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Product’s material cost categories and measures

Master of Science in Technology Thesis

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Materials Engineering

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Shipbuilding is a complex process where the selection of appropriate materials in the design phase ensure the ship's structural properties, performance and long lifetime. Shipbuilding aims to design and build a product meeting owner's requirements while also securing sustainable product and long working life.

The purpose of this thesis was to define and analyse measures to follow and compare the total material costs of a case company operating within a maritime industry. Accurate and easy to use cost follow-up measures are expected to improve the forecasting quality, identify the required action points and ease managing of the cost estimates. Within a competitive market and with low profit margins, the pricing of the product as well as managing the future company insights require accurate and reliable means to create the cost estimates.

The literature review of the thesis started from describing the basic principles of ship design processes and material categorization and followed by presenting the key aspects of forecasting and cost estimation of shipbuilding materials.

The thesis suggests material categories to support better material cost follow-up and comparison. The categories were defined based on the similar properties of the materials and typical categories presented by the literature. The selected and analysed material categories were stock materials, machinery systems, electrical systems, hotel systems and deck systems.

As a result of the thesis, it was found that especially the materials with low individual price and high volume had a good linear dependency on the gross tonnage of the analyzed ship. The machinery system costs were well comparable to the installed power of the main engines. The categories containing more variation independent materials, especially the deck systems, were found to be more difficult to group and measure.

The KPIs presented in this thesis are suitable for a high-level analysis and comparisons but a further investigation of the shown deviations would be recommended to reach results that are more accurate.

Key words: material costs, material categorization, forecasting, ship

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1 Introduction

Shipbuilding is a complex process where the selections of materials to be utilized is crucial to ensure the ship's structural properties, performance and long lifetime. The selection of appropriate materials in the design phase enables to meet the targets in the building process and maintenance of the vessel. The selection of materials in shipbuilding is a complex decision-making process, influenced by factors such as weight, strength, corrosion resistance, environmental impact and fire safety. As technology advances and new material solutions become available, shipbuilders need constantly evaluate and adopt innovations to improve the efficiency, safety and sustainability of maritime transportation.

Ship design aims to design a product meeting owner’s requirements while also considering solutions, such as suitable energy solutions, for a long ship working life. Important aspect of a ship design is to design a profitable trade to give best possible returns for owner’s initial investment together with the running costs. (Eyres & Bruce, 2012)

Majority of the new building ship’s lifetime costs are determined already in early stage of the ship construction process. During the pre-contract design phase, already 70% of the ship’s lifetime expenses are determined. (Nishi & Matsuo, 1997) Therefore the follow-up, control and planning of the shipbuilding activities and creation of accurate forecast of the total costs should start already in a very early phase of the construction process.

The control and accuracy of the forecast are important aspects of forecasting. Forecasts for groups of items are usually more accurate since the errors related to a single item have a cancelling effect. Therefore, the opportunities to group items in a meaningful way is an important step while improving the forecast accuracy. Forecast accuracy is based on the historical errors occurred with the forecast values. Most of the real-world forecasting cases are extremely hard to forecast due to the random variation. Accurate forecast are needed to successfully run the organization in terms of resources, costs, customers and management.

Series shipbuilding costs are usually different compared to single ship construction and design. In series shipbuilding, the repeat ships will use the design created for the first vessel of the series and the familiar construction methods will lower the costs for the repeat vessels. For repeat vessels, the cost estimation has also greater accuracy since the calculation of the costs can be made by using the cost difference method. If the ship is only slightly different in size and output from another ship, it needs to be considered whether an existing design should be modified or should a complete new design be created. (Molland, 2008)

This study is focused on identifying the suitable KPIs to validate and identify differences between the ship project material forecasts and occurred final costs in the case company. The case company is operating in the shipbuilding industry that is strongly focusing on projects with high level of custom-built properties. Due to the variations between the projects, the comparison of different projects and material costs may not be straightforward. In order to identify materials and categories that are comparable, this thesis also aims to clarify the material processes and material categories used in the case company. The conclusive object of this study is to find suitable KPIs to improve the material forecast accuracy and therefore enable the possible corrective actions earlier in the process.

2 Background

In this chapter, the basic principles of the ship design process, material process and cost follow-up are reviewed.

2.1 Ship design process

Ship design aims to design a product meeting owner’s requirements and to take into account long term considerations such as suitable energy solutions for a long ship working life. Important aspect of a ship design is to design a profitable trade to give best possible returns for owner’s initial investment together with the running costs. Ship design process is traditionally divided into three stages including concept design, preliminary design and contract design. (Eyres & Bruce, 2012) Shipyard usually divides the design process to pre-contract design, including the concept and project design, and to a design after the contract, including basic and detail design. The amount of working hours used in design process depends on the size and complexity of the vessel as well as how closely the new vessel follows the pattern of the previous successful design. (Rawson, 2002)

Design process flows towards best solutions in phases that can be illustrates as a design spiral (Figure 1.). The design is detailed and specified step-by-step and the final result is formed after a several continuous development steps. Each step is usually performed several times, such as estimating the cost of the system, when the information is detailed and possible change request are taken into account. (Eyres & Bruce, 2012)

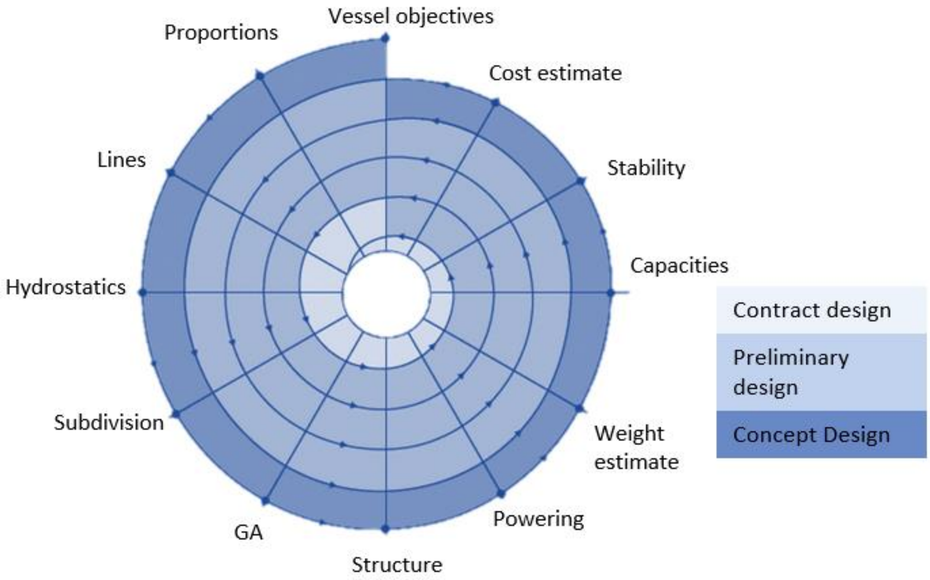

Figure 1: Design spiral. Adapted from (Eyres & Bruce, 2012)

The ship design process can be described by the means of concurrent engineering. In the design process the information flows in many directions between several disciplines and therefore the process is not straightforward. It is important in the concurrent engineering that the communication and change management between the teams is functioning. The main advantage of the functioning concurrent engineering process is that it allows a shorter throughput time. The other advantages are the lower amount of re-design, lower long-term costs and improved productivity. (Sapuan, 2017)

2.1.1 Pre-contract design

In a pre-contract design phase, a ship concept is created. The goal of the pre-contract design phase is to create an offer towards the owner. The pre-concept design phase is divided into concept design and initial design phases. (Räisänen, 1997)

In a concept design phase the main goal is to investigate the feasibility of different solutions and options. A ship concept includes the basic objectives providing the needed information related to technical and economical assessment. (Eyres & Bruce, 2012)

The initial design phase is performed if the owner accepts the ship concept. In the initial design phase a technical specification is created, design methods are specified and further calculations are made. Usually the first general arrangement (GA) of the ship is created during the initial design phase. The initial design phase aims for a profitable ship contract and therefore the technical and conceptual details together with the production methods and timelines need to be clarified.

Based on the concept and initial design output a ship contract between the yard and the owner is made. (Räisänen, 1997)

2.1.2 Basic design

Ship concept together with the rules and regulations create a starting point for the basic design. The basic design aims for a functional and cost-efficient design and acts as an input for the detail design.

The designed systems and areas are determined based on the drawings list. The drawing list describes all the needed drawings together with a timeline for the production of the documents. Especially in a cruise ship design, the amount of the drawings is huge and therefore the document management and follow-up plays crucial role. The drawings needed in the first production steps are usually created as a first step. The creation of the basic design drawings continues so that the production and basic design phases can be overlapping. At this basic design phase, also the building method, area- and block divisions and activity schedules are made.

A key task for the basic design is to create the material specifications and component lists. In a basic design phase all the main equipment are purchased and the suppliers are chosen. The basic design aims to find the suitable material solutions considering the economical, technical and environmental factors together with the feasible installation and operation properties.

After the basic design phase, system diagrams and specifications, component lists and basic design drawings are ready. (Räisänen, 1997)

2.1.3 Detail design

In a detail design phase the installation drawings, detail design drawings and part lists are created. Detail design utilizes almost all the output from the previous phases including the arrangements, system design, material specifications, and architectural material and building method.

Detail design creates input for the production process and the aim is that the production worker is able to install all the needed materials in a correct way utilizing the installation drawings and part lists. Detail design is further specifying the component lists created by the basic design by adding all the needed smaller materials for production purposes as well as creating meaningful work packages for the production purposes. (Räisänen, 1997)

2.2 Ship systems

Ship systems consist of machinery systems, deck equipment, electrical systems, piping systems and other functional systems. In addition, cabins, galleys and others can be described by using term ship system. (MobiShip, 2001) The ship has a certain WBS (work breakdown structure) describing its systems. The WBS structure includes all the needed elements including the hull structure, propulsion plant, large equipment as well as the electrical, piping and HVAC distribution systems. (Lamb, 2003)

Shipbuilding project is managed by dividing different assignments into individual components in a hierarchy structure. A work breakdown structure allows definition, estimation and follow-up of the work packages. Work breakdown structure of a ship is required in each stage of the ship project and therefore the definition of complete and accurate WBS is an important activity. The WBS is used from the inquiry and concept design to basic and detail design and continues through the definition of commissioning work and as-build documentation. It is important to understand the linkages between the defined WBS structure and the various phases of a design and construction processes. The WBS needs to serve the purpose throughout the whole lifecycle from concept design to production and for the maintenance purposes after the ship has entered its service life.

Detailed technical objectives and work tasks are defined for every WBS element. Each WBS element is also assigned to relevant organizational responsibilities and the required processes, resources and materials are defined and linked to the WBS. The WBS together with the specifications, work progress and schedules provide output for the cost, schedule and performance tracking. Work breakdown structures used in shipbuilding are typically either system or product oriented. (Pal, 2015)

System oriented shipbuilding work breakdown structures can vary based on the needs of the project. From literature (Pal, 2015) two different example ship WBS structures are presented: Expanded Ship Work Breakdown Structure ESWBS and SFI (Senter for Forskningsdrevet Innovasjon) group system.

The Expanded Ship Work Breakdown Structure is used for organizing and evaluating project costs, specification, weight, system function, design, production and maintenance. Also for example numbering of ship drawings and other documents can be based on the WBS structure. The main elements of the WBS can be further braked down to describe the functions for logistics, life cycle support or maintenance. The main functional elements of ESWBS are:

- 000 General Guidance and Administration
- 100 Hull Structure
- 200 Propulsion Plant
- 300 Electric Plant
- 400 Command and Surveillance
- 500 Auxiliary Systems
- 600 Outfit and Furnishings
- 700 Armament
- 800 Integration/Engineering
- 900 Ship Assembly and Support Services

The SFI group system is a functional breakdown of ship’s or offshore’s technical and economical properties. The SFI system acts as an international standard and can be used throughout the ship’s lifetime. The system structure acts also as a cost work breakdown structure in cost management activities. There are 10 main items in the WBS out of which two are reserved for additional specific needs:

- 0 reserved
- 1 Ship general
- 2 Hull
- 3 Cargo equipment
- 4 Ship Equipment
- 5 Crew and Passenger equipment
- 6 Machinery main components
- 7 Systems for machinery main components
- 8 Ship common systems
- 9 reserved

(Pal, 2015)

2.3 Material categorization

Shipbuilding is a complex process that demands careful consideration of utilized materials to ensure the ship's structural properties, performance and long lifetime. The selection of appropriate materials in the design phase plays a crucial part in construction and maintenance of the vessel. The selection of materials in shipbuilding is a multifaceted decision-making process, influenced by factors such as weight, strength, corrosion resistance, environmental impact and fire safety. As technology advances and new material solutions become available, shipbuilders need to constantly evaluate and adopt innovations to improve the efficiency, safety, and sustainability of maritime transportation.

The mechanical, chemical and physical properties of the materials determine the material solutions and choices used in shipbuilding. In a modern shipbuilding steel, aluminium alloys and composite materials are the main materials used in a construction. Steel structure in large ships has replaced almost entirely the wood structures used in the past. Steel materials have huge advantages in terms of strength, price, availability and features. Usage of the aluminium in the superstructures of the ships and yachts has also lately been increased due to the lightness of the material type. Composite materials are currently used mostly only in the yacht production. Metallic materials are mostly used materials used in shipbuilding and they require inspection and approval by the classification society. (Mentes & Çağlayan, 2022)

Development of material solutions together with the development of production techniques and processes are driven by the requirements of low cost, long lifetime, strength and safety factors. (Mentes & Çağlayan, 2022) There is a high need to increase the payload to weight ratio in ship construction, which requires development of lighter material solutions, both from the traditional materials and from the new innovative materials. The new solutions and innovations coming through the development in material sciences improve the use of adaptive structures and materials. The improved structures enable the ships to adapt wide range of operational scenarios. (Josefson, et al., 2018)

Cost efficiency in shipbuilding can be improved for example by focusing on the multi-material joining techniques, such as the modularization, improved planning, resource management, logistics in outfitting and the supply chain management. Increased demand of transportation within Europe and neighbouring regions together with the aims towards more environmentally friendly transportation solutions have caused the research activities starting to focus on the new ship concepts. By increasing the service life of the existing ships by retrofit solutions, the demand for the environmental aspects can be also met. There is also a high demand for environmentally friendly and energy efficient fuels and propulsion. Currently this leads to a higher demand of liquefied natural gas (LNG) but also some alternative solutions such as methanol or hydrogen are constantly researched. (Josefson, et al., 2018)

2.3.1 A-B-C approach

Materials can be classified based on A-B-C approach according to certain measures, usually annual currency value. Materials are typically categorized into three classes: A-, B- and C-materials. A-class describes the materials that are important within the inventory management. Only around 10-20 % of the number of items belong to the A-class but about 60-70 % of the annual euro value is accounted by these materials. C-class describes materials that covers 50-60 % of the number of items but they account only to around 10-15 % of the annual euro value. B-class covers materials in between the A- and C-class. The number of classes and the percentages used for categorization may vary from organization to organization but in most instances, a rather small number of different items cover the majority of the annual euro value. Figure 2 illustrates the A-B-C classification concept.

The materials that account to large share of the annual value or costs should receive higher controlling effort. A-class materials should be monitored throughout frequent reviews and with closer customer co-operation. C-class materials are usually handled with bulk orders and require looser control activities. However, the C-materials still play important role in the production processes but the additional costs occurred if ordering too large amount or in a too early stage of construction process is not that significant. B-class materials should be controlled in means between the two extremes. (Stevenson, 2021)

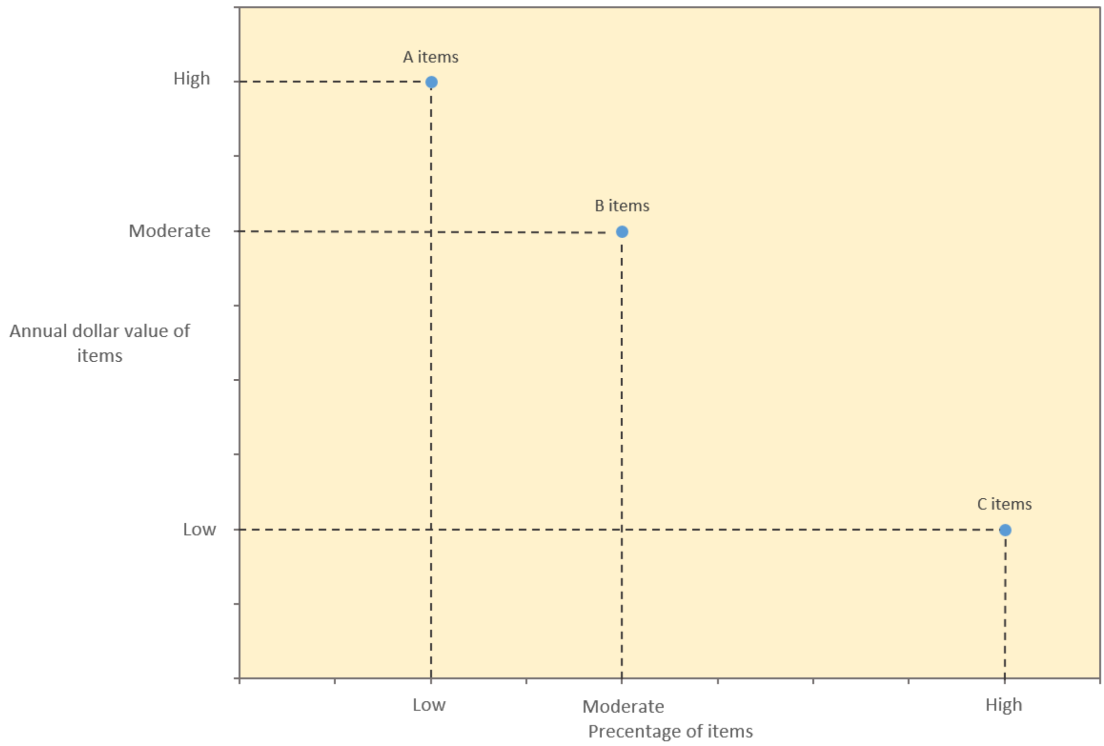

Figure 2: A-B-C Breakdown in terms of annual dollar value and percentage of items in a category. Adapted from (Stevenson, 2021)

In the shipbuilding area the A-materials contain the main equipment required for ship operation, such as main engines, propellers, anchoring systems or laundry equipment. B-materials are components that are in some means unique and require closer control, such as special valves, windows, doors or CCTV cameras. C-materials or so called stock materials are materials that usually have a constant stock level and are used among all the projects and systems, such as nuts, bolts, cables, fittings or small valves. All the mentioned material classes differentiate from each other in many means, e.g. in procurement, controlling, approvals, inventory management and material management.

2.4 Material cost forecasting

In this chapter the main principles of material cost forecasting are reviewed. The parameters and units suggested based on the literature review for ship cost calculation are presented as well.

2.4.1 Material value chain

Materials planning, forecasting and sourcing activities require co-operation between the design and procurement functions. The design team is responsible to provide the material definitions and estimations for different material categories and systems, such as piping materials, cables, mechanical and electronic components, ship's subsystems and deck equipment. The procurement team utilizes the technical information provided by the design to approach and select the suitable suppliers.

The shipbuilder in coordination with the owner is typically conducting the procurement for the hull and structural materials. The ship's subsystems, especially the mechanical and electrical equipment, are typically purchased in coordination with the system integrators, design team and procurement. Selection of the equipment used in the ship systems is an iterative process. The supplier provides the complete information about the components. The ship designer uses in early stages of the design process usually generic components as a placeholder until more information is gathered. The design and procurement teams can evaluate different alternatives during the process and the final product is selected in a later design phase. (Gereffi;Brun;Stokes;& Guinn, 2012)

Majority of the newbuilding ship's lifetime costs are determined already in an early stage of the ship construction process. During the pre-contract design phase, already 70% of the ship's lifetime expenses are determined as described in the Figure 3 while there is around 35% possibility to still affect the expenses. (Nishi & Matsuo, 1997) During the detail design and production phases, most of the costs are already determined and there is only 2-5% possibility to affect the expenses.

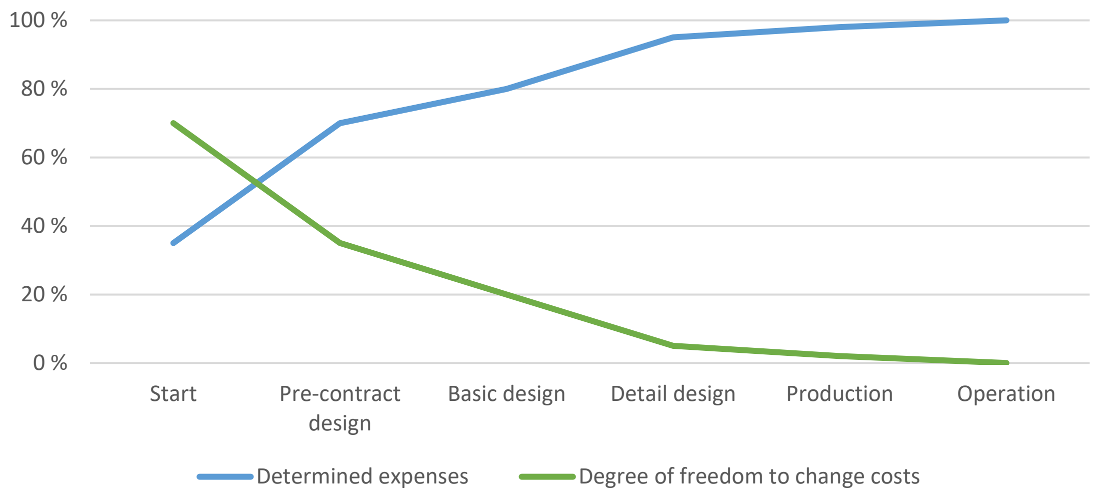

Figure 3: Determination of the ship's lifetime costs over the construction timeline. Adapted from (Nishi & Matsuo, 1997)

While evaluating the success of an invest to a newbuilding vessel, the ship owner needs to compare the occurred costs to the income. The ship owner's cash outflow during the construction as well as the operation of the vessel is caused by:

- down payment and instalments on building costs
- loan repayments and interest
- running costs for crew, bunkering, port charges, etc.
- maintenance and repair
- corporation and other taxes

The profitability of the product can be determined by calculating the net present value over a period of n years. By an investment P_0 at an interest rate r over the period of years i, the compound interest to be earned in this basis is:

$$P_i = P_0(1+r)^i$$

The present value P_0 that would produce value P_i in i years' time is:

$$P_0 = P_i(1+r)^{-i}$$

After n years, the annual cash flow A_i in each year i has a net present value NPV:

$$NPV = \sum_{i=0}^{i=n} A_i \, (1 + r)^{-i}$$

The above-described principle acts as a basis to evaluate the investment. The higher the positive net present value NPV is, the more profitable the investment. Definition of suitable discount rate r might be difficult and can be argued but the basic principle remains. (Rawson, 2002)

2.4.2 Forecasting ship costs

Cost estimation is a process to estimate the expected cost of producing a work or executing a manufactured product before the actual costs are known. It may also reflect to a process where the cost of a new product is predicted. The estimated cost of final product is calculated by adding the expected expenditure on all the items that are used to finalize the product is added. (Adithan, 2007)

A forecast is an estimate about the future value of a variable such as cost or demand. Accurate forecast provides good basis for decision-making. Forecasts can be long-range estimates covering several years or short-term estimates covering a day or a week. Operations management uses forecasts as a basic input in the decision process and making the future business plans.

Forecasts have an effect to several activities throughout the organization in finance, accounting, marketing, operations, human resources and others. They act also as a basis for capacity planning, sales, budgeting, production and inventory management. Forecasts are usually made with reference to a time horizon that can be short or long. Short-term forecasts are considered in daily ongoing operations as long-term forecasts are considered with new products or with long lead-time processes.

Forecast is contains two important aspects. It is firstly providing information on the future expected values. The other aspect is the degree of the accuracy, meaning potential error in the forecasted value. The expected value for the future can be a function of variation, such as seasonal variation or trend. The forecast accuracy describes the forecasters' ability to model the forecasted values and consider the random variations or unseen events correctly.

Forecasting can be qualitative or quantitative. Qualitative forecasting techniques are based on experience, judgement and expertise. Forecasts can by approached by consumer surveys, estimates obtained by sales or customer service, executive opinions, anonymous questionnaires or outside opinions. Quantitative forecasting techniques as based on some historical data or utilization of different variables. Forecasts can be approached by estimations based on time series such as using directly the previous value, using moving averages or exponential smoothing or regression models. Forecasting method can be also a combination of qualitative and quantitative techniques. Forecast always includes a certain inaccuracy and the common techniques usually assume that the trend in the history will continue in future as well. The used forecasting technique should be chosen so that in addition of minimizing the errors also the forecasting process should require meaningful amount of effort and resources. The forecast users including the management need to be able to understand the forecast with the error range included.

There are certain requirements for a forecast. Good forecast should be:

1. **Timely.** Usually the possible needed changes and actions foreseen based on the forecasts need certain amount of time to be implemented and therefore the forecasting horizon should cover these possible changes.
2. **Accurate.** The degree of forecast accuracy should be informed. This enables users to consider the possible errors.
3. **Reliable.** Forecast should work consistently.
4. **Expressed in meaningful units.**
5. **In writing.** A written forecast provides the values that are used among all the users. It also provides possibility for later comparisons when the actual values are known.
6. **Simple to understand and use.** Users may face lack of confidence to the forecasts if they cannot understand the principles how the forecast was made.
7. **Cost-effective.** The benefits should always outweigh the required costs.

The control and accuracy of the forecast are important aspects of forecasting. Although forecasts are not perfect and actual results most likely differ from the estimated values, the errors should be minimized. Forecasts for groups of items usually creates results that are more accurate since the errors related to a single item have a cancelling effect. Therefore, the opportunities to group items in a meaningful way is an important step while improving the forecast accuracy. It should be also noted that while the forecasting time horizon increases the accuracy of the forecasts decreases. Long-range forecasts tend to contain more inaccuracy than the short-term forecasts.

Forecast accuracy is based on the historical errors occurred with the past forecasted values. Most of the real-world forecasting cases are extremely hard to forecast due to the random variation. The forecast should include an indicator of the deviation that the forecast might have compared to the actual value. Accurate forecast are needed to successfully run the organization in terms of resources, costs, customers and management.

Forecast accuracy can be described by the equations (1)-(3) presented below. The equations compare the actual and forecasted values over the time series. Mean absolute deviation (*MAD*) describes the absolute error of the forecast, mean squared error (*MSE*) describes the average of squared errors and mean absolute percent error (*MAPE*) the average absolute percent error. (Stevenson, 2021)

$$MAD = \frac{\sum |Actual_t - Forecast_t|}{n} \tag{1}$$

$$MSE = \frac{\sum (Actual_t - Forecast_t)^2}{n - 1} \tag{2}$$

$$MAPE = \frac{\sum \frac{|Actual_t - Forecast_t|}{Actual_t} x100}{n} \tag{3}$$

Shipyards usually deal with high degree of variation among products and services, which makes bidding and cost estimations extremely difficult. This considers both shipyards doing new construction and ship repair. Within a competitive market and with minimal profit margins in a fast-paced bidding process, the pricing of the product may be random unless there is a fast, accurate and reliable means to make the cost estimates.

Typically, the ship cost estimates are made at various ship process phases. Normally the cost estimates are made according to a work breakdown structure (WBS). Material and work costs are calculated using breakdown to ship system categories. This makes it easier to review the costs on some practical levels identifying the basic ship systems and components.

Ship cost estimate includes all direct costs including labour, subcontracted services and materials belonging to the ship scope. If possible, estimates should also cover all the miscellaneous costs linked to direct costs such as freights, transportation and taxes. While considering the full costs of the ship construction, also indirect costs for overheads, general administrative tasks and maintenance should be taken into account.

Shipyards usually have their own WBS that is the basis to manage the operating systems and collecting the costs. The estimates are summarized within the categories that enables the monitoring of the estimates and secures the historical basis for the cost follow-up. The cost follow-up categories should include the following scopes:

- Assembly and manufacturing operations
- Production support
- Design and engineering
- Subcontracted services
- Material and equipment (Lamb, 2003)

Literature review suggest several different models to estimate total ship construction costs. Azhar and Kristiyonoe (Azhar & Kristiyono, 2022) suggested a linear regression model for estimating a newbuilding ship construction costs for few ferries. The linear regression equation was depending on the gross tonnage of the vessel. The equation was compared to other ship price calculation method, gross tonnage cost per USD, developed by Adji, S W (Adji, 2004). Both of the calculation methods resulted to significant deviations compared to known contract prices, on average 21,36 % difference. The difference is significant especially for larger vessels and therefore indicates ship construction costs to be highly depended on the ship specifications and complexity as well as the preferences of the ship buyer. In addition, the changes in the world economy during the recent years created inaccuracy and unseen factors to the results. The main factors affecting the price were seen to be ship type, ship size, material choices, main engine type and drive system.

2.4.3 Ship cost calculation parameters

Shipbuilding costs can be classified into direct labour, direct material and overhead costs. Production related costs could be divided into variation dependent and variation independent costs. Variation dependent costs are dependent of the ship main dimensions and such costs are related to hull, propulsion unit, pipes, hatchways and similar. Variation independent costs are not affected by the changes of the ship main dimensions such as navigation system. Some of the components and equipment are also only slightly variation dependent such as anchors and chains.

Variation dependent costs can be divided to hull steel costs, propulsion unit costs and costs of equipment that will change based on the main dimensions. Hull steel costs include the raw steel material, wastage and work costs to cut and build the hull structure. Propulsion unit costs can be assumed to change continuously with the needed propulsion power. Propulsion plant costs can be determined by multiplying unit costs per power unit by propulsion power. Another option is to use list prices for engines, large plant components and gears and add the costs of smaller needed machinery components by certain empirical factor. In addition, wages are variation dependent while the needed total hours used for the whole shipbuilding process depend on the ship size and other properties. The spent hours are highly differing based on the complexity of the ship and used production method. (Molland, 2008)

Ship's 3D model can be used in the cost calculation by exactly similar means than for the ship weight calculation. 3D model will provide useful parameters from the geometry, steel model and outfitting model. Typical basic parameters form the 3D model than can be used in cost calculation are:

- Main dimensions
- Interior and exterior deck area
- Bulkhead area

- Machinery areas; volume and area
- Cargo volume
- Deck area
- Interior area
- Technical spaces, volume and area
- Storages, volume and area
- Public areas
- Cabin areas

All the above-mentioned parameters can be directly derived from the 3D model. The model is prepared at the end of the basic design phase. The model includes all different kind of spaces with the relevant type information. During the each design phase, also the accuracy of the 3D model will improve. While preparing the initial 3D model, it is important to evaluate the high-level properties such as arrangements and layouts. During the later stages topics will be specified in to details, as an example the positions of the valves will be specified. The parameters used together with relevant unit prices will provide the cost estimate. (MobiShip, 2001)

3 Research methodology

The research methodology used in this thesis is examined and explained within this chapter. The used procedures and framework of the study are explained. In addition, it is evaluated whether the achieved objectives are reliable.

3.1 Research design

This thesis study was conducted using both qualitative and quantitative research methods, so called mixed methods research. The use of mixed methods research was seen beneficial approach for this study since the results collected from different methods allowed to enrich the understanding of the current status and validate the suggested results. (Molina-Azorin, 2016)

Qualitative approach was used to evaluate the current best understanding of the current status regarding the material process and material cost follow-up in the case company. The information source included several sources such as work and process instructions and topics earlier described by the literature. The qualitative results were later on analysed with quantitative methods, including data analysis with historical and present values. The collection of the data and selection of suitable measures to compare the data was made based on the suggestions gathered by the qualitative analysis. The thesis worker was already familiar with the common practices in the case company and business area around the thesis topic.

The main research questions regarding the case study is: How are the material costs comparable between the ships of different sizes, production timelines and properties? In order to find suitable categories to compare the materials, it was firstly essential to clarify the material processes and responsibilities within the case organization. The material processes, roles and material types were investigated by using existing process and work instructions as well as know-how within the case company. The material process will be described in chapter 4.1 and high-level process chart presented in Appendix 1.

After the processes were understood and described, the possible units for material cost comparison were analysed by using qualitative research methodologies in Chapter 4.3. The final step was to collect the relevant material cost data and analyse the suggested measures on a high-level in Chapter 4.4.

3.2 Validity and reliability of the study

The used research methodologies create assumptions and are depending of the existing knowledge and study field. The research approach differ based on the field the study is concerning and the presumptions support chosen methods. The personal view of the researcher together with the practical limitations are influencing the chosen research design. To reach the research questions, hypotheses are outlined in an early phase. At the end, the research methods aim to test the relation of the theory on the empirical statements. (Collins, 2019)

The thesis study was made by using mixed method research approach as well as following the daily operations and problems within the case company. The existing knowledge and beliefs of the employees in the case company as well as the thesis worker might have effected on the collected information and results. However, it was noticed during the studies that the processes, measured categories and units used in the case company were in line with the information collected during the literature review. As the main purpose of the thesis was to find improvement items and suggest measures for better future follow-up procedures, the possible errors in the research design will not prevent the success of the main goal. The case company evaluated in the thesis is working in a maritime industry, which is limiting the possible wider usage of the objectives in this thesis.

4 Results and analysis

The aim of this chapter is to present the findings of the study, analyse the results and compare the results with the previously reviewed theory. This chapter is divided into two sections. First section introduces the current status of the material process and material classification in the case organization. Secondly, the attributes of the cost estimation and cost comparison are presented.

4.1 Material process

Material process in the case organization varies based on the type of the material. The material process in this study contains the whole timeline from the project sales phase until the material is installed and commissioned. The material process contains many steps with large amount of parties involved and the timeline of the process can be often described in several years. The material processes can be divided in to five main categories: procurement entities (critical components), components, stock material, M-orders and prefabricates.

Procurement entities consist of critical components that form majority of the material costs. These materials require more attention on the overall process because of their high impact on expenditure. The procurement entities are followed carefully along the process and the correct timeline, costs and quality are crucial. The procurement entities could be also described as A-class materials as reviewed in Chapter 2.3.1. Typically, within the procurement entity process the supplier provides materials while commissioning and installation activities are organized by the case organization. Supplier does also part of the basic design and defines the material lists, so called component list or EBOM (engineering bill of material). The definition and clarification of the technical dimensions of the procurement entity materials starts often in a very early stage of the process, usually directly after the ship contract with the owner is made. M-order is a procurement entity with installation to the final product included.

Components are materials with larger volume and lower value. They could be described as B-class materials as reviewed in Chapter 2.3.1. The correct technical specifications and timing of the component deliveries are still crucial. These components are defined in the basic design diagrams and purchased based on the EBOMs. The material specification and component lists are defined by the case organization. Purchasing of the components is done either based on frame contracts or based on individual purchase orders.

Stock materials are reusable standard materials kept on stock. They could be described as C-class materials as reviewed in Chapter 2.3.1. These materials can be replaced relatively easily with an alternative product from another supplier or manufacturer. Their individual value is relatively low and procurement is a routine process. The stock materials in the case organization are more freely distributed and used compared to the other material types. Detailed material lists and the amount of stock materials needed in production are defined in the detail design phase. The total consumed quantity of the stock materials is extremely high and therefore the overall stock material costs form big share of the whole products costs.

Prefabricates are components that are pre-assembled by supplier and manufactures based on the drawings. The prefabricate drawings are made during the detail design phase. Prefabricates are typically different kind of pipes and ducts.

4.1.1 Sales phase

In sales phase the ship concept, technical specification and contractual definitions are prepared and agreed between builder and buyer. The agreements made during the sales phase affect also highly to the material solutions.

4.1.2 Basic design phase

Basic design combines requirements of systems, areas and hull with optimal solutions in co-operation with the owner, classification society and authorities. Input data for basic design consists of the information applied in ship contract, documentation produced during the sales and initial design phase, technical information from suppliers, regulations and environmental requirements. An important part of the basic design phase is to collect technical data from equipment suppliers and confirm the main material attributes in order to have the design documents approved. Basic design is responsible to create the component lists to the ERP system with complete technical as well as process related data. Each component in the component list has a responsible person from the basic design organization, so called system responsible, who is responsible of the technical properties of the material, participates to the negotiation with the suppliers, and follows the costs and timeline of the delivery. System responsible is also responsible to define alternative material solutions if needed. Basic design is responsible of 3D model and delivering the models for the following detail design phase. In 3D model, the components are designed in their right positions and with space reservations.

Master schedule prepared by the planning function defines the base for timing of the basic design drawings, work drawings, purchases, information flow between the departments and architectural schedule. Basic design uses the schedules prepared by the planning organization and connects all the components to a specific period. Period consist of the object of work and stage of work and provides the needed schedule in order to have the material on time before the installation.

4.1.3 Detail design phase

Detail design produces the documentation needed for production process. The detail design data is created based on the basic design documents and prepared to meet the requirements of the shipyard's own production processes. The detail design is responsible of defining and allocating all the needed materials in accordance to the production plans. The material lists created by the basic design are completed during the detail design phase by adding all the needed stock and installation materials.

The detail designer defines the needed information for hull structures, prefabrication and installation works based on the initial data. All the materials are reserved, allocated to correct locations and scheduled according to the best knowledge of the production schedules. Any mistakes or necessary modifications detected during the detail design phase should be corrected to basic design documentation as well. During the detail design phase, the materials defined by detail design and any materials that are possibly not ordered during the basic design phase are purchased. Rough material reservations made by the basic design are further specified and the final part list reservations are made. The detail designer allocates all the materials to production activities.

4.1.4 Procurement

Procurement makes the enquiries and purchasing activities related to any materials to be purchased. The system responsible persons within the basic design organization support the procurement process. Purchasing of the critical components is made according to the pre-defined procurement schedules. Many of the critical procurement entities are purchased already right after the sales project phase. These entities are inquired during the sales phase for the original cost calculation and it is possible to make binding preliminary agreements with chosen suppliers.

The procurement process of components begins in the basic design phase after the system responsible has defined the material demands technically and quantitatively. Material is purchased only if the demand is technically and time-wise feasible and complete. The procurement is responsible of the commercial details of the purchase orders, negotiations with the supplier as well as agreement and following the material delivery schedule. The procurement process is always made in co-operation with the system responsible all the material costs are allocated directly to the project.

4.1.5 Logistics

The logistics process described in this section contains the steps within the work planning, warehousing and transportation of the materials.

The work planning function making the delivery request for the materials is responsible of the contents of the delivery request. A correctly created delivery request ensures the operation of the entire material process and timely production. By using specified delivery requests, it is ensured that the materials are used according to the plans and part lists. This reduces waste and costs significantly since the amount of total materials used in the overall process is huge. All the materials used in construction should be collected from the warehouse by using the delivery request.

Delivery request list (DRL) should be derived from the part list created by the detail design. By picking the materials from the part list, it is ensured that the consumption of materials can be forecasted and the stock has the required balance on the required time. This also improves the whole operation and reliability of the material supply chain. In case of material shortages, some of the requested materials in DRL may not be delivered on time. In these cases, it is important to follow the post-delivery process and ensure that the status of the deliveries is correctly defined in the ERP system.

The free distribution locations at the shipyard area are the only exception of the delivery request process. Around the production area, there are some freely distributed materials available for all those working at the shipyard. The free distribution materials are freely collected from certain locations without a separate picking request. The supplier or logistics personnel is responsible to monitor the stock balances within the free distribution locations and fills the empty storage locations.

The warehouse function ensures the timely and correct delivery of the material request. They are also responsible to deliver the correctly packaged materials to the requested shipping area. The transport operators transport the materials from the shipping area to the final production location.

The receipt of material consists of arrival inspection and receipt inspection. Materials are immediately inspected during the arrival inspection by the warehouse function. During the arrival inspection, it is validated that the received amount of materials is correct and the package looks feasible. The receipt inspection consist of comparing the materials with the order and packing list. The received materials are entered in the material handling system and placed in the warehouse or directly forwarded to the requested delivery area.

4.1.6 Material process chart

The high-level material process within the case organization is described in the Appendix 1. The process chart describes the component material process from the very first sales phase activities until the ship operation and warranty period. The axis on the left describes the responsible organization and the activities are assigned in a roughly correct order in a timeline.

The demand for a new ship creates interest for the ship owner to buy a new ship. The process chart in Appendix 1 describes the ship material process but the steps within the case organization are independent of the ship type. The ship type affects however to the material solutions, complexity of the process and activities, timeframe and the output of the process.

The process to create the component items is described in Figure 4. Basic design uses the information provided by the planning organization to ensure proper scheduling of the materials. Basic design diagrams are defined in CAD (computer-aided design) systems and material master data is stored in ERP system. The case company has currently several different CAD tools in use. One of the CAD tools has a direct data transfer between the design tool and the ERP system but the other processes require manual entering of material data directly to the ERP system. The material data can be created either by mass upload tool or individually. The ERP system contains all the needed attributes to support procurement and production processes. Based on the created component lists, materials are procured in co-operation between the purchaser from the procurement and technical handler from the basic design. Detail design drawings and part lists are created based on the component lists.

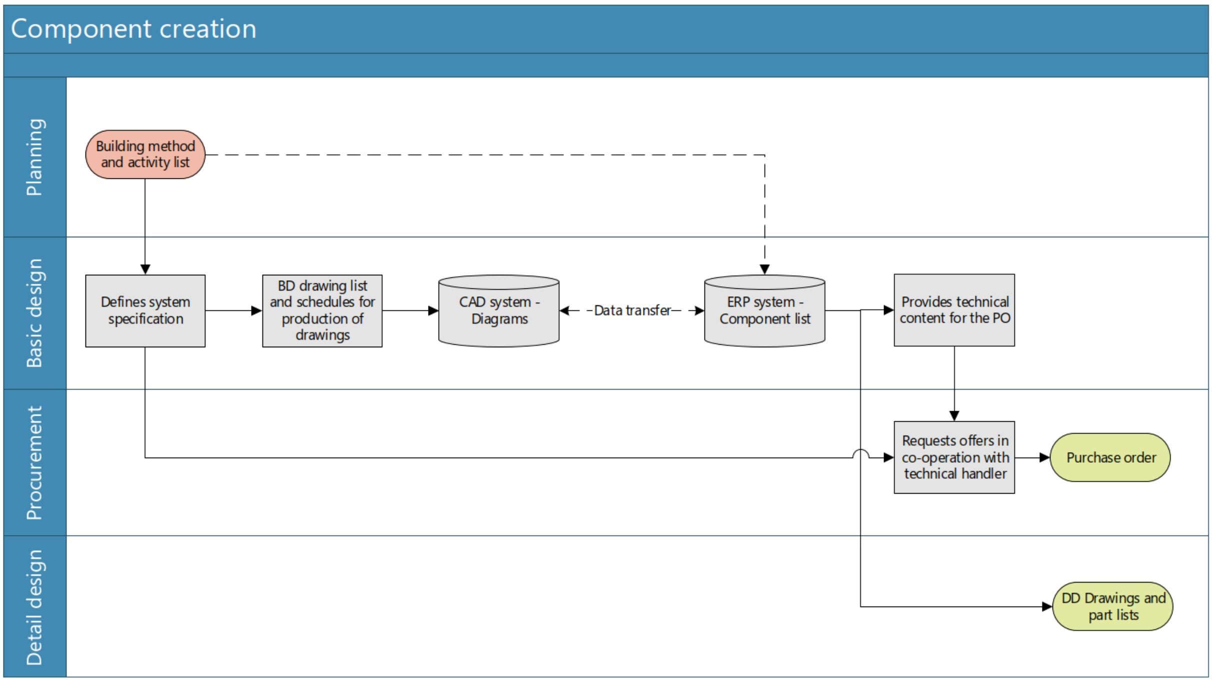

Figure 4: Component creation process

Process to create the part lists is described in Figure 5. Detail design starts the material process based on the component lists and diagrams provided by the basic design. Detail design picks the components from the component lists and checks that the timing of the material is correct regarding to the installation of the materials. In case the original schedules defined by the basic design are wrong, detail design is responsible to contact basic design and request schedule changes, otherwise the materials may not arrive early enough for the production process. The part list corresponds a list of materials needed for a certain installation activity. Detail design adds all the materials needed to complete the installation and production of the areas. Materials are picked from the warehouse based on picking requests that should be directly derived from the part lists.

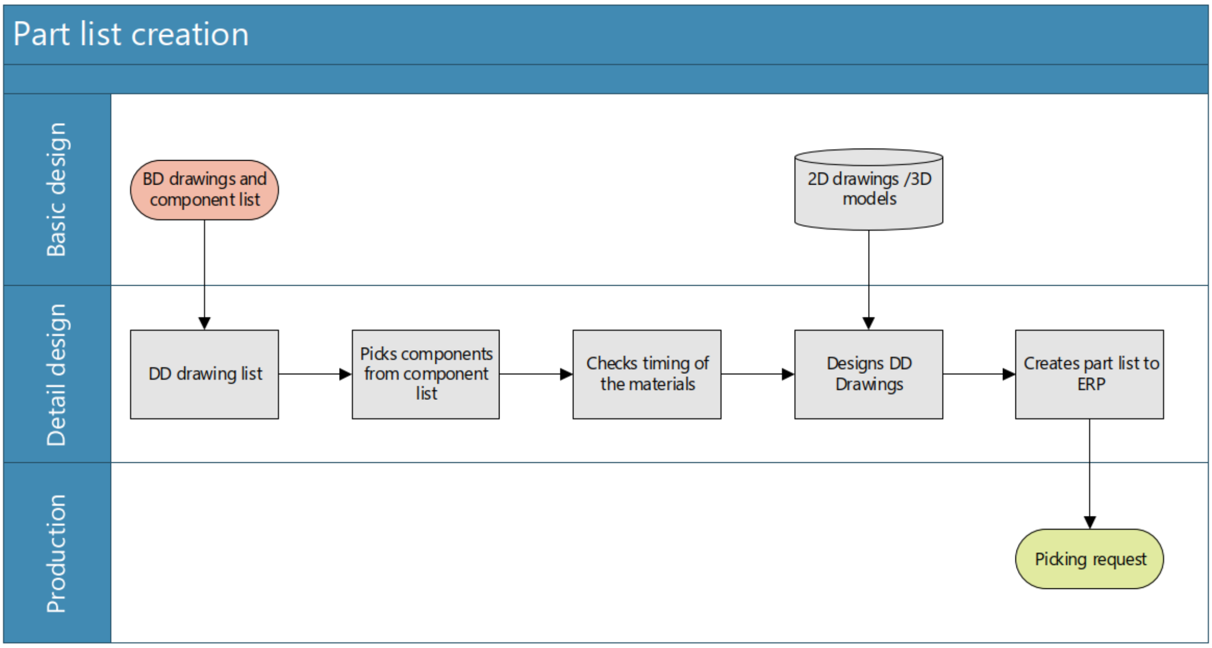

Figure 5: Part list creation

4.1.7 Material process roles

The high-level roles participating to the material process for components are described in a Table 1. The roles are according to the process chart in Appendix 1.

The process starts from the demand and continues within the sales phase. In a sales phase, the ship contract and specifications are negotiated between the ship owner and sales project team, including the management of the case company. The sales phase provides already lots of information for the next process phases. The output of the sales phase includes general arrangement, technical specifications based on systems, areas and spaces, additional documents further specifying the technical specifications, such as preliminary cabin layouts and different king of diagrams and calculations.

After the sales phase, planning and basic design will start their activities. The planning creates the project main schedule, main milestones and building method. The schedules are acting as a basis for the more detailed operational planning, timing of the material purchases and installation and project follow-up. The main schedules may change over the project timeline and the communication and approval of the biggest schedule changes is important.

Basic design is responsible to design the systems and routings, define material specifications and provide technical content to the purchase orders. All the main components and material specifications are defined in a relatively early project phase, especially for materials with long lead-times. New material solutions and technologies with improved technical, environmental and cost-efficient properties are search within the basic design organization.

Detail designers are providing the detail design drawings and part list. Detail design completes the material lists provided by the basic design with all the materials needed for the installation. The materials added in detail design phase are typically standard materials with shorter lead-time. The quantities of the single material items added by the detail design are typically extremely large.

Procurement makes contracts with the suppliers, creates purchase orders and controls the material deliveries. All the main materials are purchased based on the information provided by the basic design. The materials added to part lists by the detail design are purchased closer to the production and according to the output provided by the detail design. The procurement is responsible to monitor the performance of the suppliers and that the suppliers are delivering the materials according to the agreed time and quality. The finance and controlling team is responsible of the cost follow-up and invoicing processes.

When the material orders are arriving to the shipyard, the warehouse function will receive the materials and store them. The materials are picked form the warehouse based on the picking requests created by the work planning. The warehouse function picks the materials from the warehouse and logistics delivered the materials to the requested location. In case the materials are not available from the warehouse by the time needed, the warehouse will inform the requestor of the missing materials.

In the production phase, the production workers install the materials. The activities and working principles in the production phase have a high effect to the overall material waste. The material waste can be reduced for example by careful usage of the materials, clean production environment, properly planned part lists and following the material return processes. After the materials are installed, the systems are ready for commissioning. The ship is ready to be delivered to the owner and the ship will start the operation.

Table 1: As-is high-level material process and roles

Role	Phase
Cruise passenger	Searches for leisure activities; demand
Cruise line (Owner)	Initiates negotiations with the shipyard; makes the agreement with the shipyard
Sales	Negotiates for the ship contract and specifications with the owner and the management of the shipyard
Planning	Creates the high level project plan; the project main schedule, main milestones and building method
Basic Design	Designs the systems and routings, defines material specifications, provides technical content to the purchase orders
Detail Design	Designs the detail design drawings and creates part lists
Procurement	Makes contracts with the suppliers, creates purchase orders, controls the delivery
Supplier	Delivers the materials
Work planning	Creates picking requests
Warehouse	Receives the materials, stores the materials, makes the picking
Logistics	Delivers the materials to production
Production	Installs the materials
Commissioning	Makes the commissioning, notes remarks
Warranty	Takes care of the warranty actions
Finance and controlling	Makes the invoicing and controls the costs

4.2 Current situation and target setting

Today the material cost follow-up for direct materials in the case company is made for each ship project and for each agreed cost follow-up category. The key figures to review the status are current budget, forecast, committed costs and actual costs. Committed cost describes the total value that is purchased and therefore committed.

In this thesis, we are focusing on the process and measurement of direct material costs. In the case company, the direct material costs are for example:

- Direct material (systems, raw materials, spare parts, components and finished products, scrap)
- Bulk items; bolts, nuts, etc.
- Purchase discounts and rebates of material purchases
- Surcharges on purchase prices
- Inbound freight
- External warehousing

The majority of the costs are driven by the purchase price and consumption of direct material and bulk items. The other possible additional costs such as inbound freights are not on focus of this thesis.

The material cost follow-up is made on a monthly basis and the deviations are discussed in a monthly ship project budget meeting. The final value to reach a ready and functioning product is forecasted on a monthly basis. Forecast is an estimate at completion. Maintaining accurate and realistic forecast is crucial and allows the project and company management to make proper decisions, corrective actions and long-term strategies.

The material cost data can be collected and analysed based on the following categories:

- System Numbers
- Block Types
- Area Groups and Area Types

The system numbers act as a primary material cost follow-up category. Each system number has a dedicated budget responsible. The budget is split for each system and for each dedicated categories of the system. The scope of the latest budget equals always to the scope of estimation. All the costs coming from the purchases and later on actual paid value are collected to the exact same system numbers. Strict budget ownership is essential and needed to reach accountability.

The monthly ship estimate process is presented in the Figure 6. Monthly ship estimate reviews start with analysis of the data related to commitments, actuals and deviations. In the case company, committed value for materials equals to purchase value and actual value equals to paid value. The forecasting process is prepared and lead by the department controller. The controller prepares the needed reports that contain information of the current status. The data of the commitments as well as the work progress act as a key input for the correct estimates. In addition to the forecast, also contingencies, risks and opportunities are discussed and collected during the monthly review process. Each budget responsible calculates the estimated material costs in co-operation with the department controller. The head of department reviews the changes and afterwards the controller finalizes the department reports including the proposed forecast changes. The forecast changes are reviewed in the monthly meeting and either approved or disapproved by the head of unit. Department controller finalizes the ship reports and the values are used in the project result reports as well as the company result report.

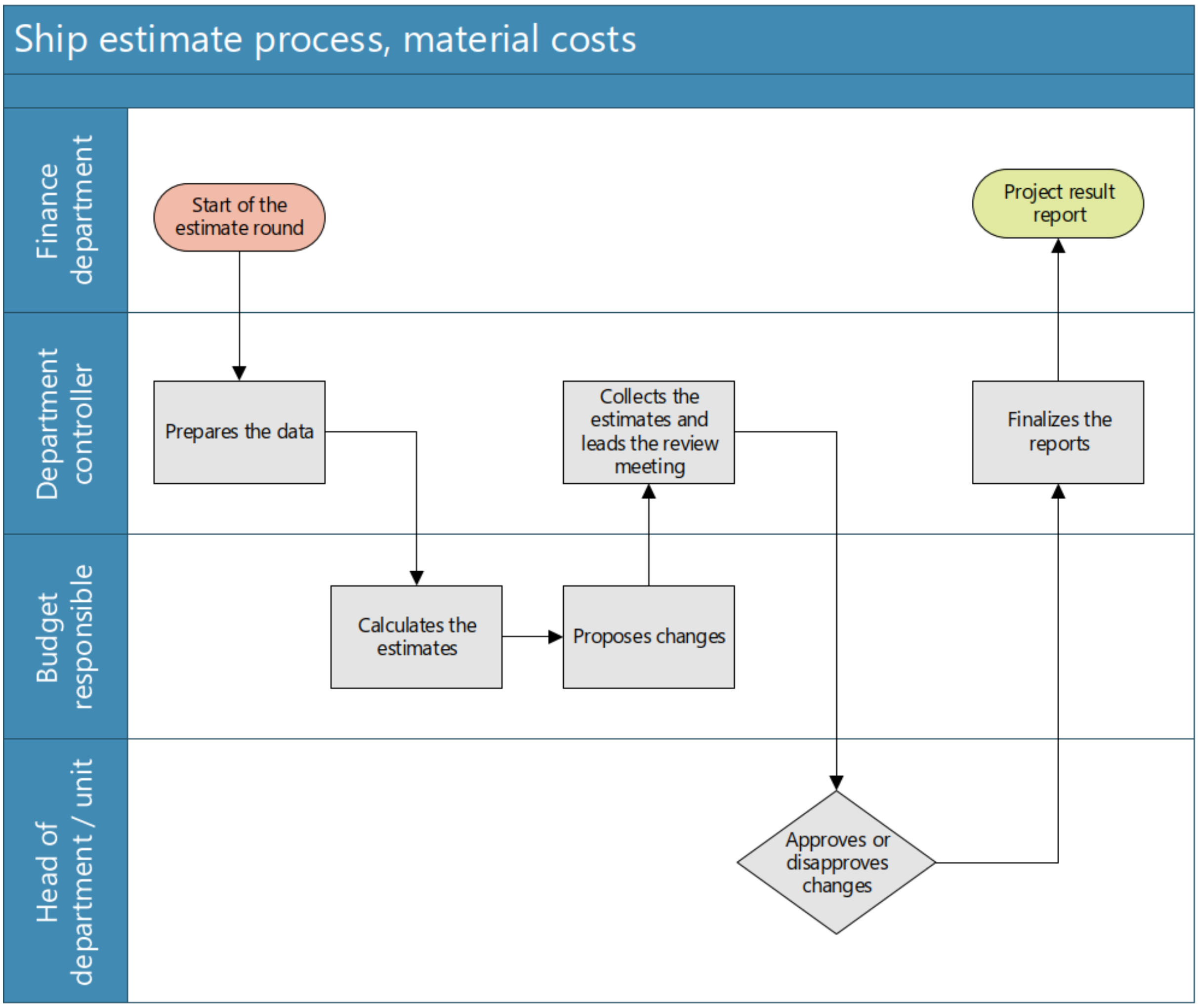

Figure 6: Ship estimate process

Currently the cost calculation is highly focusing on controlling via budgets. The experience is gained though the previous comparable and finalized projects. The targeted level of transparency, cost-awareness and understanding of the key drivers may not always be achieved. Few example problems identified in the case organization:

- Difficulty to understand after a long time how the budget was originally calculated
- Forecasts are based on experience and are difficult to adopt by the new employees
- Possibility for hidden too high budgets
- Focus on the forecast calculation rather than definition of product value
- Reacting rather than foreseeing
- Repeating errors in forecasts

To improve the forecast quality and therefore be better and earlier prepared for result variations, measuring and tracking the cost-effectiveness over the time needs to be improved. The estimates could be improved by better comparison of the products by their size and complexity. The categories to be compared need to be stable over the time. Categories such us department or material type are not stable over the time and may vary for example due to organizational changes. It is assumed that the system and area based categories such as propulsion system, mooring systems, public spaces or cabin spaces are categories that would be more stable over the time and since make a solid foundation for cost comparison and evaluation of the estimates.

4.3 Definition of KPIs

This chapter describes the properties related to the units used to compare the material costs. The use of easy and simple attributes of the product such as size, installed power, number of persons on board or size of the area are seen as a target units to compare. With those attributes the normalized KPIs such as €/m^2 or €/GT could be calculated.

The Table 2 defines the main dimensions used in the case company to define the normalized KPIs. They are similar than the units found from the literature review and presented in Chapter 2.4.3.

Table 2: Main product units

Unit	Description	Calculation
GT	Gross Tonnage	Function of the moulded volume of all enclosed spaces of the ship. (International Maritime Organization, 1969)
m^2	Square meters	Area of the space. Such as public areas, cabin areas, deck areas, machinery areas
kW	Installed Power	Installed power of the main engines (Wang;Callahan;& Corbett, 2007)

The easiest and best single KPI is €/GT which compares the costs over the total size of the ship. However, this KPI does not take into account the complexity of the product and therefore creates error for other than relatively standard materials. Best approach would be to use multiple KPIs based on the specific need of each case.

The ship area is a unit that can be used for multiple purposes. The area can be presented as a total area of the ship or then as an area of certain location. In the case company, the areas are divided into area groups. These area groups are for example machinery or deck areas. The area groups are further divided into area types, such as crew cabin areas or restaurant areas. For the purpose of cost comparison, the total area, deck areas and hotel/interior areas have been used. The interior area contains areas from different area groups.

The earlier cost comparison between the vessels has been based on the scope of each department in the case company. After the organizational changes, the measures have not been valid anymore. The approach used in this thesis was based on the scope of the systems and therefore is assumed to be more suitable in a long run. The literature (Kajaste & Liukko, 1994) suggests that the improvement actions created by the development projects may often be forgotten and the company ends at the end to the initial processes and procedures. Therefore the continuous improvement actions would be necessary. This was noticed in the case company as well since the old departmental level KPIs were forgotten and not commonly used anymore.

During analysis of the available data and information, the ship materials were suggested to be classified into main groups based on the system content such as: stock materials, machinery systems, electrical systems, hotel systems or deck systems. The main groups can be also specified into different sub-groups. The selected structure follows the common system structure presented by the literature in Chapter 2.2. The detailed content of each group will be presented in chapter 4.4. The consumption and material process of the stock materials is different compared to other materials, so called components, and therefore the stock materials are suggested to follow separately even though they are used in all the ship systems. The stock materials can be describes as C items if following the A-B-C categorization presented in Chapter 2.3.1.

In order to achieve the most accurate results it is usually seen that the big individual items could be followed separately and the remaining largest amount of the materials as a group. For example the cabin costs are clearly directly linked to the amount of cabins and the used cabin types. Also all the special features of the ships should be analysed separately. This is in line with the literature review suggesting to follow variable independent materials separated from the variable dependent materials as described in Chapter 2.4.3.

4.4 Quantitative KPI analysis

This chapter describes the quantitative analysis of the KPIs presented in Chapter 4.3. The analysis was made using eight reference ships that were different in size, timeline, project phase and complexity.

The primary data used in the analysis described the material cost data. The used data included the amount of the used materials, price of each purchase and purchasing time for each reference ship and system. The data was exported from the ERP system used at the case company. The total values were summed per each system and ship. The material cost data was normalized using the suitable KPIs.

The used KPIs in quantitative analysis were €/GT, €/m^2, including the total area, interior areas or deck areas and €/kW. The sizes of the ships used in the analysis were approximately 100 000 GT and the areas over 100 000 m^2. The data describing the ship main dimensions was collected from the ship specifications and area partitions.

The results presented in this thesis describe the percentage differences compared to the average value of the eight reference ships. The ships were numbered from 1 to 8 and presented in same order across all the Figures 8-13. Different KPIs were compared to each other to validate the accuracy of the measure. The data was analysed for different material groups: stock materials, machinery systems, electrical systems, hotel systems and deck systems. For stock materials, the total value is also presented as a cumulative value over the whole project timeline.

The quantitative analysis in this thesis is aiming to validate on a high level if the suggested units for the cost comparison KPIs are suitable or not. The results shown in this thesis will not be suitable for direct comparison between the vessels since there are at least two aspects creating errors if the values are used for direct comparisons: inflation and scope of the systems. During the last 10 years the inflation has on a global level been 57% and during the last 5 years 35% (Statista, 2023). The inflation was taken into account in this thesis on a high level based on the rough project timelines. The more accurate inflation, for example considering purchasing time of individual materials, should be noted if the figures and reasons between the deviations would be further investigated. Also the scope of the systems for each vessel should be taken into account since some of the ships may include lots of materials that are not in scope of the others. As an example the entertainment systems and fuel solutions are creating scope differences.

4.4.1 Stock materials

The stock materials are materials used in various places and systems throughout the whole construction phase. The amount of the consumed stock materials is huge but the price of individual material item is relatively low. The stock materials are usually ordered and consumed during relatively late construction phases. The stock materials do not have long lead times and therefore the purchases are made according to the occurred consumption and consumption forecasts.

Typical materials classified as stock materials within the case organization are piping materials, cables, smaller steel bars and plates, screws, nuts, adhesives, glues and similar kind of materials. The stock materials can be picked from the warehouse by using delivery request. For selected materials, the case organization also provides few locations where the materials are stored and can be freely picked. The looser control and free distribution of the materials enables flawless production but also creates risk of misusing, wasting and overconsuming the materials. Better control of the consumption within these freely picked materials has been identified as a future improvement action in the case company.

Since the stock materials are not highly depending on the complexity or technical properties of the vessel, the consumption and therefore also the total material cost can be assumed to be size-depending. As described in the previous chapters, the ship overall size is usually described by Gross tonnage (GT).

In Figure 7 the accumulation of the stock material costs divided by the ship GT over the ship construction phase is shown. As a reference, six different ship projects were chosen and the related data was collected.

Figure 7 shows that the costs of typical bulk materials or stock materials used in the case company are highly matching to assumption that the consumption is size-dependent. The Y-axis contains the €/GT measure and X-axis describes the timeline until the delivery of the vessel. The high level yearly inflation rate between the vessels was taken into account. Both the ending point of the cumulative curves as well as the shape of the curves are surprisingly well matching between the reference vessels. The smaller differences of the final values were explainable by other reasons than the difference in size, mainly identified differences on material consumption behaviour.

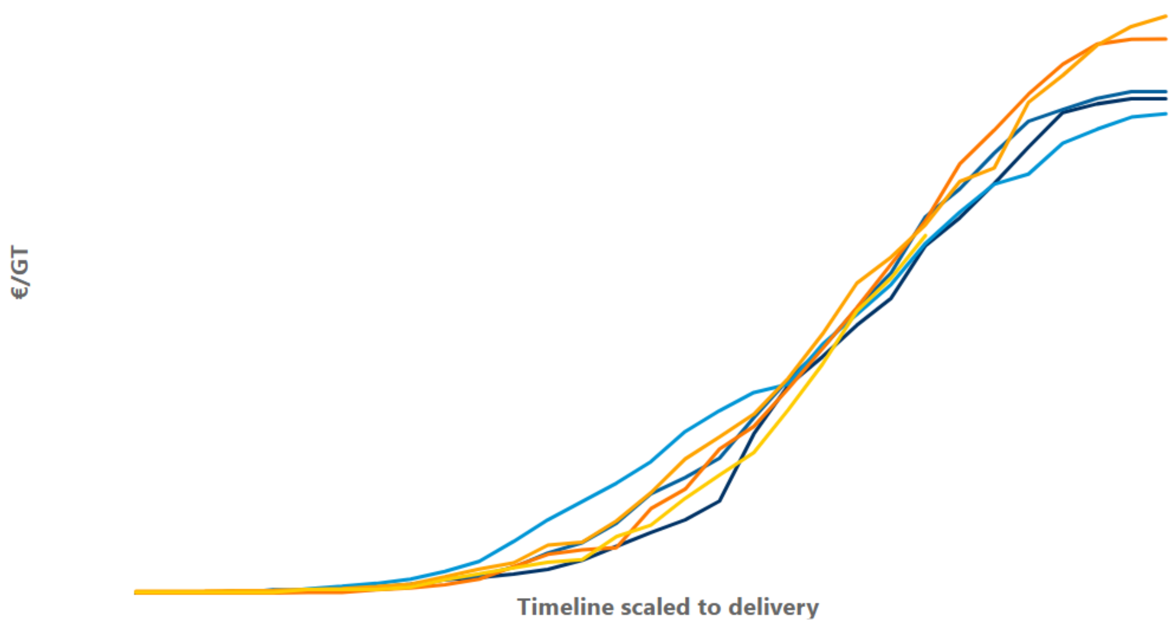

Figure 7: Cumulative stock material costs

4.4.2 Machinery systems

Machinery systems are systems located in machinery areas. In the context of this thesis, the machinery systems contain the fuel system, oil system, propulsion, cooling system, steering and stabilizing systems. The machinery systems contain typically items having big individual purchasing price, such as main engines, but also many small items such as filters, valves and sensors. Since the machinery systems are highly related to the main engines and materials used for the machines enabling the ship operation, the installed power kW is seen as a primary product unit describing the systems.

The value used in the analysis contains the full cost of the systems, meaning it includes all the materials but also the possible storage or transportation costs. However, the additional costs coming from storage or transportation are minor part of the total value.

Figures 8 and 9 describe the machinery system costs compared as a function of either gross tonnage GT or installed power kW of the vessel. The Y-axis contains the full costs of the systems and X-axis the value of the selected parameter describing the properties of the vessel. The positive Y-axis value means that the vessel has higher normalized costs than the average value. Negative value means that the normalized cost was lower than the average.

Figure 8 shows €/kW KPI for the machinery systems is relatively well linearly dependent. Based on the Figure 9, the value of the machinery systems is not that well linearly dependent on the gross tonnage values. The €/GT value seem to have rather exponential dependency. Since the installed power clearly describes the properties of machinery systems better and the €/kW seems to have linear dependency, it can be assumed that the €/kW KPI fits for the machinery systems better than €/GT. It needs to be noted that the amount of the data points described in the figures is quite small so the result has a certain error margin.

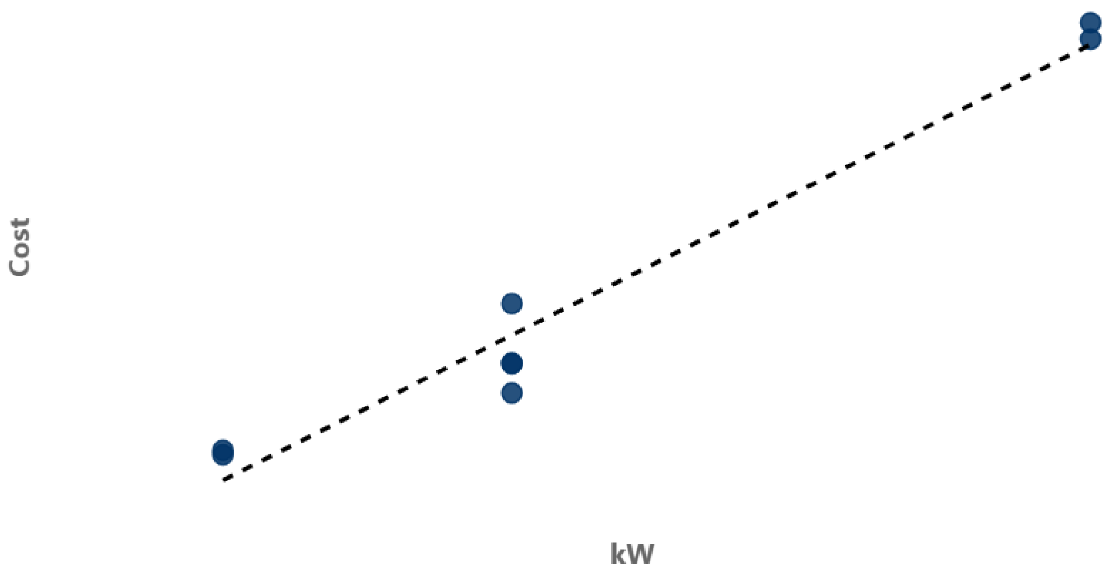

Figure 8: Machinery systems, €/kW

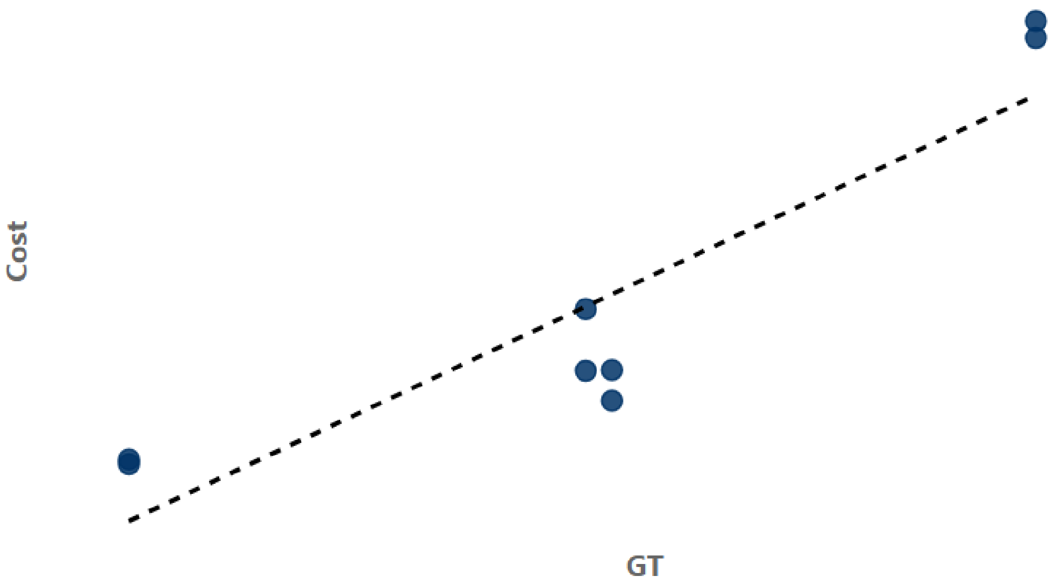

Figure 9: Machinery systems, €/GT

From the figure 8 we can still see that some of the data points are lower than the others. The lower values cannot be directly explained by the different properties or other know factors show directly from the data, the difference is most probably caused by the success in the project. Based on the results it can be recommended to compare the machinery system costs by €/kW KPI and the deviations from the expected value should be explained by external factors such as delay in the project.

4.4.3 Electrical systems

Electrical systems are systems containing components consuming electricity. In the context of this thesis, the electrical systems contain the automation system, navigation system, electricity generation system, safety and monitoring systems. Entertainment systems and lighting in public areas were left out and analysed as part of the hotel systems. Cabling materials were seen as slightly different objective compared to other electrical systems and therefore analysed separately. Unlike the electrical systems, the cabling systems contain also the cable materials used in hotel areas. Cabling systems include cables, cable trays and cable penetrations. The cables used in all the areas around the ship create most of the system value.

Figure 10 describes the deviation of electrical system costs compared to the average of the sample data divided by either gross tonnage GT or installed power kW of the vessel. The Y-axis contains the %-share of the value compared to the average. The installed power is assumed to be suitable unit also for the electrical systems since the systems included in the scope were all machinery related.

Figure 10 shows that ship number 3 had significantly lowest values for €/kW and ship number 7 for €/GT. Ships number 1 and 8 result in highest relative value by both of the units €/kW and €/GT. The electrical systems contain some variation independent systems like the navigation system as stated in Chapter 2.4.3. This will create certain error to the measures since the normalization of the costs assumes that all the systems are depending on the size. Most of the electrical systems are clearly depending on the installed power kW and therefore would be suitable for the comparisons.

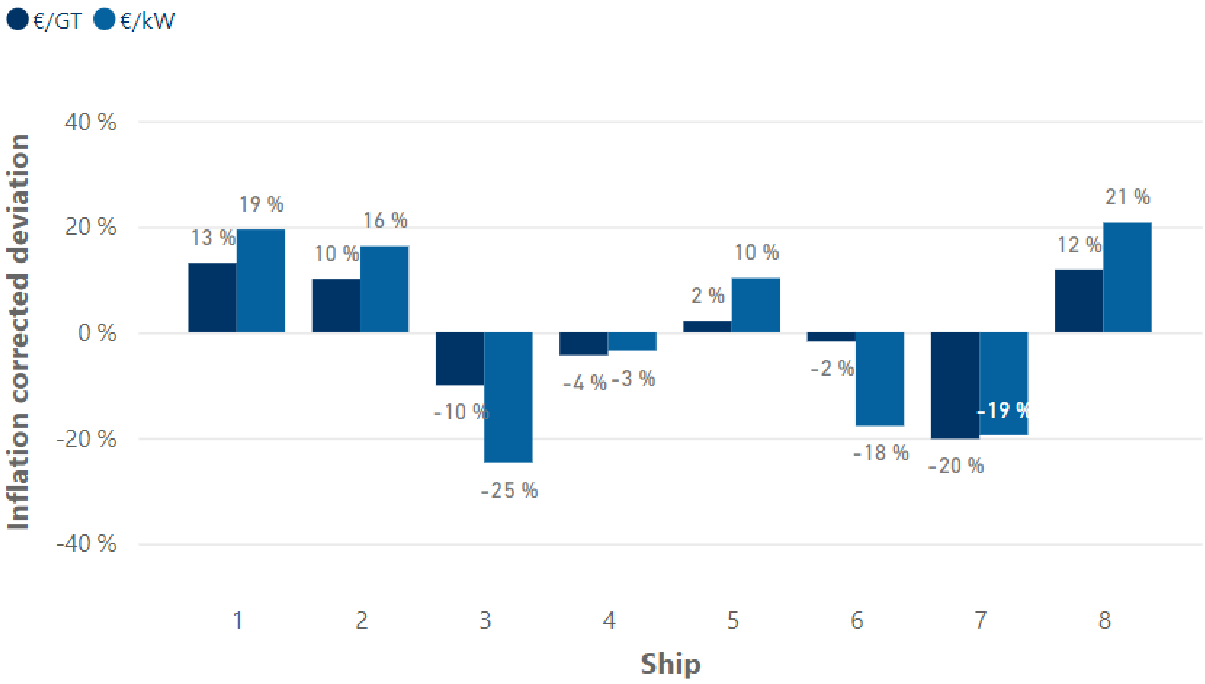

Figure 10: Electrical systems

Figure 11 describes the deviation of cabling material costs compared to the average of the sample data divided by either gross tonnage GT or installed power kW of the vessel. The KPIs vary a lot between the ships, number 3 having the lowest value and number 4 the highest. The cabling materials were previously combined with the other electrical systems and measured by €/kW in the case company. However, the €/GT measure could be assumed to be more suitable for the cable materials since the materials are used in all the ship areas. The cable materials also behave similarly than the stock materials analysed in chapter 4.4.1 having low individual purchasing price and high consumption volume.

The deviation of cable materials costs between the ships is higher than expected and especially ship number 4 shows double the amount of relative costs than the other vessels. Based on the dimensions and absolute cost values the reason behind the deviations is not seen. It is suggested that the ship number 4 would be further investigated and the reasons behind the significantly higher cost would be clarified.

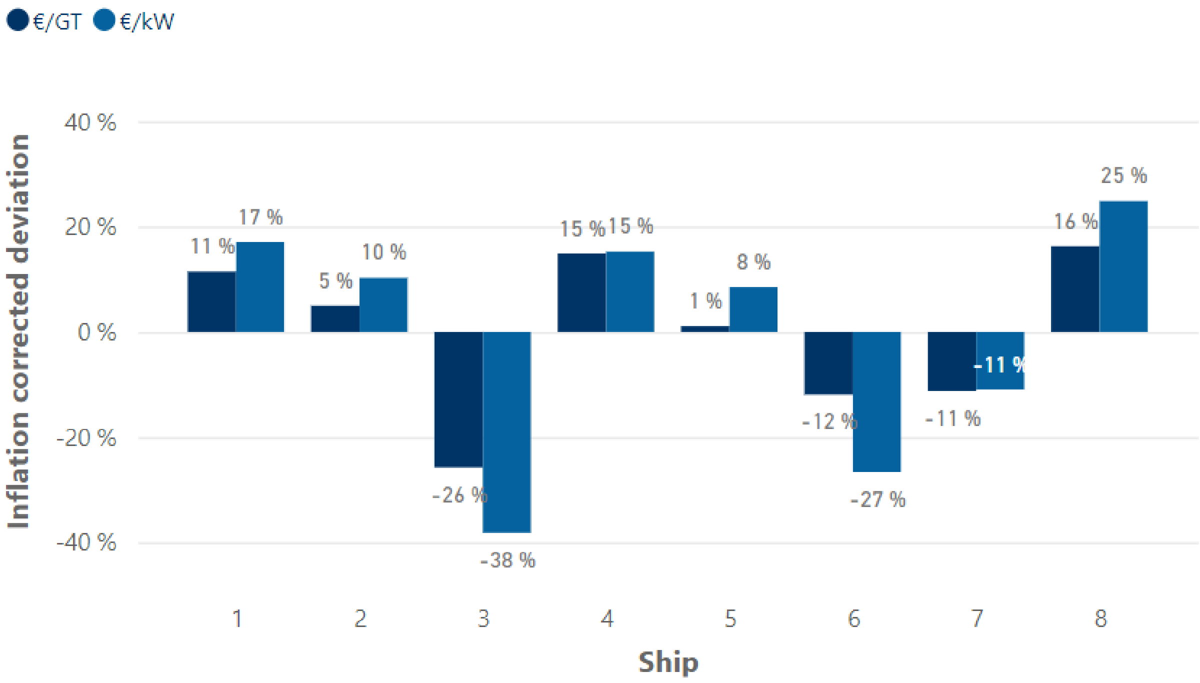

Figure 11: Cabling materials

As an additional observation, it was noted that ship number 4 show higher costs within cabling materials but the electrical systems did not follow the same result for the vessels. The observation supports the assumption that the cost comparison should be made on a more detailed level and comparing for example the whole ship or machinery and electrical systems together could result in wrong assumptions and focus areas. The result is in line with the result seen also from the literature review in Chapter 2.4.2.

4.4.4 Hotel systems

Hotel systems are systems containing items located in public or interior areas, such as cabin spaces, restaurant and galley areas and corridors. In the context of this thesis, the hotel systems contain the galleys, entertainment system, doors, general interior materials such as carpets and ceiling, lightning and signs. The cabins were excluded since the cabin costs are clearly comparable with the amount of cabins as stated in chapter 4.3.

Figure 12 describes the deviation of hotel system costs compared to the average of the sample data divided by either gross tonnage GT or interior area m^2 of the vessel. Similar analysis than for machinery systems in figures 8 and 9 was made for hotel systems and the KPIs €/GT showed good linear dependence while €/interior area showed more logarithmic dependence. The figure 12 shows that the ships 3 and 6 vary more between the two used units, €/m^2 measure being much lower than €/GT. This is explained by the fact that the interior areas are relatively larger for ships 3 and 6 compared to the total size of the ship. The deviations for the €/GT are much smaller between the vessels which would suggest to use €/GT KPI especially for the high level analysis.

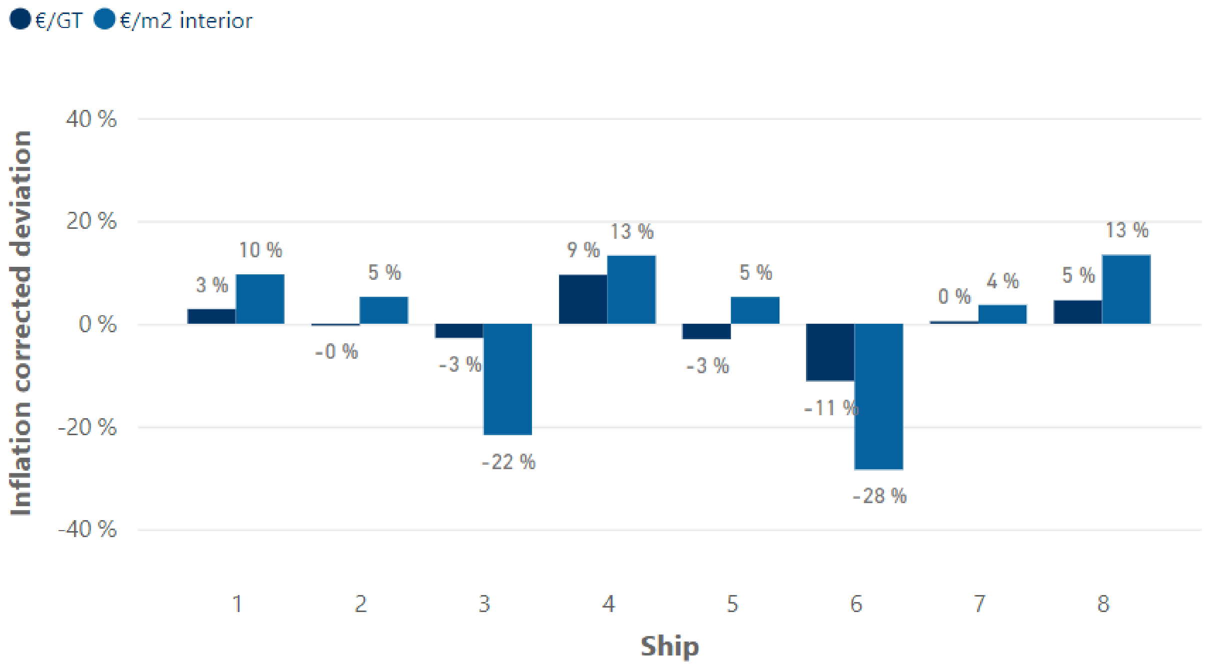

Figure 12: Hotel systems

Piping and AC systems contain different kind of pipes, fittings and ducts. In the context of this thesis, the piping and AC systems contain the fresh, black and grey water systems, ventilation and air conditioning systems, fire protection system and prefabricated pipes and ducts.

Figure 13 describes the deviation of piping and AC material costs compared to the average of the sample data divided by either gross tonnage GT, total area m^2 or interior area m^2 of the vessel. The €/GT and €/m^2 describing the total area show similar results between the vessels but the KPI normalized by the interior areas gives slightly different results. Especially for the vessels 3 and 6 the €/interior area results in much lower values.

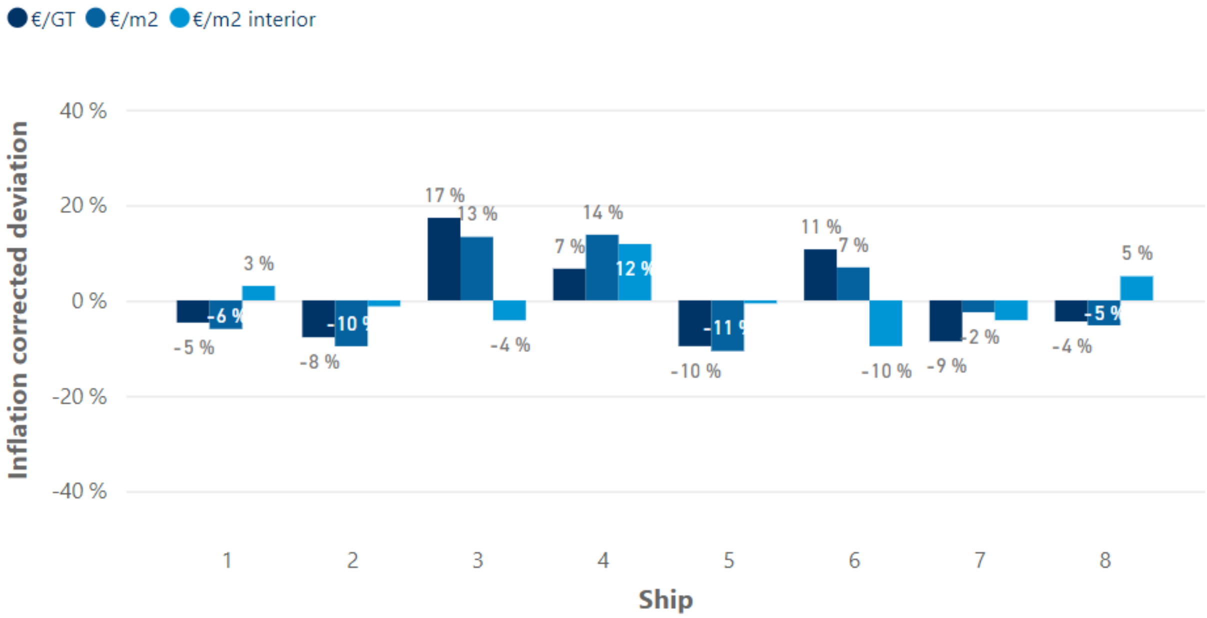

Figure 13: Piping and AC

Similarly than the cabling materials argued in chapter 4.4.3, the piping and AC materials could be classified as stock materials due to the similarities in process and consumption. The piping and AC systems are also located around the ship. Due to these facts, it would be suggested that the €/GT would be suitable measure also for piping and AC materials. The piping materials were measured in past by the KPI €/interior area in the case company which would interestingly differ the most compared to the suggested €/GT.

4.4.5 Deck systems

Deck systems are systems mainly containing items located in deck areas. In the context of this thesis, the deck systems contain the cranes, anchoring and mooring systems, lifeboats, windows, windscreens and possible entertainment and sport equipment located in deck areas. The material content of the deck systems vary a lot between the vessels. Some of the vessels may have for example areas with big waterslides and some may not.

Figure 14 describes the deviation of deck system costs compared to the average of the sample data divided by either gross tonnage GT or deck area m^2 of the vessel. The figure shows high deviation between the vessels. This was expected based on the different content of deck systems between the vessels. Since the values are variating a lot, the comparison between the vessels from different ship buyers and between the different ship series is not showing fully reliable and comparable results. The deck area is usually also relatively small compared to the scope of the systems.

Figure 14 shows that the wide comparison of deck systems may not be meaningful between the different vessels. However, the comparison of similar vessels is possible but the calculated KPIs will naturally show the same results than just comparing the absolute cost values. Different ships could be compared by analysing data in smaller scope, such as mooring system, and therefore comparing similar items to each other.

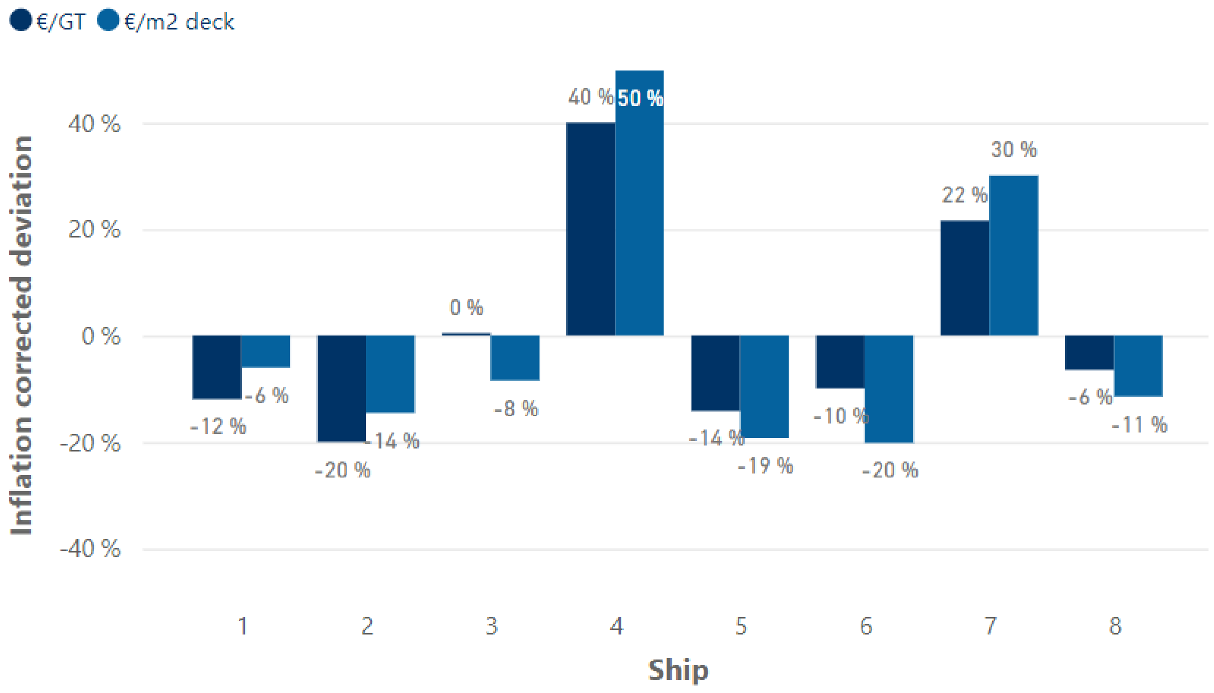

Figure 14: Deck systems

5 Conclusions

Shipbuilding industry among many other industry areas is currently operating in the highly competitive market. Within a competitive market and with low profit margins, the pricing of the product as well as managing the future company insights require accurate and reliable means to create the cost estimates.

The purpose of this thesis was to analyse and describe the current status of material process and measures to follow the material costs in a case company operating within a maritime industry. The development of the cost follow-up measures would improve the forecasting quality, identify the required action points and ease managing of the cost estimates. In order to suggest and analyse measures, the processes and main characteristics of to product needs to be described.

The literature review of the thesis focused on describing the shipbuilding and ship design processes as well as the theory behind the material cost follow-up. The theory was later compared with the practices used in the case company.

As a result of the thesis, the high-level material process in the case company was described. The process description included the roles and responsibilities as well as the main process steps. The amount of different materials from different categories consumed among the material process was found to be enormous. The process contained several responsible persons and the timeline of the process was described in several years. To serve different sub processes and needs, the materials were categorized with different principles. The study described two main categorization principles used by the case company: material type based categorization and system based categorization.

The second part of the analysis was focusing on the material cost follow-up measures. The measured categories were defined and data analysis was performed. The study suggested categories to support better material cost follow-up and comparison. The categories were defined based on the similar properties of the materials and typical categories presented by the literature. For each category, the most suitable normalized cost comparison KPI was presented. It was found out that especially the materials with low individual price and high volume were directly proportional to the gross tonnage of the analysed ship. The categories containing more variation independent materials were found to be more difficult to group and measure.

The stock materials, piping and cabling materials were found to be well comparable by the unit €/GT. The dependency was clearly linear and especially for the pure stock materials also the accumulation of the costs over the project timeline was surprisingly constant between the projects. The machinery system costs were found to be well comparable by the unit €/kW, where the kW describes the installed power of the main engines. Both hotel and electrical systems had more deviations and the measures did not seem to be as accurate. However, the electrical systems had a certain dependency to installed power kW as well as the size of the ship. The hotels systems showed good linear dependency to the gross tonnage of the vessel but the normalization by the interior area had more deviation. Out of all the analysed categories, deck systems had poorest comparability to any of the suggested measures. This was due to the different content of deck system materials between different vessels.

As the main purpose of the thesis was to suggest measures for better future cost follow-up procedures as well as to ease managing the cost estimates, the target can be assumed to be achieved. As expected, any of the measures used individually do not cover the total costs for materials required to complete a new building ship. Detailed cost calculation should always be carried by calculating costs for small set of materials and comparing the data to currently known actual values. However, the presented KPIs are well suitable to describe the high level trend of the total costs as well as to identify the main deviations caused for example by the process performance issues.

As a future action point, it is recommended that the KPIs presented in this thesis would be regularly monitored and the deviations would be further investigated. The case company is aiming to wider the product portfolio in near future, which would create a possibility for additional studies aiming to search similarities and differences between the different products and characteristics describing the cost measures.

References

Adithan, M. (2007). *Process Planning and Cost Estimation.* New Delhi: New Age International.

Adji, S. W. (2004). Industri Perkapalan Indonesia Menyongsong Masa Depan: Prospek Dunia Usaha. *Workshop Bank Indonesia Jakarta*.

Azhar, A., & Kristiyono, T. (2022). Method for Estimating Cost of New Ship Building with Linear Regression. *IOP Conference Series: Earth and Environmental Science 972.1*.

Collins, H. (2019). *Creative Research: The Theory and Practice of Research for the Creative Industries.* Bloomsbury Visual Arts.

Eyres, D. J., & Bruce, G. J. (2012). *Ship Construction.* Amsterdam: Elsevier.

Gereffi, G., Brun, L., Stokes, S., & Guinn, A. (2012). *The NSPS Shipbuilding value chains.* Nova Scotia, Canada.

International Maritime Organization. (1969, June). Retrieved from https://www.imo.org/en/About/Conventions/Pages/International-Convention-on-Tonnage-Measurement-of-Ships.aspx

Josefson, L., van Duin, S., de Carvalho Pinheiro, B., Yang, N., Luo, Y., Zamarin, A., . . . Roland, F. (2018). Committee V.3: Materials and fabrication. *M. Kaminski , & P. Rigo (Eds.), Proceedings of the 20th International Ship and Offshore Structures Congress:*, (pp. 143-191).

Kajaste, V., & Liukko, T. (1994). *Lean toiminta: Suomalaisten yritysten kokemuksia.* Tampere: Tekninen tiedotus.

Lamb, T. (2003). *Ship Design and Construction.* Society of Naval Architects and Marine Engineers.

Mentes, A., & Çağlayan, M. (2022). Metallic materials used in ship construction - Fabrication techniques, classification and certification. 23-31.

MobiShip. (2001). Description of the System design flow. *WP1.1.4 Ship Systems Design. EU-project*.

Molina-Azorin, J. F. (2016, May). Mixed methods research: An opportunity to improve our studies and our research skills. *European Journal of Management and Business Economics, 25*(2), 37-38.

Molland, A. F. (2008). *The Maritime Engineering Reference Book: A Guide to Ship Design, Construction and Operation.* Elsevier Science & Technology.

Nishi, Y., & Matsuo, M. (1997). *Development of the System for Initial design of Ships based on the product model.* Yokaholma, Japan: ICCAS.

Pal, M. (2015). *Ship work breakdown structures through different ship lifecycle.* Bremen, Germany: International Conference on Computer Applications in Shipbuilding.

Rawson, K. J. (2002). *Basic Ship Theory* (Fifth edition ed.). Oxford: Butterworth-Heinemann.

Räisänen, P. (1997). *Laivatekniikka: modernin laivanrakennuksen käsikirja.* Helsinki: Gummerus.

Sapuan, S. (2017). *Composite Materials : Concurrent Engineering Approach.* Elsevier Science and Technology.

Statista. (2023, October). Retrieved from Global inflation rate from 2000 to 2022: https://www.statista.com/statistics/256598/global-inflation-rate-compared-to-previous-year/

Stevenson, W. J. (2021). *Operations management.* New York: McGraw-Hill.

Wang, C., Callahan, J., & Corbett, J. (2007). Geospatial Modeling of Ship Traffic and Air Emissions. Retrieved from https://www.researchgate.net/publication/238031107_Geospatial_Modeling_of_Ship_Traffic_and_Air_Emissions

Appendices

Appendix 1 Material Process, Components