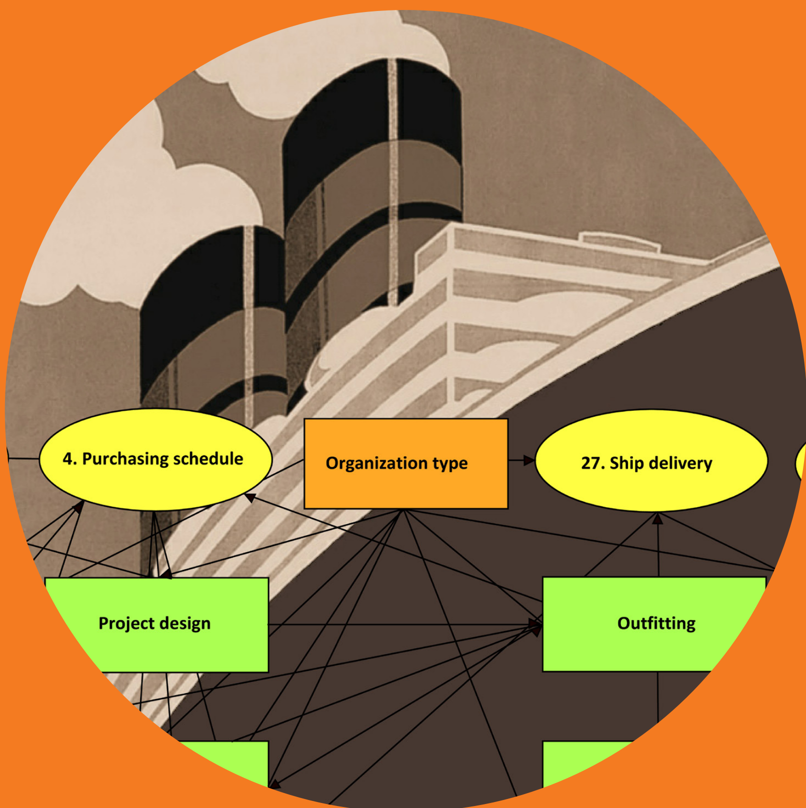
Department of Mechanical Engineering

# The Bayesian Model for Cruise Shipbuilding: a Process for Production Efficiency and Organization

Sisko Hellgren

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# The Bayesian Model for Cruise Shipbuilding: a Process for Production Efficiency and Organization

**Sisko Hellgren**

A doctoral dissertation completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Engineering, at a public examination held at the lecture hall A1, Otakaari 1, of the school on 15 December 2016 at 12.

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# Abstract

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**Abstract**

Production efficiency is an important part of the cruise shipbuilding process. The technical level of production facilities as well as their tools and practices play an important role in increasing overall efficiency. The studies on the production efficiency of shipbuilding have yielded better working methods, including efficient welding techniques, increased welding automation, and extended use of modularization and block outfitting. Additionally, research into three-dimensional design systems and other integrated information technology tools have allowed cruise ship design to become a fully three-dimensional that should also have a significant positive impact on productivity. While these afore-mentioned findings have had a positive impact on production efficiency, there remains the question of whether it is possible to increase production efficiency further by organizing a shipbuilding project in a specific manner. There is no available research information on how organizing the cruise shipbuilding process can affect production efficiency.
This thesis investigates how certain organization of the shipbuilding process influences production efficiency by creating a model of that shipbuilding process utilizing a Bayesian network. In this model, the variables are determined by factors that impact production efficiency. The causal dependencies between these variables create the network. Three different organizational configurations are included: Line Organization, Project Organization and Hybrid Organization. All model probabilities for achieving a specific targeted production efficiency are elicited from experts. Based on these results, project organization has the highest probability of achieving the desired efficiency, mainly because in project organization, clear responsibilities will lead to target-oriented problem solving and decision-making. This model demonstrates that organization type does indeed impact production efficiency. The model validation is done using a framework that includes face validity, content validity and concurrent validity. Also, an assessment of sensitivity, uncertainties and bias is undertaken. The model with elicitations helps in understanding how the process works in this particular case and circumstances. It also makes it possible to investigate optimal procedures for the future. Further, the results of this study can be used in shipyards to target and deliver better production efficiency because the main phases of the process are at high level similar to those undertaken in shipyards.

**Keywords** organization, cruise ship, production efficiency, shipbuilding

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# Tiivistelmä

**Tekijä**
Sisko Hellgren

**Väitöskirjan nimi**
Bayes-malli risteilylaivan rakentamisesta tuotantotehokkuuden ja organisaation näkökulmasta

**Julkaisija** Insinööritieteiden korkeakoulu

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**Tiivistelmä**

Tuotantotehokkuus on tärkeää risteilylaivan rakentamisprosessissa. Tuotantolaitosten ja –laitteiden teknisellä tasolla sekä työkaluilla ja menetelmillä on merkittävä rooli kokonaistehokkuuden parantamisessa. Laivanrakennuksen tuotantotehokkuuden tutkimus on edesauttanut parempia menetelmiä, kuten tehokasta hitsaustekniikkaa, lisääntynyttä hitsausautomaatiota sekä laajentunutta moduloinnin ja lohkovarustelun käyttöä. Lisäksi, 3D-suunnittelujärjestelmien ja muiden integroitujen IT-työkalujen kehitys on mahdollistanut kolmiulotteisen suunnittelun, jolla niin ikään pitäisi olla merkittävä positiivinen vaikutus tuottavuuteen. Edellä mainittujen, tuotantotehokkuuteen positiivisesti vaikuttaneiden asioiden lisäksi, on vielä avoinna kysymys, onko mahdollista lisätä tuotantotehokkuutta organisoimalla lavanrakennusprojekti tietyllä tavalla. Risteilylaivan rakentamisprosessin organisoinnin vaikutuksesta tuotantotehokkuuteen ei ole käytettävissä tutkittua tietoa. Tämä väitöskirja tutkii, miten laivanrakennusprosessin organisointi vaikuttaa tuotantotehokkuuteen luomalla mallin risteilijän laivanrakennusprosessista käyttäen apuna Bayes -verkkoa. Tämän mallin muuttujat ovat tekijöitä, jotka vaikuttavat tuotantotehokkuuteen. Muuttujien väliset vaikutussuhteet muodostavat verkon. Tutkittavana on kolme erilaista organisointitapaa: Linjaorganisaatio, Projektiorganisaatio ja Hybridi Organisaatio. Kaikki tavoitellun tuotantotehokkuustason saavuttamiseen liittyvät todennäköisyydet arvioidaan asiantuntijoiden toimesta. Näiden tulosten mukaan projektiorganisaatiolla on korkein todennäköisyys saavuttaa haluttu tehokkuustaso pääosin siksi, että projektiorganisaatiossa selkeät vastuut johtavat tavoiteorientoituneeseen ongelmanratkaisuun ja päätöksentekoon. Tämä Bayes-malli osoittaa, että organisaatiotavalla on vaikutusta tuotantotehokkuuteen. Mallin validoinnissa on tarkasteltu mallin yhdennäköisyys muihin vastaaviin malleihin, mallin sisältö ja toiminta. Myös herkkyysanalyysi, näytön vahvuudet ja ennakkokäsitykset on arvioitu.
Elisoitu malli helpottaa ymmärtämään tätä prosessia ja sen toimintaympäristöä. Se myös mahdollistaa tulevaisuuden optimaalisen prosessin tutkimisen. Edelleen tämän tutkimuksen tuloksia voidaan käyttää telakoilla yleisesti paremman tuotantotehokkuuden tavoittelemiseksi, koska prosessin päävaiheet ovat telakoilla yhteneviä.

**Avainsanat** organisaatio, risteilylaiva, tuotantotehokkuus, laivanrakennus

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# Preface

Without question, scientific research helps in developing industrial processes. In the shipbuilding industry, there is not much researched information on the topic of this thesis or on the cruise ship building process control overall. That is why this topic is important to examine.

Shipbuilding, especially the cruise shipbuilding, has been a continuous source of personal inspiration for me during my long career. I have experienced the whole process of cruise ship building process through a variety of tasks in a shipyard and that motivated me to do this research.

This thesis would not have been possible without the support and assistance of several people. As I have mainly been working alone it was vital that there were abutments where I could go when things did not proceed as I had planned. First of all I want to thank Professor Pentti Kujala, my supervisor and supporter, who encouraged me from the very beginning. Similarly I want to express my gratitude to my second advisor, Professor Jani Romanoff for his constructive comments. They helped me see many ideas in a new way. I also want to thank the Aalto University Maritime Risk and Safety research group, especially Dr. Maria Hänninen and M.Sc. Osiris Valdez Banda, both of whom helped me greatly with the Bayesian method when we created the model.

I also want to thank the experts for their contributions and my numerous colleagues in the shipbuilding industry with whom there have been many truly memorable moments. Many challenges have been solved and many fine ships have been constructed and delivered working together. Finally, I want to express my deepest gratitude to my family members, Risto, Juho and Iida, for tolerating and strongly supporting my enthusiasm for shipbuilding.

Further, during the course of this thesis, several cruise ships were built where I had the good fortune to participate in one way or another. All of those projects are unique achievements, and I believe they make this industry not only interesting, but also an inspiring venue. I hope this thesis encourages other students to research this field.

Rusko, Friday, 29 July 2016

Sisko Hellgren

# Contents

# Original features

In the cruise ship industry the ongoing trend seems to be that in the future cruise ships will be built as a co-operative effort with the shipyard and the surrounding network of the numerous suppliers, including authorities. It would be difficult to imagine that any shipyard that builds cruise ships would recruit all needed experts and workshops inside the shipyard. Part of that network comprises of business that are extremely specialized in their fields, and competing with them seems unrealistic. Instead, the role of the shipyard is to be the main contractor of the ship building effort and a coordinating manager of the network during the building of a cruise ship. This means that co-operation between all parties in the network is essential and indeed a key factor in achieving a successful ship delivery. Further, it seems that the competition in the rapidly-moving cruise ship business will also in the future be increasingly tight which means that the costs of the shipyard and its network need to be kept as low as possible and lead times as short as possible. Thus, the targeted productivity is not just a matter of a single shipyard, but also a matter of the entire network. This thesis researches the efficiency of the cruise shipbuilding process production as it relates to organization type using a Bayesian model in these circumstances. The original features of this thesis are the following:

1. **The cruise ship building process** as a whole has not been researched earlier like it has here. Also, the way that production efficiency, which as such has been studied widely, is connected to the phases of the cruise ship building process here is new.
2. **The efficiency of different organization types** has not been studied using the Bayesian model earlier and thus it makes this topic also new. Now, when the comparative model does exist in shipbuilding, it can become useful also for other fabrication industries in the future.

3. **Choice of perspective**: This study has taken into account the combination of a shipyard and its network by modelling the process from the *point of the product*, the cruise ship, and included in the model factors that impact production efficiency no matter whether the activity is done by the shipyard or network member. A shipyard's network can comprise of a considerable amount of outsourced multinational companies to only a handful of specialized local businesses. As such, the network is heterogeneous, but herein it is treated on a general level as a singular unit for the research purposes of this thesis.
4. **The choice and clustering of the main elements**: The factors that form the basis of the model were chosen by reviewing the cruise shipbuilding process phase by phase. On that basis, those factors that could potentially affect production efficiency were chosen for closer review and only the most evident of these were chosen for the model. These factors were clustered according to the main phases of the process.
5. **The developed model**: This kind of quantitative model, which combines the players into a single model of a very complicated system, is new in this connection. This model presents production efficiency factors that are not directly production-related such as production facilities, methods, and tools. By using this model, those factors can be identified more clearly and their impacts can be studied in a new way. This is a new approach of modelling the process.
6. **The results of the model**: Through the choice of essential factors, defining the interdependencies, having a decision formula with three organization type options, and elicitation, the model presents the results. According to that information the Project Organization gives the best probability of achieving targeted production efficiency. Hybrid Organization, or in other words, a matrix organization, is the second best choice, and the third is Line Organization. The possibility to use this model to study other topics has been recognized. Such is effectivity of, e.g., a WBS-based project organization or minimizing lead time or studying whether the model can work the other way round to indicate necessary preconditions for settled targets. Other fabricating industries can also find this model useful.

# Special Terms

**Light weight** measures the actual weight of the ship with no fuel, passengers, cargo, and water

**Gross tonnage** is the volume of all of a ship's enclosed spaces measured to the outside of the hull framing

**Just in time** is a methodology aimed primarily at reducing flow times within production as well as response times from suppliers and to customers

**Built in quality** means that company has quality built in their processes

**5S** is a method for organizing a work space for efficiency and effectiveness (sort, sustain, straighten, standardize, and shine)

**7 wastes** defines roots of all unprofitable activity within organization (overproduction, transport, waiting, movement, over processing of inventory, and defects)

**Kaizen** is continuous improvement

**Lean manufacturing** is a systematic method for the elimination of waste within a manufacturing system

**CoPS** means complex high value products, systems, networks, capital goods, and constructs, in a project-based organization

**SMILE** is Structural Modeling, Inference, and the Learning Engine, software, portable library of C++ classes implementing graphical decision-theoretic methods, such as Bayesian networks, its Windows user interface is GeNIe

**Variable** is a node in Bayesian network directed acyclic graph

**Line organization** mean that line of authority flows from top to bottom

**Project organization** is a structure that facilitates the coordination and implementation of project activities

**Hybrid organization** is a matrix organization structure in which the reporting relationships are set up as a grid, or matrix, rather than in the traditional hierarchy; employees have dual reporting relationships

# Abbreviations

| | |
|---|---|
| ERP | Enterprise Resource Planning |
| WBS | Work Breakdown Structure |
| BN | Bayesian Network |
| CAD | Computer Aided Design |
| PLM | Product Lifecycle Management |
| KPI | Key Performance Indicator |
| GA | General Arrangement |
| TK | Turnkey |
| PBO | Project-Based Organization |
| DEA | Data Envelopment analysis |
| FDH | Free Disposable hull |
| SFA | Stochastic Frontier Analysis |
| MCDA | Multi Criteria Decision Analysis |
| AHP | the Analytic Hierarchy Process |
| PROMETHEE | Preference Ranking Organization Method for Enrichment evaluations |

# 1. Introduction

## 1.1 Background and Research Environment

The cruise ship industry is an industry handling large, complicated projects. The economic value of one cruise ship is high, and the lead time for the completion of a single ship, starting from the first idea or concept to that ship's delivery, is typically several years. The competition between shipyards is also very tight, and in order to be successful in such competition, shipyards must continuously develop their knowledge and processes as the demands of technical complexity are growing, while simultaneously lead times are shortening and at the same time there is a demand for lower costs. Today, holiday cruises are marketed to all ages and social groups, which means that the requirement for onboard activities are numerous and new innovations for attracting more passengers are being researched constantly. Often, these new features also involve new technologies which must be applied to achieve a more attractive venue. It is a major exercise to develop a totally new solution in an environment that is so strictly regulated by classification societies and authorities, and where passenger safety is the most important factor.

In today's highly competitive market environment, shipyards must continuously develop their processes and be ready to adopt the newest technologies. The processes that can take place from a ship owner's creative idea to a ready cruise ship is available to passengers is both long and complicated. Figure 1 describes the cruise ship process from original concept to the operational ship.

Production efficiency is an important aspect of the cruise shipbuilding process (Bruce & Garrard, 2013; Pires et al., 2009). One can apply informal definition for efficiency, namely that "efficiency is the degree of producing a set of desired effects" (Färe et al., 2013). In shipbuilding production, efficiency consists of those factors that date back to design and material decisions in addition to key production factors. Production efficiency is often measured by consumed working hours or working cost per square meter or steel weight in tons. On the ship level, the measuring of production efficiency is often presented as consumed working hours or cost per light weight or gross tonnage.

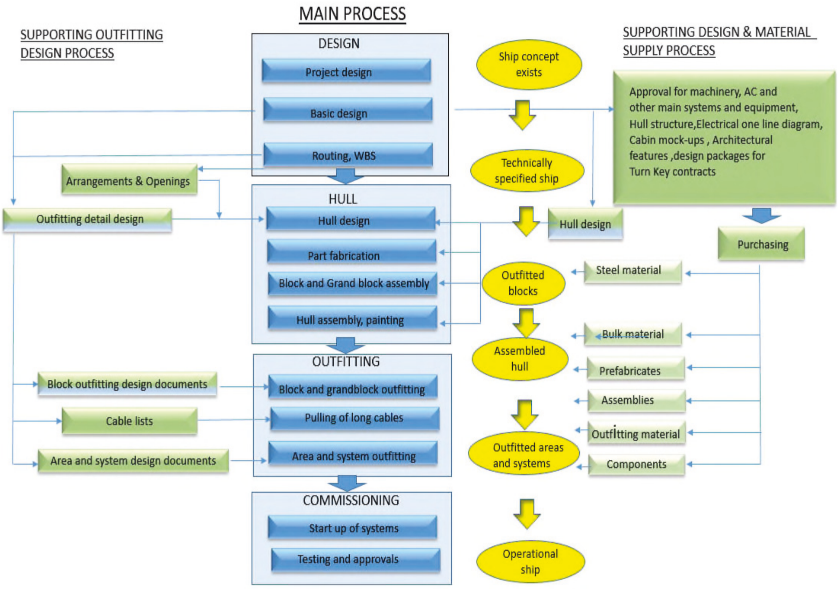



**Figure 1.** The cruise ship process from ship concept to full operations as a ship.

It is typical practice in cruise ship business that after the cruise ship contract is solidified between ship owner and shipyard, the shipyard creates the actual design of the ship. Also the shipyard obtains acceptance from the ship owner, class, and authorities, and builds the ship for minimal costs, desired lead time, and agreed-upon quality. If the building process is carefully planned and controlled it will effectively handle the numerous changes that are common during this process. If the process is not well controlled, however, these changes can cause severe disruption in that process and a delay in construction and thus in delivery. In the last few years, as expected lead times have become shorter, technical complexity has grown at the same time. This change has complicated the shipbuilding process even more.

Nowadays shipyards build cruise ships in co-operation with a supplier network. Depending on the shipyard, that network can participate in multiple varying tasks ranging from material deliveries to undertaking design work and production. Part of the network offers high level of know-how in their specific field, and another part is acting as sole resource providers. The control of this heterogenic network is of key importance when managing such a project. Also securing the knowhow of this large team is vital. Meyer (2010) studied the organizational features related to on-job-learning. According to him, knowledge of economy leadership is a strong driver today and long-term partnerships support the managing of knowledge.

Because this process is complicated, simulation models have been developed to better understand the dependencies in the process. McLean and Shao (2001) offered an overview of a generic simulation of shipbuilding operations. This shipbuilding simulation model can be an effective tool to analyze the schedule impact of new workloads, evaluate production scenarios, and identifying any resource problems. The simulation also helps identify resource constraints and conflicts that may occur between the competing jobs. Krause et al. (2004) also state that the complexity of the product, the ship, and the shipbuilding process make planning these tasks over the long, medium, and short term difficult and can produce serious uncertainties. Discrete event simulation are useful when testing and evaluating the different scenarios of investment planning, scheduling, and resource planning. By using a virtual shipyard environment, the cost of finding the most optimal solutions and the risks related to wrong decisions in the real world can be drastically reduced. They note that German shipyards already successfully use this simulation tool set. Further simulation research has also resulted in Enterprise Resource Planning (ERP) systems, which have improved both process control and productivity (Krause et al., 2004; Tu, 1997; McLean &Shao, 2001). Additionally, research on three-dimensional design systems and other integrated IT tools that are used to manage the building process have allowed cruise ship design to become a fully three-dimensional model, and that model should have a significant positive impact on productivity as well (Liu et al., 2011; Cho et al., 1998).

The performance level of production facilities, tools, and practices plays an important role in increasing efficiency. Studies on the production efficiency of shipbuilding have yielded better working methods, including more efficient welding techniques, increased welding automation, and extended use of modularization and block outfitting (Erikstad, 2009; Greve, 2007; Roland et al., 2004; Koenig et al., 2002; Park et al., 2011). During ship production, one of the key processes is welding. Roland et al. (2004) studied joining processes as an important key factor related to the competitiveness of European shipbuilders. In addition to their contribution to shipyard productivity, joining techniques have had a significant impact on material properties and thus on overall product performance and quality. These factors have become increasingly important for new complex structures that use comparatively thin and high-strength materials. Based on these research results, more practical industrial applications have recently been developed.

While the aforementioned findings have had a positive impact on production efficiency, the question still remains whether it is possible to further increase production efficiency by organizing the shipbuilding project in a specific manner. Currently there is not enough available research information on how organizing the cruise shipbuilding process can affect overall production efficiency.

## 1.2 Objectives and Research Scope

The current lack of information about organization effect thus leads to the research question, RQ:

Does organization structure have an impact on production efficiency?

To answer the question of whether organizing the cruise shipbuilding process will impact production efficiency, a suitable tool is required to examine the issue in closer detail. Problematically, such a tool is not currently available. Any modeling of the cruise shipbuilding process is difficult to portray accurately due to the complexity of the process. This complexity is due to numerous variables, changes made during the process, and a schedule that can affect production activities even if the design is not yet fully complete. The objective, therefore, is to create a model of the cruise shipbuilding process from the perspective of production efficiency. When made available, such a model can also be used to develop and refine the construction process from other points of view, such as lead time, in addition to its successful application for studying the impacts of the organization process to overall production efficiency.

In this thesis, controlling and managing the shipbuilding process encompasses the combined individual elements of project management, building practices, Work Breakdown Structure (WBS), and planning and implementing the entire process. The model is built using the Bayesian Network (BN) techniques (Darwiche, 2009), and the influence of the organization is captured by using decision variable that enable the different organization types present in the model.

To summarize, the objective of the work is to create a model of the cruise shipbuilding process related to production efficiency, and to investigate whether the organization structure of that process has an impact on overall production efficiency. The ultimate goal is to provide a tool with which it is possible to obtain information on how to best control and manage the entire shipbuilding process, resulting in maximized production efficiency.

## 1.3 The Research Process and the Dissertation Structure

When selecting the method for modelling the cruise shipbuilding process, various options were considered. Given that there are a large number of variables and the interactions and dependencies between different variables are not fully known, this modelled process obviously involves uncertainty, which herein led to selection of Bayesian Network techniques as the modelling approach. BN has been used in the marine industry before, e.g., marine safety related studies widely, but particularly for studying production efficiency relating specifically to organization types that still remain absent.

The model was created after a review of the cruise ship building process. Based on the wide experience of being responsible for various positions that range from project planning, purchasing, production, development and quality to leadership of the entire ship project, precise observations were undertaken by the researcher. Typical causes of inefficiency in the process were also mapped. Based on this analysis, the factors that related to production efficiency were identified. The selection of variables was done using the Pareto principle where the assumption is that 20% of actions contribute to 80 % of costs (Koch, 2011). Then, due to the rather large number of candidates, only the most evidently pivotal ones were considered for the model.

Due to the large number of variables still remaining in the model structure, an initial clustering of those variables was then executed. For every variable, two alternative states were determined. Then, the dependencies between these variables were determined. In order to utilize the model for studying the effects of organizing the process, the decision variable was added to the model namely, organization type, which reflected the organizing method for the shipbuilding process. Then, the variables that this decision formula impacted were clarified.

The next phase was to fill in the conditional probability tables, i.e., the model parameters, which were based on expert judgment. The qualification requirements for an expert was the wide knowledge and experience of the shipyard cruise shipbuilding process and understanding the procedure for the elicitation of probabilities. Three experts were qualified and provided their views on the parameters. A searched model output is the probability with which the set target for desired production efficiency is earned within this scope. Using the model, it was possible to investigate the differences between the probabilities of the organizational structures and production efficiency.

This thesis introduces a quantitative model for the cruise ship building process. The model allows for the examination of how the production efficiency of the cruise shipbuilding process is linked to the ways that the process is organized and managed. In Section 2, a brief description of the cruise shipbuilding process is presented together with the theoretical background of any related items. Also the methods are described. In Section 3 the creation of the model as well as the actual model with its structure and the results of the analysis are presented. In Section 4 the results are discussed and both model reliability and validity are analyzed. Finally conclusions are offered and recommendations for future research are discussed.

### 1.4 Main Limitations

This study is based on the assumption that all production-related factors, such as production facilities, methods, and tools, do remain constant throughout the cruise shipbuilding process. Therefore, their impacts have been excluded in this study in order to clarify only the influence of the organization model. However, numerous uncertain dependencies, variables, and connections do still remain. The number of experts could be more, but herein the demanded qualifications for experts were special including long working period in the same shipyard in the different parts of the process for knowing the process well. In shipbuilding, this parameter changes slowly because the lead time for the projects is long and the any timing of changes in the process must be considered carefully. The typical timeframe for getting changes in the process implemented can range from three to five years based on past experience. The study was done in one shipyard only because the information needed for this kind of study is very broad and not generally available.

# 2. Background

## 2.1 Description of the cruise shipbuilding process

The cruise shipbuilding process is complicated (Eyres & Bruce, 2012). The process contains numerous tasks that link to each other technically as well as in terms of scheduling and cost. In several studies a general description of the shipbuilding process is offered in regards to both shipbuilding practices and ship structures (Eyres & Bruce, 2012; Hiekata & Grau 2015). According to them, the process consists of a concept and preliminary design, detailed design, production design, and actual production. In terms of the design, they indicate that design activities are carried out with a high level of concurrency that is supported by different computer software systems. That process is highly dependent on the experiences and insights of the skilled experts. Further, detailed design information is difficult to share, and design conflicts are resolved via a common effort by the design engineers during the downstream design stages. The number of detail design drawings is typically thousands, which offer further perspective on the nature of such huge design work. Meyer (2010) suggests that effective creating, sharing and use of knowledge is a principle factor of corporate competitiveness in today's global economy. Further, he argues that business success critically depends on how well companies with highly trained employees and high labor costs protect, combine and utilize the knowledge of their employees, their organization, and partner organizations.

The design and material definition proceeds through several stages toward an entity, a ship that is a luxury, self-containing hotel with an optimized steel hull, equipped with energy production and propulsion. The design is guided by the rules and regulations of a classification society and authorities. Sometimes the projects also reflect the development of rules because the concepts and innovations can prevail for structures that have not been considered in the existing rules and requirements. This circumstance can produce long term development processes with classification societies. That process needs to be managed so that the project stays under control during its development, and design can proceed despite any possible changes needed when new rules have been confirmed and must be applied by the shipyard. Safety and environmental issues are a necessity. As an example of this Figure 2 show the typical leisure features of cruise ships that have been developed over the years. They have demanded a great deal of development work and testing before they could be offered for everyday use on board cruise ships.

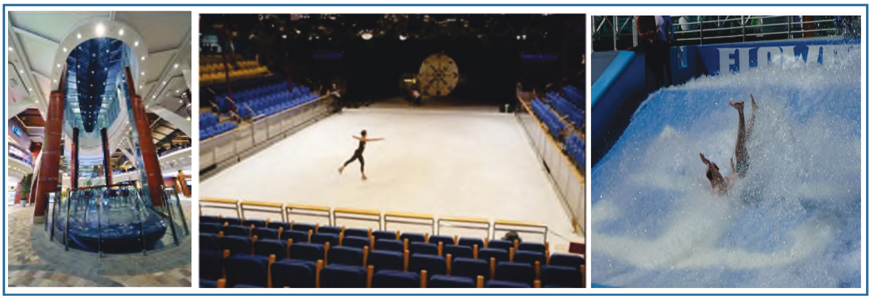


**Figure 2.** A rising bar, ice rink and flow rider on board cruise ships.

Indeed, today the execution of a cruise ship project is a collaboration of a huge network of design offices, authorities, classification societies, material suppliers, and turnkey (TK) contractors together with the shipyard. This scenario means that shipyard needs to have the ability to control its network in order to be successful. A portion of the suppliers and turnkey contractors participate to the tendering phase, i.e., when the shipyard is offering the ship to the owner. The long co-operation has resulted in many highly specialized companies which are absolute tops in their field. The overall scheme of the cruise ship process can be seen in Figure 3.

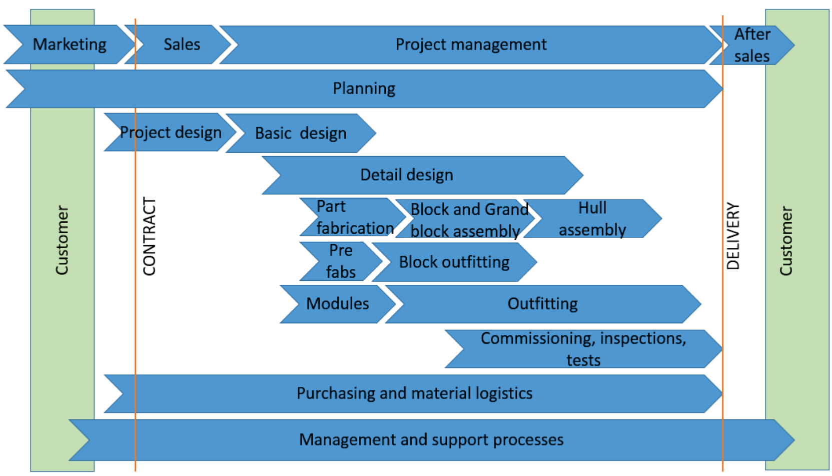



**Figure 3.** The overall scheme of the cruise shipbuilding process.

A modern production process combines hull production activities and outfitting activities, with simultaneous execution performed on both fronts. This prevails with developed computer aided design (CAD) systems. Fernández and Lado (2015) describe how naval shipyards have increased their demands for an integration of CAD applications with product lifecycle management (PLM) systems and present advanced architecture for CAD-PLM integration in a naval shipbuilding environment.

As stated earlier, ship contracts have traditionally been compiled in such a way that when entering into one, the shipyard is committed to deliver the technically specified vessel within the required time frame given only the operational and architectural demands, but with no detailed technical plans or drawings. As a result, the ship must be defined in detail while the construction process is already ongoing. This situation puts considerable pressure on the planning effort.

**Planning** is the basis for successful execution of any cruise ship project. Without proper schedules and a resource plan, it will not be possible to achieve the intended results on time. The basis for the schedule is WBS (Work Breakdown Structure) and the building practice. Shipyards in the cruise ship industry have their own processes and ways to control that process. Some shipyards use a combination deck-fire zone as the basic element of WBS whereas other shipyards use the functional area – system WBS. Typically, one cruise ship project will consist of tens of thousands of individual activities which all have a workload and connections to other activities in between the different disciplines. It is evident that without the help of computer this task would not be possible. As stated earlier, the ship contract includes the deadline for the whole project. To achieve the planned financial result, it is extremely important to meet the targeted delivery date. That is why schedule is important and through that focus the planning itself.

Every shipyard has their own IT environment and procedures. The planning system is typically the core system with which all other systems need to co-operate. That is why numerous links need to be created between the design systems, the material and logistic systems, as well as the document handling system. This process leads to a situation where the planning systems as entity are tailored and different in the shipyards. It can also be the reason that a lot of development work is done by the planning system suppliers who need to do this tailoring work inside the shipyards to get the contract to the system. However, some shipyards have developed totally individual planning systems for their own use only.

Nowadays the supplier network is an essential part of the cruise ship project and thus their role in the scheduling process is essential. There are cases where suppliers participate in the planning by creating their own schedules and then combine them with the main schedule and also cases contractors just follow the schedule already set by the shipyard. The schedule is also the basis for progress reporting. The broader the reference data is, the easier it is to create follow-up and controlling reports.

According to Liu et al. (2011) shipbuilding is a complex production system that is characterized by a complicated work and organization structure, prolonged production lead time, and heterogeneous resource requirements. This entity means that planning all needed activities from the design phase until the last activity of commissioning is a challenging task. They studied an aggregate production planning model for ship production in efforts to minimize the variation of aggregate man-hours and simultaneously minimize the logistics demands of any interim products. They developed a directed genetic algorithm-based solver for this optimization problem. Emblemsvåg (2014) developed a new approach for project planning called Lean Project Planning that was intended to overcome any shortcomings in the earned value management approach and found it to be successful.

Restricted parts and elements of the planning process can be studied in general terms but the whole planning system of a shipyard is so big an economic and operational effort that it needs an investment decision by shipyard to start developing it.

A vast amount of careful planning, technical detailing, and co-ordination of resources, materials, and work is required to manage a process that can produce the agreed-upon high-level cruise vessel, with all its technical performance indicators within a predetermined time, and the agreed-upon quality in a profitable way (Bruce & Garrard, 2013). Several different tasks and activities are interdependent and will affect each other, and thus complicating the process even further. The creation of a schedule is based on the shipyard and its Key Performance Indicators (KPIs). Improvement in these results shorter unit times and naturally helps to shorten the overall lead time. The demands of shortening these lead times have resulted in a situation where the next phase can start before the preceding phase has completed; thus parallel work is required. An illustration of a typical project main schedule is presented in Figure 4.

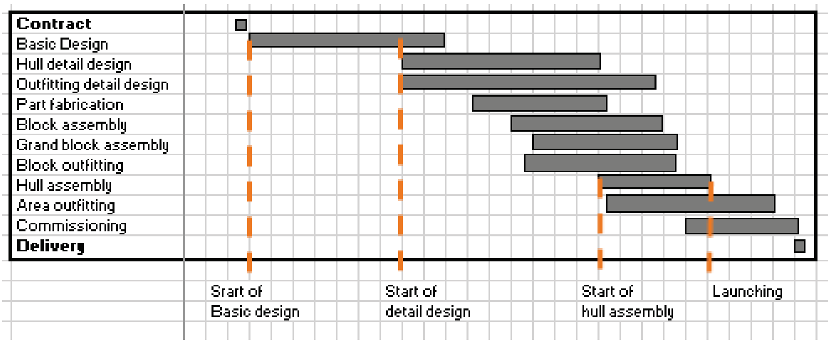



**Figure 4.** A typical full schedule for construction of a cruise ship with its main phases noted.

It shows how the different work is being done in parallel terms to still keep the overall lead time short. The shortening of lead time prevails the efficient parallel work and strict control of all preconditions. In Figure 5 a typical outfitted block is being lifted to the hull during the hull assembly period. It shows one example of parallel work progressing as, during the hull block building, remarkably outfitting is also being done. However, as a result of a tight plan, many individual issues can become critical during the process, and quick reactions are then needed to maintain the planned schedule.

**Figure 5**. An outfitted block is being lifted to the hull during the hull assembly period.

The first steps in the cruise ship building process are taken before the ship contract even exists. That phase is typically called **project design**. After receiving an enquiry from a client, the specification is reviewed and the shipyard's own specification is written, taking into account the owner's definitions and demands in addition to the shipyards own solutions, standards and procedures. Based on this review, system descriptions are outlined, and system diagrams are defined. Hull design in this phase includes calculations and modelling, and the result is a preliminary hull shape with a mid-ship section. Figure 6 shows an example of a geometry modelling tool. In addition, the specified rules and regulations play a big role for the structures. In this phase, the planning work is starting to define the main building practice and the schedule. Necessary planning activities are done including all the main schedule options. Also the network is being contacted now. Especially, all big and critical materials and components are quoted. General arrangement (GA) design is started to make the layouts as attractive as possible. Based on the GA and the main WBS, the turnkey systems and areas are then quoted. Simultaneously cost calculations are ongoing. First, calculations are based on the statistics but also when the offers from contractors are received, they can be used to determine a cost basis. When specification, GA, mid-ship section with necessary structures, the building practice, and the main schedule have been agreed upon, the cost and the overall budget can be compiled with the help of statistics and received offers for components, materials and TKs. Based on this compilation, the offer for building the cruise vessel can be completed, and the commercial negotiations start.

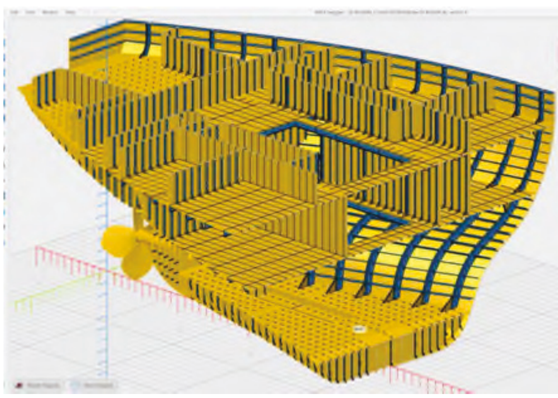


**Figure 6.** A geometry modelling tool (www.napa.fi ).

The **Basic design** phase starts normally after the contract has been signed. The most important activities during basic design are classification design, basic design of all machinery, propulsion, electricity, HVAC, deck and interior. The overall scheduling has to be done at a more detailed level as well as detailed capacity planning for the design. Normally, the purchasing of expensive and critical components is done in this phase, as well as any turnkey contracts. In order to be able to do this task, planning work has to have proceeded already, so that procedures and schedules for purchasing all material categories exist and detailed building practices with their schedules have been determined. System design proceeds together with the suppliers, and architectural design proceeds together with the owner. Basic design is documented in the form of hull drawings, technical calculations, system descriptions, layout drawings, and architectural drawings. All necessary documentation needs to be approved by the owner and the classification society.

All the standards for further use in later phases are also agreed upon in the basic design. Inspection plans and testing procedures are agreed during this phase for later purposes. In general, all common procedures needed for the course of the building and the co-operation with the owner, classification society and authorities should be agreed upon during the basic design phase. The overall capacity planning for later phases is also included in the basic design to ensure all needed resources are available later on. Purchasing of resources also needs to be planned in detail for these schedules.

**Detail design** consists of both hull detail design and outfitting detail design. Hull detail design can be part of the hull process. Based on the basic design decisions, calculations, module plans, architect design area arrangements and all approved area-based documentation, respective workshop drawings, defining of materials in parts lists, and prefabrications are done during this phase. System design is also taken to a detailed level, so that working drawings for piping, ducting, and electrical work are done and ready for production. Installation drawings for all equipment, machinery, and technical spaces are detailed as well. In order to secure planned block outfitting for each respective phase of hull work, the working drawings need to be done early enough to secure the necessary materials and prefabricates. In case different openings are planned in connection with the steel process, the outfitting design is done simultaneously with the hull detail design. In the detailed design, all documentation needed for purchasing these materials is finalized. This means that all workshop drawings, component lists, technical specifications for enquiries, and orders are done. During the detail design phase, all material enquiries and purchasing contracts are completed, and all prefabricated items are put into production. For certain materials, only frame agreements are done first and call-offs based on need during production are made afterwards. Other working-related documentation is also produced in this phase. In order to organize the work in production, job orders are produced based on the working drawings and the parts lists. This work is based on WBS and thus is defined into controllable entities that help the right work order in the blocks, grand blocks and in the area phase onboard.

The **hull production** phase includes the detail design, material-related activities, part fabrication, part assembly, block assembly, grand block assembly, and hull assembly. Block outfitting in different phases is part of the hull process, which is why planning combines outfitting design and hull design. It is essential to keep the process effective. Logistics also play an important role in the hull phase due to the tight lifting schedule of grand blocks.

**Outfitting** has various phases. Depending on the building practice, there can be different phases in action in different parts of the ship. The first outfitting effort is done in workshops when the pre- fabricates and modules are fabricated. If there is block outfitting, that can be started already during the steel process when openings are done and also when the first welded parts are installed. During the steel process, there can be several block outfitting phases, depending on the type of area in the block. The cabin area has different block outfitting than the machinery areas, galleys, outer decks or public spaces.

After the grand blocks are installed, the area outfitting phase begins. In the hotel interior and technical areas, the background work is finalized, and the interior work, including system work, is done. In the machinery areas, the outfitting is mainly for system work. Figure 7 shows phases of the hull and outfitting process.

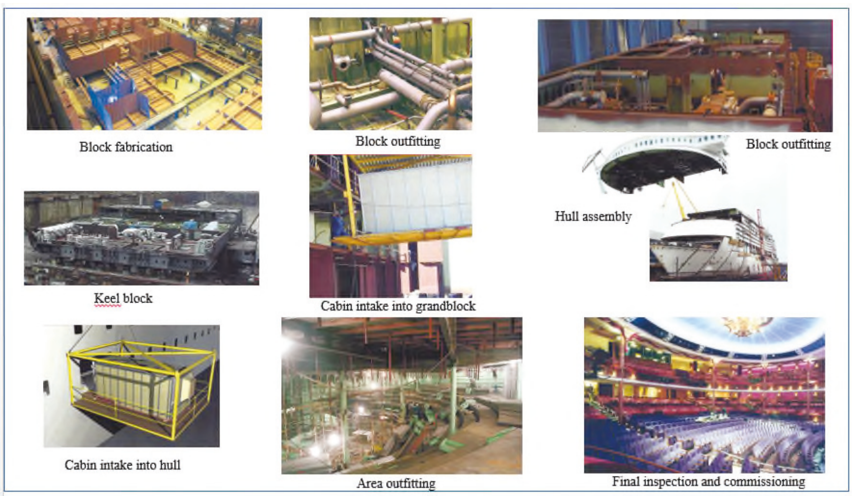



**Figure 7.** The phases of hull and outfitting production.

In the **commissioning phase,** all the systems are tested and checked, so that their functionality corresponds with what was defined in the specification.

The ship project can be **organized** in several ways, either by using line organization or project organization. Traditionally, shipyards have been organized as basic line organizations. In a basic line organization, the main departments, meaning other than the administrative departments, are those for design, procurement, hull, and outfitting. For projects, separate project organizations can be established. Line organization is a stable, but in contrast, the content and role of the project organization has changed over the years. Project group responsibilities can vary from a purely client interface to real project management in terms of cost, schedule, content, and quality. In project organization, the main department of every line organization nominates its representative to join the project group. That representative uses the power of their respective departments in the course of the project.

The cruise shipbuilding **process includes uncertainties** due to fluctuations and incomplete information, all of which must be addressed to maintain the total lead time for the process. One has to know which information is permanently fixed and which is subject to change. Every cruise vessel project is different. Even if it is a sister vessel and technically identical, the circumstances during the project process can still be different. Whereas many of the technical uncertainties have been clarified already for the sister vessel, factors such as the resource situation, the supplier network, the shipyard organization, key personnel, and the processes can still change. Thus, from a project perspective, these types of changes make the new situation quite different from the previous one.

## 2.2 Production efficiency

Production efficiency and productivity are defined as the relationship between the output generated by a production or service system and the input provided to meet responsibilities and create this output (Prokopenko, 1987). According to this author, productivity is defined as the efficient use of resources, such as labor, capital, land, materials, energy and information, for the production of various goods and services. He also states that productivity is the point wherein human skills and interests, technology, management, and the social and business environments all converge. Further, that productivity should be managed, not just measured. The techniques used to improve productivity are in his opinion industrial engineering techniques, economic analysis and behavioral techniques. Also improving the use of capital resources can be improved by undertaking waste reduction, energy conservation, and maintenance improvement. Further, improving productivity through quality is also one method this author suggests to be used for improving production efficiency.

The producers are efficient if they have produced as much as possible with the inputs they have used and if they have produced that output at minimum cost (Greene, 1997; Porcelli, 2009). Efficiency is one part of the overall performance as seen in Figure 8 (Porcelli, 2009).

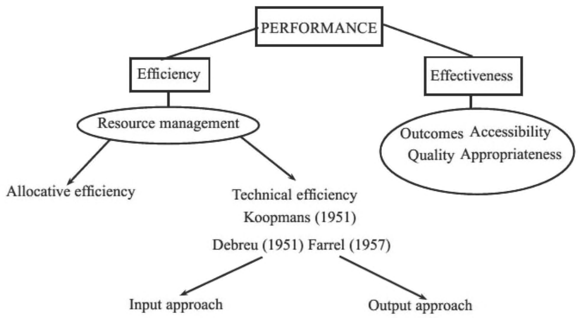



**Figure 8.** A framework for performance assessment

In Figure 8 allocative efficiency refers to the ability to combine inputs and outputs in optimal proportions in the light of prevailing prices, and is measured in terms of behavioral goal of the production unit like observed cost vs optimum cost. Technical efficiency is measured as the ratio between the observed output and the maximum output, under the assumption of fixed input, or, alternatively, as the ratio between the observed input and the minimum input under the assumption of fixed output (Porcelli, 2009). Both technical and allocative efficiency can be measured by the input approach or the output approach. According to Porcelli, the input approach means evaluating the ability to minimize inputs keeping outputs fixed and the output approach means evaluating ability to maximize outputs keeping inputs fixed.

Semenick (1994) has reviewed benchmarking methods such as non-parametric, deterministic Data Envelopment analysis (DEA), Free Disposable hull (FDH) and Stochastic Frontier Analysis (SFA). DEA has its roots in mathematical programming. It creates an envelope of observed production points. It provides linear approximations to model the best-practice reference technology and measures of technical efficiency levels are developed for firms that operate inside this data envelope. FDH is a variant of DEA. When DEA creates a piecewise linear best-practice frontier, FDH creates a best-practice frontier resembling a staircase (Semenick, 1994). SFA is based on statistical regression techniques. It is a parametric approach and is more linked to econometric theory (Bogetoft and Otto, 2011). SFA compares a firm with an average technology by using data from all time periods and for all firms (Semenick, 1994).

Multi Criteria Decision Analysis (MCDA) is a technique to help the decision makers to choose, prioritize or sort alternatives in situations when there are conflicts between criteria and between different interpretations of the criteria and preferences among the different actors. It structures and solves decision and planning problems including multiple criteria. MCDA problems can be classified into multiple-criteria evaluation problems and multiple-criteria design problems. "The applications of MCDA problems are numerous and in different fields. Most real-world decision problems occur in a complex environment where conflicting systems of logic, uncertain, and imprecise knowledge, and possibly vague preferences have to be considered. To face such complexity, preference modeling requires the use of specific tools, techniques, and concepts which allow the available information to be represented with the appropriate granularity. " (Greco et al., 2005).

The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to drive priority scales (Saaty, 1998; 2008). Preference Ranking Organization Method for Enrichment evaluations (PROMETHEE) method helps decision makers find the best alternative for the problem. It provides framework for structuring a decision problem, identifying the conflicts and highlight the main alternatives and the structured reasoning behind. Dağdeviren (2008) uses these both methodologies in making equipment selection. The AHP is used for analyzing the structure of the equipment selection problem and PROMETHEE is used for obtaining final ranking and sensitivity analysis. Combining Fuzzy set theory with AHP creates Fuzzy AHP method. It resembles human reasoning in its use of approximate information and uncertainty in creating decisions (Dağdeviren and Yüksel, 2008).

The concept of virtual manufacturing has been developed for sheet metal forming process in order to increase the industrial performances. According to Banabic (2010) it is the one of the most efficient way of reducing the manufacturing times and improving the quality of the products.

In lean philosophy, there is resource effectivity and also flow efficiency, which refers to the amount of products produced in given unit of time. Liker & Lamb (2002) examined lean ship construction. According to them, the Toyota Production System was the basis for "lean manufacturing." The purpose of lean manufacturing is to improve product cycle time, cost competitiveness, and quality by eliminating waste in the manufacturing process through continuous improvement generated by a motivated workforce. According to the authors, the key points are specifying the product value from the customer's perspective, identifying the value stream, constant flow, pull and perfection or acceptable quality. In addition to Just in Time and Built in Quality, other principles used in lean manufacturing are 5S (sort, sustain, straighten, standardize, and shine), 7 wastes (overproduction, transport, waiting, movement, over processing of inventory, and defects) and Kaizen, which is continuous improvement. According to Kolić et al. (2016), the idea of lean manufacturing in shipbuilding is being applied in shipyards worldwide. Erdem (2015) studied the lean manufacturing effects of modularization on the outfitting process in shipbuilding. He analyzed several Lean Manufacturing effects on reducing the items on the bill of materials for outfitting using data. The goal was to increase the pre-outfitting percentage by identifying waste and thereby facilitating modularization in shipbuilding. He concluded that the reduction of movement leads to less confrontation and interruption of employees' working in the shipyard and increases the overall pre-outfitting percentage when compared to all the outfitting activities.

In a cruise shipbuilding project, thinking for process and the efficiency in design can be seen as the use of standards and repetitive solutions as well as the ability to keep to the design schedule and budget. Avoiding wait time or lack of clarity in the initial information, and securing approvals and resources are essential for such effectivity. In procurement, that effectivity can be seen as on-time material or service deliveries in a specified condition. Clear, well-defined purchasing scopes, acceptable suppliers, and keeping to a purchasing schedule and budget are also important. In addition to keeping to the schedule and budget, in hull production the design documentation, materials, information regarding outfitting design on time, the availability of needed resources and working logistics are the keys to productivity. In outfitting the co-operation of the supplier network, shipyard, classification society, and authorities creates the basis for efficient work. Avoiding wait times by having detailed planning and regular control of the prerequisites for continuous outfitting work and commissioning can be achieved. In outfitting a pre-outfitting grade, modularity grade and block outfitting grade indicate the level of efficiency. Change management can give good indicators of project efficiency or inefficiency and the reasons behind any of the changes in the process throughout the whole time span of the project.

The challenge in improving production efficiency during the cruise ship building process is that majority of the ships are customized to a detail. The shipyard needs to create something new for the next projects. Even in serial ships, the interior is often changed to give a new look for passengers. This means that restoration and standardization need to be done in a clever way so that it still offers the possibility of looking new and unique.

## 2.3 Organization structures

Lægaard and Bindslev (2006) describe the theories which contain contributions to organizational theory over the past 100 years. They say that the greatest contributions to organizational theory were made in connection with the build-up of the industrial society, which created a need for theories about the management of many people gathered around industrial tasks. The development resulted in organizational theories with normative rules for structuring of work. Further, they clarify the theories that are scientific management, administrative theory, bureaucracy and organizational structure and administrative behavior.

Scientific management is no longer prevalent as a managerial ideology. However, it still functions as a guideline for technical procedures, not only in the industrial sector, but also in the service sector.

Administrative Theory has the form of the management's hierarchical pyramid structure were to function as the basis of the part of the organization that involved activities, i.e. a top down approach. Bureaucracy and Organizational Structure includes that the public employee must act as if the superior's interests were his own and thus stay in his bureaucratically assigned role. On the basis of the thoughts about organizational structure as a link between the company's strategy and implementation of action plans, the following models for organizational structures can be identified: Simple structure, Hierarchical system, **Functional organization**, **Product organization** and **Matrix organization**. There are no perfect organizational forms and no completely correct solutions when it comes to structuring organization. Administrative Behavior has attempted to clarify goal specificity and formalization and explain their connection to rational behavior. There the objectives only affect the individual member if they are significant in his daily conduct. In this way, it becomes the organization's role to delimit the objectives that are significant to the individual member.

Lundin and Söderholm (1995) have researched the theory for temporary organization. According to them four basic concepts — time, task, team and transition — provide a suitable foundation for a theory of the temporary organization as well as a framework for identifying these demarcations. Further, they suggest that the four sequencing concepts are of central importance: action-based entrepreneurialism, fragmentation for commitment-building, planned isolation and institutionalized termination. The basic concepts — time, task, team and transition — are thus the foundation for our understanding of temporary organizations. Time in temporary organizations can be envisaged as a linear section of a continuous time-flow that is predictable and plannable. The presence of a task, something that calls for attention, is the main reason for creating a temporary organization. Team focuses on interpersonal relations, on how teams can be made to function through commitment-building, and how they interrelate with the surrounding environment through processes of legitimization. Transition is a basic aim of temporary organizations; something has to be achieved in terms of transition before success can be proclaimed.

Brady et al. (2006) describe mega project management in projects at Heathrow airport. These range from routine capital projects to a one-off mega project — Terminal 5 (T5). They concentrate on the learning gained from previous projects, individuals and organizations that contributed to the innovative approach used to manage the T5 project. The T5 project uses 'integrated team working' to ensure that safety, time, budget and quality constraints are met. It has already reached 50% completion (March 2005) on time, within budget and with a high safety record. The T5 project is Europe's largest and most complex project. Central to the delivery of T5 has been the concept of integrated teams. They proceeded with an approach based on strong leadership, simplicity and openness. The approach was liked by members of the project team. However, it was not liked their parent organizations because the team members became identified more strongly with the project than their own organizations. The various teams were co-located and fully integrated. They were run as if they were a small business with them all taking joint responsibility for the outcome. Teamwork was mentioned as a major success factor. There it was claimed that teamwork has been excellent both at the Heathrow Airport Limited level and also through to construction activities where the co-location of the team provided huge benefits. It was also noted that the team members 'left their companies at the door' when they came to work on the project.

The cruise ship building process is a large project that can be organized in several ways. Depending on the organizational structure and working procedures of a shipyard, the project can be executed using the permanent line organization of the shipyard, setting up a temporary project organization or both techniques. The organizational structure shows where the people in the organization belong to and to whom they should report. The most common organization structures are Functional, Project, and Matrix.

The typical functional shipyard organization, the **line organization** in this study, is often divided into the following functions: sales, marketing, design, purchasing, hull, outfitting, administrative, planning, human resources, quality, service, maintenance, and economics. Department managers report to the shipyard director, see Figure 9 for details.

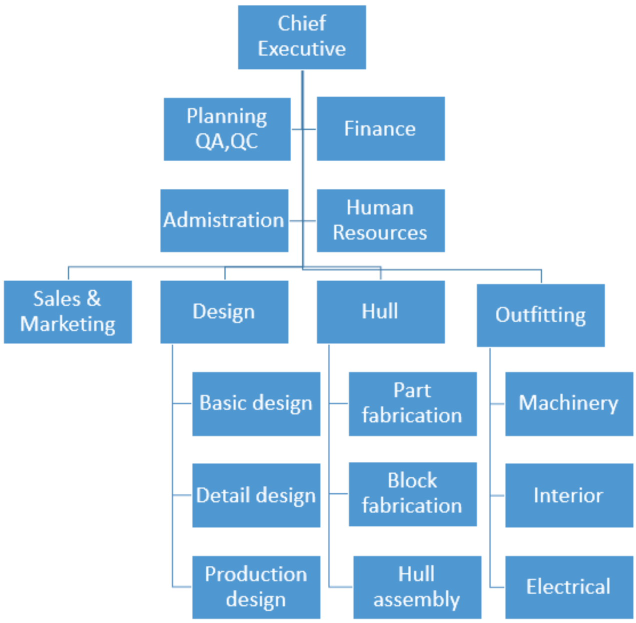



**Figure 9**. An example of a line organization.

**Project organization** is a temporary organization that is set up to fulfill a special task (Atkinson, 1999; Hobday, 2000; White & Fortune, 2002). This task can be building a cruise ship according to the agreed upon contract. In the cruise ship project group there are typically the following responsible persons: planner, controller, design responsible, procurement responsible, hull responsible, outfitting responsible, commission responsible, and often a document controller. All of them report to the project manager, see Figure 10 for an illustration of a project organization for cruise ship project.

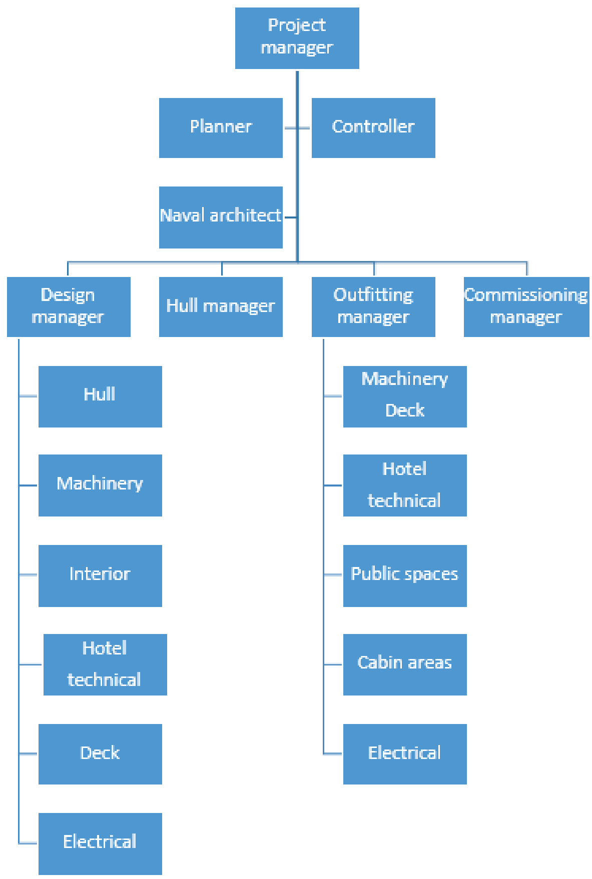



**Figure 10**. An example of a project organization.

The **matrix organization**, a **hybrid** in this study, includes part from both the functional organization and the project organization. There can be several types of cases, depending on how strong or weak the project manager is. If a project manager has only limited authority, then the functional managers maintain control over their own resources and project activities. If that authority is shared equally between the project manager and the functional managers, then the matrix is in balance. If the project manager has main responsibility for the project and the function managers support the technical expertise and provide resources when the project asks for them, then the project is a strong one, see Figure 11 for details.

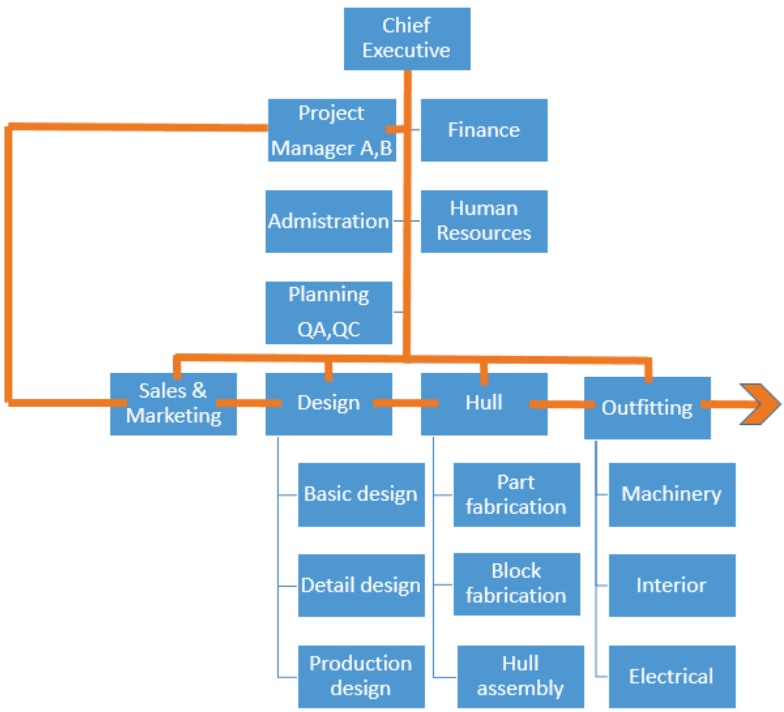



**Figure 11**. An example of a hybrid organization.

According to Robbins (1983), an organization represents the planned co-ordination of the collective activities of two or more people who, while functioning on a relatively continuous basis through the division of labor and a hierarchy of authority, also seek to achieve a common goal or a set of goals. Robbins also notes that organizational structure has three components: Complexity, Formalization and Centralization. Complexity considers the extent of any differentiation within the organization, e.g., the levels of an organization's hierarchy. Formalization describes the degree of rules and procedures on which the organization relies, while Centralization considers and establishes the actual decision-making authority. Based on these factors, one can evaluate different kinds of organizations very precisely.

When evaluating the complexity of an organization, Robbins (1983) notes three elements: Horizontal Differentiation, Vertical differentiation, and spatial dispersion. The more complex an organization is, the greater is the need for effective communication, co-ordination, and control devices. As complexity increases, so do the demands on management to ensure that differentiated and dispersed activities are working smoothly and together in order to achieve the organization's declared goal.

The measuring of organizational effectiveness, according to Robbins, has proven to be a difficult aspect to define. Evaluating productivity usually means defining the quantity or volume of the major product or service that the organization is providing. Efficiency can be seen as a ratio that reflects a comparison of some aspect of unit performance to the costs incurred for that performance.

Robbins also describes an organization using the term "adhocracy" which means a flexible, adaptable and informal organization. He states that "when it is important that the organization be adaptable and creative, when individual specialists from diverse disciplines are required to collaborate to achieve a common goal, and when tasks are technical, etc." and "too complex for any one person to handle or for individual supervision, the adhocracy represents a viable alternative". As an example he mentions the most popular application of adhocracy, a matrix organization, which is a combination of departments by function or by product or by project. The matrix breaks down the unit command concept. Employees in the matrix have two bosses - their department manager and their project manager. This matrix is designed to benefit from the strengths of both the functional and the product/project structures. The strength of a functional structure rests in bringing specialists together. Project structure facilitates the co-ordination between these specialists so as to achieve timely completion of the project and meet budget targets. Further, this structure defines those with the clear responsibility for all activities related to that project.

Aurélio de Oliveira et al. (2012) analyzed the influence of leadership style and the factors associated with organization agility on project performance. They studied which combination of leadership style, agility, and organizational factors can achieve the highest project performance. Their effort "helps clear up the mistaken view that high agility only takes place when all constituent factors display maximum values. The leadership style and people contribution to agility is clearly addressed".

Ford and Randolph (1992) reviewed and summarized the literature on cross functional organization forms and focused on the commonalities of the literatures that deal with matrix organization and project management, ending with a discussion on needed research. Their article ends with a call for more research and theory building on cross-functional organizations, which they argue is continuing to grow in application importance.

According to Greve (2007) a central theoretical problem in organizational evolution is how organizations acquire new capabilities. The organizational exploitation of current capabilities often reduces the exploration of new capabilities, resulting in a short-term bias regarding of organizational adaptation. When talking about large projects, the capabilities of the organization must be ready to change when needed because during long lead times, circumstances can and do change.

Hobday (2000) examined the effectiveness of producing so-called CoPS, i.e., complex high value products, systems, networks, capital goods, and constructs in a Project-Based Organization (PBO), compared to that same process within a more traditional functional matrix organization. According to Hobday the PBO become an intrinsically innovative form, as it creates and recreates new organizational structures to meet the demands of each CoPS project and each major customer. The PBO is able to cope with emerging properties during production and respond flexibly to changing client needs. It is also effective at integrating different types of knowledge and skills and coping with each project's risks and the uncertainties that are common in CoPS projects. However, the PBO is inherently weak whereas the matrix organization is strong whenever performing routine tasks, achieving economies of scale, coordinating cross-project resources, facilitating company-wide technical development, and promoting organization-wide learning.

There is a lot of knowledge available on organizations as seen from the discussion above. However, the impact of different types of organizations on productivity in shipyards has not yet been researched to its fullest extent.

## 2.4 Critical evaluation of the available models to study organizational and production efficiency

Previous models that have been developed on the shipbuilding process are mainly simulation models. In general, these models help to understand the dependencies that exist in the shipbuilding process.

McLean and Shao (2001) offer an overview of the generic simulation of shipbuilding operations. This shipbuilding simulation model can thus be an effective tool to use when analyzing the schedule impact of new workloads, evaluate production scenarios, and identify any resource problems. The simulation also helps to identify resource constraints and any conflicts that may occur between competing jobs. Further, when integrating new technologies or equipment into a shipyard, the simulation can be used to show planned or expected results. However, it is not suitable to use when studying production efficiency of the whole process nor organization effectiveness because the model concentrates on resource and equipment planning only.

Krause et al. (2004) introduce a discrete event simulation. According to them it is useful for evaluating the different scenarios used for investment planning, scheduling, and resource planning. They argue that traditional static tools no longer provide sufficient outcomes for controlling the complex elements of shipbuilding. Further, they say that only by compiling a simulation of the great number of variant parts can their dynamic effects be evaluated. The simulation includes the product, resources, process structure, continuous product data flow, shipyard layout planning, production planning, and logistics. According to them, to achieve an appropriate result from the simulation data management, each part of a ship including all material with all relevant geometrical dimensions, the weight and quality must be described in the product data. Because of this feature, this kind of modelling tool is not feasible for studying production efficiency and organization in shipbuilding case as the needed information for a viable simulation of this aspect is not available.

Kim et al. (2005) introduce a model for a simulation-based shipbuilding system in the shipyard manufacturing process. It is a process model for block erection processes. It can simulate crane operation and block erection in a virtual dock. As it concentrates on a limited part of the process only, it is not a feasible tool to use for studying production efficiency and the impact of organization.

Alfeld et al. (1998) describe a software program that simulates the dynamic complexities of the ship construction process. According to them, this simulation model of the shipyard production process captures both the essential physical shipbuilding activities and the essential management decision-making activities that work to support the physical production processes. According to their description, the application consists of two independent sub-models that identify the overall shipyard facility and manpower resources and the construction tasks required to build a ship. They interact to calculate over time the specific allocation of resources necessary to produce a ship. The output is the durations and man-hour loadings based on dynamic resource availability. It also helps to quantify the cost and schedule impact of delays and disruptions as well as identifying the actions to overcome such problems. This model also focuses on resources and scheduling and thus is not suitable for studying production efficiency and the impact of organization.

König et al. (2007) present a constraint-based simulation of the outfitting processes in shipbuilding and civil engineering. That is an approach used to detail outfitting tasks and their corresponding restrictions and requirements. It is also an appropriate instrument to use to support the planning process, while focusing only on outfitting. It is not suitable for studying production efficiency and the impacts of organization.

Additionally, when considering the methodology for this study, one option would be to analyze the process KPIs of several cruise ships and then study which organization type gives the best result. However, this kind of quantitative historical data was not available for analyzing. Also the use of the benchmarking methods described in Section 2.2 were not feasible, because of the needed data for that purpose is very large and it is typically company confidential information and not available for this kind of research.

Bayesian Network techniques were chosen due to the large number of variables involved in any shipbuilding project, and the interactions and dependencies between them, and also as that complicated process obviously involves uncertainty. Also, the fact that BN has been used in the marine industry before, e.g., widely in marine safety-related studies, encouraged us to choose BN as the modelling approach for the current research.

## 2.5 Bayesian Networks

Bayesian Networks (BN) is the process of reasoning under uncertainty, using a graphical model with variables and nodes with interdependencies. It is the consistent combination of information from various sources. According to Charniak (1991), it is a way to model a situation wherein causality plays a role, but also where the understanding of what is actually going on is incomplete, so the process must be described probabilistically. These dependencies or arcs in BN specify the independent assumptions that must hold true between the random variables. These independent assumptions determine what kind of probability information is required to specify the probability distribution among the random variables in the network. To specify the probability distribution of a Bayesian Network, one must know the prior probabilities of all root nodes and the conditional probabilities of all no root nodes, given all possible combinations of their direct predecessors. Figure 12 shows an example of Bayesian Network concerning system safety (Fenton & Neil, 2012).

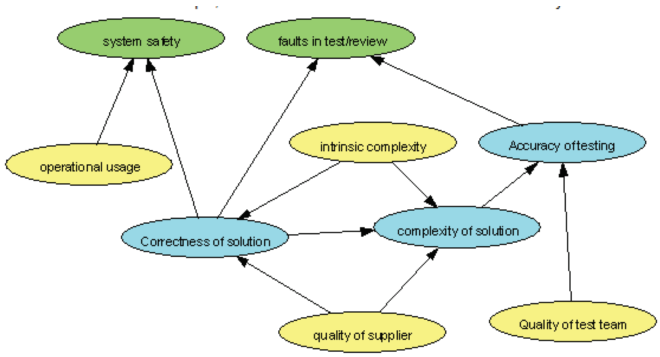



**Figure 12.** An example of Bayesian Network.

Bayesian Networks are techniques used for graphically representing the joint probability distribution of a set of variables (Darwiche, 2009). The structure of a BN model is a directed acyclic graph, wherein the graph nodes represent the model variables and the arcs between the nodes describe the direct variable dependencies. Each network node has a finite number of mutually exclusive states with their probabilities of occurrence. These probabilities depend on the current states of the potential parent nodes for each variable, i.e., the variables that have an arc to the variable in question. BNs can be utilized for descriptive modeling of a system and can include uncertainty, but also prediction. By augmenting a BN with the variables that describe potential decisions and variables that measure its utilities, the resulting influence diagram can be applied to a decision analysis whenever uncertainty is involved (Jensen, 1996; Nielsen & Jensen, 2009; Stamelos et al., 2003).

According to Joyce (2003) Bayes Theorem is a mathematical formula that is used for calculating conditional probabilities, using subjectivist or Bayesian approaches to epistemology, statistics, and inductive logic. Subjectivists lean on conditional probabilities and the models of empirical learning. Bayes Theorem simplifies the calculation of conditional probabilities and clarifies the features of the subjectivist position. Further according to Joyce the probability of a hypothesis $H$ is conditional on a given body of data $E$ and is the ratio of the unconditional probability of the conjunction of the hypothesis and the data to the unconditional probability of the data alone. Thus, the probability of $H$ conditional on $E$ is defined as

$$\mathbf{P}_E(H) = \mathbf{P}(H\&E)/\mathbf{P}(E), \quad (1)$$

provided that both terms of this ratio exist and **P**(E <0

Here:

$\mathbf{P}_E$ is a probability function.

If $E$ entails $H$, then $\mathbf{P}_E(H) = 1$.

If $\mathbf{P}(H) = 1$, then $\mathbf{P}_E(H) = 1$.

The Bayes Theorem relates the direct probability of a hypothesis conditional on a given body of data, $\mathbf{P}_E(H)$, to the inverse probability of the data conditional on the hypothesis, $\mathbf{P}_H(E)$.

$$\mathbf{P}_E(H) = [\mathbf{P}_{\boldsymbol{H}}(E)\, \mathbf{P}(H)]/\mathbf{P}(E) \quad (2)$$

Where:

$\mathbf{P}(H)$ is the prior probability of hypothesis $H$.

$\mathbf{P}_E(H)$ is the posterior probability of hypothesis $H$ (in the light of evidence $E$).

$\mathbf{P}_H(E)$ is likelihood of evidence $E$ on hypothesis $H$.

To evaluate Bayesian Networks, there are several software programs that have implemented the needed algorithms, e.g., SMILE (Structural Modeling, Inference, and the Learning Engine). SMILE is implemented in C++ in a platform independent fashion. SMILE is equipped with an outer shell, a developer's environment for building graphical decision models, known as **GeNIe** (Graphical Network Interface), a simple interface to SMILE, is a development environment for building graphical decision-theoretic models. It enables promoting decision-theoretic methods in decision support systems. It has been developed at the Decision Systems Laboratory, University of Pittsburgh (Bayes fusion, 2016). According to them the structure of a GeNIe network is a graphical, qualitative illustration of the interactions among the set of variables that it models. Nodes are usually drawn as circles or ovals. The network also represents the quantitative relationships among the modeled variables. Numerically, it represents the joint probability distribution among them. This distribution is described by exploring the probabilistic independences among the modeled variables. Each node is described by a probability distribution conditional on its direct predecessors. Nodes with no predecessors are described by prior probability distributions. Both the structure and the numerical parameters of a Bayesian Network can be elicited from an expert.

As experts individually assess the probabilities, the sessions produce multiple probability tables for the variables. Separate Bayesian Network models are built based on the assessments of each individual expert. In addition to the individual expert models, the experts' answers are to be combined with linear opinion pooling and applying equal weights for each expert, creating a simple but robust and well-performing method for combining multiple expert judgments into one single judgment (O'Hagan et al., 2006).

BN has been widely applied to problems in medical diagnosis, map learning, language understanding, and many other fields including shipbuilding (Lee et al., 2009). However, as very few process/management problem BN models have been published, their application to the cruise shipbuilding process description or its evaluation is still unresolved (Aurelio de Oliveira et al., 2012). In more recent years, however, BNs have been applied to several maritime-domain related studies (Eleye-Datubo et al., 2006; Antao et al., 2008; Kelangath et al., 2011; Hänninen & Kujala, 2012; Martins & Maturana, 2013; Montewka et al., 2013; Lehikoinen et al., 2013; Hänninen et al., 2013; Akhtar & Utne, 2014; Montewka et al., 2014; Goerlandt & Montewka, 2014; Hänninen & Kujala, 2014; Hänninen et al., 2014). Most of the aforementioned studies came from The Maritime Risk and Safety research group at Aalto University quite recently. Based on those results, one can argue that BN is an effective tool for modeling complicated systems, which also encourages the use of BN for modeling the cruise ship building process.

## 2.6 Description of other methods used in this thesis

**Observation** was the method utilized for defining the variables for the model. According to Taylor-Powell and Steele (1996), observation provides an opportunity to document activities, behavior and the physical aspects without having to depend on the willingness and ability of any others to respond to specific questions. They argue that observation is a good tool when trying to understand an ongoing behavior, process, unfolding situation or an event. Also, observing the management operations and procedures may provide better information than relying on reports. They add that recording the observations can be done in various ways such as keeping checklists, photos, and field notes.

The use of observation here was based on the vast experience of the researcher after having held various positions at a shipyard over the course of a long period of time. The matters observed were activities which will impact production efficiency as such or in any later stage of the process. This observation was done on every phase, starting from the time when an owner's inquiry is received in the shipyard until ship delivery. Also, the typical causes of inefficiency in each phase were noted. In addition to this, other typical problems related to efficiency in the cruise ship production process were reviewed.

According to Koch (2011), the 80/20 **Pareto principle** states that there is an inbuilt imbalance between causes and results, inputs and outputs, and effort and reward. Typically it can mean that 80 percent of consequences flow from 20 percent of causes. To find the essential factors affecting to production efficiency, Pareto principle was used. On that basis, the amount of potential variables found through observation was reduced by selecting the most important variables relating to production efficiency. Afterwards, a portion of those factors were chosen as model variables for the model.

# 3. Material analysis and research related to Bayesian model use for cruise shipbuilding process production efficiency

### 3.1 Creation of the model

In order to study the impact of organization type to production efficiency, a model of the cruise shipbuilding process is required. The intention is to build a Bayesian Network model for a process resulting in the probability of agreed property at the end of a particular process. Herein that process is cruise shipbuilding and the targeted result is a settled production efficiency level. The aim is to clarify whether the organizational structure used to manage that process impacts this probability, so the level of efficiency itself is not thus the focus here. The effect of organizational structure can be studied using the model by applying a decision formula that contains different types of organizational structures. The core part of the model is to determine the variables in question, define their states, and identify the dependencies between them.

**Variables**

In this study, the process in question is a cruise shipbuilding process in a shipyard that has built several big cruise ships. An illustrative visual presentation of that process is shown in Figure 2 and Figure 3. It is necessary to understand the entire cruise ship building process starting with the project design phase before any contract until the delivery of the vessel. The variables related to production efficiency were discovered during a review of the process. This process was studied phase by phase, starting from the time when an owner’s inquiry is received in the aforementioned shipyard.

Six main phases can be observed in this process: *Project design*, *basic design*, *detail design*, *hull building*, *outfitting*, and *commissioning*. Of the above *project design* begins before the contract is signed, that is, while the vessel concept is still being defined. Simultaneously to all the aforementioned phases, the planning process is ongoing. The planning process consists of defining the building practices, milestones, schedules, resource planning, reporting, and certain supportive activities. Project management continues during the entire process as well.

This review was based on the vast experience of the researcher after having been involved in building several cruise ships and being responsible for various processes ranging from design, purchasing, production, quality and planning to an actual project manager. When the researcher was working in design planning, the process for *basic design* and *detail design* was reviewed and the everyday challenges of the process were met. During the purchasing period of subcontracting and interior material and TK-contracts, the essential features of the purchasing process were handled to show the importance of clear scopes and purchasing schedules. Being given the responsibility of the interior outfitting manager finally demonstrated the complexity of building cruise ship cabin areas and public areas for passengers and crew, while at the same time taking care of the inspections and commissioning of the hotel part of the ship. The role of the quality manager in outfitting deepened the importance of having a clear understanding of the key processes involved. A project planner is responsible for the plan of the whole project from *project design* to actual delivery of the vessel. Working as a project manager on cruise ships further increased the researcher's knowledge of the various interdependencies that must combine all the individual activities into one complicated and complete entity.

The method that was utilized for this study was observation. Every main phase was first analyzed by clarifying the steps in the activity flow diagram. Then the inputs and outputs of these steps were identified. After that, the whole process, including *project design, basic design*, *detail design*, *hull building, outfitting,* and *commissioning* was investigated as an entity of thinking which factors impact production efficiency either directly or indirectly. The failure analysis, i.e. a review of the possibilities that can cause inefficiency, resulted in the gathering of a number of items. They were reviewed and the reasons behind them were clarified. Also, typical problems related to scheduling and efficiency during the cruise ship production process and the reasons behind those issues were also reviewed.

Based on observation during the researcher's experience in different parts of the process, the typical outcomes that resulted from activities in *project design* leading to inefficiency at some stage can be:

- technical calculations are not reliable,

- rules have not been followed,
- specification is incoherent, unclear, expensive and contains risks,
- a supplier network has not been checked and confirmed,
- owner demands have not been followed,
- general arrangement is unclear and constricted,
- cost calculations not based on building strategy and confirmed cost elements, and main milestones and work load studies are unrealistic.

In the *basic design* phase, the typical outcomes leading to inefficiency at some stage can be:

- faulty calculations,
- poor classification design,
- inadequate system process descriptions,
- delayed architectural design,
- delayed purchasing activities,
- unclear supplier scopes,
- a wrong work load plan,
- a faulty *basic design* schedule and inadequate building practices and poor schedule and module plan.

In *detail design* phase, the typical outcomes leading to inefficiency at some stage can be:

- poor design coordination,
- unclear drawings,
- faulty parts lists,
- insufficient number of standards,
- delayed purchasing,
- an ignored area/system relationship,
- non-specific job orders.

In *hull* phase the typical outcomes leading to inefficiency at some stage can be:

- inadequate strength and vibration analysis,
- delayed opening information from the *outfitting* design,
- poor dimensional accuracy,
- poor welding quality,
- poor loading plan for heavy lifts and modules,
- non- synchronized hull services,

- low block *outfitting* rate,
- delays in the production schedule and material delivery.

In the *outfitting* phase, the typical outcomes leading to inefficiency at some stage can be:

- low prefabrication and modularization rate,
- low block/ grand block *outfitting* rate,
- unclear responsibilities,
- wrong work order,
- wrong document revisions,
- material delays,
- delayed system work effort.

In the *commissioning* phase, the typical outcomes leading to inefficiency at some stage can be:

- inspections not done in connection with the actual work,
- delayed system readiness,
- unclear scope and role of the suppliers,
- an inadequate inspection plan and program.

Generally delays in schedule and incompetence cause inefficiency in phases of the process. All of the above failure possibilities lead to different consequences later in the process, and therefore need to be corrected before the delivery of the vessel. Executing these corrective actions can add several additional tasks to the original plan, which means extra time spent on the delivery and therefore, greater cost.

Every detailed phase of the shipbuilding process was thus analyzed by clarifying the inputs and outputs, the content and what can cause inefficiency either during each unique phase or when entering into the production phase. Following the completion of this analysis,, the mapped process was reviewed by considering which activities will impact production efficiency in any later stage of the process. This evaluation was done on every phase and activity in the described process. Afterwards the typical causes of inefficiency in each phase were noted and clarified. Additionally, other typical problems related to scheduling and efficiency in the cruise ship production process and their causes were reviewed.

On that basis, the factors that could potentially affect production efficiency were chosen for a closer review using Pareto (Koch, 2011). According to that evaluation, 20% of sources cause 80% of the problems, which leads one to concentrate on the causes that will have the greatest impact on the process if satisfactorily remedied. Afterwards, a portion of those factors were chosen as model variables for the respective sub-models and the main model as described in Section 3.2. Because there was a rather large number of candidates, only the most evident ones were considered for the model. Due to the large number of variables needed for the model structure, an initial clustering of these variables had to be executed. These clusters were named using to the aforementioned main phases as the sub-models of the cruise shipbuilding process, namely *project design, basic design*, *detail design*, *hull*, *outfitting* and *commissioning*. In addition, the model included a so-called "main model", that contained planning and project management activities and combined the sub- models into a single comprehensive entity.

**States of the variables**

The variables in this model are discrete, meaning that they can take values from a set of states. For every variable, two states were determined. These states were chosen so that they best describe the status of production efficiency related to each variable in both the best and worst case scenarios. In other words, describing the feature of the variable from production efficiency point of view. For instance, the supplier network, in terms of production efficiency, it becomes meaningful whether the network is "good" or "poor". The good network means that the shipyard has reliable contractors who work according to the contracts in the best possible way. Further, when considering variable competence, the states are "high" or "low". The states can also describe the features of the variable in as specific way, e.g., the variable job order that has such states as "Defines the budget for specified work" and "Does not define the budget for specified work". This definition means that first state is better for production efficiency because it gives a clear target for the person and therefore enabling better efficiency. The states for all the other variables were determined by applying this same principle. It is important that the experts understand the nature and content of the states correctly, because these definitions form the basis for the elicitation.

In this phase, the variables and their states were documented and entered into the GeNIe software by a Bayesian Network expert who properly guided the building of the network system wise. Figure 13 shows the principle.

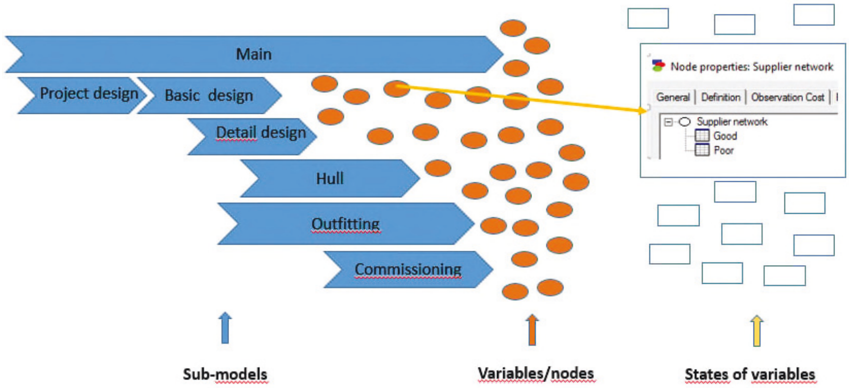



**Figure 13**. States of variable Supplier network.

The variables and their states are explained in detail in Section 3.2.

### Interdependencies

Based on experience with the processes and the relationships between the variables, the arcs between the model variables were determined to show their dependencies. To avoid an overly complicated model, only those dependencies assumed as the most important ones were modeled. The dependencies of these variables are explained in Appendix 1 and were added to the GeNIe model by the Bayesian expert who checked the proper technical structure of the model.

### Decision formula

To utilize the model to study the effects of organizing the process, one decision variable was added to the model, organization type, which reflected the organizing method for the shipbuilding process precisely. The type of organization states are Project Organization, Line Organization or Hybrid Organization. Hybrid Organization means that the project is partly controlled by the project group and partly by the line organization. The presentation of these organization structures can be found in section 2.3. All three mentioned organization structures have been used in the shipyard in question for the last 30 years when cruise ships have been built.

The first state is a basic line type of organization, which normally has a vertical hierarchy between its different organizational levels. Typical line departments in shipyard are sales, design, procurement, and production. In a Line Organization, control of a project is divided between main departments and the shipyard director is responsible for fulfilling the ship contract. In this case, the role of the project manager is to take care of the owner interface. Decisions that affect costs, scheduling, and quality are all made in these functions, i.e., the departments.

Alternatively, a Project Organization is established to take care of specific projects by using teams of specialists from different functional areas within the organization. This is the next state. After a project is completed, the Project Organization as such no longer exists. In a Project Organization, the named group of representatives from the main departments is responsible for taking care of the project for that part of and is also responsible for decisions concerning costs, scheduling, and quality. In cruise ship Project Organization a naval architect is also named as a project group member due to the large field of rules and regulations. The project group can also be nominated, so that the responsibilities of the project group members are based on, for example WBS (Work Breakdown Structure). The members of project group report to the project manager. The responsibility for fulfilling a ship contract belongs to the project manager along with the project group.

Finally, the project can be conducted within a Hybrid Organization, a matrix, which in this study means that organizational structure responsibilities concerning the project are divided between the Line Organization and the Project Organization. Typically, this process is carried out so that the main functions, i.e., departments have the responsibility for technical contents and costs, while the project group is responsible for the scheduling and the owner interface. These decisions are made together with the line managers and the project manager.

The most important aspect of the model is determining which variables this decision formula will impact. After being responsible for a production department in a shipyard that was acting as line organization , as well as having been involved and responsible for several project groups in different cruise shipbuilding projects, these dependencies were determined based actual practical experience of the researcher.

### Elicitation of the variable probabilities in the model

To specify the probability distribution of a Bayesian Network, expert judgment is needed. In the model that means that the conditional probability tables, i.e., the model parameters, were specified by experts using judgment. The qualification requirement for being an expert was possessing broad knowledge and experience with the shipyard in question cruise shipbuilding process and also understanding the procedure undertaken for the elicitation of those probabilities. The experience needs to be in the cruise ship building process, coming from different disciplines such as design, purchasing, production, management and project management for several cruise ship projects to clearly understand the dependencies, reasons, and consequences in the shipyard under review. Experience is needed in several different kinds of situations in order to be able to see the entities and reason- consequence-relationships in the broadest way. After carefully considering three experts who had worked continuously for about 30 years in this specific shipyard and determining they were qualified, they were asked to provide their opinions and views on the suggested parameters. Before eliciting the model content itself, including nodes, their parameters, links and discretizing were discussed with the experts. Based on their opinions and comments the model was updated so, that the consensus of the model was achieved. The experts agreed that the model responded to the actual process.

The first expert, Expert A in the following, had 30 years' experience in shipbuilding at the shipyard. This experience consisted of purchasing, quality management, interior outfitting production, planning, and project management. The first elicitation session featured Expert A and a facilitator, the Bayesian expert. The facilitator first briefed Expert A. In practice, the preparation for the actual probability elicitation was also conducted. Background material on the probability concept and any potential biases regarding expert elicitation was sent to the expert before the session. In the beginning of the elicitation session, the same matters were again introduced to the expert. Also, the purpose, content, and motivation for the elicitation were explained. The expert then conducted a brief calibration assessment to become aware of the potential tendencies toward biases when following the technique proposed for an elicitation situation (Simola et al., 2005).

For the elicitation, a direct probability estimation method was applied. For this purpose, the option to visualize the probabilities as bars, available in the GeNIe BN software (SMILE, Druzdzel, 1999), was utilized. Every node was judged by experts. After activating the node definition in GeNIe, the dialog box presented in Figure 14a displays where the probabilities of occurrence of each of the states can be entered. As the variable Supplier network has no parents, the elicitation is based straight on the experts' view for which state for the variable is more probable than other. As each variable consisted of two states, the actual elicitation was the expert assessing which state was most probably true and to what extent it was true.

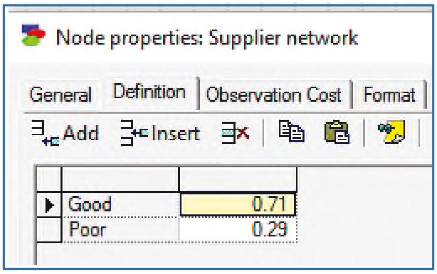



**Figure 14a**. The screenshot of GeNIe: A numerical elicitation of the "supplier network" variable with no parents between the states "good" and "poor".

The other option is to make the elicitation by visual tool as presented in Figure 14b.

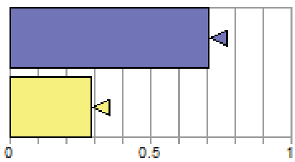
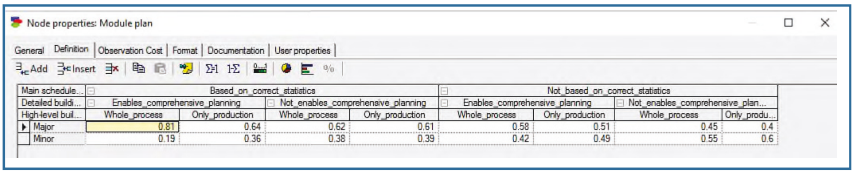



**Figure 14b**. The screenshot of GeNIe: A visual elicitation of the "supplier network" variable between the states "good" and "poor".

Figures 14a and 14b show that the expert decided that a state "good" (blue) was a more probable state than "poor" state for the supplier network with probability values 0.71 / 0.29.

If the node has parents, it creates conditional options and the elicitation becomes more complex. The more parents there are, the more complicated the elicitation is. Figure 15 shows the node Module plan, which has three parents: (1) the main schedule with main milestones; (2) the detailed building practice; and (3) high level building practice. The judgment was done for every separate case shown in the table by assessing which of the states, either Major or Minor, were more probable and how much so in each case. For example, is it more probable to have a Major module plan in the case where the Main schedule with milestones is based on correct statistics and where detailed building practice enables comprehensive planning and the whole process is included in a High level building practice. The results can be seen in the left side columns, which indicate that the Major module plan is true with a probability of 0.81 against the Minor plan is true with a probability of 0.19.



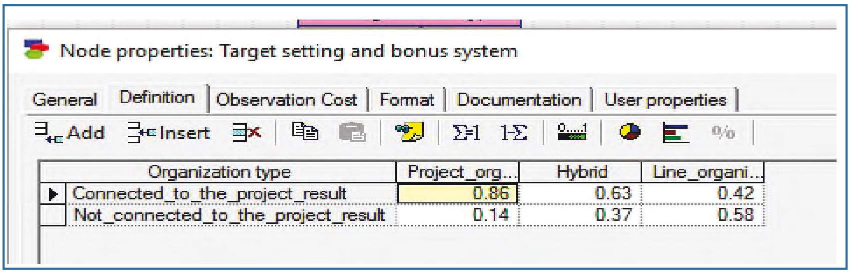
Node properties: Module plan

General | Definition | Observation Cost | Format | Documentation | User properties

| Main schedule... | Based_on_correct_statistics | | | | Not_based_on_correct_statistics | | | |
|---|---|---|---|---|---|---|---|---|
| Detailed buildi... | Enables_comprehensive_planning | | Not_enables_comprehensive_planning | | Enables_comprehensive_planning | | Not_enables_comprehensive_plan... | |
| High-level buil... | Whole_process | Only_production | Whole_process | Only_production | Whole_process | Only_production | Whole_process | Only_produ... |
| Major | 0.81 | 0.64 | 0.62 | 0.61 | 0.58 | 0.51 | 0.45 | 0.4 |
| Minor | 0.19 | 0.36 | 0.38 | 0.39 | 0.42 | 0.49 | 0.55 | 0.6 |

**Figure 15.** The screenshot of GeNIe: A conditional probability table

Whenever the decision formula impacts the variable, it can be seen in the conditions table. If there are no parents, as seen in Figure 16, then the case is simple. But if there are parents, then the judging becomes more complicated especially when in addition to organization type, several parents impact the variable. Figure 16 shows a node where the decision formula has an impact. In this case, there are no parents, and thus the case is simple.



Node properties: Target setting and bonus system

General | Definition | Observation Cost | Format | Documentation | User properties

| Organization type | Project_org... | Hybrid | Line_organi... |
|---|---|---|---|
| Connected_to_the_project_result | 0.86 | 0.63 | 0.42 |
| Not_connected_to_the_project_result | 0.14 | 0.37 | 0.58 |

**Figure 16**. The screenshot of GeNIe: A node with decision formula impact.

For each variable, parent, and decision formula combination, the expert and the analyst adjusted the bars together until the expert was able to provide the most accurate probability representation. The software was utilized as is, as no changes were required.

The eliciting process had the expert consider the different probabilities based on the expert's experience in three different organizational structures over the course of several years spent at the shipyard. The expert had to judge which of the states is more true and how much more true taking into account the conditions defined by the predecessors. The Facilitator and Expert A undertook the elicitation together. Elicitation was done in sessions of one sub-model at a time.

The elicitation with Expert B was done separately with Expert A serving as the facilitator. Expert B had 32 years' experience in shipbuilding. That experience consisted of purchasing, engineering, planning, project management, sales, and shipyard management. Initial guidance regarding expert practice elicitations was given to Expert B by Expert A. The elicitations were done in three sessions. The first session addressed the elicited *project design*, *basic design*, and *detail design*. The second session included *hull*, *outfitting*, and *commissioning*. The last session elicited the main model from the expert. Expert C had 32 years' experience in shipbuilding consisting of research and development, purchasing, design management, working on several cruise ship project groups, production development, and sales. The procedure for the Expert C elicitation was similar to that of Expert B.

The total amount of the individual judgments for the probabilities in this model was 5610 with the variables having two states. These values are seen in Appendix 2, which describes the extent of the elicitation work. If there were additional states, they would complicate the process and broaden the judgment considerably wider.

As these experts individually assessed these probabilities, the sessions produced multiple probability tables for the variables. Separate Bayesian Network models were elicited based on the assessments of each individual expert. After this, the experts' answers were combined with linear opinion pooling and applying equal weights for each expert into one single judgment (reference to formula (3)) (O'Hagan et al., 2006). It is a simple and widely used technique. There, a consensus distribution $f(\theta)$ is obtained as some function of the individual distributions $\{f_1(\theta), \ldots, f_n(\theta)\}$, with the consensus distribution then used for decision-making purposes.

The simplest such function is the linear opinion

$$f(\theta) = \sum_{i=1}^{n} w_i f_i(\theta), \tag{3}$$

which just a weighted average of the individual distributions with weights $w_i$ summing to 1. For instance, the decision maker may choose to give each expert equal weight, so that $w_i = 1/n$ (for all $i$) and $f(\theta)$ is the simple average of the $f_i(\theta)$s.

## 3.2 The structure of the model

The model is not a process description of the cruise shipbuilding process; rather it is a network of factors that then together through the mechanism of interactions affect the production efficiency of the cruise shipbuilding process (Hellgren et al., 2016). The cruise shipbuilding process contains numerous activities and interdependencies and it is not easy to find the most important issues affecting production efficiency. This model helps to identify those factors in the process and dependencies between them. It enables one to focus on the essentials when improving the production efficiency.

The model consists of six sub-models and a main model that compiles the sub models into a single entity. The sub-models reflect the main disciplines of the process, which are *project design*, *basic design*, *detail design*, *hull, outfitting*, and *commissioning*. The main model also reflects planning- and project management-related factors. There is also one decision variable in the model called "Organization type". It represents the different methods that can be used to organize and manage the cruise ship building process. Altogether, there are 85 random variables called nodes in the model. Every variable has two states. The states of these variables have been determined depending on the individual variable and its nature and the consideration on its production efficiency aspect. In addition, the decision variable has three states.

The structure of the model is presented in detail in Appendix 1. Figure 17 shows the overall dependencies between the main model variables and the sub-models. The green rounded rectangle represents the sub-models, and the yellow ovals are variables. A red rectangle indicates the decision variable.

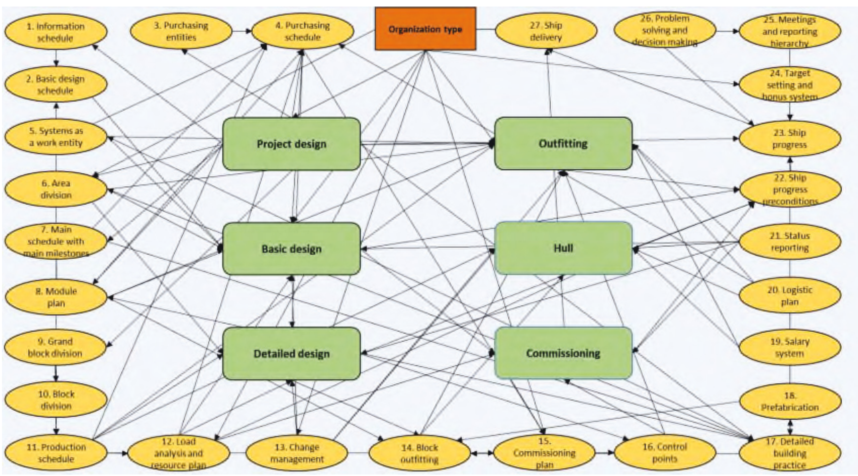



**Figure 17.** The main model for the cruise ship building process for production efficiency.

Appendix 1, Table 1.1, presents the description of all the main model variables, their parents, children, and states together with a short description of each variable. Appendix 1, Table 1.2 includes a description of the sub-model "*project design*" with its variables, their parents, children and states together with a short description of those variables. Appendix 1, Table 1.3 contains, respectively, the description of the sub-model "*basic design*". Appendix 1, Tables 1.4, 1.5, 1.6 and 1.7 describe the sub models, the "detailed design", "*hull*", "*outfitting*", and "*commissioning*", in a similar manner.

The model shows the structure of the production efficiency-related variables in the context of the studied shipyard. A comparison of the effect of different organizational options is presented using the decision formula. The use of the model requires that there are qualified experts who have the necessary experience of the whole process and all the alternative organization circumstances in question for a long enough time span.

The **sub-model project design** shown in Figure 18 includes 12 nodes.

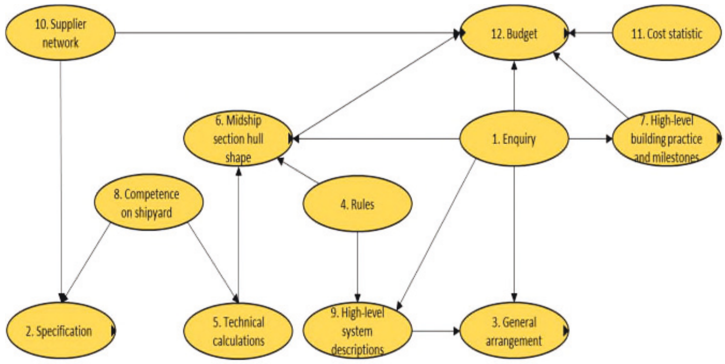



**Figure 18**. Project design network for the model

The variables chosen for *project design* phase have either a direct or an indirect impact on production efficiency. See Table 1 below for details.

**Table 1**. Project design variables for the sub-model.

| | |
|---|---|
| **Enquiry** | Owner's enquiry to shipyard to deliver a cruise vessel is a variable in the sense of its accuracy. This means that the more detailed the enquiry; the more it may restrict that shipyard possibilities to use its own effective working methods. The general specification makes it possible to use freely working methods typically used at the shipyard. States are Detailed and General. |
| **Specification** | Specification is a document, which defines the technical and architectural contents of the ship with respect to complexity. If the specification is complicated, then the design and actual work is complicated. If the specification is easy and clear, it becomes possible to execute the work clearly and efficiently. States are High complexity and Low complexity. |
| **General Arrangement** | General arrangement defines the layouts of the decks of a ship. If GA is clear and open it is possible to work efficiently without difficult shapes and a tightly packed working place. States are High complexity and Low complexity |
| **Rules** | Rules define the technical conditions to be followed in the structures and operation. Depending on the complexity of rules the structures can be in a production phase more or less production friendly. States are High complexity and Low complexity |

| | |
|---|---|
| **Technical Calculations** | Calculations form the theoretical basis for defining the actual technical properties. The more reliable the calculations are, the more clearer and efficient are the phases coming afterwards (*basic design ->detail design ->hull -> outfitting*). States are High reliability and Low reliability. |
| **Mid ship Section Hull Shape** | Defines the essential part of the ship's steel hull. The complexity of the mid ship section impacts the production efficiency of the *hull*, as complex structures cause inefficiency. States are High complexity and Low complexity. |
| **High-level System Descriptions** | The system's functional description presents the main features of its functionality. The content can be clear and simple or unclear and complicated, thus impacting the productivity of the entire process. This leads to the statuses High clarity and Low clarity. |
| **Competence of Shipyard** | The level of know-how is a variable that affects the effectiveness of the *project design*. If the know-how is a high level, it becomes evident, as the effectivity of the work is greater. If there is a need for subcontracting, that circumstance creates inefficiency because the know-how in this phase is crucial and also NDAs (Non-Disclosure Agreements) are demanded. Here the states are High and Low. |
| **High-level Building Practice and Milestones** | Building practice defines the main principles of WBS structure, i.e., how design, purchasing and building the ship are controlled. This variable indicates the overall comprehensiveness of planning. Comprehensive planning enables better productivity than doing it separate planning. States are Whole process and Only production. |
| **Supplier Network** | The quality and diversity of accepted design, components, materials, subcontracting, and turnkey contractors is a variable that has a big impact on resources and thus on productivity. The state of a network can be described within respect to quality and diversity. States are Good and Poor. |
| **Cost Statistic** | For calculation purposes unit prices of cost elements of the ship are used. The validity of the cost elements is crucial when setting a cost target. So, the reliability of this variable affects the realistic basis of a budget and through that motivation keeping the targets. States are the good and poor reliability of Key Performance Indicators. |
| **Budget** | The prime cost that corresponds the specification, mid ship section and GA will be the budget. The budget variable describes the WBS-based target of responsible persons and thus connects costs to WBS. Whether the target is realistic and achievable or not |

| | |
|---|---|
| | it influences productivity, which suggests that the budget and work breakdown structure are corresponding. States are Enabling a realistic target and Not enabling a realistic target. |

**The sub-model basic design** includes 11 nodes. See Figure 19 below.

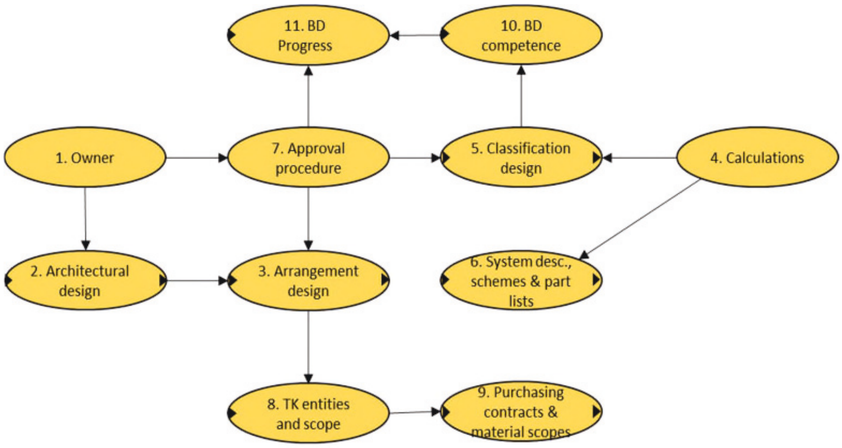



**Figure 19**. Basic design network for the model.

The variables chosen for the *basic design* phase will have either a direct or an indirect impact on production efficiency. See Table 2.

**Table 2.** Basic design variables for the sub-model.

| | |
|---|---|
| **Owner** | The activity of the owner can influence the shipyard's daily work. The more the owner participates in the daily activities, the more that can lower productivity due to numerous inspections and demands for clarifications. States are High activity and low activity. |
| **Architectural Design** | If the architectural design is the responsibility of the owner it influences productivity. Owner works according to their own schedules, which does not necessarily comply with the production phase schedule of the shipyard. Also, if the architectural design is the responsibility of shipyard, then production friendliness can be taken into account in a more efficient way. States are High production friendliness and Low production friendliness. |

| | |
|---|---|
| **Arrangement Design** | The layout design of the interior and machinery areas can be done so both the production friendliness of these structures and the working space onboard are taken into account. Both of these aspects impact production efficiency. States are High complexity and Low complexity. |
| **Calculations** | Calculations deliver a theoretical basis for the technical properties. The more reliable the calculations are, the clearer and more efficient will be the phases coming after (*detail design* ->*hull* -> *outfitting*). States are High reliability and Low reliability. |
| **Classification Design** | In classification design, the dimensions of the steel structures are defined. The more it is possible to use recurrence in these structures, the more efficient will be the *detail design* and production. States are High recurrence in structures and Low recurrence in structures. |
| **System Descriptions & Schemes & Parts lists** | Complexity of systems and their expression influences production efficiency because it is the basis for the detailed design for all the vessel. If there are ambiguous and not clear details in the system design, the detail designers will need to clarify them at a later stage. Also, if details are clear in the *basic design*, production can be more efficient and need no additional clarifications. States are Unambiguous and Ambiguous. |
| **Approval Procedure** | If the process for how the classification society and the owner give their approval for any specified documentation is time consuming and difficult, there can be delays in the design schedule and thus inefficiency in the production phase. If the approval activities are scheduled into the design schedule, it will be easier to see their overall influence on the latter phases of the project and prevent such delays. Statuses are a Whole process scheduled in the basic design schedule and a Whole process not scheduled in the basic design schedule. |
| **Turnkey Entities and Scope** | Basing both scopes and borders of turnkey deliveries on a work breakdown structure is a more efficient way of controlling both because then they are a natural part of the entire control system. Also, when the borders follow the functional entities onboard, more efficiency is achieved. States are Functional entities, based on the work breakdown structure and Not |

| | |
|---|---|
| | functional entities, which are not based on the work breakdown structure. |
| **Purchasing Contracts & Material Scope** | When the scope of suppliers are based on a work breakdown structure and are not dependent on the progress of other suppliers or shipyard work, the commercial terms are bound to their own progress which creates more effectivity. States are Independent entities with progress- related payment terms and Dependent entities having no progress-related payment terms. |
| **Basic Design Competence** | The level of know-how is a variable that affects the effectiveness of the *basic design*. If the know-how is a high level, it is evident that effectivity of the work is better. Any need for subcontracting creates inefficiency because of borderlines. Solid know-how in this phase is crucial and NDAs complicate this. The states are High and Low. |
| **Basic Design Progress** | Normally when the work is done according to the schedule with adequate resources, there is better efficiency than having delays and struggling with them. When delays occur, catch up activities have to be established to keep to the schedule, which creates inefficiency and additional costs. States are In schedule and In budget and Delays and/or budget overruns. |

**The sub-model detail design** includes 13 nodes. See Figure 20.

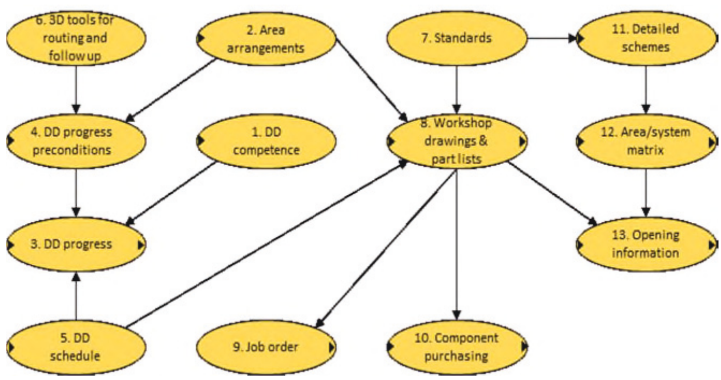



**Figure 20**. Detail design network for the model.

The variables chosen for the *detail design* phase have either a direct or an indirect impact on production efficiency. See Table 3.

**Table 3**. Detail design variables for the sub-model.

| | |
|---|---|
| **Detail Design competence** | The level of engineering know-how available in shipyard affects productivity directly because skillful and experienced designers can do their work more effectively and with fewer issues. States are High and Low. |
| **Area Arrangements** | Layout of areas impacts productivity during the *outfitting* phase onboard. Depending on the layout, it is either easy or not easy to plan different ongoing work simultaneously there. States are Enables planning of sub-areas for better effectivity and Does not enable planning of sub-areas for better effectivity. |
| **Detail Design progress** | When detailed design documents are done according to the schedule, that success enables better productivity. Work preconditions exist if no delay occurs. States are In schedule and In budget Delays and budget overruns. |
| **Detail Design Progress Preconditions** | When *basic design* is proceeding according to plan, it enables DD to proceed effectively. If budget enables a realistic target for design teams, there are possibilities for support productivity to increase. States are Good and Poor. |
| **Detail Design schedule** | The design documents are produced according to the detail design schedule. If the need of the documents is connected to the production schedule and they are met accordingly, productivity in *outfitting* is helped because there are no delays in starting the work due to missing drawings or materials. States are Need is based on the respective production phase and Need is not based on the respective production phase. |
| **3D Tools for Routing and Follow-up** | With the help of an integrated 3 D design system with standards and material components in an electronic format it is possible to prepare a design effectively including the routes of pipes, ducts and cables. Also connecting actual work readiness to the system enables additional effectivity of the *outfitting* work as commission preconditions. States are In use and Not in use. |
| **Standards** | The more ready-made standards there are for materials and for working details, the better the efficiency that can be achieved. Working standards for installation ease design and also make the training of workers easier. States High extent and Low extent. |
| **Workshop Drawings & Parts Lists** | When the design documentation for manufacturing and installation is done as corresponding entities to the |

| | |
|---|---|
| | production, it contains all essentials, is clear, and it enables the logical scheduling of items and purchasing entities. The tighter the connection is between detailed design and production, the more efficient will be the process. States are Unambiguous and Ambiguous. |
| **Job Order** | With a job order, the work is prepared beforehand, so the worker can immediately start the work without studying what it is about and whether all needed materials are available. When a piece of work is prepared in advance, it can include description as the instructions for the worker and also an estimate or budget for the worker and make the process thus more efficient. States are Defines the budget for specified work and Does not define the budget for specified work. |
| **Component Purchasing** | If there is a possibility to purchase materials via competition, getting the best product with the best price and the right time is easier. This process also affects to productivity. To be able to do this task there needs to be enough time for it. States are Possibility for competition and No possibility for competition. |
| **Detailed Schemes** | When the systems' schemes are properly finalized, so additional working drawings are not needed. There is greater productivity because design work time is saved. States are Can be used as working drawings and Cannot be used as working drawings |
| **Area-system Matrix** | After designing the routing of systems, the area system matrix can be published. It defines the areas where different system pipes, etc., pass. Using this matrix makes it easier to identify the key points of *commissioning* and helps to concentrate on essential work thus speed up the *commissioning*. States are In use and Not in use. |
| **Opening Information** | It is efficient to make the holes and openings needed for penetrations, doors, windows, etc. during the plate preparation phase in steel production. Information about openings and penetrations to *hull* design is needed at an early stage and needs a dedicated process that takes care of scheduling of the design and communicating the information on *hull* design. States are Known process in use and Known process not in use |

**The sub-model hull** includes 6 nodes. See Figure 21 below.

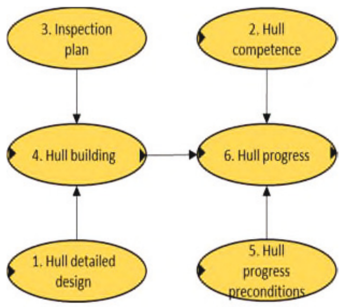



**Figure 21**. Hull network for the model.

The variables chosen for *hull* phase have either a direct or an indirect impact on production efficiency. See Table 4 below.

**Table 4**. Hull variables for the sub-model.

| | |
|---|---|
| **Hull detailed design** | Hull workshop drawings are based on the classification design, various calculations, and standards. The information from *outfitting* in the form of area layout and openings is also the starting information. The more possible it is to use standard structures in *hull* design the more efficiency can be achieved. States are Standard solutions in use and Standard solutions not in use. |
| **Hull Competence** | A level of know-how is needed for successful execution of welding. The competence of welders has direct impact on productivity. States are High and Low. |
| **Inspection Plan** | When the plan of inspections for securing the correct quality is a normal part of the production process, it can be taken into account when creating the production schedule. It also makes it possible to start corrective actions early enough when defects do occur. The earlier the corrections are competed, the more effective it will be when targeting agreed upon building accuracy. States are Integrated to production schedule and Not integrated to production schedule. |
| **Hull Building** | The better the building accuracy is during the steel work process, the more effective will be the *hull* assembly. If the accuracy is not good, a lot of fitting work will be needed in the grand block assembly and *hull* assembly phases. This need has a direct impact on effectivity and also causes delays in the schedule. States are High amount of fitting work in *hull* assembly and Low amount of fitting work in *hull* assembly. |

| | |
|---|---|
| **Hull Progress Preconditions** | When the conditions for *hull* work exist, there is also better production effectivity. Having working drawings, materials, and work procedures in place is just a matter of competence to achieve productivity. Here motivation is seen as a driver. If the budget enables a realistic target for teams and there are possibilities for a supporting salary system, productivity can increase. States are Good and Poor. |
| **Hull Progress** | When the work is done according to the assigned schedule with adequate resources, there is better efficiency than having delays and struggling with catch-up plans. Keeping to the schedule also makes it possible to stay within budget. States are In schedule and in the budget and Delays and/or budget overruns |

**The sub-model outfitting** has 10 nodes. See Figure 22 below.

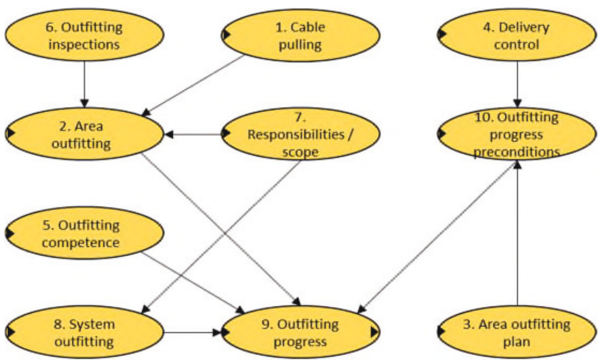



**Figure 22**. Outfitting network for the model.

The variables chosen for outfitting phase have either a direct or an indirect impact on production efficiency. See Table 5.

**Table 5**. Outfitting variables for the sub-model.

| | |
|---|---|
| **Cable Pulling** | If pulling of the cables is not done according to schedule, it will cause a delay for later phases making it very difficult to catch up. Especially, the main cables play an important role in keeping to the critical path. Interior work is dependent on cable work and also the *commissioning*. The better the accuracy of keeping the schedule the better will be the |

| | |
|---|---|
| | productivity.  States are Scheduled to production schedule as preconditions for area work and Not scheduled to production schedule as preconditions for area work. |
| **Area Outfitting** | Area-based *outfitting* is a work entity. If *hull* work and block *outfitting* is proceeding according to schedule, main cable pulling is done according to the schedule, job orders define the short term work, resources are available, and the necessary coordination is available, so effectivity improves. If inspections have been planned to be part of the work they do not cause surprises. States are Outfitting is done in a correct order and Outfitting is not done in a correct order. |
| **Area Outfitting Plan** | If area *outfitting* has a realistic schedule with correct dependencies on the *commissioning* and the prerequisites have been identified and taken into account in their respective schedules, it is possible to plan the work in the area effectively (the design documentation exists, delivery control makes correct material deliveries etc. ). States are Comprehensive and Limited. |
| **Delivery Control** | Control all purchasing contracts, including material, work, and turnkey, whether there are regular follow-up and catch-up activities for keeping to the schedule. Lack of material causes ineffectiveness. States are Deliveries on time and Delays in deliveries. |
| **Outfitting Competence** | The level of know-how needed for execution of *outfitting*. In *outfitting* the possibility to train multi-talented outfitters would increase effectivity. States are High and Low. |
| **Outfitting Inspections** | Plan for inspections produce the correct quality. Because inspections are an essential part of the process, the time needed for them and any possible repair work must be taken into account when making the schedule. States are Integrated to production schedule and Not integrated to production schedule. |
| **Responsibilities/Scopes** | The work is efficient when everybody knows their jobs and roles are clear. Due to the large amount of different parties building in the areas and the impacts from outside the area, it is most important to have good coordination in the work place. The main |

| | |
|---|---|
| | responsibilities should follow the WBS and the division of responsibilities regarding discipline. This is also the basis for target setting for time and cost. WBS target setting against a budget produces concrete goals and improves effectivity. States are WBS-based target setting and Not WBS-based target setting. |
| **System Outfitting** | If systems are built as a work entity, it becomes more effective to build and control, as the technical details remain the same no matter in which area. Also, there are better prerequisites for *commissioning*, as status follow-up is clear. States are System is built ship-wide by a single team and System is not built ship-wide by a single team. |
| **Outfitting Progress** | Actual readiness of *outfitting* work. For keeping efficiency high in the planned level, one should be aware all the time of actual progress and the cost status. Then it is possible to react quickly and repair any situation. If the work is delayed and there has to be a special task to catch up to the schedule, it creates inefficiency. Also if the budget has overruns, it is not possible to use resources as one should and that leads to even more inefficiency. States are In schedule and in budget and Delays and budget overruns. |
| **Outfitting Progress Preconditions** | When the conditions for *outfitting* work exist, there is better production effectivity. Having working drawings, materials and work procedures in place is just a matter of competence to reach productivity. Here motivation can be seen as a driver. If the budget enables a realistic target for teams, and there are possibilities to have a supporting salary system, productivity can increase. States are Good and Poor. |

**The sub-model commissioning** includes 6 nodes**.** See Figure 23 below.

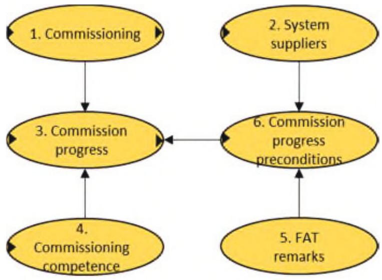



**Figure 23.** Commissioning**.**

The variables chosen for *commissioning* phase have either a direct or an indirect impact on production efficiency. See Table 6.

**Table 6**. Commissioning variables for sub-model.

| | |
|---|---|
| **Commissioning** | If the *commissioning* is planned according to WBS, the tests can be done in right order. *Commissioning* should be the driver when creating the production schedule. The more deeply the *commissioning* affects to building schedule, the more effective will be the process. States are Based on WBS and Not based on WBS. |
| **System Suppliers Scope** | The better the supplier's scope responds to the *commissioning* plan the more effective will be the work. States are Based on WBS and Not based on WBS. |
| **Commissioning Progress** | When *commissioning* is on schedule the process will be more effective. States are On schedule and In budget Delays and budget overruns. |
| **Commissioning Competence** | The level of know-how that is needed for the execution of *commissioning*. States are High and Low. |
| **FAT Remarks (open)** | If there are open FAT remarks when *commissioning* is ongoing, the work can be inefficient. States are High and Low. |
| **Commissioning Progress Preconditions** | When the preconditions are there the progress can be achieved which ensures the effectivity. States are Good and Poor. |

**The main model has 27 nodes.** See Figure 17**.** The main model includes the variables related mainly to planning and overall co-ordinating. The variables chosen to main co-ordination phase have either a direct or an indirect impact on production efficiency. See Table 7 for details.

**Table 7.** Main model variables for the model.

| | |
|---|---|
| **Information Schedule** | This schedule defines the order and schedule for design information needs during the *basic design* process. Integration with the purchasing schedule is important because a lot of information that is needed comes from the suppliers' equipment. States are Integrated into purchasing schedule and Not integrated into purchasing schedule. |
| **Basic Design Schedule** | Work is split and scheduled for a workload for all basic design documentation. The need for information is based on to the right work order serving later phases. States are Based on need of information and Not based on need of information. |
| **Purchasing Entities** | It is entities plan for purchasing A, B, and C materials, turnkey deliveries, design work, and subcontracting the *hull* and *outfitting*. When scopes of purchasing to be scheduled are based on work breakdown structure, effectivity is impacted. States are Based on WBS and Not based on WBS. |
| **Purchasing Schedule** | Purchasing schedule is the schedule for purchasing entities. It takes into account the time for preparing the enquiry, offering, commercial negotiations, manufacturing, and delivery time. Scheduling the purchasing of main equipment and material, the driver is in need of information. States are Based on WBS and Not based on WBS. |
| **Systems as Work Entity** | It defines which systems will be designed, purchased, outfitted and commissioned as ship-wide systems. Defines a system as a job ship-wise according to WBS. System work by one team is more efficient than that made by several teams. States are In use and Not in use. |
| **Area Division** | Area division defines the borders of the functional areas on ship decks that are controllable entities for design, purchasing, installation, and inspections. It defines the borders of outfitting work entities for WBS. If the areas are functional entities, then the work can be more effective. States are High functionality and Low functionality. |

| | |
|---|---|
| **Main Schedule with Main Milestones** | Main schedule defines the 6-10 main milestones (start of the *basic design*, start of the *detail design*, start of production…) which form the basis for the ship schedule. Main schedule defines timing of the basic and *detail design*, the start of production, keel laying, launching, other main milestones and delivery. If based on correct statistics the schedule will be correct and enables effectivity. States are Based on correct statistics and Not based on correct statistics. |
| **Module Plan** | Module plan describes the prefabrications that will be extensively outfitted before being taken inside the vessel. States are Major and Minor. |
| **Grand Block Division** | Grand block division defines the borders of the grand blocks of the steel hull, which are the controlling entities for the detail design, manufacturing, and block outfitting. Defines the borders of the steel blocks according to WBS. The better the borders comply with the area division, the more effective is the work. States are High compatibility and Low compatibility. |
| **Block Division** | Block division defines the borders of the blocks of the steel hull, which are the controlling entities for detail design, manufacturing, and block outfitting. Defines the borders of the steel blocks according to WBS. The better the borders comply with the area division, the more effective will be the work. States are High compatibility and Low compatibility. |
| **Production Schedule** | Production schedule sets the dates for production inside the main milestones for block and grand block fabrication, block and grand block outfitting, outfitting, and commissioning. Gives the framework for the design work and purchasing. Timing of work activities is based on WBS. The better the awareness of the actual status, the better is the possibility to react to delays and keep effectiveness. States are Good schedule control and Poor schedule control. |
| **Load Analysis and Resource Plan** | Load analysis and the resource plan indicate the need for resources and subcontracting based on the work budget. High subcontracting here means that the resources needed for the project are allocated to project based on plan, not so, that resources are common to all projects. States are High need of subcontracting with an accurate plan and Low need of subcontracting. |
| **Change Management** | Change management is a procedure that defines how any change is documented, put into the workflow and followed |

| | |
|---|---|
| | up on. The better the process, the more effective is the work. States are Known process for change work flows and responsibilities and No known process for change work flows and responsibilities. |
| **Block Outfitting** | *Outfitting* work is done in block or in grand block. The greater the progress, the more efficient is the *outfitting*. States are High and Low. |
| **Commissioning Plan** | Defines the schedule and content for *commissioning*, inspections, and tests on systems integrated into the production schedule. Integration into the production schedule ensures efficient working. States are Integrated into the production schedule and Not integrated into the production schedule. |
| **Control Points** | Milestones in the area production schedule which are based on the system schedule. Gives preconditions for *commissioning*. States are Based on system schedule and Not based on system schedule |
| **Detailed Building Practice** | Defines the building practice by WBS. Describes how design, purchasing, and building the entity is done and controlled. This variable describes the overall comprehensiveness of planning. Comprehensive planning enables better productivity. Building practice is the description of each block, grand block, area and system. States are Enables comprehensive planning and Does not enable comprehensive planning. |
| **Prefabrication** | Work that is done in the factory not onboard is prefabricating. The more prefabrication, the more efficient is the work. States are High and Low. |
| **Salary System** | Can be time based or not time based. Team bonus system can motivate working well together. States are Time based and Not time based. |
| **Logistic Plan** | Plan for how the blocks, grand blocks, and other materials are transported to their working places. When it is integrated into the production schedule, the plan enables effectivity. States are Integrated into production schedule and Not Integrated into production schedule. |
| **Status Reporting** | By reporting the readiness of work, the awareness of the situation is adopted and known, and it is possible to react to delays and secure effectivity. States are Regular follow-up and possibility to catch up and Irregular follow up. |
| **Ship Progress Preconditions** | These preconditions create the possibility to work according to the schedule. States are Good and Poor. |

| | |
|---|---|
| **Ship Progress** | Ship progress describes the total readiness of the ship project. Working according to schedule is always more effective than working via catch-up plans and special actions. States are In schedule and in budget and Delays and budget overruns. |
| **Target Setting and Bonus System** | When targets and bonus systems are connected to the project result, they create motivation which creates effectivity. States are Connected to the project result and Not Connected to the project result |
| **Meetings and Reporting Hierarchy** | If the meeting calendar that is connected to the reporting hierarchy in line and in project is complicated, the most important issues can get lost and thus hurt effectivity when not reacted to early enough. States are High complexity and Low complexity. |
| **Problem-solving and Decision making** | When problems and decisions related to project target achieving are identified and taken care of, productivity is better than when not identifying them or making these decisions. States are Project target oriented and Not target oriented. |
| **Ship Delivery** | When the ship is delivered and all costs are closed, the result of the process can be seen. States are Targeted production efficiency achieved and Targeted production efficiency not achieved. |

**The decision variable**

The decision variable Organization Type/'organization type' has three states; Project Organization, Line Organization, and Hybrid Organization. The decision variable has an effect on the model in change management, area division, the commissioning plan, meeting and reporting, target setting, load analysis and resource plan, the budget, problem solving, status reporting, turnkey entities, and responsibilities and scopes.

## 3.3 The Model Operation

After the variables and their dependencies have been defined, they are saved into the system which in this study was GeNIe. After that, each expert made the elicitations individually with the software by estimating conditional probabilities of the variables. Based on these elicitations, the software calculates the achievance probability by organization type based on the structure of the model (reference to the formulas (1) and (2)). Figure 24 shows the results of experts based on the calculations.

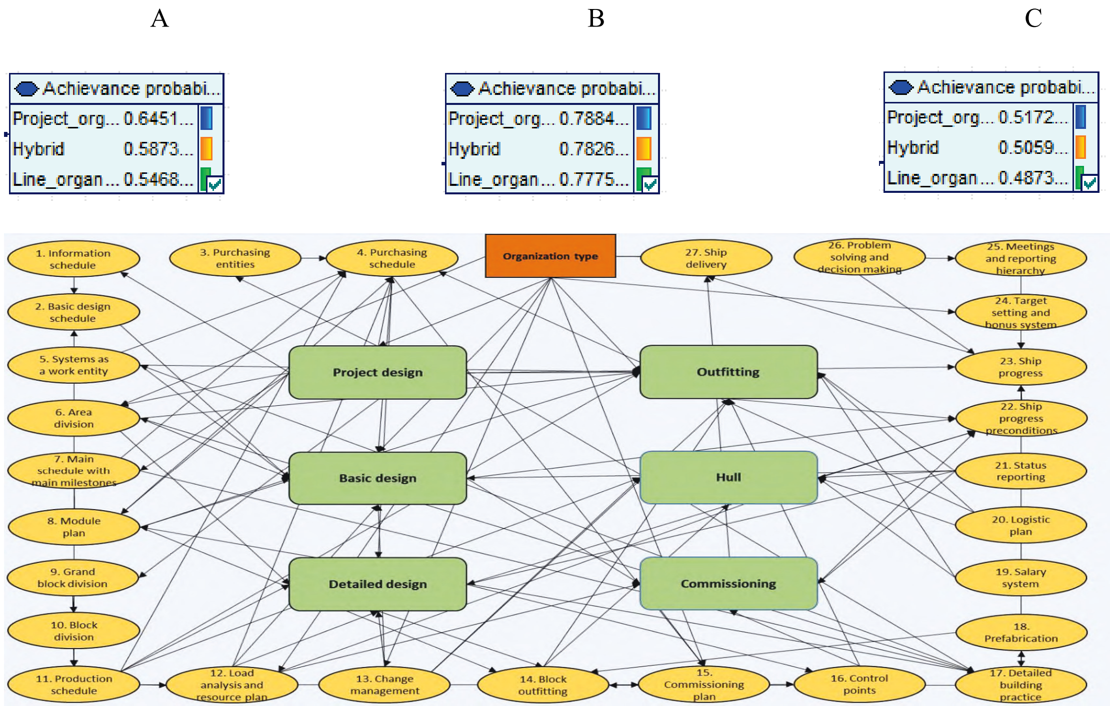



**Figure 24**. The results of Experts based on calculations of the model.

After that the expert models are combined into one linear opinion pool model. This was done by BN expert. From this combined model the final results can be achieved.

An example from the combined model with the detailed values of expert elicitations can be seen in the Table 8a and Table 8b. The values concern variable Area outfitting plan and the example also shows the condition levels related to this variable. The more parents the variable has, the more complicated the elicitation is.

**Table 8a**. An example of expert elicitations to variable "Area outfitting plan".

Area outfitting plan

| CS6 | Expert A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Major | | | | | | | | | |
| CS4_2 | Based_on_system_schedule | | | | | | | | Not_based_on_system_ | |
| CS3_5 | Integrated to production schedule | | | | Not integrated to production schedule | | | | Integrated to productic | |
| CS5_5 | Good schedule control | | Poor schedule control | | Good schedule control | | Poor schedule control | | Good schedule control | |
| C32 | Unambigux | Ambiguous | Unambiguc | Ambiguous | Unambigux | Ambiguous | Unambiguc | Ambiguous | Unambiguc | Ambiguous |
| Comprehensive | 0.87 | 0.81 | 0.67 | 0.62 | 0.53 | 0.48 | 0.33 | 0.27 | 0.64 | 0.59 |
| Limited | 0.13 | 0.19 | 0.33 | 0.38 | 0.47 | 0.52 | 0.67 | 0.73 | 0.36 | 0.41 |

| CS6 | Expert A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Major | | | | | | Minor | | | |
| CS4_2 | Not_based_on_system_schedule | | | | | | Based_on_system_schedule | | | |
| CS3_5 | Integrated to producti | | Not integrated to production schedule | | | | Integrated to production schedule | | | |
| CS5_5 | Poor schedule control | | Good schedule control | | Poor schedule control | | Good schedule control | | Poor schedule control | |
| C32 | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous |
| Comprehensive | 0.42 | 0.37 | 0.45 | 0.4 | 0.25 | 0.22 | 0.71 | 0.66 | 0.51 | 0.46 |
| Limited | 0.58 | 0.63 | 0.55 | 0.6 | 0.75 | 0.78 | 0.29 | 0.34 | 0.49 | 0.54 |

| CS6 | Expert A | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Minor | | | | | | | | | |
| CS4_2 | Based_on_system_schedule | | | | Not_based_on_system_schedule | | | | | |
| CS3_5 | Not_integrated_to_production_schedule | | | | Integrated_to_production_schedule | | | | Not_integrated_to_proc | |
| CS5_5 | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | |
| C32 | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous |
| Comprehensive | 0.48 | 0.43 | 0.28 | 0.23 | 0.56 | 0.51 | 0.36 | 0.31 | 0.39 | 0.34 |
| Limited | 0.52 | 0.57 | 0.72 | 0.77 | 0.44 | 0.49 | 0.64 | 0.69 | 0.61 | 0.66 |

| CS6 | Expert A | | Expert B | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Minor | | Major | | | | | | | |
| CS4_2 | Not based on system | | Based on system schedule | | | | | | | |
| CS3_5 | Not_integrated_to_proc | | Integrated_to_production_schedule | | | | Not_integrated_to_production_schedule | | | |
| CS5_5 | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | |
| C32 | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous | Unambiguc | Ambiguous | Unambioux | Ambiguous |
| Comprehensive | 0.2 | 0.17 | 0.89 | 0.77 | 0.81 | 0.72 | 0.74 | 0.71 | 0.7 | 0.64 |
| Limited | 0.8 | 0.83 | 0.11 | 0.23 | 0.19 | 0.28 | 0.26 | 0.29 | 0.3 | 0.36 |

| CS6 | Expert B | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Major | | | | | | | | Minor | |
| CS4_2 | Not based on system schedule | | | | | | | | Based on system sche | |
| CS3_5 | Integrated_to_production_schedule | | | | Not_integrated_to_production_schedule | | | | Integrated_to_producti | |
| CS5_5 | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | |
| C32 | Unambigux | Ambiguous | Unambiguc | Ambiguous | Unambigux | Ambiguous | Unambiguc | Ambiguous | Unambigux | Ambiguous |
| Comprehensive | 0.81 | 0.76 | 0.71 | 0.65 | 0.68 | 0.66 | 0.61 | 0.51 | 0.84 | 0.78 |
| Limited | 0.19 | 0.24 | 0.29 | 0.35 | 0.32 | 0.34 | 0.39 | 0.49 | 0.16 | 0.22 |

| CS6 | Expert B | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Minor | | | | | | | | | |
| CS4_2 | Based on system schedule | | | | | | Not based on system schedule | | | |
| CS3_5 | Integrated to producti | | Not integrated to production schedule | | | | Integrated to production schedule | | | |
| CS5_5 | Poor schedule control | | Good schedule control | | Poor schedule control | | Good schedule control | | Poor schedule control | |
| C32 | Unambigux | Ambiguous | Unambigux | Ambiguous | Unambigux | Ambiguous | Unambiguc | Ambiguous | Unambigux | Ambiguous |
| Comprehensive | 0.78 | 0.71 | 0.71 | 0.69 | 0.64 | 0.58 | 0.78 | 0.7 | 0.68 | 0.61 |
| Limited | 0.22 | 0.29 | 0.29 | 0.31 | 0.36 | 0.42 | 0.22 | 0.3 | 0.32 | 0.39 |

**Table 8b.** An example of expert elicitations.

Area outfitting plan

| CS6 | Expert B | | | | Expert C | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Minor | | | | Major | | | | | |
| CS4_2 | Not_based_on_system_schedule | | | | Based_on_system_schedule | | | | | |
| CS3_5 | Not_integrated_to_production_schedule | | | | Integrated_to_production_schedule | | | | Not_integrated_to_proc | |
| CS5_5 | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | |
| C32 | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous |
| Comprehensive | 0.6 | 0.58 | 0.55 | 0.42 | 0.85 | 0.7 | 0.71 | 0.56 | 0.75 | 0.61 |
| Limited | 0.4 | 0.42 | 0.45 | 0.58 | 0.15 | 0.3 | 0.29 | 0.44 | 0.25 | 0.39 |

| CS6 | Expert C | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Major | | | | | | | | | |
| CS4_2 | Based_on_system_sche | | Not_based_on_system_schedule | | | | | | | |
| CS3_5 | Not_integrated_to_proc | | Integrated_to_production_schedule | | | | Not_integrated_to_production_schedule | | | |
| CS5_5 | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | |
| C32 | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous |
| Comprehensive | 0.61 | 0.46 | 0.75 | 0.61 | 0.61 | 0.46 | 0.65 | 0.51 | 0.49 | 0.34 |
| Limited | 0.39 | 0.54 | 0.25 | 0.39 | 0.39 | 0.54 | 0.35 | 0.49 | 0.51 | 0.66 |

| CS6 | Expert C | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CS5_3 | Minor | | | | | | | | | |
| CS4_2 | Based_on_system_schedule | | | | | | | | Not_based_on_system_ | |
| CS3_5 | Integrated_to_production_schedule | | | | Not_integrated_to_production_schedule | | | | Integrated_to_producti | |
| CS5_5 | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | | Good_schedule_control | |
| C32 | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous |
| Comprehensive | 0.75 | 0.61 | 0.6 | 0.45 | 0.65 | 0.49 | 0.49 | 0.34 | 0.65 | 0.51 |
| Limited | 0.25 | 0.39 | 0.4 | 0.55 | 0.35 | 0.51 | 0.51 | 0.66 | 0.35 | 0.49 |

| CS6 | Expert C | | | | | |
|---|---|---|---|---|---|---|
| CS5_3 | Minor | | | | | |
| CS4_2 | Not_based_on_system_schedule | | | | | |
| CS3_5 | Integrated_to_producti | | Not_integrated_to_production_schedule | | | |
| CS5_5 | Poor_schedule_control | | Good_schedule_control | | Poor_schedule_control | |
| C32 | Unambiguou | Ambiguous | Unambiguou | Ambiguous | Unambiguou | Ambiguous |
| Comprehensive | 0.51 | 0.36 | 0.55 | 0.41 | 0.4 | 0.25 |
| Limited | 0.49 | 0.64 | 0.45 | 0.59 | 0.6 | 0.75 |

## 3.4 The results

The cruise shipbuilding process is complicated, and the modeling of that process has not been done before in this specific way. Thus, the actual modeling itself is a result here (Hellgren et al., 2016). It enables future development of the process in several ways. In this study, production efficiency was the viewpoint used for choosing the variables, and the decision variable was the organizing type. However, the model can also be built by using other viewpoints and different decision variables.

Table 9 present the probability that the targeted production efficiency can be reached based on the linear opinion pool model. It can be seen here that Project Organization has the highest probability of 0.65 and it is followed by the other two organization types, namely, the Hybrid Organization reached the second highest score with probability of 0.63 and the Line Organization achieved the lowest score with the probability of 0.60.

**Table 9.** Achievance probabilities of the decision variables in the model.

| **Organization Type** | **Probability** |
|---|---|
| Project organization | 0.65 |
| Hybrid organization | 0.63 |
| Line organization | 0.60 |

The results by each Expert can be seen in Table 10. Figure 25 is indicating the level that each expert was using in their elicitation.

**Table 10**. Achievance probabilities by the Experts and the combined value.

| | A | B | C | combined |
|---|---|---|---|---|
| project org. | 0.6451 | 0.7884 | 0.5172 | 0.65 |
| hybrid org. | 0.5873 | 0.7826 | 0.5059 | 0.63 |
| line org. | 0.5468 | 0.7775 | 0.4873 | 0.60 |

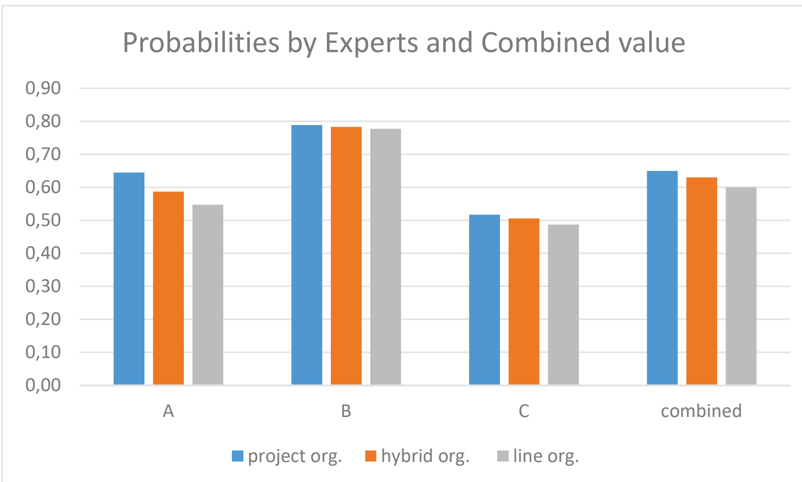



**Figure 25**. Achievance probabilities by the Experts and combined value.

In order to understand what is the range where the values of the probabilities can vary by each Expert the model can be elicited by extremely optimistic expert and extremely pessimistic expert. For optimistic expert all the variables affected by organization type get values 1/0 and for pessimistic expert the values are 0/1 depending on the variable. This gives the maximum values for each expert that can be seen in Table 11. The Figure 26 illustrates these values.

**Table 11**. The optimistic, pessimistic and actual values from elicitation.

| expert | Optimistic | Elicited Project Org. | Elicited Hybrid Org. | Elicited Line Org. | Pessimistic |
|---|---|---|---|---|---|
| A | 0.6894 | 0.6451 | 0.5873 | 0.5468 | 0.5420 |
| B | 0.8029 | 0.7884 | 0.7826 | 0.7775 | 0.7032 |
| C | 0.5296 | 0.5172 | 0.5059 | 0.4873 | 0.4294 |

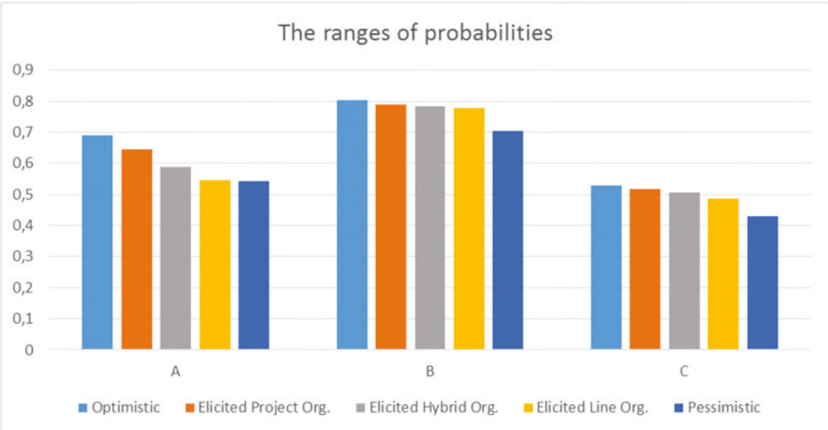



**Figure 26.** The ranges of elicitations

In this model, the organization type directly affects the model in change management, commissioning plan, problem-solving and decision making, area division, meeting and reporting hierarchy, target setting, load analysis and resource plan, budget, status reporting, and also turnkey entities, and responsibilities and scopes. According to the elicitations offered by Experts A, B, and C, the magnitude of these probabilistic effects are presented in Figures 27 to 36. The Figures indicate the results of the expert values for the variables that organization type directly affects. Figure 26 shows that Expert A probability for the Known process for change management is in use in Project Organization is 0.81. Next is Hybrid Organization with the value of 0.64 and third is Line Organization with the value of 0.59. All experts share the same trend with different values. The same trend can be seen in Figure 27 for probability for integrating commissioning plan to production schedule. Further, Figure 28 shows same trend where experts see that Project Organization includes the best probability for Project target oriented problem-solving and Decision-making. The same amount of order can be seen in Figure 29 for area division functionality, in Figure 30 for low complicity in meetings and reporting hierarchy, in Figure 31 for target setting and bonus system connected to project result, in Figure 32 for load analysis and resource plan resulting accurate plan of subcontracting and in Figure 33 for budget enabling realistic target, Figure 34 for regular status reporting, Figure 35 for TK entities and scopes and Figure 36 for Responsibilities/ scopes enable WBS based target setting. In these cases experts shared the same opinion trend in probabilities except for Figure 33 for a variable Budget, Figure 35 for variable TK entities and scopes and Figure 36 for variable for Responsibilities/ scopes, where Expert C preferred Hybrid Organization. This view is based on some projects where budget keeping was successful and where the responsibilities were clearly divided between the line and the project. Expert C also felt that Hybrid Organization will lead to the best functionality for TK entities and scopes as well.

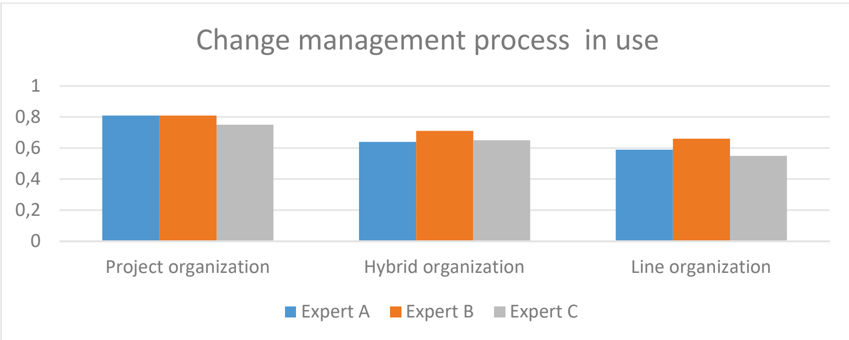



**Figure 26**. Probability of the change management process in use, given different organizational types and experts.

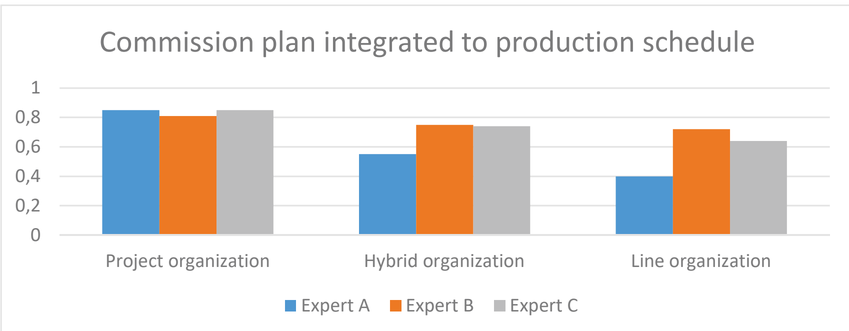



**Figure 27.** Probability of the commissioning plan integrated to production schedule, given different organizational types and experts.

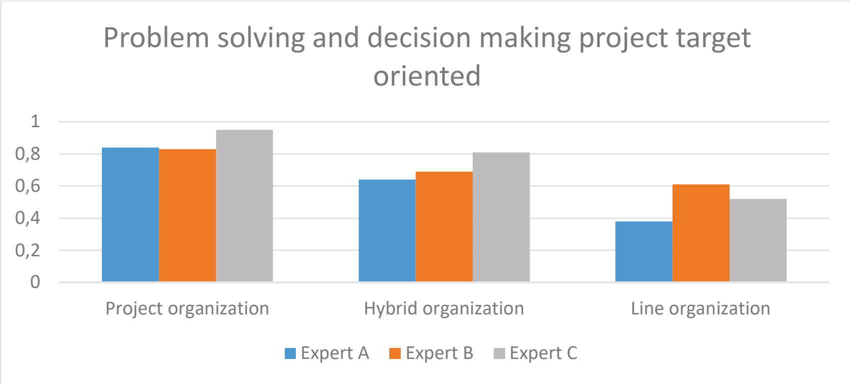



**Figure 28.** The probability of problem-solving and decision-making that is project target oriented, given the different organization types and experts.

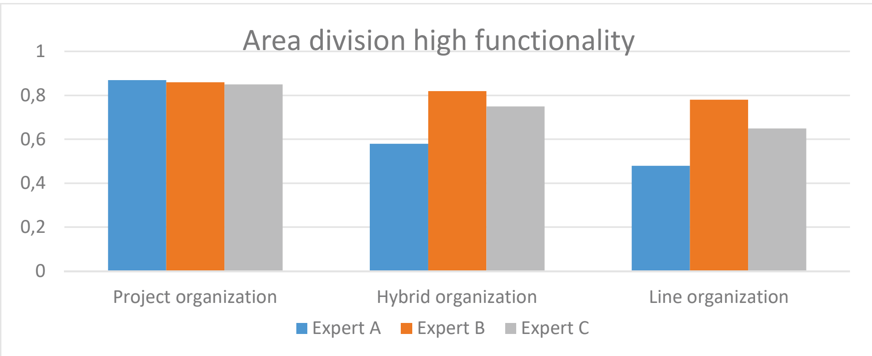



**Figure 29**. Probability of area division high functionality, given the different organizational types and experts.

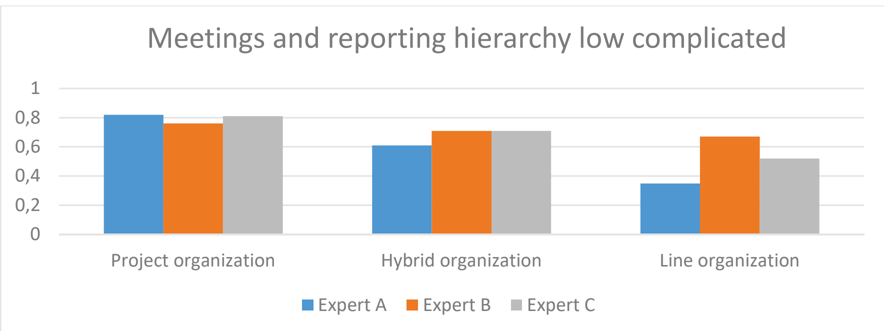



**Figure 30**. Probability of meeting and reporting hierarchy low complicated, given the different organizational types and experts.

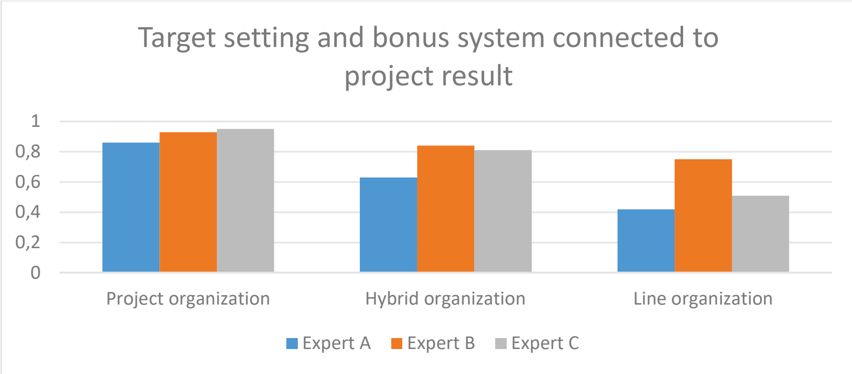



**Figure 31**. Probability of target setting and bonus system connected to a project result, given the different organizational types and experts.

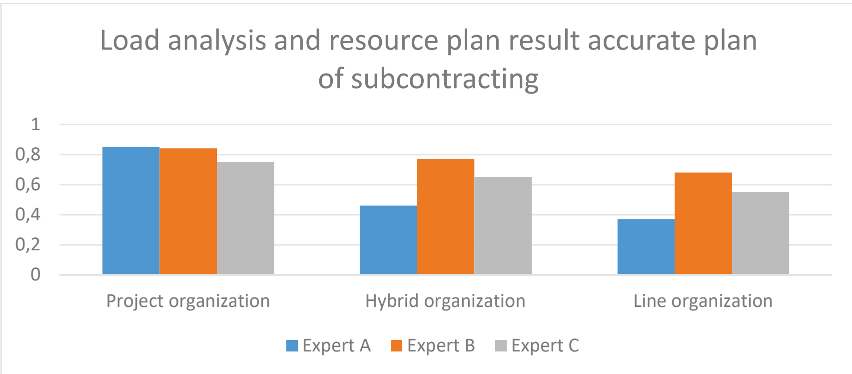



**Figure 32.**Probability of load analysis and resource plan result for an accurate plan of subcontracting, given the different organizational types and experts.

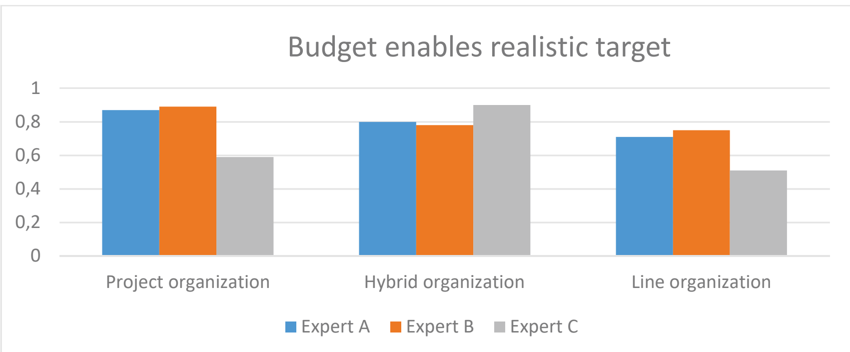



**Figure 33.** Probability of budget enabling realistic target, given the different organizational types and experts.

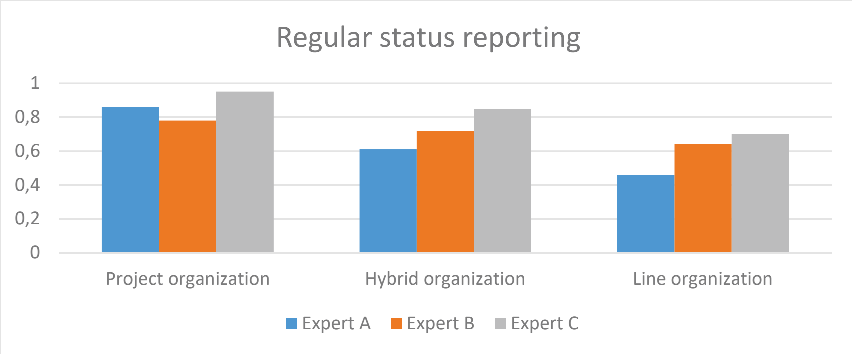



**Figure 34**. Probability of regular status reporting, given the different organizational types and experts.

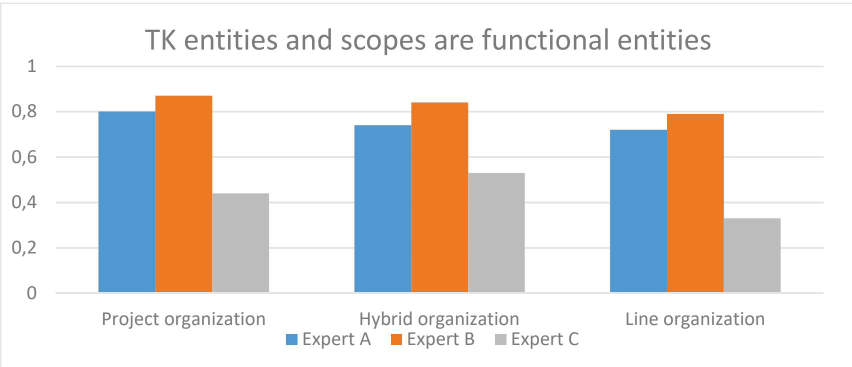



**Figure 35.** Probability of TK entities and scopes functional entities, given the different organizational types and experts.

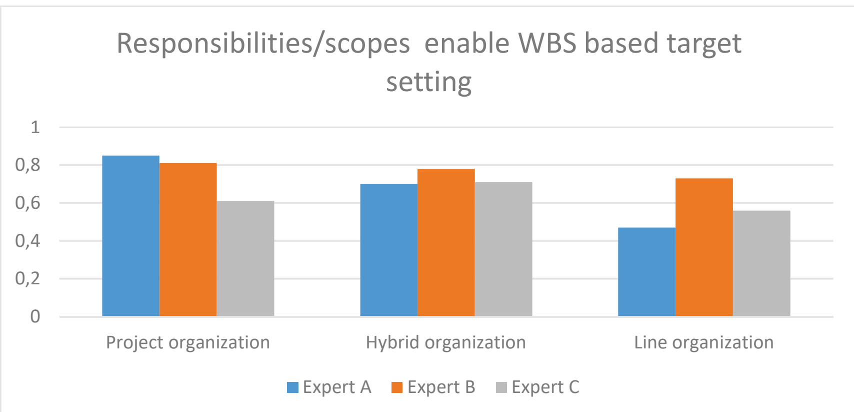



**Figure 36**. Probability of Responsibilities/ scopes enable WBS based target setting, given the different organizational types and experts.

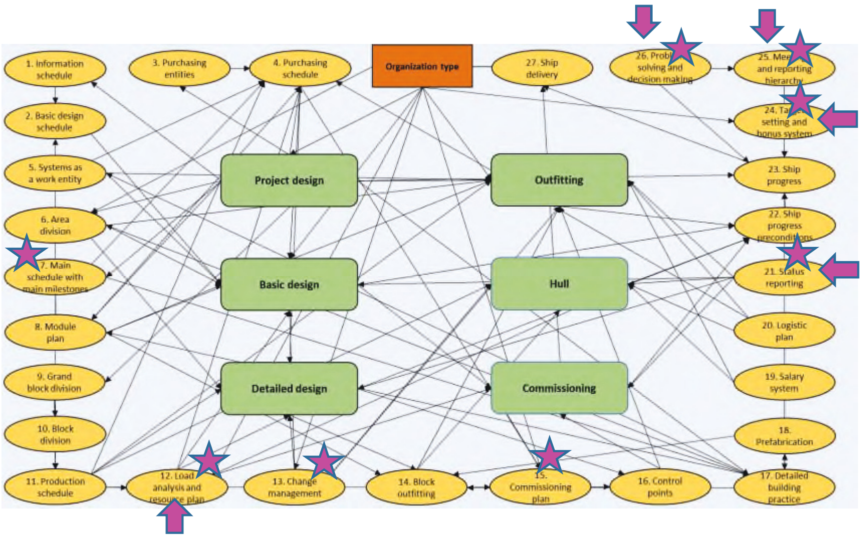
When the organization type is altered, the probabilities of the variables change. The biggest changes between different organization types are presented in Table 12, which shows that when changing from Project Organization to Hybrid, the biggest decrease in probability is related to the variable "load analysis". When comparing Hybrid to Line Organization, the biggest decrease is found in the probability of "problem-solving and decision-making". Further, when comparing Project Organization to Line Organization, the biggest decrease occurs in "problem-solving".

**Table 12**. Change of probabilities of the variables when the organization type is altered.

| Change from Project organization to Hybrid; average decrease in probabilities | | Change from Hybrid organization to Line; average decrease in probabilities | | Change from Project organization to Line; average decrease in probabilities | |
|---|---|---|---|---|---|
| Load analysis | 0.19 | Problem solving and decision making | 0.21 | Problem solving and decision making | 0.37 |
| Problem solving and decision making | 0.16 | Target setting and bonus system | 0.2 | Target setting and bonus system | 0.35 |
| Commissioning plan integrated to production schedule | 0.16 | Budget | 0.17 | Meetings and reporting hierarchy | 0.28 |
| Target setting and bonus system | 0.15 | Meetings and reporting hierarchy | 0.16 | Load analysis | 0.28 |
| Area division | 0.14 | Responsibilities and scopes | 0.14 | Status reporting | 0.26 |

In the main model the organization type directly affects the model in change management, commissioning plan, problem-solving, area division, meeting and reporting hierarchy, target setting, load analysis and resource plan, status reporting. See the Figure 37. According to Table 12 the biggest changes of probabilities of the variables when altering the organization type from Project Organization to Line Organization are:

1. Problem solving and decision making
2. Target setting and bonus system
3. Meetings and reporting hierarchy, Load analysis and resource plan, Status reporting.




★ Variable affected by organization type

⬇ Variable with biggest change when altering organization type

**Figure 37.** The variables that are affected by organization type in the main model and the variables that are affected most when changing organization type.

The model shows the range of probabilities for every variable within all the respective conditions. As an example, the ranges of probabilities of variables by Experts A, B and C in the sub-model *Basic design* can be seen in Table 13.

**Table 13**. Conditional probabilities in Basic design by experts.

| No. | Name of Variable | State | Probabilities with conditions | | |
|---|---|---|---|---|---|
| | | | Expert A | Expert B | Expert C |
| 1 | Owner | High activity | 0.81 | 1 | 0.61 |
| 2 | Architectural design | High production friendliness | 0.14-0.88 | 0.04-0.79 | 0.06-0.62 |
| 3 | Arrangement design | Low complexity | 0.18-0.68 | 0.45-0.86 | 0.05-0.61 |
| 4 | Calculations | High reliability | 0.68 | 0.79 | 0.71 |
| 5 | Classification design | High recurrence in structures | 0.39-0.81 | 0.52-0.8 | 0.18-0.71 |
| 6 | System descriptions & schemes & partlists | Unambiguous | 0.4-0.8 | 0.43-0.89 | 0.41-0.75 |
| 7 | Approval procedure | Whole process scheduled in basic design schedule | 0.41-0.64 | 0.71-0.89 | 0.35-0.6 |
| 8 | TK entities and scope | Functional entities, based on work breakdown structure | 0.28-0.8 | 0.56-0.9 | 0.09-0.68 |
| 9 | Purchasing contracts & Material scope | Independent entities with progress related payment terms | 0.52-0.81 | 0.6-0.85 | 0.35-0.71 |
| 10 | Basic Design competence | High | 0.54-0.72 | 0.23-0.78 | 0.64-0.75 |
| 11 | Basic Design progress | In schedule and in budget | 0.14-0.74 | 0.46-0.92 | 0.11-0.81 |

The variables Owner and Calculations have no parents, which is why there is only one probability value by each expert. The other variables have one or more parents, which creates the conditional situations that the experts judged during the elicitations. For example, for the variable TK entities and scopes the probability of having functional entities based on WBS will vary according to Expert A from 0.28 to 0.8, depending on the conditions that resulted from the parents. The probability of 0.28 describes the conditions as seen in Figure 38, while the probability of 0.8 results from the conditions seen in Figure 39.

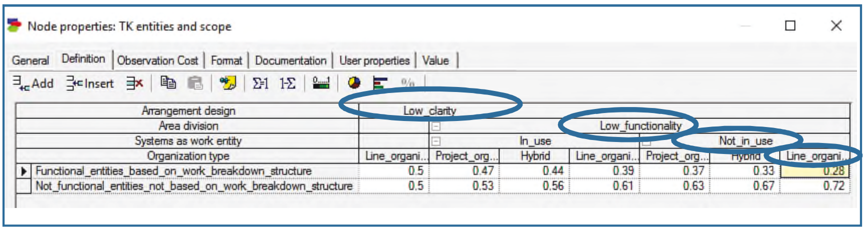



**Figure 38**. Variable TK entities and scope resulting the probability value 0.28 with the conditions.

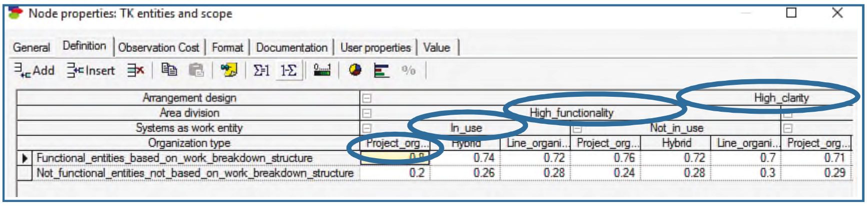



**Figure 39**. Variable TK entities and scope resulting the probability value 0.8 with the conditions.

By using the model, it is possible to clarify which conditions each expert uses to reach the best probabilities for each variable. In the *Basic design* sub-model, these conditions can be seen in Table 14. There in architectural design Experts A and B have similar conditions stating Known process for change work flows and responsibilities, basic design schedule based on need of information, Specification with high clarity and owners low activity. In arrangement design, Expert B and C share a similar view that functional area division, a major module plan, easy GA, scheduling of design process and production friendliness lead to easy arrangements. For classification design, all experts share a similar view according to which mid ship section low complexity, basic design schedule is based on the need for information, high reliability calculations and whole process scheduled in basic design schedule lead to high recurrence in the structures. For variable Purchasing contracts & Material scope, all experts have a similar opinion. According to that opinion, a Purchasing schedule that is based on WBS and the need of information, a major module plan, and TK Functional entities and based on work breakdown structure lead to Independent entities with progress-related payment terms. There are differences in the TK entities and scope where Experts A and B see that functional WBS-based TK entities are the result when Project Organization is the organization type, whereas Expert C prefers a Hybrid Organization. Variables that also have an output on this sub-model are shown in Table 14. They act as inputs and conditions for the variables where they are connected to.

**Table 14**. Conditions for the best variable probabilities by experts in the Basic sign

| No. | Name | State | Conditions for best value | | | Output from submodel |
|---|---|---|---|---|---|---|
| | | | Expert A | Expert B | Expert C | |
| 1 | Owner | High activity | NA | NA | NA | |
| 2 | Architectural design | High production friendliness | Know n process for change w ork flow s and responsibilities/basic design schedule based on need of information/Specification w ith **high** clarity/ow ners low activity | Know n process for change w ork flow s and responsibilities/basic design schedule based on need of information/Specification w ith **high** clarity/ow ners low activity | Know n process for change w ork flow s and responsibilities/basic design schedule based on need of information/Specification w ith **low** clarity/ow ners low activity | yes |
| 3 | Arrangement design | Low complexity | Area division **low** functionality/**minor** module plan/**high** complexity GA/Whole process scheduled in basic design schedule/**low** production friendliness in architectural design | Area division **high** functionality/**major** module plan/**low** complexity GA/Whole process scheduled in basic design schedule/**low**,**high** production friendliness in architectural design | Area division **high** functionality/**major** module plan/**low** complexity GA/Whole process scheduled in basic design schedule/**high** production friendliness in architectural design | yes |
| 4 | Calculations | High reliability | NA | NA | NA | |
| 5 | Classification design | High recurrence in structures | Midship section low complexity/basic design schedule based on need of information/high reliability calculations/Whole process scheduled in basic design schedule | Midship section low complexity/basic design schedule based on need of information/high reliability calculations/Whole process scheduled in basic design schedule | Midship section low complexity/basic design schedule based on need of information/high reliability calculations/Whole process scheduled in basic design schedule | yes |
| 6 | System descriptions & schemes & partlists | Unambiguous | Know n process for change w ork flow s and responsibilities/specification high clarity/high reliability calculations | Know n process for change w ork flow s and responsibilities/specification high clarity/high reliability calculations | Know n process for change w ork flow s and responsibilities/specification low clarity/high reliability calculations | yes |
| 7 | Approval procedure | Whole process scheduled in basic design schedule | ow ner high activity | ow ner low activity | ow ner low activity | |
| 8 | TK entities and scope | Functional entities, based on work breakdown structure | project organization/systems as w ork entity in use/area divsion high functionality/arranegement design high complexity | project organization/systems as w ork entity in use/area divsion high functionality/arranegement design low complexity | hybrid organization/systems as w ork entity in use/area divsion high functionality/arranegement design low complexity | |
| 9 | Purchasing contracts & Material scope | Independent entities with progress related payment terms | Purchasing schedule based on WBS and need of information/major module plan/TK entities Functional entities, based on w ork breakdow n structure | Purchasing schedule based on WBS and need of information/major module plan/TK entities Functional entities, based on w ork breakdow n structure | Purchasing schedule based on WBS and need of information/major module plan/TK entities Functional entities, based on w ork breakdow n structure | yes |
| 10 | Basic Design competence | High | low need of subcontracting | low need of subcontracting | low need of subcontracting | |
| 11 | Basic Design progress | In schedule and in budget | Regular follow up and possibility to catch up/basic design schedule based on need of information/budget enabling realistic target/basic design competence high/Whole process scheduled in basic design schedule | Regular follow up and possibility to catch up/basic design schedule based on need of information/budget enabling realistic target/basic design competence high/Whole process scheduled in basic design schedule | Regular follow up and possibility to catch up/basic design schedule based on need of information/budget enabling realistic target/basic design competence high/Whole process scheduled in basic design schedule | yes |

### 3.5 Assessment of Sensitivity, Uncertainty, and Bias

The results of the sensitivity analysis of the networks done by GeNIe is presented in Appendix 3.
The GeNIe analysis tool helps in identifying the most influential parameters. To perform sensitivity analysis, an additional indexing variable will index various values for parameters in question and have GeNIe compute the impact of these values on the results. Based on that, the most influential node is Ship delivery, which is highlighted in red to indicate its high influence. Light red indicates a moderate influence, and those nodes are Status reporting, Ship progress, Commissioning plan, Control points, Target setting and Bonus system, Meetings and Reporting hierarchy, Problem- solving and Decision-making, and Commissioning. For an evaluation of uncertainty and bias, a method presented by Goerlandt and Reiniers (2015) is utilized. The box plots are exploratory graphics for showing the distribution of a variable. The needed definition of scores is shown in Table 15. A Summary of Uncertainties and Bias for the most sensitive variables is shown in Table 16.

**Table 15**. Definition of scores for uncertainty and bias.

| Item | Score | Description |
|---|---|---|
| Strength of evidence | High | much data available |
| Strength of evidence | Medium | moderate amount of data available |
| Strength of evidence | Low | little data available |
| Bias | C | underestimating, conservative |
| Bias | N | normal |
| Bias | O | overestimating, optimistic |

**Table 16.** Summary of strength of evidence and the bias for the most sensitive variables.

| Variable no | Variable | Strength of evidence | Bias |
|---|---|---|---|
| 1 | ship delivery | high | N |
| 2 | status reporting | high | N |
| 3 | ship progress | high | O |
| 4 | commissioning plan | high | N |
| 5 | control points | high | N |
| 6 | target setting and bonus system | medium | N |
| 7 | meetings and reporting hierarchy | high | N |
| 8 | problem solving and decision making | medium | O |
| 9 | commissioning | high | N |

Table 17 gives an overall view of uncertainty related to sensitivity and Table 18 gives an overview of bias related to sensitivity.

**Table 17**. Uncertainty of the variables related to Sensitivity.

| | | **Strength of evidence** | | |
|---|---|---|---|---|
| | | Low | Medium | High |
| **Sensitivity** | High | | | 1 |
| | Moderate | | 6,8 | 2,3,4,5,7,9 |
| | Low | | | |

**Table 18**. Direction of bias of the variables related to Sensitivity.

| | | **Direction of bias** | | |
|---|---|---|---|---|
| | | Conservative | Normal | Optimistic |
| **Sensitivity** | High | | 1 | |
| | Moderate | | 2,4,5,6,7,9 | 3,8 |
| | Low | | | |

Other variables had low sensitivity and their uncertainty and bias are in green or yellow areas.

# 4. Discussion

## 4.1 The results in light of state of the art

The research on the cruise ship building process has resulted in broader knowledge about production efficiency as well as better working methods, including efficient welding techniques, increased welding automation, and the extended use of modularization and block outfitting (Erikstad, 2009; Greve, 2007; Roland et al., 2004; Koenig et al., 2002; Park et al., 2011). Additionally, the research on three-dimensional design systems and other integrated IT tools has allowed cruise ship design to become a fully three-dimensional model, (Liu et al., 2011; Cho et al., 1998). Further, simulation models have been developed for the shipbuilding process. McLean and Shao (2001) offered an overview of a generic simulation of shipbuilding operations and Krause et al. (2004) presented a discrete event simulation for testing and evaluating the different scenarios of investment planning, scheduling, and resource planning. Enterprise Resource Planning (ERP) systems have also been developed (Krause et al., 2004; Tu, 1997; McLean &Shao, 2001). Production efficiency and lean manufacturing have been studied by Kolić et al. (2016) Erdem (2015) and the organizational features related to on-job-learning by Meyer (2010). However, research about the entire process effectiveness and cruise ship building process control still remains absent, and there is no available research information on how organizing the cruise shipbuilding process can affect production efficiency. This thesis studies the effectivity of the whole process of building a cruise ship.
The different organization types have been researched in general. The measuring of organizational effectiveness, according to Robbins (1983), has proven to be a difficult aspect to define. Aurélio de Oliveira et al. (2012) analyzed the influence of leadership style and the factors associated with organization agility on project performance. Hobday (2000) compared the effectiveness of producing complex high value products in a project-based organization to a more traditionally functioning matrix organization. However, the effect of organization type in shipbuilding as it relates to production efficiency has not yet been studied. This study offers a tool and a new way of focusing on the

management of the process by comparing different organization methods when a large shipbuilding project is involved.

## 4.2 Answering the research question and discussion

It can be inferred from the model that the highest probability for achieving the intended production efficiency is reached by using Project Organization. The second best probability for the desired outcome is by using Hybrid Organization, and the third is by using the Line Organization type. As seen in Table 9, the differences between the probabilities for these organization types are not large, namely as they vary between 0.02- 0.05, but they do show a trend which organization type could be the most beneficial. Albeit the differences may seem marginal at first, but as we are studying processes with high economic values and long lead times, even the smallest of changes can translate into big benefits or losses. When studying the effect of the organizing method on the different variables, the expert elicitations show a parallel trend, with Project Organization being the best option of the variables according to all three experts.

Generally, the results of this study indicate that the best probability was achieved with Project Organization and the lowest probability was with Line Organization. All probabilities were between 0.60 and 0.65. However, even the probability level of 0.65 is low. What this means for the actual process, is that there is a lot of potential for improvement to achieve a probability that will be more satisfactory. The process is complicated, and even small problems can cause consequences that lead to unexpected inefficiency. Yet based on this study, it is quite evident that by improving the organization method, it is also possible to improve overall efficiency in the cruise shipbuilding process.

When comparing the organization types with each other, it can be seen which probabilities of the variables change the most, as illustrated in Table 10. When comparing Project Organization to Hybrid Organization, the biggest decrease in probability is related to the variable “load analysis”. This can be the consequence of allocating of resources on coarse level. In Project Organization the project defines the need of resources, in Hybrid Organization the defining process is done partly on departmental level. When comparing Hybrid to Line Organization, the biggest decrease is found in the probability of “problem-solving and decision-making”. This refers to responsibilities and goal orientation which in Hybrid Organization are more project related than in Line

Organization. Further, when comparing Project Organization to Line Organization, the biggest decrease occurs in “problem-solving and decision making”. This is also a matter of goal orientation which in Project Organization affects efficient problem-solving more than in Line Organization.

The range of probabilities in Table 11 describes the probabilities for different conditions of the sub-model *Basic design.* It can be seen that there are differences between the experts’ elicitations. In most cases, Expert B has the highest values for the probabilities. Expert C has the lowest probabilities, and Expert A stands in between the two. The experts use ranges in different positions on the scale. This shows differences in judgment.

Based on these results it seems that the Project Organization helps production efficiency by organizing change management, including a commissioning plan as part of the production schedule, by project-target-oriented problem-solving and decision-making, by functional area division, by structured meetings and reporting hierarchy, target setting and a bonus system related to project results, as well as by more accurate resource planning, by realistic budget target, and by using regular status reporting as well as functional turnkey entities.

The reason for the best values being in Project Organization can be that when Project Organization is used, responsibilities are clear (Robbins, 1983). Further, Project Organization creates the need to have all planning-related activities as WBS-based, including functional area divisions and turnkey entities, production schedules, commissioning and resource planning. It is also seen in the results of variable Area division. This choice makes it easier to state target setting accordingly in Project Organization. When responsibilities and target setting using a bonus system do comply, then problem-solving and decision-making will have a common target. Even if the differences between organization type probabilities were not significant, however, the results from Project Organization can help to develop and direct the process towards a direction where especially clear responsibilities make it possibly to improve overall production efficiency.

Furthermore, handling of changes in the cruise shipbuilding process is easier with Project Organization because the responsibilities are clear, and the consequences of changes are easier to see and also forecast. In change management process it is vital that responsibilities for the workflow are clear. In Project Organization the tasks and responsibilities are transparent which support efficiency. Reporting and meeting routines can comply with these responsibilities to create the need for regular status reporting. The comparison between Project Organization and Line Organization in table 10 shows that the biggest differences in the probabilities occur for problem-solving and decision-making, target setting and the bonus system, meetings and reporting hierarchy, and also load analysis and status reporting. This means that for Project Organization, these variables have a better probability of achieving the targeted efficiency. A common factor behind these results can also be clearer responsibilities. When someone is clearly responsible for a target, where a bonus is also possible, it is evident this the person will want to solve the problems, make decisions, clarify the need for resources, and continually inquire about the actual status of the planned target. To include commission plan to production schedule is more probable in Project Organization cases, most evidently due to the project deadline which demands the move from production to commissioning in a seamless way.

The modeling of the process was done by taking into account that the cruise ships are built as a joint effort between the shipyard and the supplier network. As a logical result, the model includes factors that impact production efficiency no matter whether the activity is done by the shipyard or a network member. This kind of model, which combines various players into a single model, is new. The development process together with network specialists during the first phases of design has been recognized in this model. During the first steps of the process, most of the costs are locked and that is why it is important to know the factors and dependencies starting from the beginning.

This model presents production efficiency factors that are not production-related factors, such as production facilities, methods, and tools. It can be seen in the model that there are many other factors than these production-related items that can impact to production efficiency. Using this model, those factors can be identified more clearly and their impacts can be studied in a new way. As noted earlier, ship building process has been simulated in many studies and applications. However, those actions that are based on human behavior always include uncertainty and thus the simulations are not precise enough. The Bayesian model also addresses the human factor and its uncertainties in this process, which in fact means the management view of the process. This made it possible to study the effect of organization type to production efficiency. This is a new aspect of modelling the process.

As said earlier, one typical feature of cruise ship contracts is that in the ship contract the shipyard commits to design and build the specified vessel within a certain deadline and for an agreed price. The model demonstrates that many factors during the first phases of the process are prohibiting the shipyard from proceeding fluently when fulfilling these obligations. If the shipyard has extremely strict control of all factors, however, it can succeed. Yet, as seen in the model, there are many aspects and details that are not supporting the shipyard's progress, which raises up the question of whether it is possible to divide a ship contract into a design part and a production part. This arrangement could also benefit the ship owner.

Bayesian Networks have been successfully used in many studies related to marine safety (Uusitalo, 2007; Quintana & Leung, 2012; Montewka et al., 2013; Hänninen et al., 2014). These studies gave the motivation to use BN in this research. The use of a Bayesian Network as a modeling approach in this study turned out to be feasible, and its use appropriately supported problem processing. The model is not a process description of the cruise shipbuilding process, but rather a combined model of the factors that do influence production efficiency throughout the entire process. Using the decision variable makes it possible to investigate how different organization approaches resulted in the probability of achievement. BN is flexible and a visual tool in this respect and indeed, it is well suited to this particular study. However, the reporting possibilities and features in the software could be better for enabling smooth analyzing work.

The structure of the model included numerous variables and dependencies. The decision to divide the main model into six sub models, according to the cruise shipbuilding process did help to clarify the entity of the model. The built model consisted of 85+1 variables. By reducing the number of variables, the elicitations themselves could offer a simpler representation but at the same time, some of the important variables would be lost and the total result would not be as comprehensive. Due to the high number of variables, only two states were allowed for each variable. This made the elicitations more reliable by keeping the number of options on a reasonable level.

Due to the challenging characteristics of this process, the required qualifications of the experts included wide experience and knowledge of the process itself, accumulated over a long time while working in various organization structures. In this case, all the experts fulfilled the qualifications, meaning that they knew the background of the process. As the variables and dependencies were already familiar to the experts, there was no need to explain the meaning of the model elements, which enabled better concentration on the probabilities. The elicitation work was demanding. If there were several condition levels the situation of elicitation would demand extreme concentration and accuracy to maintain the logic. Increasing the amount of elicitations by adding several experts would naturally broaden the perspective, but it would be necessary these persons are qualified enough to properly render a judgment.

The study was done based on one shipyard only because the information needed for this kind of study is extremely broad, and therefore expanding the study to compare different shipyards was not feasible for the purpose of this study.

## 4.3 Reliability and Validity of the model

### Validation framework

This study using the Bayesian Network for the cruise shipbuilding process led to a constructive perspective using the basis of epistemology constructivism. This means that when creating the validation framework for the study, it was necessary to provide arguments for why the interpretation would be trustworthy as a basis for decision-making. Also, it was necessary to think about the precise features that would make the assessment credible and identify uncertainties and the biases. Pitchforth & Mengersen (2013) present the framework for that validation (see Figure 40).

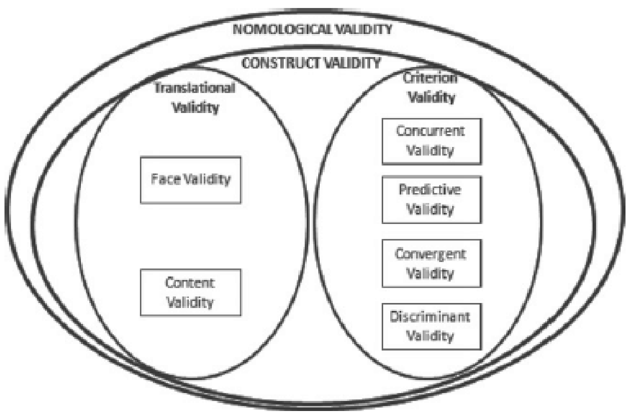



**Figure 40**. The validity testing framework.

### Face validity

For the face validity, the test checked to see whether the model structure (number of nodes, node labels and arcs between them) look the same as the experts and/or literature predicted. Face validity is also checked to see that each node of the network is discretized into sets that reflect expert knowledge. Further, the parameters of each node are checked to see if the parameters of each node are similar to what the experts expected.

Before eliciting the model content itself, including nodes, their parameters and discretizing were discussed with the experts. The experts agreed that the model responded to the actual process. In the literature there are no similar cases from shipbuilding for a comparison, but in principle this model looks generally the same as the existing models.

**Content validity**

In content, validity is checked for whether the model structure contains all and only those factors and relationships relevant to the model output. Another check done for whether each node of the network contains all and only the relevant states that a node can possibly adopt and whether the discrete states of the nodes are dimensionally consistent.

The model includes the main factors according to current knowledge of the shipyard's cruise shipbuilding process that impacts production efficiency. The content validity process should be reviewed for both project management and production efficiency. The main areas in project management generally are control of schedule, costs, and performance. All of these are represented as various nodes here in the constructed model. Concerning the main preconditions for improved production efficiency, the impact of production facilities, methods, and tools were not included in the current study. Thus, the availability of production documents, materials, and resources at the right time remain. Without them, the most efficient production is not possible. Those elements are, however, widely represented as respective variables in the model. Because of the complexity of the model it was decided to have only two states for each node. These states were chosen so that they reflected the extreme ends of the states. This aspect was agreed upon with experts. The states were specified for each node, bearing in mind actual production efficiency.

**Concurrent Validity**

For concurrent validity, the check is done to see if the model acts identically to network, models a theoretically related construct, and if the parameters of the input nodes match the nodes in a comparative model. Compared to models related to marine safety, as mentioned earlier in this study, the model seems to act in the same way. But because there is no similar model available it is difficult to say precisely.

Summary of these validation tests is offered in Table 19.

**Table 19**. Summary of validation tests.

| Test | Outcome |
|---|---|
| Face validity | high |
| Content validity | medium |
| Concurrent validity | low |

## 4.4 Examples of other possible applications of the model

It is possible to use this model to study other topics as well. One interesting topic could be how project organization that is strictly connected to WBS would improve the probability of achieving the targeted production efficiency. Minimizing lead time could be another topic. However, it would require its own respective variables and dependencies.

Further, studying whether the existing model could work the other way round to indicate necessary preconditions for settled targets would be interesting and even beneficial, as would investigating how much improving some factors might improve the end result. For example, if the probabilities of variable or variables would be improved with 20%, how much that improvement affect the end result? This can be studied with the model by improving, e.g., Expert A values for commissioning plan, commissioning and control points with 20 %. In the model this change gives about 4-5% better end result depending on the organization type. This way the model can provide information on how to control and manage the whole shipbuilding process to maximize production efficiency by making it possible to investigate optimal procedures for the future.

The model is new in this context. However, the basic concept of the model is a general one. This aspect makes the idea of the model possible for use in other industries than shipbuilding.

# 5. Conclusions

The impact of organizing the cruise shipbuilding process for its productivity has not been researched much. Thus, this thesis offers a new view on this topic (Hellgren et al., 2016). In this thesis, the cruise shipbuilding process was modelled in relation to production efficiency and that model was used to analyze the effect of organization type on production efficiency. The impact of organizing the shipbuilding process for production efficiency was modeled to compare the probabilities for three organizing methods. Based on the model presented here, it is clear that the organizing method does indeed impact production efficiency. Although that impact might not seem considerable at first glance, it illustrates a clear trend. The goal of the thesis was to clarify whether organization structure has an impact on production efficiency. The goal was reached. The highest probability of achieving an intended production efficiency is reached when using Project Organization. The second best probability is when using Hybrid Organization, and the third is when using Line Organization. The differences in these probabilities show the direction of thinking for how organizing methodology should be developed in the future when increased production efficiency is requisitioned. Project organization helps with project target oriented problem-solving and decision-making, target setting, and a bonus system related to project result, clarity in meetings and the reporting hierarchy, more accurate resource planning, functional area division, and use of regular status reporting. That is why these factors are important and they should be put much attention to in cruise shipbuilding process. The study on the effects of different organization methods is part of the discussion of organizations and their uses in different processes. The benefits of Project Organization is also noted by Hobday (2000). The model also shows how individual factors in the process act within different organization types. This result is useful when considering future organization types to develop the best cruise shipbuilding process. Further, it shows that even in a complicated process, it is possible to discover factors of improvement that will indeed affect overall production efficiency. The model with its elicitations helps to understand how the process has worked in the past, but it also makes it possible to investigate optimal procedures for the future.

The main limitations of the work are that the study was done in one shipyard only because the information needed for this kind of study is very broad and not generally available. Also the number of experts is limited, but herein the demanded qualifications for experts were special including long working period in the same shipyard in the different parts of the process and for that reason they were difficult to find.

The modelling of the cruise shipbuilding process related to production efficiency is a new study on applying Bayesian Networks. BN has been used in various studies as stated in Section 2.4 of this thesis. The basic idea and network structures are largely the same. However, raising a feature of the process as the main idea of the model and studying it for organization type is a different focus. Bayesian Network enables one to model a building process in a new way by understanding the complicity of the process and how it is possible to research it through the use of dependencies.

In the thesis the cruise ship building process has been modelled for the first time as an entire process. The model is now available for further development and the results of the impact of organization structure can now be used as a basis for decision making in shipyards.

In the future the model could provide information on how to control and manage the whole shipbuilding process in order to maximize production efficiency. Also, in shipyards the model can be used together with data mining and combine the benchmarking methods discussed in Section 2. Another topic could be how a project organization, strictly connected to WBS, would improve the probability of achieving the targeted production efficiency**.** Also the study of minimizing lead times could be one interesting topic. To study whether the model could work the other way round indicating necessary preconditions for settled targets would be interesting and beneficial. Further, the modelling was based on a one project-at-a time focus. It would be useful to study the impact of a multi-project environment and compare those results to this study. The model is new in this context, but the basic concept of the ship building process is a general one. This can make it possible in the future to compare shipyards with different organizational structures as well as doing an analysis of the consequences of reorganizing from one organization type to another in different shipyards. This model can be used in the future to also study other factors than organization structure with production efficiency in the cruise ship building process.

The study was based on the process of one shipyard and its experiences over the course of 30 years. Every shipyard has its own processes and ways of working, but the main process for building cruise ships at a high level is largely the same. Thus, the results of this study can be used in most shipyards to target better production efficiency. Hopefully this study will also encourage even further research on the topic itself.

# References


Akhtar, M. J., & Utne, I. B. (2014). Human fatigue's effect on the risk of maritime groundings–A Bayesian Network modeling approach. Safety science, 62, 427-440.

Alfeld, L. E., Pilliod, C. S., & WILKINS, J. R. (1998). The virtual shipyard: a simulation model of the shipbuilding process. Journal of Ship production, 14(1), 33-40.

Andritsos, F., & Perez-Prat, J. (2000). The automation and integration of production processes in shipbuilding. State-of-the-Art report, Joint Research Centre. European Commission, Europe.

Antao et al., Norrington et al., 2008 Antão, P., & Soares, C. G. Analysis of the influence of waves in The occurrence of accidents in the Portuguese coast using Bayesian belief networks

Atkinson, R. (1999). Project management: cost, time and quality, two best guesses and a Phenomenon, its time to accept other success criteria. International journal of project management, 17(6), 337–342.

Aurélio de Oliveira, M., Veriano Oliveira Dalla Valentina, L., & Possamai, O. (2012). Forecasting Project performance considering the influence of leadership style on organizational agility. International Journal of Productivity and Performance Management, 61(6), 653-671.

Banabic, D. (2010). *Sheet metal forming processes: constitutive modelling and numerical simulation*. Springer Science & Business Media.

Bayes fusion, http://www.bayesfusion.com/#!genie-modeler/lf73d 8.6.2016

Bogetoft, P., & Otto, L. (2011). Stochastic Frontier Analysis SFA. In *Benchmarking with DEA, SFA, and R* (pp. 197-231). Springer New York.

Brady, T., Davies, A., Gann, D., & Rush, H. (2006). Learning to manage mega projects: the case of BAA and Heathrow Terminal 5. *Learning to manage mega projects: The case of BAA and Heathrow Terminal 5.*

Bruce, G., & Garrard, I. (2013). The Business of Shipbuilding. CRC Press.

Charniak, E. (1991). Bayesian networks without tears. AI magazine, 12(4), 50.

Cho, K. K., Oh, J. S., Ryu, K. R., & Choi, H. R. (1998). An integrated process planning and Scheduling system for block assembly in shipbuilding. CIRP Annals-Manufacturing Technology, 47(1), 419-422.

Dağdeviren, M. (2008). Decision making in equipment selection: an integrated approach with AHP And PROMETHEE. *Journal of intelligent manufacturing*, *19*(4), 397-406.

Dağdeviren, M., & Yüksel, İ. (2008). Developing a fuzzy analytic hierarchy process (AHP) model For behavior-based safety management. *Information Sciences*, *178*(6), 1717-1733.

Darwiche, A. (2009). Modeling and reasoning with Bayesian networks. Cambridge University Press.

Druzdzel, M. J. (1999). GeNIe: A development environment for graphical decision-analytic models. In Proceedings of the AMIA Symposium (p. 1206). American Medical Informatics Association

Eleye-Datubo, A. G., Wall, A., Saajedi, A., & Wang, J. (2006). Enabling a powerful marine and Offshore decision-support solution through Bayesian network technique. Risk Analysis, 26(3), 695-721.

Emblemsvåg, J. (2014). Lean project planning in shipbuilding. Journal of Ship Production and Design, 30(2), 79-88.

Erdem, K. (2015). Lean Manufacturing effects of modularization on the outfitting process in Shipbuilding (Doctoral dissertation, TU Delft, Delft University of Technology).

Erikstad, S. O. (2009). Modularization in shipbuilding and modular production. Innovation in Global Maritime Production.

Eyres, D. J., & Bruce, G. J. (2012). Ship construction. Butterworth-Heinemann.

Fenton, N., & Neil, M. (2012). Risk assessment and decision analysis with Bayesian networks. CRC Press.

Fernández, R. P., & Lado, R. P. (2015). Integration between Shipbuilding CAD Systems and a Generic PLM Tool in Naval Projects. Computer Science, 2(5), 181-191

Ford, R. C., & Randolph, W. A. (1992). Cross-functional structures: A review and integration of Matrix organization and project management. Journal of Management, 18(2), 267-294.

Färe, R., Grosskopf, S., & Lovell, C. K. (2013). The measurement of efficiency of production (Vol. 6). Springer Science & Business Media.

Goerlandt, F., & Montewka, J. (2014). A probabilistic model for accidental cargo oil outflow from Product tankers in a ship–ship collision. Marine pollution bulletin, 79(1), 130-144.

Goerlandt, F., & Reniers, G. (2016). On the assessment of uncertainty in risk diagrams. *Safety Science*, *84*, 67-77.

Greco, S., Figueira, J., & Ehrgott, M. (2005). Multiple criteria decision analysis. *Springer's International series*.

Greene, W. H. (1997). Frontier production functions. In Pesaran, M.H. and Shmidt, P, editors, Handbook of Applied Econometrics, volume II: Microeconometrics. Blackwell Publishers Ltd.

Greve, H. R. (2007). Exploration and exploitation in product innovation. Industrial and Corporate Change, 16(5), 945-975.

Hellgren S., Hänninen M., Valdez Banda, O., Kujala P. (2016) Journal of Ship Production and Design, Vol 32, No.3, August 2016, pp 1-21, http://dx.doi.org/10.5957/JSPD.32.3.160009

Hiekata, K., & Grau, M. (2015). Shipbuilding. In Concurrent Engineering in the 21st Century (pp. 671-700). Springer International Publishing

Hobday, M. (2000). The project-based organization: an ideal form for managing complex products And systems? Research policy, 29(7), 871-893.

Hänninen et al., Konovessis et al., 2013 Hänninen, M. (2014). Bayesian networks for maritime traffic Accident prevention: Benefits and challenges. Accident Analysis & Prevention, 73, 305-312.

Hänninen, M., Banda, O. A. V., & Kujala, P. (2014). Bayesian network model of maritime safety Management. Expert Systems with Applications, 41(17), 7837-7846.

Hänninen, M., & Kujala, P. (2012). Influences of variables on ship collision probability in a Bayesian Belief network model. Reliability Engineering & System Safety, 102, 27-40.

Hänninen, M., & Kujala, P. (2014). Bayesian network modeling of Port State Control inspection Findings and ship accident involvement. Expert Systems with Applications, 41(4), 1632-1646.nen, & Kujala, P. (2014).

Jensen, F. V. (1996). An introduction to Bayesian networks (Vol. 210). London: UCL press.

Joyce, J. (2003). Bayes' theorem.

Kelangath et al., 2011Kelangath, S. K. (2011). A risk based framework for the analysis of intact and Damaged ships (Doctoral dissertation, University of Strathclyde).

Kim, H., Lee, S. S., Park, J. H., & Lee, J. G. (2005). A model for a simulation-based shipbuilding System in a shipyard manufacturing process. *International Journal of Computer Integrated Manufacturing*, *18*(6), 427-441.

Koch, R. (2011). The 80/20 principle: the secret to achieving more with less. Crown Business.

Koenig, P. C., Narita, H., & Baba, K. (2002). Lean production in the Japanese shipbuilding industry. Journal of ship production, 18(3), 167-174.

Kolić, D., Storch, R. L., & Fafandjel, N. (2016, January). Additive manufacturing in compliance With lean manufacturing. In ASNE Day 2016.

Krause, M., Roland, F., Steinhauer, D., & Heinemann, M. (2004). Discrete event simulation: An Efficient tool to assist shipyard investment and production planning. Journal of ship production, 20(3), 176-182.

König, M., Beißert, U., Steinhauer, D., & Bargstädt, H. J. (2007, September). Constraint-based Simulation of outfitting processes in shipbuilding and civil engineering. In *Proceedings of the 6th EUROSIM Congress on Modeling and Simulation*.

Lee, E., Park, Y., & Shin, J. G. (2009). Large engineering project risk management using a Bayesian Belief network. Expert Systems with Applications, 36(3), 5880-5887.

Lehikoinen, A., Luoma, E., Ma¨ntyniemi, S., & Kuikka, S. (2013). Optimizing the recovery efficiency Of Finnish oil combating vessels in the Gulf of Finland using Bayesian networks. Environmental Science & technology, 47(4), 1792-1799.

Liker, J. K., & Lamb, T. (2002). What is lean ship construction and repair? Journal of ship Production, 18(3), 121-142.

Liu, Z., Chua, D. K. H., & Yeoh, K. W. (2011). Aggregate production planning for shipbuilding with Variation-inventory trade-offs. International Journal of Production Research, 49(20), 6249-6272.

Lundin, R. A., & Söderholm, A. (1995). A theory of the temporary organization. *Scandinavian Journal of management*, *11*(4), 437-455.

Lægaard, J., & Bindslev, M. (2006). Organizational theory. © 2006 Jørgen Lægaard, Mille Bindslev & Ventus Publishing ApS ISBN 87-7681-169-7

Martins, M. R., & Maturana, M. C. (2013). Application of Bayesian Belief networks to the human Reliability analysis of an oil tanker operation focusing on collision accidents. Reliability Engineering & System Safety, 110, 89-109.

McLean, C., & Shao, G. (2001, December). Simulation in shipyards: simulation of shipbuilding Operations. In Proceedings of the 33nd conference on winter simulation (pp. 870-876). IEEE Computer Society.

Meyer, J., (2010). Empirical perspectives on learning at work (Doctoral thesis, Jacobs University, Bremen, Germany))

Montewka, J., Ehlers, S., Goerlandt, F., Hinz, T., Tabri, K., & Kujala, P. (2014). A framework for Risk assessment for maritime transportation systems—a case study for open sea collisions Involving RoPax vessels. Reliability Engineering & System Safety, 124, 142-157.

Montewka, J., Weckström, M., & Kujala, P. (2013). A probabilistic model estimating oil spill clean-Up costs–A case study for the Gulf of Finland. Marine pollution bulletin, 76(1), 61–71.

Nielsen, T. D., & Jensen, F. V. (2009). Bayesian networks and decision graphs. Springer.

Napa Designer, https://www.napa.fi/ 29.6.2016

O'Hagan, A., Buck, C. E., Daneshkhah, A., Eiser, J. R., Garthwaite, P. H., Jenkinson, D. J., ... & Rakow, T. (2006). Uncertain judgements: eliciting experts' probabilities. John Wiley & Sons

Park, J. H., Kim, K. H., & Bae, J. H. J. (2011). Analysis of shipbuilding fabrication process with Enterprise ontology. Computers in Human Behavior, 27(5), 1519-1526.

Pires Jr, F., Lamb, T., & Souza, C. (2009). Shipbuilding performance benchmarking. International Journal of Business Performance Management, 11(3), 216-235.

Pitchforth, J., & Mengersen, K. (2013). A proposed validation framework for expert elicited Bayesian Networks. Expert Systems with Applications, 40(1), 162-167.

Porcelli, F. (2009). Measurement of Technical Efficiency. A brief survey on parametric and non-parametric techniques. *University of Warwick*, *11*.

Prokopenko, J. (1987). Productivity management: A practical handbook. International Labour Organization.

Quintana, R., & Leung, M. T. (2012). A case study of Bayesian belief networks in industrial work Process design based on utility expectation and operational performance. International Journal of Productivity and Performance Management, 61(7), 765-777.

Robbins, S. P. (1983). Organization theory: The structure and design of organizations. Prentice-Hall.

Roland, F., Manzon, L., Kujala, P., Brede, M., & Weitzenböck, J. (2004). Advanced joining Techniques in European shipbuilding. Journal of ship production, 20(3), 200-210.

Saaty, T. L. (1988). What is the analytic hierarchy process? In *Mathematical models for decision support* (pp. 109-121). Springer Berlin Heidelberg.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences*, *1*(1), 83-98.

Semenick, I. (1994). Movements of domestic airline technical efficiency scores over time: implications for future industry structure. Transportation research record, 8-8.

Simola, K., Mengolini, A., Bolado-Lavin, R., & Gandossi, L. (2005). Training material for formal Expert judgment. JRC's Technical Report EUR, 21770.

SMILE (Structural Modeling, Inference, and Learning Engine), https://dslpitt.org/genie/ 7.10.2015

Stamelos, I., Angelis, L., Dimou, P., & Sakellaris, E. (2003). On the use of Bayesian belief networks For the prediction of software productivity. Information and Software Technology, 45(1), 51-60.

Taylor-Powell, E., & Steele, S. (1996). Collecting evaluation data: Direct observation. Program Development and Evaluation. Wisconsin: University of Wisconsin-Extension, 1-7.

Tu, Y., (1997) Production planning and control in a virtual one-of-a-kind production company. Computers in Industry, 34(3), 271-283.

Uusitalo, L. (2007). Advantages and challenges of Bayesian networks in environmental modelling. Ecological modelling, 203(3), 312-318.

White, D., & Fortune, J. (2002). Current practice in project management—an empirical study. International journal of project management, 20(1), 1-11.

# Appendices

Appendix 1: Structure of the model

Appendix 2: Result of elicitations, http://urn.fi/URN:ISBN:978-952-60-7117-6

Appendix 3: Sensitivity analysis of the model

# Appendix 1. Structure of the model

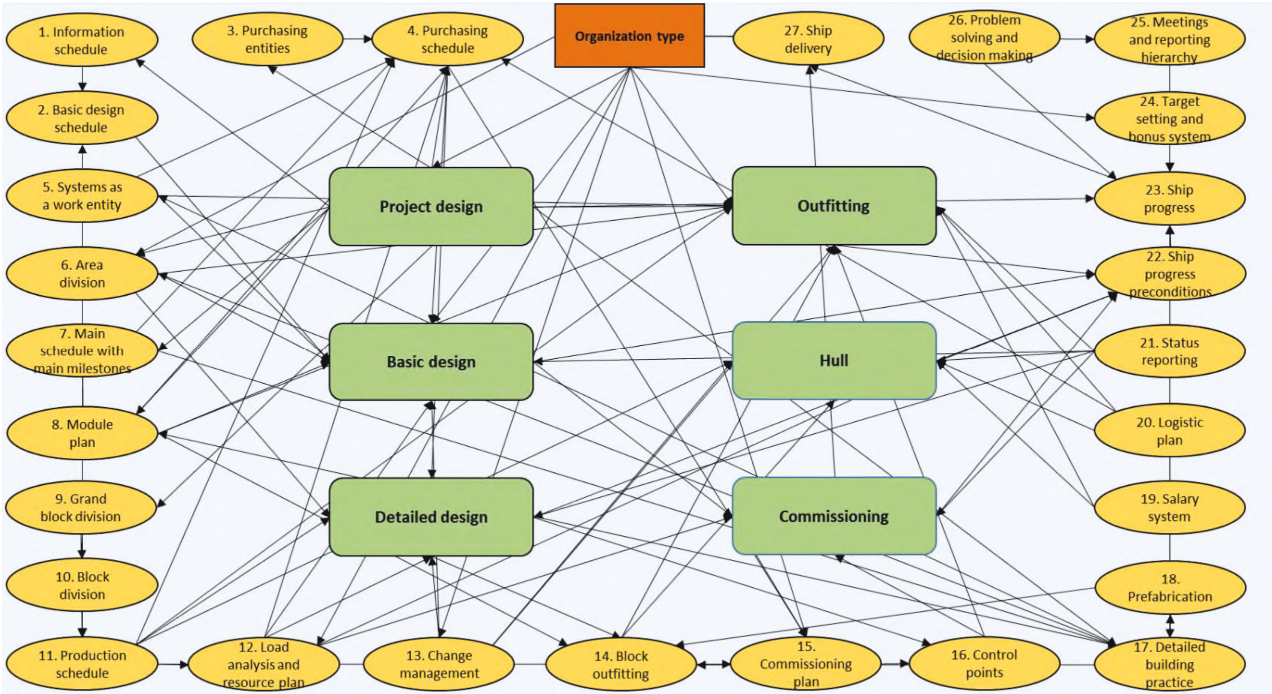



**Figure 1.1**. Main model of cruise ship building process in respect to production efficiency

**Table 1.1** Description of the main model (figure 1).

| No. | Name | Parent node(s) | Children node(s) | Description | States |
|---|---|---|---|---|---|
| 1 | Information schedule | Specification (Sub-Model (SM) project design) | Basic design schedule | Schedule that defines the order and schedule of the need of design information during the basic design process | Integrated to purchasing schedule<br>Not integrated to purchasing schedule |
| 2 | Basic design schedule | Information schedule, main schedule with main milestones | Architectural design, basic design progress and classification design. | Work split and schedule for all basic design documentation | Based on need of information<br>Not based on need of information |
| 3 | Purchasing entities | High-level building practise and milestones (SM project design) | Purchasing schedule | Plan of entities and their scopes of purchasing in material categories (A, B, C) material, turnkey deliveries (TK), design work and subcontracting in hull and outfitting. | Based on work breakdown structure<br>Not based on work breakdown structure |
| 4 | Purchasing schedule | Purchasing entities, main schedule with main milestones, production schedule ,load analysis and resource plan ,logistic plan | Component purchasing and purchasing contracts and material scopes A,B,C | Schedule for the purchasing process of purchasing entities. | Based on work breakdown structure<br>Not based on work breakdown structure |
| 5 | Systems as work entity | Detailed building practice | Production schedule, responsibilities and scopes and turnkey entities and scopes. | Defines which systems will be designed, purchased, outfitted and commissioned as ship wide systems. | In use<br>Not in use |
| 6 | Area division | General arrangement (GA) (SM project design), detailed building practice, organization type | Area/system matrix, arrangement design, production schedule, responsibilities and scopes, turnkey entities and scope and workshop drawings and part lists | Defines the borders of areas that are the controllable entities for design, purchasing, installation and inspections. | High functionality<br>Low functionality |
| 7 | Main schedule with main milestones | High-level building practise and milestones (SM project design) | Basic design schedule, detailed building practice, module plan, production schedule and purchasing schedule | Defines the 6-10 main milestones (such as start of basic design, start of detail design, start of production…), which form the basis for the ship schedule. | Based on correct statistics<br>Not based on correct statistics |
| 8 | Module plan | High level building practise and milestones (SM project design) , main schedule with main milestones ,Detailed building practice | Area outfitting plan, arrangement design, block outfitting, production schedule and purchasing contracts and material scope A,B,C. | Describes modules and prefabricates which will be extensively outfitted before taking inside the vessel. | Major<br>Minor |
| 9 | Grand block division | High-level building practise and milestones (SM project design) | Block division and production schedule | Defines the borders of steel blocks according to work breakdown structure to act as controlling entities | High compatibility<br>Low compatibility |
| 10 | Block division | Grand block division | Production schedule | Defines the borders of blocks of steel hull, which are controlling entities for detail design, manufacturing, block outfitting | High compatibility<br>Low compatibility |

| | | | | | |
|---|---|---|---|---|---|
| 11 | Production schedule | Systems as work entity, area division, main schedule with main milestones, grand block division, block division, module plan | Area outfitting plan, commissioning plan, detail design schedule, hull detailed design, hull progress preconditions, load analysis and resource plan and purchasing schedule. | Sets the dates for production inside the main milestones for hull assembly (prevailing block and grandblock fabrication,block outfitting), outfitting, commissioning with workloads | Good schedule control<br>Poor schedule control |
| 12 | Load analysis and resource plan | Production schedule, organization type | Basic design competence, commissioning competence, detail design competence, hull competence, outfitting competence, purchasing schedule, responsibilities and scopes. | Indicates the need of resources based on the work budget | High need of subcontracting with accurate plan<br>Low need of subcontracting with accurate plan |
| 13 | Change management | Organization type | Architectural design, area outfitting, hull, hull detail design, system descriptions, schemes and part lists, system outfitting and workshop drawings and part lists. | Is a procedure which defines how any change is documented, put into workflow, followed up | Known process for change work flows and responsibilities<br>No known process for change work flows and responsibilities |
| 14 | Block outfitting | Detail design progress (SM detail design) , detailed building practice, module plan, prefabrication | Area outfitting and hull progress. | Outfitting work that is done in block or in grand block. | High<br>Low |
| 15 | Commissioning plan | production schedule, organization type | Commissioning, control points and system suppliers | Defines the schedule and content for commissioning, inspections and tests for systems | Integrated to production schedule<br>Not integrated to production schedule |
| 16 | Control points | Area/system matrix (SM detail design), commissioning plan | Area outfitting plan, system outfitting and commissioning | Milestones in area production schedule which are based on system schedule. | Based on system schedule<br>Not based on system schedule |
| 17 | Detailed building practice | high level building practise and milestones (SM project design), logistic plan, main schedule with main milestones | Area division, block outfitting, module plan, prefabrication and systems as work entity. | Defines the building practice by work breakdown structure i.e. how design, purchasing and building of the work entity is done | Enables comprehensive planning<br>Not enables comprehensive planning |
| 18 | Prefabrication | Detailed building practice | Block outfitting | Work which is done in factory, not on board is prefabricating | High<br>Low |
| 19 | Salary system | - | Hull progress preconditions and outfitting progress preconditions. | Basis for paying salary. | Time-based<br>Not time-based |
| 20 | Logistic plan | - | Area outfitting plan, detailed building practice, hull and purchasing schedule. | How the blocks, grand blocks and other materials are transported to their working place and in which entities. | Integrated to production schedule<br>Not integrated to production schedule |
| 21 | Status reporting | Organization type | Basic design progress, commissioning progress, detail design progress, hull progress, outfitting progress and ship progress | Report of readiness of work, costs and obstacles of progress | Regular follow-up and possibility to catch up<br>Irregular follow-up |
| 22 | Ship progress preconditions | Basic design progress (SM basic design), commissioning progress (SM commissioning), detail design | Ship progress. | Creates the possibility to work according to the schedule | Good<br>Poor |

| | | | | | |
|---|---|---|---|---|---|
| | | progress (SM detail design progress), hull progress (SM hull), outfitting progress (SM outfitting) | | | |
| 23 | Ship progress | Meetings and reporting hierarchy, problem solving ,ship progress preconditions ,status reporting, target setting and bonus system | Ship delivery | The total readiness of ship construction | In schedule and in budget<br>Delays and budget overruns |
| 24 | Target setting and bonus system | Organization type | Ship progress | Defines the schedule and budget targets | Connected to the project result<br>Not connected to the project result |
| 25 | Meetings and reporting hierarchy | Organization type | Ship progress | The meeting calendar which defines the reporting hierarchy in line and in project | High complexity<br>Low complexity |
| 26 | Problem solving and decision making | Organization type | Ship progress | Procedure for identifying and solving the most critical problems | Project target oriented<br>Not target oriented |
| 27 | Ship delivery | Commissioning (SM commissioning), ship progress | Achievance probability. | Ship accepted for delivery by owner | Targeted production efficiency achieved<br>Targeted production efficiency not achieved |

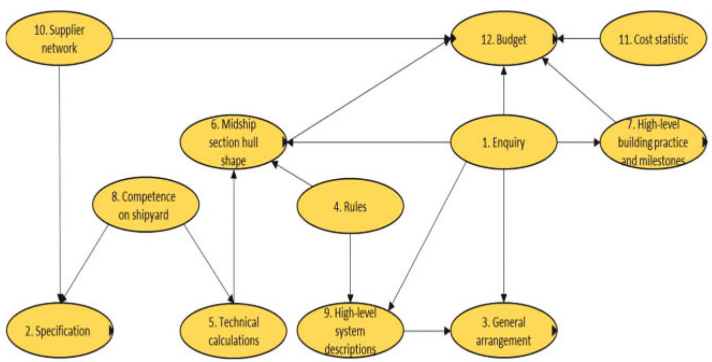



**Figure 1.2**. Sub- model Project Design

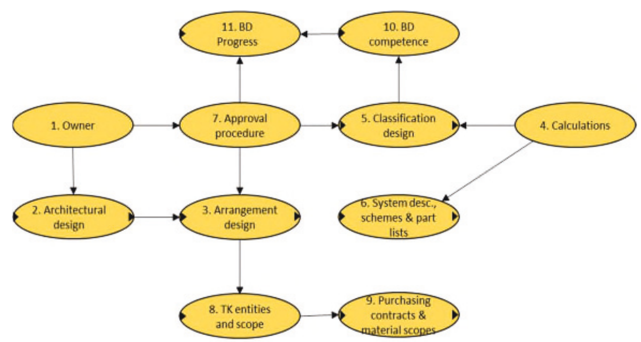



**Figure 1.3**. Sub-model Basic Design

**Table 1.2**. Description of the Sub- model Project Design (figure 2).

| *No.* | *Name* | *Parent node(s)* | *Children node(s)* | *Description* | *States* |
|---|---|---|---|---|---|
| *1* | Enquiry | - | High level-building practice, midship section hull shape, high-level system descriptions, GA and budget. | Owner's enquiry to shipyard to deliver a cruise vessel. | Detailed<br>General |
| *2* | Specification | Competence on shipyard, high-level system descriptions, supplier network, technical calculations | Information schedule,system descriptions and architectural design | Document, which defines the technical and architectural contents of the ship in respect to complexity. | High complexity<br>Low complexity |
| *3* | General arrangement | Enquiry, high-level system descriptions | Area division and arrangement design | General arrangement defines the layouts of the decks of ship. | High complexity<br>Low complexity |
| *4* | Rules | - | Midship section hull shape and high-level system descriptions | Rules define the technical conditions which are to be followed in structures and operation. | High complexity<br>Low complexity |
| *5* | Technical calculations | Competence on shipyard | Midship section hull shape, high-level system descriptions and specification. | Calculations form the theoretical basis for defining the technical properties. | High reliability<br>Low reliability |
| *6* | Midship section | Enquiry , rules, technical calculations | Classification design | Defines the essential structure of the ship's steel hull. | High complexity<br>Low complexity |
| *7* | High-level system descriptions | Enquiry , rules, technical calculations | Specification and GA | System's functional descriptions which present the main features of its functionality. | High clarity<br>Low clarity |
| *8* | Competence | - | Technical calculations and specification | The level of know-how of project design. | High<br>Low |
| *9* | High-level building practise and milestones | Enquiry | Budget, main schedule with main milestones, detailed building practice, module plan, grand block division, purchasing entities | Defines the main principles of Work Breakdown Structure i.e. how design, purchasing and building the ship are controlled. | Whole process<br>Only production |
| *10* | Supplier network | - | Budget and specification | The quality and diversity of accepted design, component, material, subcontracting and turnkey contractors. | Good<br>Poor |
| *11* | Cost statistic | - | Budget | For calculation purposes unit prices of cost elements of the ship are used. | Good reliability<br>Poor reliability |

| | | | | | |
|---|---|---|---|---|---|
| 12 | Budget | Cost statistics, enquiry, high-level building practice and milestones, organization type, supplier network | Basic design progress, detail design progress preconditions, component purchasing, outfitting progress preconditions, hull progress preconditions and commission progress preconditions. | The prime cost which corresponds the specification, midship section and GA | Enabling a realistic target<br>Not enabling a realistic target |

**Table 1.3**. Description of the Sub-model Basic Design (figure 3).

| ***No.*** | ***Name*** | ***Parent node(s)*** | ***Children node(s)*** | ***Description*** | ***States*** |
|---|---|---|---|---|---|
| 1 | Owner | - | Architectural design and approval procedure | Owner of the vessel, counterparty of the ship contract. | High activity<br>Low activity |
| 2 | Architectural design | Basic design schedule (main model), change management main model), owner , specification (SM project design) | Arrangement design and area arrangements | Defines the architectural features of the ship, outside and inside | High production friendliness<br>Low production friendliness |
| 3 | Arrangement design | Approval procedure, architectural design, area division (main model), GA, (SM project design), module plan (main model) | Turnkey entities and scope and area arrangements | The layouts of the spaces on board in interior and machinery | High complexity<br>Low complexity |
| | Calculations | - | Classification design and system descriptions, schemes and part lists. | Calculations give the theoretical basis for the technical properties. | High reliability<br>Low reliability |
| 5 | Classification design | Approval procedure, basic design schedule (main model), calculations , midship section hull shape (SM project design) | Hull detailed design and opening info | In classification design the dimensions of steel structures are defined according to the rules of classification society | High recurrence in structures<br>Low recurrence in structures |
| 6 | System descriptions & schemes & partlists | Calculations, change management (main model) ,specification (SM project design) | Detailed schemes | Description of the system functionality, the system diagram and part list. | Unambiguous<br>Ambiguous |
| 7 | Approval procedure | Owner | Classification design, arrangement design and basic design progress | The process according to which the approval of the documents is done by the classification society and owner. | Whole process scheduled in basic design schedule<br>Whole process not scheduled in basic design schedule |

| | | | | | |
|---|---|---|---|---|---|
| *8* | TK entities and scope | Area division (main model), arrangement design, organization type, systems as work entity (main model) | Purchasing contracts, material scopes A,B,C | Defines the scope and contents of the TK contracts. | Functional entities, based on work breakdown structure<br>Not functional entities, not based on work breakdown structure |
| *9* | Purchasing contracts & Material scope | Module plan (main model), purchasing schedule (main model), TK entities and scope | Delivery control | The scope and contents of design, material, prefabrication and installation contracts. | Independent entities with progress related payment terms<br>Dependent entities , no progress related payment terms |
| *10* | Basic Design competence | Load analysis and resource plan (main model) | Basic design progress | The level of know-how among basic design resources. | High<br>Low |
| *11* | Basic Design progress | Approval procedure, basic design competence ,basic design schedule (main model), budget (SM project design), status reporting (main model) | Detail design progress preconditions and ship progress preconditions. | The readiness of basic design work | In schedule and in budget<br>Delays and/or budget overruns |

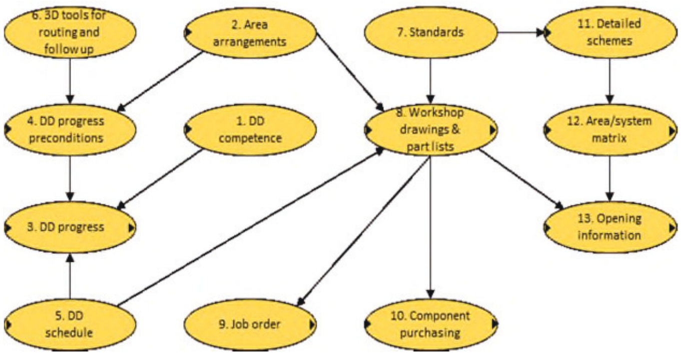



**Figure 1.4**. Sub-model Detail Design (DD).

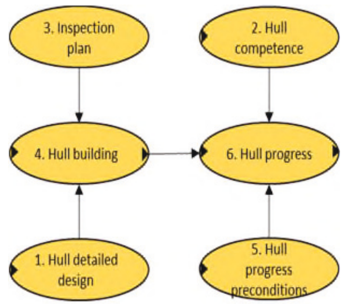



**Figure 1.5**. Sub-model Hull

**Table 1.4**. Description of the sub-model Detail design (figure 4).

| *No.* | *Name* | *Parent node(s)* | *Children node(s)* | *Description* | *States* |
|---|---|---|---|---|---|
| *1* | DD competence | Load analysis and resource plan (main model) | Detail design progress | Level of engineering know how available in shipyard | High<br>Low |
| *2* | Area arrangements | Architectural design (SM basic design), arrangement design (SM basic design) | Detail design progress preconditions and workshop drawings and part lists. | Layout of areas | Enables planning of subareas for better effectiveness<br>Does not enable planning of subareas |
| *3* | DD progress | DD competence, DD progress preconditions, DD schedule, Status reporting (Main model) | Outfitting progress preconditions, block outfitting and ship progress preconditions | The readiness of detail design work. | In schedule and in budget<br>Delays and budget overruns |
| *4* | DD progress preconditions | 3d tools for routing and follow-up, area arrangements, BD progress (SM basic design), budget (SM project design) | Detail design progress | Items which enable/prohibit the DD work to proceed. | Good<br>Poor |
| *5* | DD schedule | Production schedule (main model) | Detail design progress and workshop drawings and part lists. | The schedule for design documents | Need is based on respective production phase. Need is not based on respective production phase |
| *6* | 3 D tools for routing and follow-up | - | Detail design progress preconditions | 3 D design system with standards and material components in electrical format enabling design and follow up | In use<br>Not in use |
| *7* | Standards | - | Detailed schemes and workshop drawings and part lists | Material and work standards. | High extent<br>Low extent |
| *8* | Workshop drawings & part lists | Area arrangements, area division (main model), change management (main model), DD schedule, standards | Job orders, component purchasing, opening info, cable pulling and area outfitting plan | Documentation for manufacturing and installation | Unambiguous<br>Ambiguous |
| *9* | Job order | Workshop drawings & part lists | Responsibilities and scopes | The workplan including securing of materials and budget for the work | Defines the budget for the specified work<br>Does not define the budget for the specified work |
| *10* | Component purchasing | Budget (SM project design), purchasing schedule (main model), workshop drawings & part lists | Delivery control | Purchasing process of materials. | Possibility for competition<br>No possibility for competition |

| | | | | | |
|---|---|---|---|---|---|
| *11* | Detailed schemes | Standards, system descriptions & schemes & part lists (SM basic design) | Area/system matrix | Systems schemes in detailed level. | Can be used as working drawings<br>Cannot be used as working drawings |
| *12* | Area-system matrix | Area division (main model), detailed schemes | Opening info and control points | Defines the areas where different system pipes etc. pass | In use<br>Not in use |
| *13* | Opening info | Area-system matrix, classification design (SM basic design), workshop drawings & part lists | Hull detailed design | Information to hull process about openings and penetrations | Known process in use<br>Known process not in use |

**Table 1.5.** Description of the sub-model Hull (figure 5).

| | ***Name*** | ***Parent node(s)*** | ***Children node(s)*** | ***Description*** | ***States*** |
|---|---|---|---|---|---|
| *1* | Hull detailed design | Change management (main model), classification design (SM project design), opening info (SM detail design), production schedule (main model) | Hull building | Hull workshop drawings and other production documents | Standard solutions in use<br>Standard solutions not in use |
| *2* | Hull competence | Load analysis and resource plan (main model) | Hull progress | Level of know-how of hull detail design, plate work and welding. | High<br>Low |
| *3* | Inspection plan | - | Hull building | Plan of inspections during the production process | Integrated to production schedule<br>Not integrated to production schedule |
| *4* | Hull building | Change management (main model), hull detail design, inspection plan, logistic plan (main model) | Hull progress and area outfitting. | Building of blocks and grand blocks and hull assembly | High amount of fitting work in hull assembly<br>Low amount of fitting work in hull assembly |
| *5* | Hull progress preconditions | Budget (SM project design), production schedule (main model), salary system (main model) | Hull progress | Items which enable/prohibit the hull work to proceed | Good<br>Poor |
| *6* | Hull progress | block outfitting (main model),hull building, hull competence, hull progress preconditions, status reporting (main model) | Ship progress preconditions | Readiness of hull | In schedule and in the budget<br>Delays and/or budget overruns |

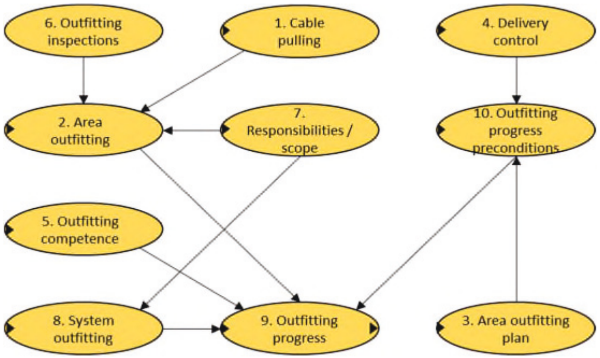



**Figure 1.6**. Sub-model Outfitting

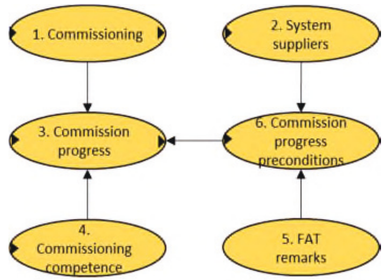



**Figure 1.7**. Sub-model Commissioning

**Table 1.6**. Description of the sub-model Outfitting (figure 6).

| ***No.*** | ***Name*** | ***Parent node(s)*** | ***Children node(s)*** | ***Description*** | ***States*** |
|---|---|---|---|---|---|
| *1* | Cable pulling | Workshop drawings & part lists (SM detail design) | Area outfitting | Pulling of the long cables passing through the spaces of ship. | Scheduled in production schedule as preconditions for area work<br>Not scheduled in production schedule as preconditions for area work |
| | Area outfitting | Block outfitting (main model), cable pulling, change management (main model), hull building (SM hull) , outfitting inspections, responsibilities and scopes | Outfitting progress | Outfitting work in area phase after hull assembly | Outfitting is done in planned order<br>Outfitting is not done in planned order |

| | | | | | |
|---|---|---|---|---|---|
| *3* | Area outfitting plan | Control points,(main model), logistic plan (main model) , module plan (main model), production schedule (main model), workshop drawings & part lists (SM detail design) | Outfitting progress preconditions | Consists of schedule with allocated resources, design documentation, proper delivery control etc. | Comprehensive<br>Limited |
| *4* | Delivery control | Component purchasing (SM detail design), purchasing contracts & material scope A,B,C (SM basic design) | Outfitting progress preconditions | Control and follow up of purchased items/contracts including material, work, turnkey | Deliveries in time<br>Delays in deliveries |
| *5* | Outfitting competence | Load analysis and resource plan (main model) | Outfitting progress | The level of know-how which is needed for execution of outfitting | High<br>Low |
| *6* | Outfitting inspections | - | Area outfitting | Plan of inspections during the outfitting process. | Integrated to production schedule<br>Not integrated to production schedule |
| *7* | Responsibilities/scopes | Area division (main model), job order (SM detail design), Load analysis and resource plan (main model), organization type, systems as work entity (main model) | Area outfitting and system outfitting | The principle how responsibilities and work scopes are directed to the people. | WBS-based target setting<br>Not WBS-based target setting |
| *8* | System outfitting | Change management (main model), control points (main model) , responsibilities and scopes | Outfitting progress | Outfitting work by systems. | System is built ship wide by one team   System is not built ship wide by one team |
| *9* | Outfitting progress | Area outfitting, outfitting competence, outfitting progress preconditions, status reporting (main model), system outfitting | Commission progress preconditions and ship progress preconditions. | Readiness of outfitting work. | In schedule and in budget<br>Delays and budget overrun |
| *10* | Outfitting progress preconditions | Area outfitting plan, budget (SM project design), DD progress (SM detail design), delivery control, salary system (main model) | Outfitting progress | Items which enable/prohibit the outfitting work to proceed | Good<br>Poor |

**Table 1.7**. Description of the sub-model Commissioning (figure 7).

| *No.* | *Name* | *Parent node(s)* | *Children node(s)* | *Description* | *States* |
|---|---|---|---|---|---|
| 1 | Commissioning | Commissioning plan, control points (main model) | Commission progress and ship delivery | Plan how to take different systems into use and test them. | Based on WBS<br>Not based on WBS |
| 2 | System suppliers scope | Commissioning plan (main model) | Commission progress preconditions | The scope of the system suppliers | Based on WBS<br>Not based on WBS |
| 3 | Commissioning progress | Commissioning progress preconditions, commissioning, commissioning competence, status reporting (main model) | Ship progress preconditions | Readiness of commissioning. | In schedule and in budget<br>Delays and budget overruns |
| 4 | Commissioning competence | Load analysis and resource plan (main model) | Commission progress | The level of know-how which is needed for execution of commissioning | High<br>Low |
| 5 | FAT remarks | - | Commission progress preconditions | Amount of open FAT (factory test) remarks when commissioning is ongoing | High<br>Low |
| 6 | Commissioning progress preconditions | Budget (SM project design), FAT remarks , outfitting progress, system suppliers | Commission progress | Items which enable/prohibit the commissioning work to proceed | Good<br>Poor |

# Appendix 3. Sensitivity analysis

The most sensitive variables based on GeNIe sensitivity analysis are marked with the symbol ☆.

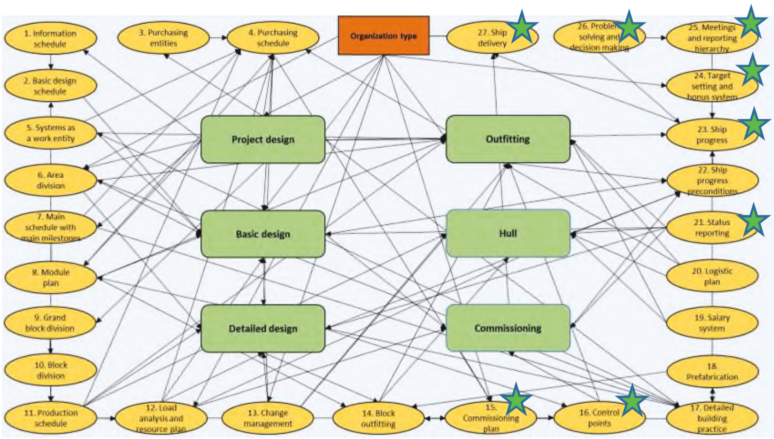



**Figure 3.1**. Main model variables.

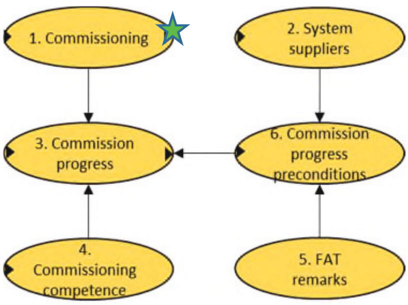



**Figure 3.2.** Sub-model Commissioning variables.

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The cruise shipbuilding process is a complicated chain of events. The shipyard executes the project together with a vast network of suppliers. Production efficiency as such has been studied widely, but the effect of project organization methods of this process has not yet been examined. This thesis studies the effect that organization methods have on overall production efficiency. For research purposes, the Bayesian network is utilised to model the entire cruise shipbuilding process, with focus on three organization methods; Line Organization, Project Organization and Hybrid Organization. The results show that Project Organization offered the best probability for achieving set targets from the view point of production efficiency. The results can be utilised as basis for decisions on best possible organization for similar projects, not only in shipyards but also in other industries that deal with project type deliveries. The compiled Bayesian model is first of its kind, representing the entire cruise shipbuilding process as well as the comparison between the organization

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