weight estimate, loading conditions, stability calculations, performance calculations, fuel oil consumption, electrical load calculation, rendered images for sales purpose and price target is established. These decisions lay the foundation for the rest of the project, so this phase is crucial for making the vessel good and to minimize the resources needed in the following stages. With a good master plan, the rest of the project is easier to plan and predict. The contract is signed based on the GA, SLD and building specification, so all critical components needs to be included and necessary calculations needs to be performed before signing the contract

Naval Architects, Machinery-, Electrical-, Stability-, Weight-, Hydrodynamics- and Structural engineers cooperate in defining the concept which is based on the requirements from the owners and the basis of design. Ship design is iterative due to the complexity introduced by having multiple systems and functions in a limited space, with strict requirements about stability and vessel performances. These size issues, cost issues, complex systems, interconnected sub systems, stability issues and deadweight requirements is managed by the naval architect, who serves as the technical project manager.

Ship design is as mentioned an iterative process, so for one project the number of iterations and different GAs needs to be limited. A relative normal situation at UDS is that the design department is working on 30 projects on the same time, so the available resources is also an important factor in the ship design process. Figure 2.14 gives an illustration of this situation were each box represent the sequential work for each revision. Some departments consist of only 1 - 2 persons, so these are involved in all the projects at UDS.

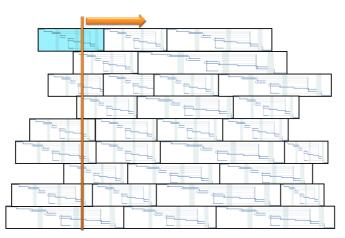


Figure 2.14: Multiple projects running simultaneously at UDS, Sollid (2016b)

Throughout the design process all documents are being revised and changed as new knowledge about the specific case arises. Inside the projects the different contributors keep track of the revisions of their work inside the project.

Innovation and creativity is a strong side of UDS, and according to Innovation and development manager at UDS Mr. Sollid, "designers with ownership to the specially designed solutions and with passion for the work is a huge part of in the great culture for innovation at UDS. We do not only have persons following orders without question the method or solution, but persons with own ideas and thoughts challenging the limits, methods and solutions".

Projects are currently organized using the SFI taxonomy, were the library of components on the server is stored in folders, and the chapters of the building specification is also structured in this way. The main SFI groups (AMOS (2005)) and examples of sub-groups can be found in Table 2.1.

SF	SFI group		SFI sub-group		SFI sub-group		
1	Ship in General	10	Specifications, estimating, drawing, instructions, courses	101	Contract/Specific. work, general design, model testing		
2	Hull	22	Engine area	221	Shell panels, separate shell plates		
3	Equipment for Cargo	30	Hatches, ports	305	Bow ports		
4	Ship Equipment	43	Anchoring, mooring and towing equipment	437	Towing equipment		
5	Equipment for Crew and Passengers	54	Furniture, inventory, entertainment equipment	548	Furniture for passengers		
6	Machinery and main components	63	Propellers, transmis- sions, foils	631	Fixed propeller plants incl. nozzles		
7	Systems for machinery main components	70	Fuel systems	703	Fuel oil supply systems		
8	Ship Common Systems	86	Electric power supply	865	Transformers		

Table 2.1: SF	I taxonomy with	examples of	sub-groups

Design phase

Next upstream phase is the design phase, which for some projects goes through an early start process before contract. Whether this early start is done or not, is highly dependent on the project and the customer. For cases were the building yard is confident that the contract will be signed and run on a tight schedule, the early start is initiated on the yards bill to begin the pre-cutting of the steel early. In other cases, the ship owner would like class drawings and more documentation in the LOI period than in the scope, then the job is financed by the ship owner. The third case where early start is done is for projects with high risk for UDS, to minimize the risk and solve potential problems early. Also for periods with less pressure on the engineers, the available resources in the department can be used in early start to speed up the process, or to be able to deliver on time in a department with less resources than earlier.

In the engineering phase the whole vessel is modelled in 3D at UDS. The hull shape and arrangement of the vessel is already chosen in the concept phase, so in this phase the structure of the vessel is designed with plates, girders, stiffeners, foundations and pillars. Components are added according to building specification and placement on the GA. Ducts for ventilation, piping throughout the vessel, electrical components, cables and all other details are designed and inserted to the 3D model. The output from this phase is class drawings, building drawings and the 3D model.

Design team is in contact with the class companies, for instance DNV GL, to make sure the vessel is in compliance with the rules and regulations for the specific vessel type. The engineering team is also in contact with the ship builders to ensure the correct craftsman method and to assist in technical questions. These three actors (design company, yard and ship owner) needs to cooperate in realizing the final product.

2.3.2 Design Focus

Critical systems thinking

There are different references and approaches for value chain activities for different companies. Since this thesis is written in cooperation with Ulstein, published articles from Ulstein is used as guide and reference. The challenges of improving the systems based ship design with critical systems thinking is addressed in Ulstein and Brett (2012). The holistic or systemic-based design approach is according to them the key for developing complex designs able to meet operational, commercial and technical requirements. With multiple criteria in the decision-making process, the result will be more in compliance with the requirements and with more balanced properties for other missions. The authors question the diversity of most of the other design approaches available (compared in Appendix 1, Ulstein and Brett (2012)), and how slow the development in the field of establishing new design approaches is.

Critical systems thinking is a method which covers a more versatile and complete range of design focuses than previous methodologies. Appendix **??** shows their summary of the 29 different design approaches available as a comparison of what each cover. The elements are organized under the subjects Commercial, Technical and Operational aspects and shows which aspects the different approaches are in compliance with and which is not. According to Brett and Ulstein the key for ship design is to combine these three aspects, and focus more on the Commercial and Operational aspects than earlier.

In the article, it is stated that little development has occur the last 50 years. The balance between the process and solution oriented work is important according to Ulstein and Brett. In the future, they predict that classical naval architecture will be more process oriented rather than technical. "Too little time and effort is spent concerning the processes of clarifying the overall new building project and the interphases between the stakeholders, reporting processes, and clarifying the job definition. Critical thinking concerning the requirements from the ship owner is crucial for capturing what is important for the given ship and the different stakeholders", Ulstein and Brett (2012). The *All-encompassing metastrategy oriented approach* is their design approach able to handle the above mentioned challenges.

According to these authors, "the most powerful fuel to secure long-term growth and brand development is the culture for innovation in the company. In Norway where the cost-level of operations are high, the business needs to be focused on activities which can sustain a high cost level. With these opportunities fully explored and capitalized on few alternatives the situation will be in dire straits". Innovation is then the key for reducing business risk, and to conduct competence intensive activities. In the continual changing market situation, the need to reduce risk is significant. With a systemic approach, the present situation should be fully understood before developing a future vision, which the participants should agree upon.

"Ship's life cycle is becoming longer and longer, i.e., it is no longer unusual to have ships operating for 25 - 30 years", Engels (2013), so the vessel characteristics should ideally be appropriate for other missions and contracts later on (tenders are typically for up to 5 years of operation). In real life, the statement of designing the vessel for multiple purposes can be of a more challenging character than implied since the tender requirements occasionally is forcing the development of a customized vessel for a special operation. In the competition of winning the tender contract, the design companies will design a specialized vessel for the specific task. According to naval architect Aasmund Eide: "The decision makers are choosing between the best designs, and in most cases the most specialized vessel for the specific task is chosen and the contract signed".

Foresight in the market

Upstream value chain activities should be focused on rewarding activities with a fruitful outcome. In Ulstein and Brett (2009) the theme of the article is to find a method which makes it easier to foresee a need and adapt to it. "With severe market fluctuations, the companies need to be entrepreneurial, agile and adaptable to the situation in order to survive. With deliberate strategic and slow changes, the companies can grow and survive in the challenging market. Profitable growth creates predictability, longevity and sufficient volume of business to facilitate continual productivity gains to retain necessary competitive power to survive and thrive", Ulstein and Brett (2009).

Foresight is mentioned a few times in the context of being able to see what's next in the market, "the foresight process aims to identify emerging technologies and be ahead of the situation by having a strategic management. Foresight is about communication within and outside firms, about coordinating research and development initiatives, about creating a consensus of future directions and priorities", Ulstein and Brett (2009)..

Three requirements is listed as a necessity to form a culture for innovation in the company, Ulstein and Brett (2009):

- To know something
- To be willing to use this knowledge

• To be allowed to use this knowledge

Logistics-based ship design

"A systems management approach is the way forward to advance naval architecture to better support effective transport system development with integrated ship design fleet operations", Brett et al. (2006). The logistics-based ship design (LOGBASED) presents the methodology as a guide to capture assumptions, presuppositions, limitations and restrictions for the given project. The suggested form of the LOGBASED methodology is in an Excel-sheet, where the information is linked to different modules. This excel sheet can be used as a checklist for all the details that should be captured in the initial phase of the project.

According to the authors, the methodology is more than only a design procedure since it also encompasses commercial, economical, and social aspects, making the gap between these aspects smaller. "This guide for ship designs is used for collecting information both about communicational and decision-making support instruments, to make the interaction between these two aspects less separate and deliver what the decision-maker is eager to get; a ship design with a high Goodness of Fit (GoF) score. This is done through Multi-Attribute Decision-Making (MADM), where combinations of parameters are assigned with scores so the GoF for the combinations can be identified and evaluated", Brett et al. (2006).

The authors advise ship designers to make a rapid prototype in compliance with the expectations early in the conceptual phase to reduce time to market. "When the context and boundary conditions of the problem is settled, the more detailed design phase can begin, elaborating the sub-systems and design choices. With a Parametric Design Tool (PDT) different alternatives can be judged based on an available historical database of main particulars, and compared with different parameters, for example through different filtering options and regression analyses of a historical database of ships", Brett et al. (2006).

Accelerated Business Development (ABD)

The Accelerated Business Development (ABD) process is an extension of the LOGBASED methodology from Brett et al. (2006). Figure 2.15 shows the modules in the approach. The aim is to speed up the decision making process, by doing thorough preparation work before initiating the concept development and the ship design.

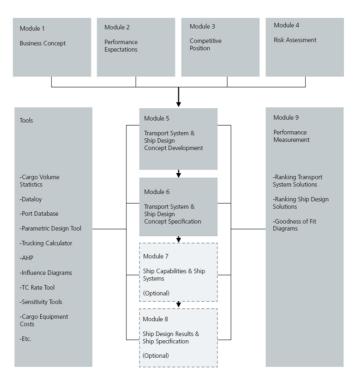


Figure 2.15: Accelerated Business Development, Brett (2015)

2.4 PLM during Upstream ship design

2.4.1 Implementation of 4GD framework in Ship Design for improving exchange and 3D reuse

4GD is short for fourth generation design tool, which is "a component-based concept incorporated in Siemens NX Teamcenter integration which provides comprehensive and efficient methods for design of systems comprising large amount of data", Leviauskait (2016). In the MSc theses with title: *Implementation of 4GD framework in Ship Design for improving exchange and 3D re-use*, Greta Leviauskaits investigated this software by modelling an engine room for a vessel and modelling a simplified Platform Supply Vessel, and performed different changes to the model. With the 4GD tool, these changes were applied without severe complications. "Each design element is an independently managed component of collaborative design environment with unique and declared: access privileges, maturity status, position in ship, set of attributes, revision history, unit effectivity, and locking status. In other words, the design elements do not need to be hierarchically ordered for controlling, accessing and managing the design data. Thus, it leaves the option

for the shipbuilder to decide the level of detail in assembly by making separate parts or subassemblies as design elements in 4GD environment", Leviauskait (2016).

Traditional modelling "which deals with connection features between pre-defined geometric entities defining the geometric positions, orientations, mating conditions, and parent-child relations", Leviauskait (2016) is harder to manage and harder when replacing components and perform changes. The assembly three with constraints is rather rigid.

"Companies consider PLM system as too much time and resource consuming before bringing benefits and they avoid to implement it", Leviauskait (2016). With increased customer requirements and wishes for innovation "the challenge to combine rich product lifecycle management (PLM) systems and well developed designing tools, to perform 3D modelling of a ship with thousands of units and parts, arises", Leviauskait (2016) for the ship building industry. Her concluding statement is 4^{th} generation design tool has a great potential for innovation in ship design and is potentially beneficial for the shipbuilding companies.

2.4.2 Product Life-Cycle Management in Ship Design: From Concept to Decommission in a Virtual Environment

Through simulation of virtual models, using virtual prototype concepts, PLM concepts have been applied to ship design. "Our assumption is that combining PLM techniques with virtual prototype concepts enables a good control over the ship design project as a whole, through means of efficient modelling and simulation management. That way, the time and cost necessary for the product development can be reduced", Andrade et al. (2016).

"PLM methods provide a way of dealing with huge amount of data in complex products life-cycle. This can be achieved through many techniques, such as efficient information indexing, database management, product decomposition and analysis and project management. Many decisions during the ship design phases are based on key performance indicators (KPIs) tradeoffs, such as structural strength vs. building cost vs. cargo capacity, vessel speed vs. fuel consumption, seakeeping vs. seafaring. The cost and complexity of these decision making processes make virtual prototyping (VP) a very handy tool to simulate designs during several phases of the VC, identifying improvements quickly and in a controlled environment" Andrade et al. (2016).

Concluding remark of the aforementioned article is that "It is observed in current practice a lack of unification among the VC tools, as well resistance to install and try brand new technologies due to the strong traditional aspect of the ship design industry...In this sense, the same ships that were already decided in the initial phase needed to be redone and recreated in several other software, mainly due to the lack of integration among applications...an integrated PLM platform which re-uses and builds up former designs, with a same language...allowing the designer to really use former designs database, building up new concepts based on the previous information, as well as re-using advanced 3D models for many VC phases (sales, concept, basic, construction)", Andrade et al. (2016).

2.4.3 PLM in Ship Design

Ships and Space vehicles have in common a high level of complexity in a limited physical shell, making the theories and methods used in aviation industry applicable for ships also. The PLM approach is described as a good best practice principal at NASA, under the name Data Management, to control documentation for the whole lifecycle of components. If the methodology is applicable for NASA, it also should be for ships. The software Siemens NX has integrated 3D modelling tool and PLM tools. According to Frode Sollid "the Cardinal Challenge using 3D tools pre-contract is if the total savings in engineering can make up for the assumed losses in conceptual design process. This looks like an impossible challenge, but we believe that the numerous aspects of doing 3D pre-contract will change the way we look upon concept design together with engineering today".

Figure 2.16 illustrates a situation where the involved in the ship design project is pulling the projects in different directions, based on their understanding of the situation or their perspective. By having a clearer requirement capture method and applying SE methods, the target point is given more concern before the project is initiated, causing the stakeholders to pull in the same direction towards a common goal and being more aware on the stages to get there. Figure 2.17 illustrates this. This approach with Systems Engineering and PLM is preserved in the modelling software.

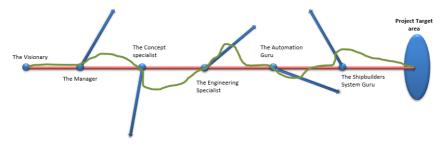


Figure 2.16: AS IS situation, Sollid (2016b)

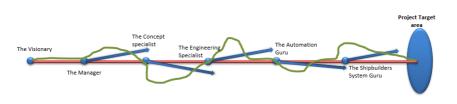


Figure 2.17: TO BE situation, Sollid (2016b)

Systems Engineering is also a logical approach in designing good vessels, since the methodology aids in the process of balancing the vessel as best as the designer can, under the given circumstances. The theoretical benefits with PLM along with NASAs experience gives good indications that PLM will be beneficial for the ship building industry also.

Chapter 3

Methodology

3.1 System and Assumptions

The system to be evaluated is the PLM process only in the conceptual phase at UDS. The conceptual phase is from a customer expresses a demand and requirements of the vessel, until the design is conceptualized and the contract is signed. The current working method is a result of 100 years of ship building experience in Ulstein. Assumption are listed below.

- Possible to create parametric components in a manageable file size
- Variations and modifications of hull to be done quicker in NX
- Assumptions of time duration
- The number of employs and tasks is balanced currently
- The stereotypes formed is assumed sufficient to comment the processes
- The stakeholders and processes is fixed, system must be adapted
- Documentation of calculations will be uploaded to Team Center automatically

Time is a difficult aspect for this thesis investigation. No project is executed in the same way and with the same persons involved, so to measure time is close to impossible with the current available information. Currently the longest running project which led to a contract lasted for two years, while the shorted was designed in only 2,5 weeks. Assumptions and simplifications will be made when it comes to the temporal aspect.

3.2 Evaluating PLM Process

3.2.1 How to evaluate a process

Before evaluating a process, the objective and purpose for the process need to be known. Figure 3.1 bives an illustration of the methodology which is applied for this thesis to evaluate the PLM process in UDS. When the input, output and of the process is understood, more information about the taxonomies for the process is investigated. Based on the findings of applying the taxonomies, the system performance parameters or system properties can be settled. The fourth step in the methodology is to make a few change cases, Gaspar (2015). Last step is to evaluate the system properties for the different change cases.

The next sub chapters will describe more in detail each of these steps in the evaluation work (Step 1-5).

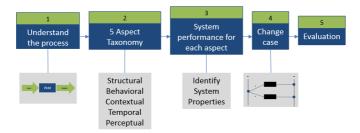


Figure 3.1: Methodology applied to solve the thesis, Step 1-5

3.2.2 Understand the PLM process (Step 1)

In this part, the background and objective of the processes is investigated. By understanding what the input and output from the process is, a deeper understanding of the process itself needs to be gained through the next steps. To get a grasp of the processes itself, internal quality- and process documents is found and familiarized with.

3.2.3 5 Aspect Taxonomy applied to the PLM process (Step 2)

To dig deeper in the PLM process, the 5 aspect taxonomy is applied. The five taxonomies are: Structural-, Behavioral-, Contextual-, Temporal-, and Perceptual Taxonomy.

Structural taxonomy

Structural taxonomy is applied to gain more information about what the PLM process will cope with at UDS and how it will be different from the current approach. The product,

processes and product documentation is investigated by looking at the current written process descriptions and perform interviews to see if the basis is up to date and applicable in the real practical design process. If areas are considered more complex and of interest, additional breakdown of the activities is executed in a WBS. Also, what input the different activities in the ship design process need to continue is investigated to see what actions need to be sequential and which can be done in parallel.

Behavioral taxonomy

The behavior of a physical object is describing "how good it is"; for instance, how much a crane can lift, how fast a vessel can sail, and how much the vessel can carry. A process should be simple to execute and deliver an end-product with the right quality. To investigate if the process is good, the process steps from the structural taxonomy is further investigated and elaborated.

Another way of collecting behavioral information about a process is to see the time needed to deliver what the customer wants, but for this case the time aspect is discussed in the temporal taxonomy.

Contextual taxonomy

Contextual taxonomy is the outer limitations and boundary conditions for the process. Rules and regulations from the class society, constraints set by the top management, work force limitations, etc. which is limiting and constraining the solution space for the process to work in. The contextual taxonomy is established based on the interviews with the stakeholders and own considerations and observations.

Temporal taxonomy

The temporal taxonomy is applied to collect information about the time line for the process, about what input the different processes need to be initiated. Sequential and parallel steps are emphasized here to investigate bottlenecks. Interviews about "typical" duration for three project types is investigated small changes to equipment, hull change and prototype design.

Perceptual taxonomy

Perceptual taxonomy is applied to investigate what the stakeholders with different perspectives feel about the process and what they need for it to deliver. Through interviews with different persons from different departments and assumed stereotypes, the generalized opinions will be presented in this taxonomy. Since many factors are influencing how people will answer, these generalized stereotypes are formed.

3.2.4 System performance (Step 3)

Based on what type of information is found through the 5 aspect taxonomy, the quantitative and qualitative system performance measures regarding the processes is identified. The five different aspects will enlighten different comparison points relevant to the process. In Ross and Rhodes (2015) numerous of relevant "ilities" is collected, for instance *flexibility, scaleability, modifiability, reliability, quality, and robustness.* "Qualitative research fits process oriented evaluation with a broad approach", Flick (2009). Quantitative measures is estimated based on prerequisite and assumptions due to the lack of experience with 3D and PLM in UDS.

3.2.5 Systems Change Case (Step 4)

Change cases is created to show how different influences is affecting the processes states. Gaspar (2015) introduces the term change enabled paths to display the states during the lifecycle of ships. As illustrated in Figure 3.2 processes can go in different directions based on the different scenarios. The agents are the external elements affecting the process, named α and β . The mechanism 1 and 2 is the path the process must take based on α and β . The result of the path is shown as State 2.

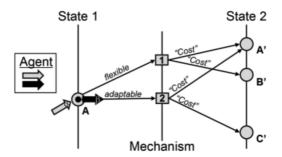


Figure 3.2: Change Enabled Paths, Gaspar (2015)

With this illustration of the situation, it is easier to compare the different processes. Here only reasonable, likely and possible processes is displayed. Relevant agents in a ship design perspective is statements and demands from the customer or class society or experience as projects mature.

3.2.6 Evaluation (Step 5)

The evaluation of the PLM process is done by comparing the system performance measures for the different change cases in a decision matrix (Table 3.1). Risks in the projects are rated in a risk matrix.

Table 3.1: System property evaluation setup

System property	Weighting [%]	Scale range $[1-3]$	2D	3D
Quality				
Reliability				
Safety				
		SCORE:	%	%

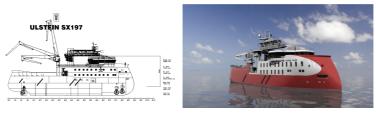
3.3 Simple evaluation of 2D and 3D drawing process

3.3.1 Understand the Drawing Process (Step 1)

In a ship design perspective, the General Arrangement (GA), Single Line Diagram (SLD) and building specification is the key deliveries to the customer in the contract negotiation phase. The GA show hull shape, machinery configuration, propulsion configuration, main components, tank arrangement and generally how the vessel is arranged. Currently the hull is created in 3D, while 2D modelling tool is in use to arrange the vessel with the main components and functions. For presentation purposes rendered illustrations of the vessel is also created for many cases. The drawing process (Appendix 2) is sequential and iterative due to the reciprocal deliveries.

UDS has recently invested in the software Siemens NX PLM to be used as the main design tool pre-contract. This is a 3D software with possibility to create hulls, components and assemblies of the vessels. "The background for wanting a 3D tool is to tidy up the drawing process and establish a library with re-usable components with the possibility to search for components and features", Ulstein (2016). Figure 3.3a shows the GA in 2D, and Figure 3.3b shows a rendered illustration of the vessel.

The input to the drawing process is what is agreed upon in the discussion with the customer, documented in the Basis of Design document, showing what they expect from the vessel and how it will be operated.



(a) General Arrangement

(b) Rendered illustration

Figure 3.3: Wind service operation vessel

3.3.2 Investigate with the five aspect taxonomy (Step 2)

Structural Taxonomy

The first step in the drawing process (Appendix 2) is *prepare conceptual layout*, and here the whole architecture of the vessel is planned to allocate the areas and volumes needed. The GA is not completed in this step, but zones and main equipment is indicated or imagined. In this taxonomy, this first step is investigated further to see were the two approaches are different. The first breakdown is shown in Figure 3.4 as five sub steps.

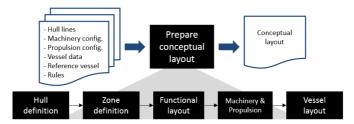


Figure 3.4: WBS of "Prepare Conceptual Layout" process from Appendix 2

Hull definition is done differently in the two approaches, with two different software. Current practice is that the hydrodynamicists model the hull in one software, and export the hull lines, decks and midship-section for further work with the arrangement. In the hull creation step, often two different programs is needed to model the hull as they like. The new approach with NX is different due to the possibility of parametrizing UDS hulls.

Zone definition is also different in 2D and 3D; in 2D zones are indicated as simple lines, while in the 3D domain expressions, links and datum planes need to be defined to be able to move the boarders around. For both cases, structural integrity and damage lengths regarding stability needs to be considered. The three last steps from Figure 3.4 is more or less to have an idea of what the vessel will look like.

When the hull boundaries and architectural limits is indicated, the next phase in the GA

drawing process is to go more in detail of the functional layout (Appendix 2). Insertion of components to fulfill functions in the payload systems aboard the vessel is performed in this activity. The specifications for this kind of equipment is shared by the naval architects in a folder system organized with SFI taxonomy. Some parts come with a 2D model and a separate technical specification for the component in PDF format. The naval architect need information both on performance and size of equipment. In NX the goal is to have a re-use library with geometries of manageable file size which can be modified parametrically and with searchable attributes. With the possibility to search and filter the components, the work of choosing the right one can be simpler and more appropriate for the vessel. For both cases, the designer can move components relatively freely without constraining it too much. The output of both drawing processes is a representation of the vessel in 2D as a traditional GA. NX can automatically generate this drawing from the 3D model.

Behavioral Taxonomy

The 3D tool offers more possibilities for exports and multiple actions within the software, which reduces the number of software needed for certain operations. Currently several geometrical models of the vessel are created; hull model, stability model, structural model and rendering model, all with different library and database content. With a hull update, components can be moved within the hull in a simple way, allowing good utilization of the volumes inside the vessel. When the 3D model is compiled and technical calculations are done, the time to make changes is short in 3D. Still, the analyses and calculations made by the other disciplines needs to be done, so the number of official revisions should still be limited.

Different roles with necessary access and relevant information are to be defined in NX to allow all affected disciplines to get only the information they need. With NX there will be less repetitive actions like for instance moving bulkheads lines when the hull is changed, but with more repetitive constraining and definition actions to set up the model and plan the architecture.

Contextual Taxonomy

"No ship design process has been executed in the same way at UDS" according to Geir Sivertstl at UDS. Different customer demands, reference vessels, segment knowledge, combinations of the specialists, market situation, pressure from other ongoing projects and different time frames is affect the process flow. Due to these reasons, the design process is flexible and iteratively, so the designers have the freedom to design what the customer wants without the frames around being very strict. Rules and regulation for the technical aspect is off course present.

Computer capacity and software configuration along with training of personnel is also physical factors affecting the process. The cognitive skill of the architects should be spent on fruitful action enhancing the design, not waiting for the software to calculate and update models. In this way, the software need to be adapted to the personnel and the design processes.

Temporal Taxonomy

No design project is executed the same way, so to give a statement of how long time is needed to deliver a design is not possible. Generally, three different design approaches are used; standard design, modification and prototype designs. When the naval architects in UDS got this question about time, the most generalized answer they coluld come up with was respectively 50, 50 - 200 and from 300 hours to draw the first GA.

A conservative estimation of drawing time done internally at UDS, Ulstein (2016), shows an assumed increase in design time of 30% in 3D. Figure 3.5 gives an illustration were the difference is expected.

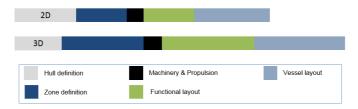


Figure 3.5: Assumed duration of drawing process for 2D and 3D approach

The situation described above is illustrating the first revision of the project. When making the next revision or variation, the time is assumed to be shorter in NX than in AutoCAD, since components can be replaced and moved easily within the model. "NX offers a good opportunity for re-use in the future, making the design time shorter as the experience and library is developed more", Ulstein (2016).

Perceptual Taxonomy

How each of the stakeholders in the design process feels about the drawing process is information gained through interviews with some of the stakeholders with some assumptions and predictions on how the situation will become. A generalized summary of these interviews is shown in Appendix 3. Generally, the ones who will use the 3D software is a bit adverse and have open questions for how the new situation will be. Higher workload and more complexity in the modelling space is a concern for them. Also, to deliver on time with enough freedom to be creative and innovative in the design process is pinpointed to be essential for the culture in the department. The ones using the information from the GA, like stability department, weight department, structure, sales and SCM is all positive to the ripple effects.

3.3.3 System performance (Step 3)

Time is the main system performance parameter investigated for this simplified evaluation case. Three types of project and their assumed duration is shown in Table 3.2. Information is based on interviews. The work of drawing the lines is not that long, but to come up with a well utilized and practical solution for the vessel takes time, and this is done in parallel with the drawing process. Especially for the new designs the hour consumption is strongly dependent on the project and customer, so this "standard design time" is not accurate, rather a assumed average.

Туре	Description	
Standard design	Standard design with small adjustments in equipment	50
Modification	Good reference vessel, but need hull modification	50-150
Prototype	Brand new design	300

Table 3.2: Hour consumption by project type of generalized projects

From the taxonomy investigation the most relevant qualitative performance attributes which can be discussed is: quality, reliability, compatibility, adaptability, flexibility, reusability, usability, efficiency, accessibility, maintainability, and traceability.

3.3.4 Systems Change Case (Step 4)

Four change cases is created to display the differences in time and process activities for the two approaches after a revision of the GA is created (Figure 3.6). First one (#1) is a case were the hull needs modification due to poor stability. Currently a hydrodynamicist need approximately a day to come up with a new modified hull and further export the lines to 2D. The old lines for decks and profile must manually be deleted from the GA. With NX, the hydrodynamicist at UDS is already capable of modifying a hull in only 2 hours due to parametrization of the shape. When the hull is ready it can simply be replaced in the global vessel model and all other components preserved. Change case #2 is a situation where the component is no longer applicable. With the current 2D approach, the designer need to brows in the product datasheets of components to find a component with the right specification. When the right product name is found, the corresponding drawing is browsed for to copy into the drawing. The lines of the old part manually need to be removed. With NX the attributes are filtered and searches is done to find the component. The function replace component is used to correct the model.

If the component is in the wrong location (#3) the lines can simply be moved in the GA, but if lines are cut or modified, the original drawing is again opened and copied from. In this process, the designer need to keep an eye on that all the lines are moved correctly. In NX, the component is found in the global model and simply moved. When working in the 3D domain it is easier to envision the vessel and select a good location for components with regards to volume utilization and function. Change case #4 shows the difference when requesting a rendered illustration of the vessel for presentation purposes. Currently one person creates these pictures by familiarizing with the vessel specification and GA to understand what to display and the space allocation. Then the work of populating components to the hull takes approximately one day. With NX rendered illustrations can be made within a few minutes from anywhere in the vessel. The quality of the picture with these two approaches is different, since simplified geometry will be used in the conceptual model to keep the file size low.

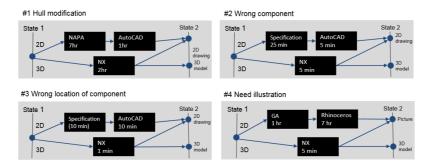


Figure 3.6: Change Cases

3.3.5 Process Evaluation (Step 5)

The main system performance measure, which is time, shows that an increase in the effort for the first revision of the GA is needed. This increase in time is assumed to be re-gained in the following revisions before delivering the final vessel design. Qualitative product performance can be found in the Decision Matrix in Appendix 4. The result from this study shows higher score on the 3D case, but the prerequisite is that the software is usable and the duration to create the 3D model is only 30% longer.

Chapter 4

Analysis of PLM during Upstream Ship Design Processes

4.1 PLM Applied to Conceptual Phase

4.1.1 Understand the PLM process (Step 1)

The background for wanting the PLM processes implemented in the conceptual ship design process is to keep better control of the documentation and solution documentation gained and created in the projects. The knowledge about why different solutions were chosen, how projects evolved, what has been done previously, and good reference projects are mostly in designers head. In this way, the persons with their experience is the most important elements in the company for creating successful designs in the best possible way.

With better control of the documentation the goal is to be able to re-use parts and arrangements and find documentation more easily. The computer tool selected to deal with the PLM concept also includes the 3D modelling tool investigated in Chapter 3.3.1. Currently five geometry models are created for each project - one hull model, GA, stability model, visualization model and one structural model. For each revision, these models need to be updated when required, causing a lot of non-value adding hours in the projects. This re-engineering is also a source of error since the models may not be coherent and timely inefficient due to the sequential work and input/output steps.

"Product Lifecycle Management is an information platform for managing intelligent and complex product models where innovation, realization and usage becomes connected and enables new growth opportunities for Ulstein", Ulstein (2016). PLM consists of the following nine components: *Product, product data/documentation, processes, PLM/PDM application, people, methods, facilities and equipment, metrics, and organizational structure*, Stark (2011).

"The objective with the 3D implementation in the conceptual phase is to reduce the total amount of hours per. project across the design and engineering phase to reduce the overall costs in UDS. Other expected results are better quality in the design phase and lower technical risks in projects. A better collaboration between design and engineering department is also considered very positive by working on a uniform platform and having the possibility to re-use vessels and components both ways instead of re-modelling between the phases. Improved product presentation to the customer is also part of the objective of the 3D implementation" according to the internal pre-study Sollid (2016a).

4.1.2 Five aspect taxonomy applied to conceptual phase (Step 2)

Structural taxonomy - Product

The product delivered from UDS is ship designs which is fulfilling the customer demand and is within rules and regulations for the specific vessel type. Ship design is as mentioned very complex with customized solutions and mostly one-of-a-kind designs specifically designed for a customer and specific operations. Thousands of components are forming the vessel, with sub-systems and interfaces. Figure 4.1 shows the different disciplines working together to be able to deliver a vessel design with good technical capabilities.

As seen from the illustration the number of persons working together in all the projects are quite high. Each involved is adding their technical or commercial opinion on what is important in their perspective. Ship design is according to Frode Sollid a giant compromise in balancing the input from the different disciplines and the customer requirements.



Figure 4.1: Disciplines involved in conceptual phase of Ship Design

Structural taxonomy - Process

The process of how to get to the final design is further explored in this taxonomy. Appendix 5 shows the main conceptual design process as it is documented at UDS. Figure 4.2 is created with the basis of the current process, but a more detailed breakdown is added in some areas based on observations in the design department and interviews about the actual documents created and the required input to the work. In the following paragraphs this process is elaborated more, and with reference to the numbering in Figure 4.2.

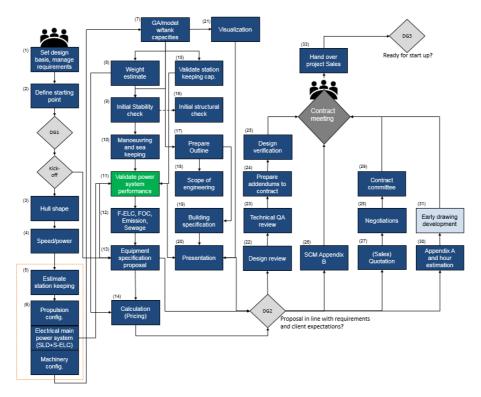


Figure 4.2: Conceptual design phase

Though a meeting with the customer (1) and tender documentation the pre-sales project is initiated. Normally a naval architect and sales persons is in contact with the customer to extract the clients requirements and operational intentions. *Basis of Design* is a document clarifying design requirements and boundary conditions for the concept design. This document is established in the process of evaluating the customer requirements and validate them. In the next phase (2) the starting point of the design is determined, whether it is a portfolio modification, a standard design or a prototype design. Technical solutions are discussed here in how to solve the design problem. DG1 is the first decision gate where it

is determined if UDS will initiate the project or not. If the design project is accepted, the next milestone is the Kick-off meeting where the project is initiated as a sales project.

Hull (3) is next created, modified or copied. Hydro dynamic department perform a speed-power calculation (4) of the hull if it is modified. This analysis determines how much power the propellers need to deliver for given speeds. Station keeping capability (5) is estimated based on references and assumptions, because the real calculation is dependent on wind projected area from the GA. Machinery, electrical and hydro dynamic representatives next collaborate (6) to select the propulsion configuration, electrical main power system, thrusters and machinery configuration for the vessel. The decisions made in this step is documented in the Single Line Diagram and the simplified electrical load calculation (S-ELC). This step is performed to be able to have a base for the design, since the calculations are interdependent.

Now the naval architect split the hull in zones and add payload equipment, ship equipment and define the tank arrangement and capacities (7). This is the first GA with limited information about the technical feasibility of the design if it is a new design. With the chosen propulsion configuration, hydro continues doing a station keeping capability calculation (15). This calculation need input of the wind area and the draught of the vessel to calculate the external loads on the vessel from wind, waves and current. Based on the environment the percentage of utilization for each force generator is calculated. This information is further used to validate the power system performance (11) and used in the calculation of the Full Electrical Load Calculation (F-ELC) (12). Definition of failure modes is done in collaboration with electrical and machinery specialists (15).

Based on the SLD, GA and short specification (if it is made) the lightship is estimated (8). Output is light weight, center of gravity and longitudinal weight distribution, which is input to the stability calculations. The light weight is split in steel weight and equipment weight, the steel weight is used for pricing purposes (14).

Stability creates their own model in a specialized calculation software (9). The hull and hydrostatics is imported allowing calculation of the summer water line (SWL). The draught of the vessel is calculated based on the light ship parameters and tank plan. Intact stability is calculated after defining the flooding points and the relevant rules for the vessel. Max vertical center of gravity curve and minimum righting arm is calculated. Damage stability according to the watertight subdivision of the vessel gives max VCG and min GM in addition to damage waterlines and allowable ventilation positions. The relevant loading conditions are defined based on rules and regulations for relevant and feasible loading condition. Currently there is no link between the GA and the stability model, forcing manual updates of the stability model when the GA is changed. Longitudinal strength, sagging and hogging moment, and tonnage calculation is also calculated for the different loading conditions. The moments acting on the hull beam is used in some cases were an initial structural check is done (16).

Maneuvering and sea keeping (10) is calculated based on the hull, loading condition and roll damping. In this stage, the Response Amplitude Operator (RAO), accelerations and operability for the vessel is calculated. Based on these results, the performance of the power systems is validated (11). Electrical load calculation, fuel oil consumption, emission- and sewage calculations (12) is performed if the results from the calculations is ok. If not, a new revision of the GA is needed (possibly a hull change as well). The loop is run again until the technical performance of the vessel is within the requirements.

Supply Chain Management (SCM) compile the equipment package (13) based on the discussions in the Kick-off meeting and the validated propulsion, electrical and machinery configuration. This information is directly used in the price calculation (14) and to ensure the agreed milestone dates is possible to reach with regards to equipment delivery. The outline document (17) is created after it is calculated if the vessel is floating the right way, and is a short description of the vessel specification. Building specification (19) is a detailed description of the vessel, typically between 100 - 200 written pages, containing a general description, standards, agreements and technical specifications organized with the SFI system. Scope of engineering (18) is settled on basis of the outline or building specification. Illustrations (21) of the vessel is created based on the GA and directly used in presentation material (20). In this presentation, the main features of the vessel are also presented.

Decision Gate 2 is a check whether the designed vessel is within the customer requirement and client expectations. Based on the output from this consideration the vessel design can either go through more iterations with the lessons learned or continue to the contract negotiation phase. Now the documentation is checked and reviewed with relevant personnel (22-25). The specific documents in the contract signing is the GA, SLD, building specification, weight estimate, makers list and tank plan. Before the contract meeting SCM creates "Appendix B - Technical equipment specification" (26). Sales prepare the strategy (27-29) to convince the customer and engineering plans the further work (30-31). When/if the contract is won the project is handed over from the design team to engineering team (33).

Structural taxonomy - Documentation

Through the work in the process of mapping all the steps in the design process and the sequence, different documents and reports is mentioned earlier in the chapter. Table 4.1

sums up the documentation created in the conceptual design process.

The first meeting with the customer and the clarification done before the Kick-off for the project is captured in the *Basis of Design* document. This document clarifies the design requirements and boundary condition for the conceptual design as what the vessel should accomplish. This document is not elaborating on how to solve the design challenge.

Next documentation is the hull line and hydrostatics. Currently these lines are exported from 3D to 2D and the hydrostatics is a table with different draughts and displacements. Speed and power prediction is done with either empirical methods like Holtrop & Mennen and/or Computational Fluid Dynamics (CFD). From these calculations, the required power from the propulsion is calculated. How the propulsion and thrusters are configured is showed in the Single Line Diagram. The electrical department oversees this document, but valuable input from machine and hydro dynamics is included.

With the hull lines and main machinery components determined, the Naval architect can arrange the vessel on the GA. Along with drawing the arrangement of the vessel the selected components and characteristics are written in the outline or short specification for the vessel. The ship consists of a huge amount of parts which currently is grouped using the SFI taxonomy. There the vessel is split in eight main groups - *Ship in general, Hull, Equipment for Cargo, Ship Equipment, Equipment for Crew and Passengers, Machinery Main Components, Systems for Machinery Main Components, and Ship Common System.*

Weight estimate is done using a specialized software, and documented manually in a weight report. The weight distribution curve is also exported for stability to further use it. The stability team make a vessel model in a specialized software with different export possibilities for automated reports. From the model the intact stability, loading condition, tonnage calculation, tank plan, and hogging/sagging conditions is written in reports. For some cases, the structural properties are also checked, using the loading conditions, local loads, weight distribution and longitudinal strength. With the input from stability, hydro again is active in calculating motions and sea keeping characteristics.

Station keeping capability calculation need input from the GA with the wind area and from electrical and machinery in the definition of the failure modes. This collaboration is highly important to the quality of the solutions selected. Motions and sea keeping calculation need input from the loading condition to perform the calculation. The output from this calculation is further used for calculating the equipment number, and determine the layout and size of the mooring equipment. The horizontal line in the table represents work which is done late in the process, after the solution is validated. Supply Chain Management department need to collect the data of specific components used in the vessel to have an updated list of the components and the makers list.

Document owner	Documentation
Naval Architect	Basis of Design
Hydro	Hull lines
Hydro	Hydrostatics
Hydro	Speed and Power prediction
Electrical (Hydro, machine)	Thruster and power system (SLD)
Naval Architect	GA
Naval Architect	Short specification/outline
Weight engineer	Weight estimate
Weight engineer	Weight distribution curve
Stability	NAPA model
Stability	Intact stability
Stability	Loading conditions
Stability	Tonnage calculation
Stability	Tank Plan
Stability	Hogging/sagging condition
Structure	Initial structural check
Hydro	Station keeping capability
Hydro	Motions and sea keeping
Naval architect	Equipment number calculation
Electrical (machine)	Electric Load Calculation
Machine	Fuel Oil Consumption
Machine	Endurance Calculation
Machine	Sewage Calculation
Machine	Emission Calculation
Naval Architect	Building specification
Naval Architect	Design philosophy
Electrical	Electrical System Philosophy
SCM	Equipment specification
SCM	Makers list
3D modelling specialist	Illustration
Naval Architect + team	Presentation
Sales	Offer

Table 4.1: List of documentation and document owner

Based on all the steps until this stage, the electrical- machinery- and propulsion configuration need to be updated and validated. The electrical load calculation is officially created now. Based on the chosen configuration, the fuel oil consumption, endurance calculation, sewage and emission calculation is performed. Endurance calculation is used in the dimensioning of the fuel tanks on the vessel and additional calculations for the sewage volume is performed.

When the design project is matured and is within the requirement of the tender, additional documentation is compiled to the contract negotiation phase. The official building specification, GA and SLD is updated to be coherent. Rendered illustrations is made for presentation purposes along with the technical specifications for the vessel. Design philosophy end electrical system philosophy is also created.

Sales are active in the ship design in the process of capturing what the customer wants and give guidelines for how much the vessel can cost to the designers.

Behavioural taxonomy

With the PLM software, design changes are automatically updating related parts and gives a full bi-directional associativity between parts, assemblies and drawings. This control makes the process good and transparent. The Master Model concept will eliminate the rendering 3D model, the GA drawing manual update, tank- and zone definition for the stability software. Weight information can also be extracted from the model, allowing automatic updates to the weight estimation software. With the implementation of the new software, the hull forming is also done using the same software. Ship design is not simple, so the design processes cannot be either. Specialized software for different purposes is needed to get accurate calculations. The sequence of the calculations is explored more in the temporal taxonomy. With a master model which can be updated often it is important to still use official revisions. With only one model and sequential actions, there will be waiting time. Then it probably will be tempting for the designer to do quick fixes to the arrangement and add their new ideas as they come.

The collaborative aspect with the software can contribute to optimize the designs when it can be seen with "fresh eyes". The time to do the actual drawing will most probably increase due to the approval process, more people involved in the design and a more complex modelling approach, but the time between revisions is assumed to be shorter. With an updated master model, a low amount of manual changes needs to be made before doing a second run for the different specialized analyses. With Team Center different roles are assigned to the involved in a project; the roles are currently designer, approver and consumer, but according to Greta Leviauskait "it is natural to add more roles and define what is interesting for the given person after the software is functioning properly to customize the amount of information displayed". The designers insert components and an approver needs to check the area of the model (in NX named the workflow) and approve it or make comments. This extra link in the process is an additional quality check of the vessel design which is not currently used. It is envisaged that a more collaborative process will be done in 3D, where each discipline is adding their components to the vessel and approving each other. The consumer role is assigned read-only rights to the updated model. The drawing process will not be more efficient adding this extra approval link, but the quality of the drawing may be better.

Contextual taxonomy

In the current down times the number of employs is lower in UDS compared to the situation a few years ago, and the largest reduction is in engineering department. To be able to deliver design in time, preferably more work must be laid down in the conceptual model. With the extra time added in the conceptual design to model the vessel in 3D, the workload of the engineers becomes higher. For new and complex designs the class rules and requirements from the customer is challenging the cognitive capacity of the naval architect already. As described in chapter 3.1 the ship designers can be assumed to be fixed and the software must accommodate the needs and expectations of the users.

From Figure 4.3 one can see the different sources of information currently available (in orange). With Team Center and NX these libraries will be compiled in the large common library (green). The number interfaces ads a new level of complexity for the library which needs to be thoroughly investigated to have a system were the stakeholders can find what they need and can perform their work efficiently. Different disciplines need different information about the same components, so to have different roles able to see what they need without being overloaded with irrelevant information is a key for making the system work efficiently. One benefit with collecting this information in the PLM system is that important documents is not only stored in one persons laptop, but accessible from anywhere.

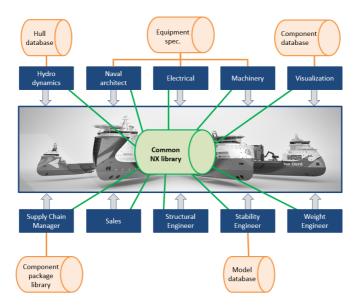


Figure 4.3: Databases - orange is current situation and green represents NX and PLM

The desired situation with a common library will encourage more re-use of components, since the same parts are available for the different phases. This common ground will eliminate the double work of finding and checking the same components for multiple departments. First the components are checked in the conceptual phase when deciding which components to use in the vessel. This conceptual design is mostly concerning the physical size of components and their specifications. SCM is interested in specifications, price and delivery time. When the project activities are shifted to the engineering department, more detailed work begins of designing the physical system interfaces inside the vessel and design all the sub-systems needed to make the vessel able to run. Different information is the focus of attention in this phase, since the technical performance measures for the vessel is designed in the conceptual phase. This second round of gathering information is unnecessary and should be eliminated. Further, when the vessel is being built different information is needed regarding mounting and maintenance, so again information about the same components is investigated. Sales is interested in the price of the components.

The duration for a project can stretch from only a few days to several years. Some projects can be formed based on reference project with minor adjustments to the arrangement, not affecting the performance characteristics of the vessel, only having to update documentation to the new project. Level of details and calculations also vary between project. Another factor is the management process of deciding which project to prioritize on and which to decline. Designers does not only perform sales projects, but also internal development projects.

Other design companies are converting their design approach to 3D, so UDS needs to step up in competition in the development and market. This extra feature in the customer communication is considered a valuable added synergy to the actual drawing process.

Temporal taxonomy

Three different scenarios are natural for UDS - *portfolio modification, standard design and new designs*. Through the process of investigating the process, the stakeholders was asked how much time they would normally use for a project like that. Appendix 7 shows the full time schedule for the three design scenarios for a general Platform Supply Vessel. These numbers are average numbers based on experience in the design department and is intended to show recursive dependencies in the calculations inside the project. This simple display does not express that multiple projects are running simultaneously with different priorities, but this is a single project with top priority.

Figure 4.4 shows a simplified version of the timeline shown in Appendix 7 of a relatively simple design were an almost identical reference vessel exists. The longest duration here is the GA drawing process, but this activity must be done before the rest of the sequence is initiated. Figure 4.5 shows an imaginary case were a good reference vessel exists, but the ship needs increased beam or length. This change results in added time for each sub-step until the final design is ready to be displayed. With higher uncertainties, more iterations are needed to hit the target.

The last time line investigated (Figure 4.6) is a new design with new technology and a different hull. With less experience and reference vessels, the overall time is minimum four times longer. This last ship has the highest uncertainties when it comes to time estimation and project planning. For very special requests from demanding customers, the schedule of the project can be impossible to predict. For this type of projects the requirements can change from one revision to the next, based on the results calculated and the customer seeing a different potential in the vessel. "Requirements-creep is describing the subtle way requirements that requirements grow impreceptibly during the course of a project", NASA (2010).

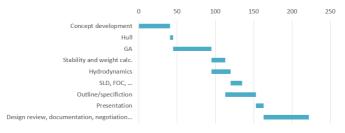


Figure 4.4: Timeline for standard project in 2D

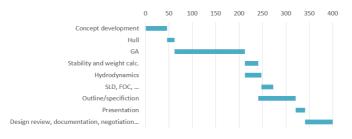


Figure 4.5: Timeline for hull modification project in 2D

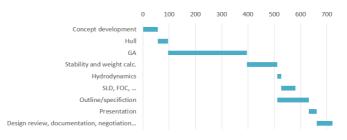


Figure 4.6: Timeline for hull new project in 2D

The organization of this library determine the amount of time to find what they are looking for. For new parts which are not available in the library, simple indications are quicker in 2D due to the level of details normally added. In 2D the designer can occasionally cheat and make practically impossible solutions which gives an indication on how it will look like to save time. These areas must later on be corrected in the detailed engineering phase. The time needed to create the GA is strongly dependent on reference vessels. By having a well-organized library of parts and assemblies, the drawing time would be reduced for both cases.

Perceptual taxonomy

Generalized perceptions of the PLM concept in the conceptual phase is compiled in Appendix 6. Figure 4.7 gives the essence from these perceptions.

Naval architect	Stability engineer
Currently the software is too slowConcerned about higher work load with 3D	Import of 3D modelMore accurate weight estimation
ModelNeed CAD engineers to maintain	Hydro
library/items Positive to shared library with searchable attributes	Parametric modelling No export of hull lines
 Positive to workflows and project control 	Sales
• Re-use	 Better control of price – reduced margins
Machine/electrical	 3D model looks better – easier communication with customer
Concerned with more rigid documentation control	SCM
 Question the need of documentation early in the projects Positive to searchable attributes 	• Better control of what the naval architect have put in the vessel
Weight engineer	
 Positive to added information (BOM, Weight of components, Center of gravity, Technical specification of components, volumes) Walk-through the vessel 	



4.1.3 System Performance (Step 3)

Based on the temporal taxonomy the current time to come up with the first revision is found to be approximately between 220 - 720 hours effective work. The longest single activity is the part of creating the GA, and most of the other actions is dependent on this step. With the new approach this time is expected to be even longer, but hull modelling, stability mode, illustration and weight extraction are expected to be shorter.

The main impacts affecting the hour consumption in the projects is rated the risk matrix shown in Figure 4.8. The most significant risks regarding time in the drawing process is the vessel type and experience/reference projects. Design software and equipment library is considered less important regarding the overall time to deliver the conceptual drawing by designers. The time is also dependent on the size of the vessel; for larger vessels, more equipment is added.

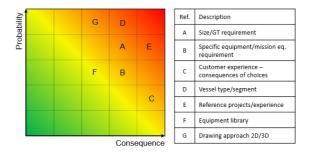


Figure 4.8: Risk assessment of hour consumption

Figure 4.9 shows the NPV results from the pre-study-model in Ulstein (2016). The three colors represent respectively Net cash flow (high), Net cash flow (low) and cash out. The high and low values comes from a estimate of the overall savings in UDS, where the business is split in three project types; prototype (advanced), medium complexity and basic w/integration. The As-is condition is the average consumed hours for these three project types. Together with the teams the assumed savings in hours per project is estimated. For the conceptual phase the hour consumption is estimated to increase by 14 - 61% across the three project types. Basic design (engineering) is assumed to save between 19 - 33%.

Project load at UDS is further assessed in this model, to come up with an estimate of the situation. Amount of projects which is worked on a bit and "all-in" projects are separated here. The idea with the model is that the fruits from the implementation is not present the first few years due to all the work om implementing the new approach, but after a some years the situation will be great according to the model. Project load is further used in the NPV calculation to asses the situation of "do nothing", "optimistic estimation" and "pessimistic estimation".

The NPV model was created a year ago, so the time frame in the figure is not valid currently due to some delays in the process, but the situation is still expected to follow this trend so the numbers are used as a reference in the following paragraphs. 2016 has a high cash out value (Figure 4.9) since the money is invested in the software. The start-up cost of buying the software and adapting it to the designers need at UDS is high, but the largest

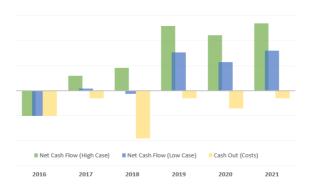


Figure 4.9: Net Present Value of 3D and PLM investment, Ulstein (2016)

fraction is own hours in training, decision making, and process mapping internally at UDS. The second year cash out is assumed to be the cost of maintaining the software and for technical support. Now the net cash flow is positive already, for both cases. 2018 has a big Cash out value, representing the implementation of NX in engineering also. Although the this cost is high, the NPV value for the optimistic case is positive. In 2019 the fruits from the implementation really will show, since the biggest savings is assumed to be in the engineering process.

4.1.4 Process Change Case (Step 4)

Change case #1 is created to estimate the difference in time to create the first revision of the project. The temporal taxonomy for the second case (Figure 4.5) is used as a basis. The assumptions here is a reduction in the time to make the hull (from current status), a 30% addition in time to create the GA, that stability can import the master model without major challenges, and rendering is done more rapid.

Second change case is the process to take out information for the weight estimate. Currently the volumes in the hull is taken out by stability personnel, and areas is measured directly on the GA. Information about components is found in the building specification of the vessel, reference data and product sheets. Location of the components is found from the GA. With a 3D master model all this information can be found from only one source, saving a lot of time.

Change case #3 is created to capture the process of finding reference projects. Currently the involved must remember or ask for references to know where to brows for information. UDS is not a very large organization, so this is not currently seen as a big challenge since the naval architects and other personnel is very experienced and it is easy to ask each other. In NX the main attributes can be searched for, so the time here is assumed shorter.

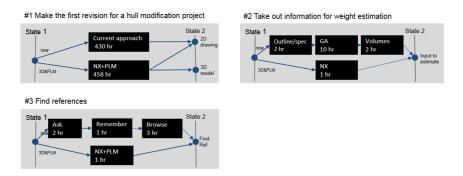


Figure 4.10: Change Cases

4.1.5 **Process evaluation (Step 5)**

Time

Prerequisite for the investigation is an increase in time to draw the vessel by 30%, when going from 2D to 3D. Table 4.2 shows the time difference in percentage for the three project types. These numbers are based on the results from the temporal taxonomy, with an increase in design time and reduced time for stability, weight, rendering.

Table 4.2: Difference per. design type

Design type	δ
Small change	6%
Hull change	9%
New design	7%

Currently observations show a lot longer design time than 30% increase. Hull modelling has proven to be shorter than the old approach already, and still the hydrodynamicists have suggestions for further improvements. Zone definition seems to be the most complex setup currently, where parametric modelling with links is created. According to Greta Leviauskait "the process of defining all the datum planes and linking them was a lot bigger than expected in NX". In 2D the lines can be moved more freely without any constraints and cumbersome definitions.

Re-use

With easier access to the database of equipment and to reference vessels, more re-use can come simply from finding information easier. The cloud based interface makes the information available from anywhere. To enhance the reuse of components, the library should ideally contain both reusable components, assemblies and vessels.

Re-use between concept design and engineering will face challenges in the level of details for the two different phases. More complex geometries are larger when it comes to file size, making the conceptual models larger and cumbersome to work in. Objective of the conceptual design is to allocate the space and design the architecture, not design all the interfaces perfectly.

Information management

In the PLM system, both documents and vessel models should be managed in the system. The largest difference is here the number of sources to find information from. With more focus on requirement capture and better control of both technical aspects and price of the vessel, it is more likely to design exactly what the customer wants. With a more uniform understanding of what the customer wants, the different disciplines can easier pull the project in the right direction.

Document can still be created the "old" way, and automatically uploaded to the PLM system. Through the software, the naval architect can request information with a deadline. Better control of the projects will help run the projects efficiently.

Bottlenecks

The longest duration in the temporal taxonomy is planning and modelling the vessel, so this can be seen as a bottleneck. With PLM and NX this bottleneck will become even larger, so actions must be taken to prevent this. Dedicated CAD engineers could be a solution to this issue. Also, the component library and maintenance of this will be a large job, and a bottleneck to have the right equipment for new vessels.

Most of the actions in the upstream ship design is sequential, so the different disciplines need to wait for each other. Multiple projects are running simultaneously, so the work stock are not out of work.

Qalitative evaluation

Results for evaluating the two approaches using a decision matrix (Appendix 8) shows a better score of theoretical benefits with PLM and NX implemented. As emphasized these are theoretical benefits, so still work needs to be done to make the software function as well as prerequisite.

Pros and cons with the approaches is also investigated, shown in Appendix 9. PLM and NX shows the best theoretical results with a much longer list of benefits.

4.2 Critical evaluation of PLM

4.2.1 Evaluation of PLM at UDS

The number of projects in the conceptual design and engineering phase (from 2012) is illustrated in Figure 4.11. This critical aspect of the perspectives is a key in the NPV model. 25 times more projects were performed in the conceptual phase that year, so by adding more time for each of the projects in the conceptual design, the overall hour consumption across the two departments is dramatically affected. The workload of the design department is currently perceived quite high.

One reason to implement 3D is the possibility of modelling the vessels main components in the conceptual phase, and continue with this information fixed for the next phase of engineering the vessel. According to Cang and Bich (2013) this will improve the quality of the design and reduce the product development time. With added workload in the conceptual phase, and reduced in the engineering, the size of the departments should be assessed.

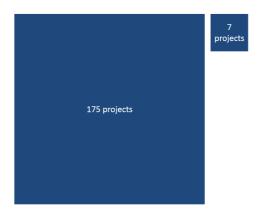


Figure 4.11: Number of projects in design and engineering from 2012, based on Sollid (2016b)

The time to deliver a vessel needs to be compared for the current situation and with PLM and 3D implemented all over the company. Frode Sollid have some ideas about this subject, illustrated in Figure 4.12. Current state of the art is that the conceptual design phase is initiated to respond to a tender, when the contract is won the design and engineering phase begins. When all the solutions are determined and decided the ship can be built. The future timeline model looks very different, both by the triangles being smaller and that the processes can be performed before the last one is finished.

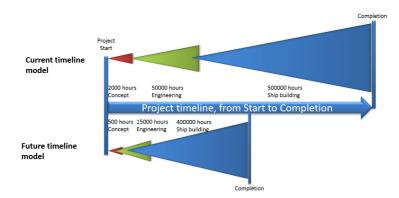


Figure 4.12: Illustration of timeline model, Sollid (2016b)

For Ulstein Group this advantage of being able to deliver the vessel in shorter time should be fully taken advantage of. By being in the situation of having both UDS and a building yard in the same site, Ulstein is in a good situation in the competitive market. To fully maximize the effects of the PLM process, all the parts of the company involved in the upstream design process should be included. The conceptual design department makes modules already in the conceptual phase and when the engineering work begins, the main components with their properties is already added, so the work here is to connect the systems and finalize the design. Already when the contract is signed the yard can begin pre-assemblies of modules in the workshop. This way of working makes the working days more balanced and predictable.

Implementation of a common library is the first step improving the communication between the different departments and phases of the project. Current situation is that the conceptual design department has its own drive in the network where information is shared. When the contract is signed the vessel specification in the contract is the recipe to go by for the engineering department. This recipe is in written form and organized with the SFI system. Now the engineering department needs to find information for the given components in their library from their disk. There is no link between these disks currently, so the work of collecting information is done twice. Based on what is available in the libraries, choices made can be questioned by the engineers continuing the project as they have a different view on the case.

One aspect of ship building is that it is close to impossible to make identical vessels. For four vessels sold with the same design, none of them is likely built to have the exact same light weight and center of gravity when finished, since so many persons are working in the vessel and components from sub-supplier change. "Especially electrical components change design often, forcing re-engineering in the areas around" according to Geir Sivertstl, Head of Electrical Systems at UDS. SCM organize the equipment to be delivered for each vessel, avoiding a large stock and guaranties to expire. In this way, the full potential with the freedom to begin building early is a bit inhibited.

4.2.2 Experience from others

Experience from Frers Naval Architecture (Siemens (2014)) reveals the company had a 15 - 20% efficiency loss in their design cycle due to 2D and 3D software incompatibility. With Siemens NX PLM implemented the company noticed improvements in both product quality and innovation. Through added value of better collaboration with shipyard, interior designer and other suppliers, the overall situation with the new processes was positive regarding efficiency. Also, the new approach with parametrized scaling and non-colliding constrains, parts can be moved more freely reducing the time for each iteration and freeing the designer in their creativity.

Experience from Hinckley enlightened "better utilization of the volumes available in the hull for components and tanks by arranging the components more efficiently with the 3D approach. In the 3D domain, our experience is fewer engineering changes by fitting the interior quicker than earlier. In addition, we experienced better control on the interfaces between systems by having everything assembled in one model", Siemens (2014).

"The main advantages with NX is how we are able to structure our data and access this data from different parts of the process. With the collaborative possibilities of Team Center, concurrent engineering can be performed to reduce the lead time of our products", Borgschulte (2013). Lurssen Shipyard is designing and building yachts, so each project is unique but the working method to design and control the documentation is standardized. Their view on making the processes transparent, increased the understanding of who is doing what, and who is the customers for the job. "This knowledge about what the engineers are doing saved the company time. Siemens NX is a good integrated tool which can handle large assemblies. The key advantages with TC is according to Borgschulte (2013)":

- Can manage more data
- Can manage access rights for each project
- Can support business processes with Team Center Workflow
- Can visualize the design from mobile devices
- The process is intuitive for integrating products and manufacturing
- Can support maintenance with information and aid in crew training

• Better control of change management

"Our experience on a 130m yacht is a reduction in lead time from 47 - 43 months to delivery. In addition larger output with multiple vessels being built at the same time. Our experience is that the engineering resources became reduced by approximately 8% in average", Borgschulte (2013).

Chapter 5

Discussion

Main research question for the thesis was - *How can System Engineering methods be applied to evaluate the PLM process during upstream ship design processes*? Through the chosen methodology, many aspects of the PLM processes were enlightened, giving a wide and systemic insight to the concept. By first understanding the objective of the new processes and what it is, the deeper study with the five aspect taxonomy had a more steady course. In line with NASA's methodology, the system performance measures were determined after knowing what kind of information the taxonomies enlightened. Change cases was a good method for envisioning different scenarios and situations. More change cases could be created for a broader picture of the situation. Evaluation process was at times guesswork due to the limited experience with the approach in the practical life, so mostly theoretical benefits and assumptions were judged.

Temporal taxonomy was created simply by asking "How many hours do you need to perform this for a *typical* project?". This is not a very scientific method for establishing the required design time, but no projects are the same and the context around also is constantly changing, so stakeholder's impression and experience was reckoned sufficient for this thesis investigation. Answer to my question about time is dependent on who I asked and how much of their work they could think about at that time. Since multiple projects are running at the same time a lot of the working day consists of jumping between projects and meetings. This discontinuous work will make the time to deliver even longer. Time to create the delivery for the different disciplines is the sum of all the preparation work, the thoughts and the part of doing it. The complex aspect of situations were different disciplines need to cooperate to solve certain thesis is also a factor with uncertainty.

The new process map was created with basis of the available documentation at UDS

and interviews. Ship design is iterative and recursively so many factors are dependent upon each other. This specific map is imagined to be a top-priority project with all required personnel available for the design project. In real life, some delays can occur between disciplines work, and for special cases the level of detail in the work delivered can be reduced. People can initiate their work before the last phase is finished for most cases, and then update information as it is available. More and more automated tasks are also being formed in the design department, for instance the building specification. Now internal projects are focused on creating templates for different vessel segments. In a lot simpler way than before, values and properties can be added directly to this document, and a finished specification can be compiled, instead of scrolling through 100 - 200 pages of text.

Different specialized software is needed to perform specialized calculations, NX and TC information needs to be imported to these software without big problems. In import/export actions information about geometry can be lost and simplified, so special concern need to be put in securing information is conserved.

With the fact that UDS previously tried to implement Siemens NX, the stakeholders are a bit adverse to these three letters (PLM). The PDM implementation in 2006 failed due to the limitations with the software at that time and the lack of capability with other necessary software. Recently the PLM software has evolved into the 4^{th} generation of technology were the previous challenges is eliminated.

The choice of using the software Siemens Team Center is perceived as a political choice from the management side, and not the most appropriate design tool by the people in UDS. With the fact that NTNU in Aalesund lectures this 3D software, the newly educated students are already trained in the software and can fit right in to the organization. This new threat with the younger and more efficient competitors can make the designers feel threatened in the situation. Siemens NX comes under the traditional mechanical category of modelling tools, while some of the other modelling tool is more an architecture approach. These have the reputation to be easier and more efficient for the ship design process in modelling. "In these challenging times in the market, the need for innovation and cost reduction in the production segment has increased in significance", Masteikait (2016). By spending more money in one company, the building cost for the yard can be reduced. This is considered a positive result for the Ulstein Group.

The largest bottlenecks are currently seen as the software configuration and performance. "The key for making the implementation of 3D in the daily working life is to have a software which can assist and help is the design phase by being logical and intuitive for the user. If the person drawing the vessel needs to put his intellect in working the way the software is pre-defined to, the creativity is lost in the constant struggle of working in an unnatural and forced way, where the order of how constraints are made is the priority in the designers intellect" according to Bjornar Hatly. The process of planning the architecture and defining different zones is cumbersome currently. It is done this way to have the freedom to alter the size of areas as main components are inserted to the vessel.

Questions have been raised on the understanding some decision makers for the customer have on technical drawings. Miss-communication and unclear requirements can cause trouble and unnecessary limits on the project. When the architects and sales team are out in the world visiting possible buyers, the ace up its sleeve is to navigate and show the 3D model of the vessel. In the challenging market the need to stand out and deliver more to the customer is what is driving the 3D modelling into the ship design industry. The conceptual phase in ship design is similar to architecture of buildings, where the layout and systems needed is defined and allocated. In that field, the 3D designing tools is well developed and applied for years. Ship design industry has not followed this evolution due to high temperatures in the market in the past and no planning ahead.

One concern of the users of the Team Center platform is the capacity to work in the common server. With more complex models, the file size becomes large. Cloud based softwares sound good in theory, were everything can be found from anywhere. However, this introduces higher requirements for the band width of the internet. Large 3D models also force the need for upgraded computer and hardware configuration. Some experience with the software already reveals that the time to load models and perform certain commands takes a few minutes. This waiting time can cause the engineers to struggle with the attention on the design and derail in other thoughts. Especially the first time when the model is loaded, the time is currently too high at the moment.

When traveling around in the world, in certain areas, the designers are not allowed to use wireless networks due to the fear of virus and espionage. Configuration of Siemens NX PLM is assumed to be secure. Working in offline mode should also be a possibility, but this is not investigated in this thesis.

The statement that the work done in the conceptual phase can be utilized more directly for the engineering phase is a good point, but when seen in the context of the number of projects in each phase, the reward is smaller. Numbers from 2012 shows 175 projects designed and only 7 won. The math in this is simple; if the company spends a lot more time than before on the huge number of projects in design, the few projects actually engineered have trouble gaining the benefits. However, the step of having a 3D model ready for the engineering department may be a crucial step of surviving. The size of the engineering department has radically dropped in the few past hard years in the market. With the low

number of employs, savings is really important. Idea of re-using engineered vessels back in the conceptual phase needs to be looked into more. With higher level of details in components and interfaces, toe conceptual model becomes very large and complex. Freedom to move components and bulkheads around need to be sufficient to be able to arrange the vessel in the most balanced way.

The process of configuring the re-use library need to include the different specialists to get a better understanding of the interfaces and how to re-use parts and systems efficiently. Key here is to ask and investigate for the different component types, and not assume how it works in real life.

PLM is perceived more like a mystery of the employs (who are not involved in the project), as a way of controlling the work and documentation. These needs to be informed and have a saying when it comes to how the software will be utilized.

Chapter 6

Concluding remarks

6.1 Conclusion

With the methodology selected, a good understanding of the situation was obtained. It is crucial to really understand the situation to evaluate how PLM will fit in the conceptual phase. Through the methodology sufficient background knowledge was obtained, as well as evaluation methodology.

Even though the time will probably increase to make the first master model of the project, the reward is a customer which has a better basis for making their decision. With more accurate properties of components, and less estimation (for instance weight estimation), the risk of the project is reduced. The Supply Chain Management can also keep better control of the components used in the vessel. By reusing agreements with subsuppliers, already negotiated, the library will contain a lot of valuable information about the components.

More resources need to be put in R&D projects to build up the vessel library for UDS. This development needs to be done by highly qualified personnel to configure the software right and define the components right with regards to re-use and interfaces.

PLM is evaluated to be beneficial, but the 3D modelling tool will only be when all the practical issues with the software is resolved.

6.2 Further work

Suggestion for further work is to investigate were the largest potential is regarding re-use in the 3D drawing process and suggest how the library should be organized. Also, when NX will be used for engineering department, more detailed models will be created. The level of details for the conceptual phase, and how engineering models can be re-used without having too big and detailed components is an area for research.

A deeper study of the software itself and all the possibilities could also be investigated to discover the full potential of the software and where it is applicable to Ulstein Group. The link between modularization (which is also worked on internally at Ulstein) and the aspects discovered in the work with modularization as a connection to 3D modelling and PLM system could also be an interesting topic for research.

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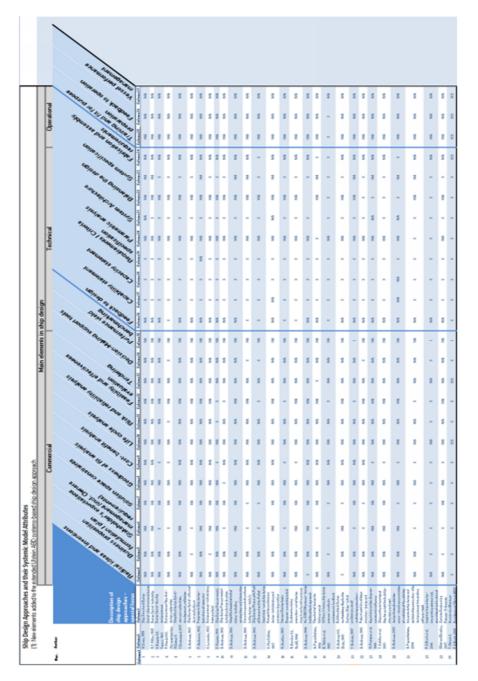
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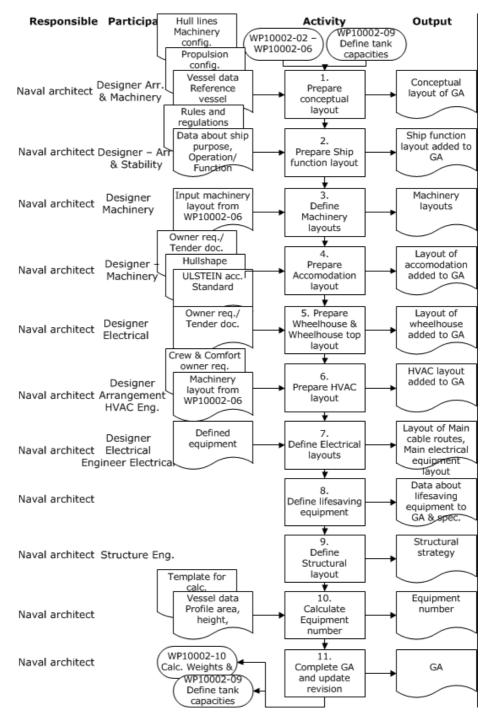
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Appendix 2: Prepare General Arrangements Process



Appendix 3: Generalized perceptions of the drawing process in 2D and 3D based on interviews

Naval architects

The Naval_architects is having some concerns when it comes to the training and the new perspective of the approach and how to utilize the new software in a good way. With this new thinking concerns about the time to respond to client tenders is raised. The added complexity with the workflow in the modelling environment is also pinpointed as an essential aspect to be settled and adapted to make the drawing process work in a good way. With more persons involved in the modelling space, more complication can be experienced with regards to collision of equipment and the overall architecture of the vessel.

The level of details in the conceptual phase is also important to keep at a minimum, even if the temptation can be higher on adding details to the design. The success rate of delivered designs could be a lot higher, so to reduce the hours spent on the designs in general should be minimized. One concern is to drown in the huge amount of data introduced with 3D, to be able to filter out non-relevant information. Some clarification on general revision rules and naming rules also needs to be determined in advance to act like one company seen from the outside, and for designers to re-use and contribute in each other's designs. When working in the same master model, the revisions should be clear and the designer should wait to get the results from the other disciplines calculations before tweaking and polishing the GA in between revisions.

The technology has advanced a lot over the years regarding calculation time and performance. We are now used to the speed of software's without having to wait for anything. With this amount of added complexity, we are now back is a situation like a few decades ago were the computations is the bottleneck. One challenge experienced during the 3D course, was the waiting time when going from one part to the next in the product three. This makes the time to do quick fixes here and there not so quick anymore.

The naval architects at UDS see a room for better communication with customers, who in some cases have trouble reading technical 2D drawings for clarifications of solutions. This forces the designs to be done in 3D to ensure clear communication with the customer. In the challenging market situation UDS needs to keep up with the technology and deliver what the customer wants and match what the competitors deliver at the same time.

Hydrodynamicists

For the hydrodynamic department, the new collaborative environment comes with the option for parametrized hull shaping and opportunity for scaling and adding appendages to the hull. With UDS hulls defined, the hull portfolio can be managed in a good way. Also, to use only one software is seen as beneficial for the hull design process. The revision control is also a good feature in TC.

Machinery and electrical department

Machinery and electrical department will have a more active role in the vessel design process with Team Center. This brings some concern when it comes to learning the new software and to encroach in the collaborative master model. The filtering of components and the updated

available main components is seen as a huge benefit with regards to the process of browsing for the right parts.

Weight engineer

The weight engineers are excited about the 3D model to get better control of what is actual inside the vessel and where. With the extra attributes of the components already in the library, less estimations needs to be done for the vessels, reducing the overall risk of the weight estimation. To be able to "walk through" the vessel will help keeping a holistic mindset and the risks of excluding components is reduced. The fact that everyone is working on the updated master model eliminates the chances of looking at the wrong drawing or vessel specification.

Stability department

Stability department will have the 3D model with bulkheads already defined in the NX approach. Today the time to define each bulkhead and tanks in NAPA can take up to a couple of days, so to get this definition finished and updated is seen as very positive if the export is considered trustworthy between the software. Stability will continue to use their calculation software. One concern is the possibility of adding more work to their already piled up workload, by having to also define critical bulkheads in the model before the naval architects can define the conceptual layout.

Supply Chain Management

Supply Chain Management will have a reduced workload regarding to keep control of what the designer actually ads to the vessel. With more time to negotiate deals and explore new products, innovation can be a consequence of this implementation.

Sales

The sales representative see the 3D model as a huge benefit when talking to the customer. With a model accessible from mobile device the process of convincing the customer can be easier. Also, to know what is in the vessel and how much it costs is a huge benefit in the negotiations. To be confident that the product presented is coherent with regards to the what the model is containing and the building specification, and also the margins.

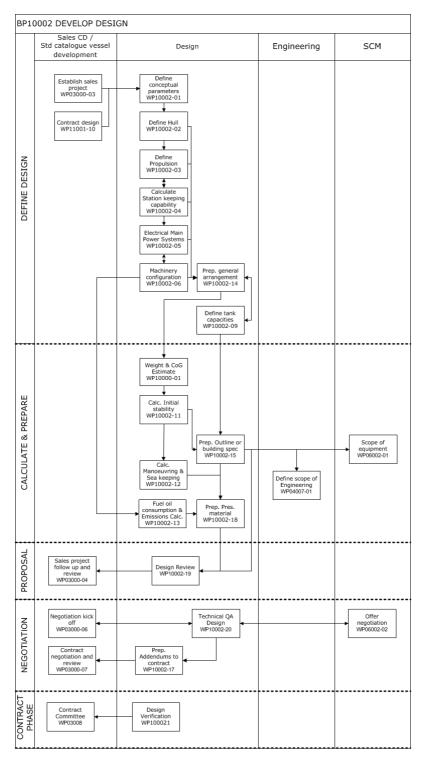
Director of Design/Engineering

The Director of Design/Engineering is confident that UDS has to take the leap into 3D and PLM to survive in the market. Statements as "can we afford not to do this"...

Appendix 4: System performance evaluation for simple case study

Criteria	Mandatory Y=1, N=0	Weight	SCORE	2D	3D
Quality	1	10 %	1 = Lowest	2	3
Reliability	1	5 %	1 = Lowest	2	3
Compatibility	1	5 %	1 = Lowest	1	2
Adaptability	1	10 %	1 = Lowest	2	2
Flexibility	1	5%	1 = Lowest	3	1
Reusability	1	20 %	1 = Lowest	2	2
Usability	1	10 %	1 = Lowest	2	1
Efficiency	1	10 %	1 = Lowest	3	1
Accessibility	0	5%	1 = Lowest	2	2
Maintainability	1	10 %	1 = Lowest	2	1
Traceability	1	10 %	1 = Lowest	2	3
Weighted total in %		100 %	3	70 %	63 %

Appendix 5: Conceptual design process



Appendix 6: Generalized perceptions of PLM in conceptual phase

Naval Architect

The use of 3D is necessary to keep up with the competitors, but the added workload is a concern. The need of dedicated CAD engineers to maintain the library and deliver new specialized parts for the projects should be considered. The naval architects are positive to get better utilizations of the vessel, by having a better control of the volumes and areas in the vessel. Currently a lot of time is spent looking for components with the right technical specifications in the UDS folders. If new components are needed we must request it from the sub-supplier, and this can take time. With 3D modelling it will be more time consuming to come up with indications on the drawing of the component, so here we see a need for dedicated CAD engineers maintaining the library and adding new parts. To be able to re-use vessels and components it must be defined in the same way to be able to continue on other projects without getting lost in the constraints, expressions and references.

The naval architects are positive on having a shared library for the entire group in the future. Now discussions and misunderstanding occur on why specific equipment is chosen between design and engineering department. With the fact that the departments have different focus, there will always be re-work and disagreements with the solutions and arrangement.

The impression on the 3D course is that the software is "too good", meaning too complex for the job. The final delivery to the customer is the GA, not the 3D model. "When I tried to load a simple model, my computer needed 20 minutes to simply open it!". Also, when the model is saved, the time is also too high. This is not acceptable for the design department, since it will cause frustration. Also, experience in the running pilot project shows that too much time is spent waiting for the model to load when switching the active work part. This must be done in the right level on the vessel hierarchy to get the references right. The workflows introduced with Team Center will help manage the projects, by having the ability to request information in the workflow and set a deadline for it. The platform will have a link to all the documents generated in the project, so it can be easier to have a general control of the project.

Machinery and electrical department

Machinery and electrical department have concerns on the level of freedom to design the vessels and to work as they like in the growing demand to documentation about what they are doing and how. As the projects can be changed dramatically between revisions, the amount of work to keep all the required documentation updated is unnecessary. Now, the electrical load calculation, fuel oil consumption, emission calculation and sewage calculation is performed quite late in the project, when much of the details is determined. Generally, with stricter processes and more documentation wanted, the delivery pace is reduced.

A different aspect of the PLM concept is the storage of documents, which can be a positive thing since documentation needs to be uploaded. The possibility that attributes can be searched is positive for us to find references more easily and re-use more. For instance, when employs work from home office, they sometimes work locally on their computers rather than to connect to VPN, and when they are re-connected they must remember to upload the documentation.

Weight engineer

The weight engineer will experience only positive effects from the new approach, with weight information included in the model, with center of gravity for single component and always an updated master model. With less parts to estimate, the added margins currently used can be reduced with time. It is also good for us to walk through the model to check if everything is included and estimated. Now a lot of time is spent studying the GA and building spec for specific equipment, and to find the specifications for this. When this is found, it is manually added to the weight estimating software. Areas and volumes are now manually measured from the GA and multiplied with a weight factor for the given space. Currently the stability team can take out the volume of the defined location. The problem of looking at the wrong version of the GA is eliminated.

Stability department

Stability department will have a reduced workload since they can import hull and divisions directly from the 3D master model. The rest of the work of defining the tank properties and the stability calculations will remain the same, but the most time-consuming part of their work (create NAPA model) will be reduced. Also, we see benefits from a more accurate weight estimate.

Hydrodynamic department

The hydrodynamicists is positive to the new drawing software because of the parametric modelling. With a deliberate portfolio development, the UDS hulls will have a uniform look and with good possibilities to adapt the hull quickly for new projects. Currently hull fairing is done by an external company (expensive) and this is expected to avoid with NX, since the model is smoot enough. The fact that the work is done when the hull is created and approved, and not to manually export hull lines and hydrostatics to stability department.

Sales department

Sales department is positive to reduced margins in the project can drive the price of vessels down, being able to offer vessels to a lower price. This can contribute strongly in the decision process for the ship owner. With possibility to show different parts of the vessel and clarify issues with the customer, the communication process can also be easier. In some cases, language barriers and cultural differences can prohibit the

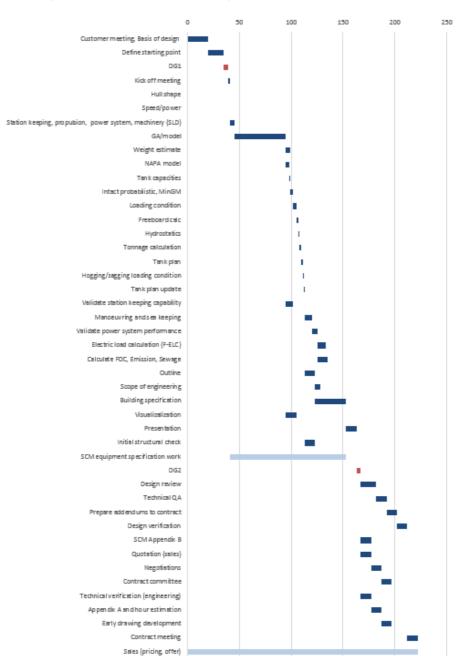
Supply Chain Management

Supply Chain Management has a huge workload currently of collecting specifications for the components added in the vessel. The design is also normally changing a lot during the projects, so to have the right components in the specification is a great challenge. This work cannot begin too early in the project, but the time to compile this document is long and cumbersome.

Director Design & Engineering

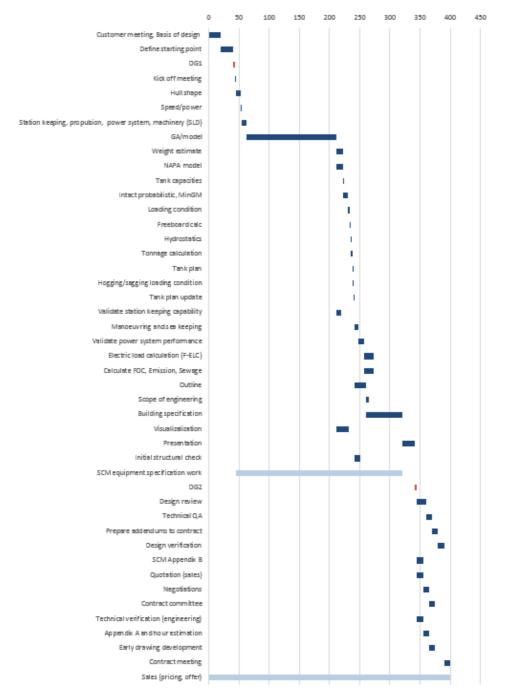
The overall cost of the design and engineering department must be reduced to survive in the market and deliver vessel designs for a good price. The load on the design department will be higher, but the synergies from the 3D model is expected to make up for this loss.

Appendix 7: Timeline for one revision of "typical" design processes

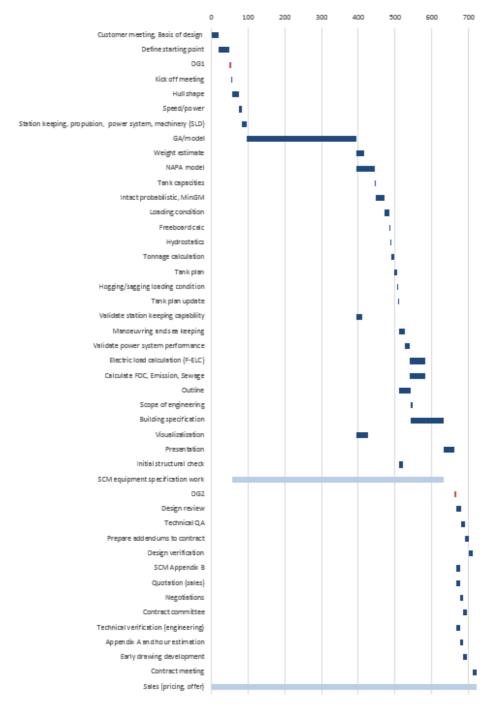


#1 SMALL CHANGES OF COMPONENTS, NOT HULL (MODIFICATION/REVISION)





#3 NEW/PROTOTYPE



Appendix 8: System performance evaluation

Criteria	Mandatory Y=1, N=0	Weight	SCORE	2D	3D
Quality	1	10 %	3 = Best 1 = Lowest	2	3
Reliability	1	5 %	3 = Best 1 = Lowest	2	3
Compatibility	1	5 %	3 = Best 1 = Lowest	1	3
Adaptability	1	10 %	3 = Best 1 = Lowest	2	3
Flexibility	1	5 %	3 = Best 1 = Lowest	3	2
Reusability	1	20 %	3 = Best 1 = Lowest	2	2
Usability	1	10 %	3 = Best 1 = Lowest	3	1
Efficiency	1	10 %	3 = Best 1 = Lowest	3	1
Accessibility	0	5 %	3 = Best 1 = Lowest	2	2
Maintainability	1	10 %	3 = Best 1 = Lowest	2	1
Traceability	1	10 %	3 = Best 1 = Lowest	2	3
Weighted total in %		100 %	3	73 %	70 %

Appendix 9: Pro/Cons with PLM

Pros	Cons
Easier to search for components	More time consuming
Filtering options to the library	More complex modelling
Can continue conceptual model in engineering	More advanced user interface
Parametric hull modification	Need to build up a new library Of components
Shorter time to design the hull	Need to build up a new library Of references vessels
Parametric items	Computer capacity
Less software needed	Need rules for naming, modelling Order, constraints naming
Stability model import	Approval
Weight information export	Cognitive attention, overall Architecture/details
Coherent information	
Project management	
Better control of product	
BOM	
Online	
Collaborative	
Roles	
Release statuses	
Templates, re-use	
Quick to make alterations to the model	
Better volume utilization	
Shorter time from design to build	
Better communication between	
Concept and engineering	
3D model to navigate in	
Re-use	
Visualization	
Change management	
Requirements capture	
Approval	
Less estimation	

A System Engineering Approach to evaluate PLM during Upstream Ship Design Processes

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Abstract. The objective of this paper is to evaluate PLM during Upstream Ship Design Process. PLM is short for Product Lifecycle Management, and is a process to manage system related information throughout the lifecycle of projects. Systems engineering methods are applied to collect information about the current practice in the conceptual design phase. Evaluation shows many theoretical benefits with PLM and 3D modelling, but still some work need to be performed to configure the software in a good way for the current workforce and design processes.

Keywords - Product Lifecycle Management, Upstream Ship Design, conceptual phase, Systems Engineering, 5aspect taxonomy.

I. INTRODUCTION

PLM is short for Product Lifecycle Management, which is a tool to manage product related information throughout the lifecycle of components and systems. PLM is mostly used in production companies, who mass produces items. Ship design is often customized design of one-of-a-kind vessels designed for specific operations and for specific customers. Currently PLM processes are being implemented at Ulstein Design & Solutions, here after referred to as UDS, in the conceptual design in a pilot project. An issue with this implementation is the stakeholder's opinions and mistrust to the PLM processes. The stakeholder's opinions is important for making the processes work and implementing it to their daily work. Ship design is complex and iterative, so the working method needs to be flexible and efficient for it to work. According to Terje Vaage, Naval Architect at UDS "no ship design process is executed the same way so to make generalized processes which will be applied for all projects is very challenging"

Many experts are working together in UDS towards a mutual goal of designing the best possible vessel for the customer, so everyone needs to cooperate to meet these expectations and requirements. By forcing everyone to work with the same PLM processes in the conceptual phase, and for the engineers in the detailed design phase to continue this work can lead to problems. Different stakeholders in different phases has different area of focus when planning and engineering Henrique M. Gaspar Norwegian Univ. of Science and Tech., NTNU Faculty of Maritime Technology and Operations henrique.gaspar@ntnu.no

the vessel, which can lead to conflicts of interest.

Figure 1 illustrates the challenge of incorporating all the different components with separate properties regarding life cycle and system interfaces into the vessel. The main components of vessel are in most cases very big and the systems connected complex. The vessel needs to house these components and support all their sub systems, for both ship systems and payload systems. This leads to a huge amount of piping and space allocation in general on the vessel. The hull of the vessel is also limiting the space available; restrictions regarding main dimensions, stability issues and performances is controlling the hull shape.

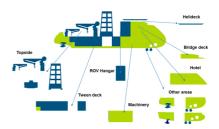


Figure 1. Illustration of Complexity, (T. Ulstein & Brett, 2015)

To evaluate the PLM process for UDS, Systems Engineering methodology is applied to collect information about the current ship design process, documentation, stakeholders and circumstances around the ship design process. Both qualitative and quantitative methods is applied to compare and evaluate the current state of the art with the assumed situation were PLM and the 3D modeling tool is implemented.

The motivation of this paper is to get a better understanding of PLM in general and a deeper knowledge about each step of the conceptual design process. With a better understanding of the situation, the paper may contribute in the process of implementing PLM in the company. Since they have open questions when implementing it, the process needs to be looked at from different stakeholder's point of view and from different perspectives.

The scope of the paper is shown in Figure 2 as the intersection between these subjects. Systems Engineering is logical and holistic approach to state what the problem is, and to investigate the circumstances around. Evaluation methods will be investigated and applied to the PLM process. Through this investigation and evaluations the goal is to collect enough information to do a proper evaluation of the current state of the art, and the PLM process. Product Lifecycle Management is a process to manage system related information throughout the lifecycle of projects. In the conceptual ship design the overall architecture of the vessel and main systems is designed. Contract is signed based on the decisions made in this phase, so the technical feasibility of the design should be well examined before offering the design for the customer.



Figure 2. Scope is the intersection between the three subjects

The main research question is - How can System Engineering methods be applied to evaluate the PLM process during upstream ship design processes?

The paper is structured in the chapters: Systems Engineering (II), PLM (III), Upstream Ship Design (IV), PLM during upstream ship design (V) Methodology (VI), Analysis of PLM during upstream ship design (VII) and Concluding remarks (VIII).

II. SYSTEMS ENGINEERING

Systems Engineering Fundamentals

"System Engineering (SE) is the bridge between the identification of needs or market opportunities and the acquisition of systems that fulfill them effectively and efficiently. SE is the glue that binds the pieces together in a project, by combining and integrating different pieces into a full system. The holistic view is a key concept in Systems Engineering and makes the approach applicable in complex systems with interdisciplinary properties. SE is both handling the complexity of products/processes and the lifecycle of the object by investigating inside the different phases and balancing between different criteria in a logical and organized manner. There are many definitions of systems engineering although all have in common the transformation of the analysis of a need or opportunity into requirements, the holistic view, the consideration of the entire life cycle and the need for the system to effectively and efficiently fulfill its goals throughout the complete life cycle", (Sols, 2016).

Systems Engineering is a method for balancing the contributions from the different disciplines into a holistic, safe and balanced product. By seeing the whole picture, the systems engineer is *not only ensuring that they get the design right (meet requirements) but that they get the right design.* The Systems Engineer is skilled in the art and science of balancing organizational and technical interactions in complex systems", (NASA, 2010).

5-aspect taxonomy

In (Rhodes & Ross, 2010) the five aspect taxonomy is introduced as an approach to investigate a system from different perspectives. Figure 3 shows these taxonomies with a short explanation.

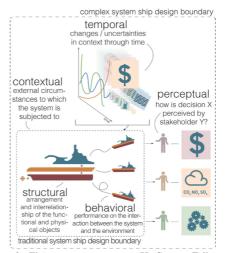


Figure 3. Five aspects taxonomy, (H. Gaspar, Erikstad, & Ross, 2012)

The current model-based systems engineering (MBSE) approach only includes the two first taxonomies - the *Structural* and the *Behavioural* taxonomy of the system, but Ross and Rhodes added three new taxonomies: *contextual, temporal and perceptual* taxonomy. The two authors does not take credit for inventing these aspects, but only "to give them adequate focus to their importance in engineering of value robust systems, which delivers value to the stakeholder of the entire lifespan of the system", (Rhodes & Ross, 2010). These new aspects come with more advanced analyses and modelling possibilities, like Epoch Modelling, Multi-Epoch Analysis, Epoch-Era Analysis, Multi-Stakeholder Negotiations, and Visualization of Complex Data Sets.

Evaluation

Decision analysis, decision matrix and risk matrix is evaluation methods described in (NASA, 2010). Decision analysis is a process to determine what to evaluate and how to do it. Decision matrix is a tool to compare both quantitative and qualitative measures. Weighting is set with reference to the subjects considered most important. Each alternative is assigned with a score for each subject. Risk matrix is also a visual display for risks, where the probability and consequence is put.

III. PRODUCT LIFECYCLE MANAGEMENT

Theory

Product Lifecycle Management is the foundation for managing product related information for components throughout their lifecycle. Product Data Management (PDM) was the precursor to PLM. "PDM emerged in the late 1980s as engineers in the manufacturing industries recognized a need to keep track of the growing volumes of design files generated by CAD (Computer Aided Design) systems", (Saaksvuori, 2008). With many drawings with multiple revisions, the number of files to keep track of increased rapidly. PLM does not only consists of management of documents and Bill of Material, but also of many other aspects, shown in Figure 4. This management continues for the whole lifecycle of the product, from an idea and until retirement and disposal.



Figure 4. PLM elements, (Andrade, Monteiro, & Gaspar, 2016)

"The benefits of operational PLM go far beyond incremental savings, yielding greater bottom line savings and top-line revenue growth not only by implementing tools and technologies, but also by making necessary, and often tough, changes in processes, practices and methods and gaining control over product lifecycles and lifecycle processes", (Saaksvuori, 2008).

Siemens NX PLM

Siemens NX PLM is a cloud based system (Team Center) for creating 3D models and manage documentation. NX handles parametrized modeling, which makes it appropriate to handle large changes in the model. Collaboration with other designers is possible within one master model. Different roles can be assigned, to make sure non authorized personnel make unplanned changes to the model, and to make sure only relevant information is displayed for the different roles.

IV. UPSTREAM SHIP DESIGN

Upstream Ship Design is described as all the phases from conceptualization and until the ship ready for delivery, shown in Figure 5. Downstream activities are defined as the activities after the vessel is delivered, like guaranties insurance, operation and maintenance, commercial operation, and demolishing and recirculation.



"Too little time and effort is spent concerning the processes of clarifying the overall new building project and the interphases between the stakeholders, reporting processes, and clarifying the job definition. Critical thinking concerning the requirements from the ship owner is crucial for capturing what is important for the given ship and the different stakeholders", (T. Ulstein & Brett, 2012). "When the context and boundary conditions of the problem is settled, the more detailed design phase can begin, elaborating the sub-systems and design choices. With a Parametric Design Tool (PDT) different alternatives can be judged based on an available historical database of main particulars, and compared with different parameters, for example through different filtering options and regression analyses of a historical database of ships", (Brett et al., 2006).

"With severe market fluctuations, the companies need to be entrepreneurial, agile and adaptable to the situation in order to survive. With deliberate strategic and slow changes, the companies can grow and survive in the challenging market. Profitable growth creates predictability, longevity and sufficient volume of business to facilitate continual productivity gains to retain necessary competitive power to survive and thrive", (T. Ulstein & Brett, 2009).

Ability to see what's next in the market is a key in this. The foresight process aims to "identify emerging technologies and be ahead of the situation by having a strategic management. Foresight is about communication within and outside firms, about coordinating research and development initiatives, about creating a consensus of future directions and priorities", (T. Ulstein & Brett, 2009). "The most powerful fuel to secure long-term growth and brand development is the culture for innovation in the company. In Norway where the cost-level of operations are high, the business needs to be focused on activities which can sustain a high cost level. With these opportunities fully explored and capitalized on few alternatives the situation will be in dire straits", (T. Ulstein & Brett, 2012).

V. PLM DURING UPSTREAM SHIP DESIGN

Ships and Space vehicles have in common a high level of complexity in a limited physical shell, making the theories and methods used in aviation industry applicable for ships also. The PLM approach is described as a good best practice principal at NASA, under the name Data Management, to control documentation for the whole lifecycle of components. If the methodology is applicable for NASA, it also should be for ships. The software Siemens NX has integrated 3D modelling tool and PLM tools.

VI. METHODOLOGY

System and assumptions

The system to be evaluated is the PLM process only in the conceptual phase at UDS. The conceptual phase is from a customer expresses a demand and requirements of the vessel, until the design is conceptualized and the contract is signed. The current working method is a result of 100 years of ship building experience in Ulstein.

Assumptions are: it is possible to create parametric components in a manageable file size, time assumptions, that the number of emplys currently is well balanced between departments, some steriotypes are assumed, that the employs and their work processes is rather fixed, so the new system must be adapted to it.

Evaluation method

Before evaluating a process, the objective and purpose for the process need to be known. Figure 6 gives an illustration of the methodology which is applied for this paper to evaluate the PLM process in UDS. When the input, output and of the process is understood, more information about the taxonomies for the process is investigated. Based on the findings of applying the taxonomies, the system performance parameters or system properties can be settled. The fourth step in the methodology is to make a few change cases, (H. M. Gaspar, 2015). Last step is to evaluate the system properties for the different change cases.

The next sub chapters will describe more in detail each of these steps in the evaluation work (Step 1-5).

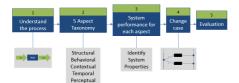


Figure 6. Methodology applied to solve the thesis, Step 1-5

1) Understand the process. In this part, the background and objective of the processes is investigated. By understanding what the input and output from the process is, a deeper understanding of the process itself needs to be gained through the next steps. To get a grasp of the processes itself, internal quality- and process documents is found and familiarized with.

2) 5-aspect taxonomy. To dig deeper in the PLM process, the 5 aspect taxonomy is applied. The five taxonomies are: Structural-, Behavioral-, Contextual-, Temporal-, and Perceptual Taxonomy.

Through this research more information about the processes, documentation, stakeholders, context and timelines is found.

3) System Performance Measures. Quantitative and qualitative performance measures is determined here based on what type of information was found with the 5-aspect taxonomy.

4) Change cases. Change cases, or change enabled paths (H. M. Gaspar, 2015), is created to investigate and display differences in process activities and system performance measures.

5) Evaluation. The evaluation of the PLM process is done by comparing the system performance measures for the different change cases. Risk matrix and decision matrix is created to display differences.

VII. ANALYSIS OF PLM DURING UPSTREAM SHIP DESIGN PROCESS

1) Understand the process

The background for wanting the PLM processes implemented in the conceptual ship design process is to keep better control of the documentation and solution documentation gained and created in the projects. The knowledge about why different solutions were chosen, how projects evolved, what has been done previously, and good reference projects are mostly in designer's head. With better control of the documentation the goal is to be able to re-use parts and arrangements and find documentation more easily.

"The objective with the 3D implementation in the conceptual phase is to reduce the total amount of hours per. project across the design and engineering phase to reduce the overall costs in UDS. Other expected results are better quality in the design phase and lower technical risks in projects. A better collaboration between design and engineering department is also considered very positive by working on a uniform platform and having the possibility to re-use vessels and components both ways instead of re-modelling between the phases. Improved product presentation to the customer is also part of the objective of the 3D implementation" according to the internal pre-study (Sollid, 2016).

2) 5-aspect taxonomy

Structural taxonomy is applied to get a better insight to the design process. Figure 7 is created with the basis of the current process, but a more detailed breakdown is added in some areas based on observations in the design department and interviews about the actual documents created and the required input to the work.

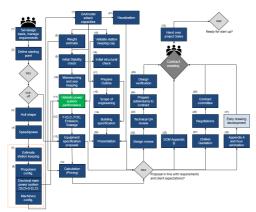


Figure 7. Conceptual design phase

Through the work in the process of mapping all the steps in the design process and the sequence, different documents and reports was discovered. Table 1 sums up the documentation created in the conceptual design process with the responsible for the document. The documents below horizontal line represents work done late in the process, when most of the decisions are made.

Three different scenarios are natural for UDS - *portfolio modification, standard design and new designs.* Through the process of investigating the process, the stakeholders was asked how much time they would "normally" use for a Platform Supply Vessel with top priority. These numbers are average numbers based on experience in the design department and is intended to show recursive dependencies in the calculations inside the project. This simple display does not express that multiple projects are running simultaneously with different priorities, but this is a single project with top priority.



Figure 8. Timeline for standard project in 2D

Figure 8 shows a simplified version of a relatively sim-

Table 1

List of documentation and document owner

ιoj	j aocumentation and aocument owner				
	Document owner	Documentation			
_	Naval Architect	Basis of Design			
	Hydro	Hull lines			
	Hydro	Hydrostatics			
	Hydro	Speed and Power prediction			
	Electrical (Hydro, machine)	Thruster and power system (SLD)			
	Naval Architect	GA			
	Naval Architect	Short specification/outline			
	Weight engineer	Weight estimate			
	Weight engineer	Weight distribution curve			
	Stability	NAPA model			
	Stability	Intact stability			
	Stability	Loading conditions			
	Stability	Tonnage calculation			
	Stability	Tank Plan			
	Stability	Hogging/sagging condition			
	Structure	Initial structural check			
	Hydro	Station keeping capability			
	Hydro	Motions and sea keeping			
	Naval architect	Equipment number calculation			
_	Electrical (machine)	Electric Load Calculation			
	Machine	Fuel Oil Consumption			
	Machine	Endurance Calculation			
	Machine	Sewage Calculation			
	Machine	Emission Calculation			
	Naval Architect	Building specification			
	Naval Architect	Design philosophy			
	Electrical	Electrical System Philosophy			
	SCM	Equipment specification			
	SCM	Makers list			
	3D modelling specialist	Illustration			
	Naval Architect + team	Presentation			
	Sales	Offer			

ple design were an almost identical reference vessel exists. The longest duration here is the GA drawing process, but this activity must be done before the rest of the sequence is initiated.

Second timeline (Figure 9) shows an imaginary case were a good reference vessel exists, but the ship needs increased beam or length. This change results in added time for each sub-step until the final design is ready to be displayed. With higher uncertainties, more iterations are needed to hit the target.

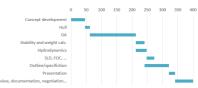


Figure 9. Timeline for hull modification project in 2D

The last time line investigated (Figure 10) is a new design with new technology and a different hull. With less experience and reference vessels, the overall time is minimum four times longer. This last ship has the highest uncertainties when it comes to time estimation and project planning. For very special requests from demanding customers, the schedule of the project can be impossible to predict. For this type of projects the requirements can change from one revision to the next, based on the results calculated and the customer seeing a different potential in the vessel. "Requirementscreep is describing the subtle way requirements that requirements grow impreceptibly during the course of a project", (NASA, 2010).

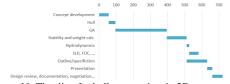


Figure 10. Timeline for hull new project in 2D

Generalized perceptions of the PLM concept in the conceptual phase is shown in Figure 11 as the essence from interviews.



Figure 11. Stakeholder perception to the PLM concept in conceptual design phase

3) System performance measures

Based on the temporal taxonomy the current time to come up with the first revision is found to be approximately between 220 - 720 hours effective work. The longest single activity is the part of creating the GA, and most of the other actions is dependent on this step. With the new approach this time is expected to be even longer, but hull modelling, stability mode, illustration and weight extraction are expected to be shorter.

The main impacts affecting the hour consumption in the projects is rated the risk matrix shown in Figure 12. The most significant risks regarding time in the drawing process is the vessel type and experience/reference projects. Design software and equipment library is considered less important regarding the overall time to deliver the conceptual drawing by designers. The time is also dependent on the size of the vessel; for larger vessels, more equipment is added.

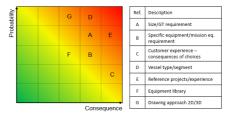


Figure 12. Risk assessment of hour consumption

The cost of the new approach is investigated in a Net Present Value calculation performed internally at UDS, (B. A. Ulstein, 2016), shown in Figure 13. The three colors represent respectively Net cash flow (high), Net cash flow (low) and cash out. The high and low values comes from a estimate of the overall savings in UDS, where the business is split in three project types; prototype (advanced), medium complexity and basic w/integration. The As-is condition is the average consumed hours for these three project types. Together with the teams the assumed savings in hours per project is estimated. For the conceptual phase the hour consumption is estimated to increase by 14 - 61% across the three project types. Basic design (engineering) is assumed to save between 19 - 33%.

Project load at UDS is further assessed in this model, to come up with an estimate of the situation. Amount of projects which is worked on a bit and "all-in" projects are separated here. The idea with the model is that the fruits from the implementation is not present the first few years due to all the work om implementing the new approach, but after a some years the situation will be great according to the model. Project load is further used in the NPV calculation to asses the situation of "do nothing", "optimistic estimation" and "pessimistic estimation".



Figure 13. Net Present Value of 3D and PLM investment, (B. A. Ulstein, 2016)

The NPV model was created a year ago, so the time frame in the figure is not valid currently due to some delays in the process, but the situation is still expected to follow this trend so the numbers are used as a reference in the following paragraphs. 2016 has a high cash out value (Figure 13) since the money is invested in the software. The start-up cost of buying the software and adapting it to the designers need at UDS is high, but the largest fraction is own hours in training, decision making, and process mapping internally at UDS. The second year cash out is assumed to be the cost of maintaining the software and for technical support. Now the net cash flow is positive already, for both cases. 2018 has a big Cash out value, representing the implementation of NX in engineering also. Although the this cost is high, the NPV value for the optimistic case is positive. In 2019 the fruits from the implementation really will show, since the biggest savings is assumed to be in the engineering process.

4) Change cases

Change case #1 is created to estimate the difference in time to create the first revision of the project. The temporal taxonomy for the second case (Figure 9) is used as a basis. The assumptions here is a reduction in the time to make the hull (from current status), a 30% addition in time to create the GA, that stability can import the master model without major challenges, and rendering is done more rapid.

Second change case is the process to take out information for the weight estimate. Currently the volumes in the hull is taken out by stability personnel, and areas is measured directly on the GA. Information about components is found in the building specification of the vessel, reference data and product sheets. Location of the components is found from the GA. With a 3D master model all this information can be found from only one source, saving a lot of time.

Change case #3 is created to capture the process of finding reference projects. Currently the involved must remember or ask for references to know where to brows for information. UDS is not a very large organization, so this is not currently seen as a big challenge since the naval architects and other personnel is very experienced and it is easy to ask each other. In NX the main attributes can be searched for, so the time here is assumed shorter.

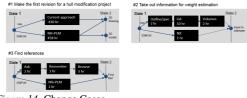


Figure 14. Change Cases

5) Evaluation

Time. Prerequisite for the investigation is an increase in time to draw the vessel by 30%, when going from 2D to 3D.

Table 2 shows the time increase in percentage for the three project types. These numbers are based on the results from the temporal taxonomy, with an increase in design time and reduced time for stability, weight, rendering.

Table 2

D	۱ţ	erence	per.	design	type
---	----	--------	------	--------	------

Design type	δ
Small change	6%
Hull change	9%
New design	7%

Currently observations show a lot longer design time than 30% increase. Hull modelling has proven to be shorter than the old approach already, and still the hydrodynamicists have suggestions for further improvements. Zone definition seems to be the most complex setup currently, where parametric modelling with links is created. According to Greta Levisauskaite "the process of defining all the datum planes and linking them was a lot bigger than expected in NX". In 2D the lines can be moved more freely without any constraints and cumbersome definitions.

Re-use. With easier access to the database of equipment and to reference vessels, more re-use can come simply from finding information easier. The cloud based interface makes the information available from anywhere. To enhance the reuse of components, the library should ideally contain both reusable components, assemblies and vessels.

Re-use between concept design and engineering will face challenges in the level of details for the two different phases. More complex geometries are larger when it comes to file size, making the conceptual models larger and cumbersome to work in. Objective of the conceptual design is to allocate the space and design the architecture, not design all the interfaces perfectly.

Information management. In the PLM system, both documents and vessel models should be managed in the system. The largest difference is here the number of sources to find information from. With more focus on requirement capture and better control of both technical aspects and price of the vessel, it is more likely to design exactly what the customer wants. With a more uniform understanding of what the customer wants, the different disciplines can easier pull the project in the right direction.

Document can still be created the "old" way, and automatically uploaded to the PLM system. Through the software, the naval architect can request information with a deadline. Better control of the projects will help run the projects efficiently.

Bottlenecks. The longest duration in the temporal taxonomy is planning and modelling the vessel, so this can be seen as a bottleneck. With PLM and NX this bottleneck will become even larger, so actions must be taken to prevent this. Dedicated CAD engineers could be a solution to this issue.

Criteria	Mandatory Y=1, N=0	Weight	SCORE	2D	3D
Quality	1	10 %	3 = Best 1 = Lowest	2	3
Reliability	1	5 %	3 = Best 1 = Lowest	2	3
Compatibility	1	5 %	3 = Best 1 = Lowest	1	3
Adaptability	1	10 %	3 = Best 1 = Lowest	2	3
Flexibility	1	5 %	3 = Best 1 = Lowest	3	2
Reusability	1	20 %	3 = Best 1 = Lowest	2	2
Usability	1	10 %	3 = Best 1 = Lowest	3	1
Efficiency	1	10 %	3 = Best 1 = Lowest	3	1
Accessibility	0	5 %	3 = Best 1 = Lowest	2	2
Maintainability	1	10 %	3 = Best 1 = Lowest	2	1
Traceability	1	10 %	3 = Best 1 = Lowest	2	3
Weighted total in %		100 %	3	73 %	70 %

Figure 15. Decision matrix

Pros	Cons
Easier to search for components	More time consuming
Filtering options to the library	More complex modelling
Can continue conceptual model in engineering	More advanced user interface
Parametric hull modification	Need to build up a new library Of components
Shorter time to design the hull	Need to build up a new library Of references vessels
Parametric items	Computer capacity
Less software needed	Need rules for naming, modelling Order, constraints naming
Stability model import	Approval
Weight information export	Cognitive attention, overall Architecture/details
Coherent information	
Project management	
Better control of product	
BOM	
Online	
Collaborative	
Roles	
Release statuses Templates, re-use	
Quick to make alterations to the model	
Better volume utilization	
Shorter time from design to build	
Better communication between Concept and engineering	
3D model to navigate in	
Re-use	
Visualization	
Change management	
Requirements capture	
Approval	
Less estimation	

Figure 16. Pros/cons

Also, the component library and maintenance of this will be a large job, and a bottleneck to have the right equipment for new vessels.

Most of the actions in the upstream ship design is sequential, so the different disciplines need to wait for each other. Multiple projects are running simultaneously, so the work stock are not out of work.

Qalitative evaluation. Results for evaluating the two approaches using a decision matrix (Figure 15) shows a better score of theoretical benefits with PLM and NX implemented. As emphasized these are theoretical benefits, so still work needs to be done to make the software function as well as prerequisite.

Pros and cons with the approaches is also investigated, shown in Figure 16. PLM and NX shows the best theoretical results with a much longer list of benefits.

VIII. CONCLUDING REMARKS

From the research many theoretical benefits with PLM was discovered. Workflow of starting a project in the concep-

tual phase, and to continue in the same model would save a lot of time across design and engineering phase. For Ulstein Group this advantage of being able to deliver the vessel in shorter time should be fully taken advantage of. By being in the situation of having both UDS and a building yard in the same site, Ulstein is in a good situation in the competitive market. To fully maximize the effects of the PLM process, all the parts of the company involved in the upstream design process should be included.

As stated this is in theory, so actions must be made when it comes to the assumed new workload, since the design time is overall increased. Observations of the software shows that it is not ready yet to be the design approach, since the software is too slow currently. When this is resolved, Siemens NX PLM could be the new approach. Experience from others show merely positive outcome after implementation of NX and Team Center.

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