Development of a proposal work schedule forecasting method

For engineering work packages in custom trailing suction hopper shipbuilding projects at Royal IHC.

By
William Groeneveld

Thesis for the degree of MSc in Marine Technology in the specialization Ship Production

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“All models are wrong, but some are useful”

George E.P. Box

Summary

An issue that arises during the execution of shipbuilding engineering projects at Royal IHC (IHC) is an imbalance between the sum of all necessary engineering work, and all engineers that are employed who are available to execute the work. If necessary, additional engineers are hired or work is outsourced to deal with the imbalances. Necessary engineering work is determined based on work schedule forecasts. A work schedule forecast determines a quantity and timing of engineering work in the future. Work schedule forecasts of different projects are combined to create an overview of total workload. These forecasts of engineering work schedules are however especially fuzzy in a proposal phase when there is limited project knowledge available. Currently, due to changes of work scope in the engineering departments, current models do not provide the required output. There currently exists potential in developing a new work schedule forecasting method in specialized planning software that produces the required output.

This research aims to develop a new method to help establish a proposal engineering work schedule forecast for all engineering work packages in custom built trailing suction hopper shipbuilding projects at Royal IHC Kinderdijk. IHC currently establishes a proposal engineering work schedule forecast by combining: 1. extrapolations of man-hour data from previous comparable projects based on experience and; 2. regression models. However, over time, the knowledge behind the regression models has been lost. Furthermore, the required forecasting comprehensiveness of the latest and future projects has been changed which causes fuzziness around the application of historical man-hour data.

To develop the input for the new method, regression analysis on usable historical engineering man-hour data was applied to develop models that quantify work, and curve fitting through the man-hour data was applied to develop models that determine the timing of work. These were done while making the following assumptions: 1. the work that result in the delivery of the project is dependent on project size (*eg.* principal dimensions) and project complexity (*eg.* vessel functionalities)(Coenen [7]) and; 2. problems are solved in the same manner across projects (Norden [26]). Division of the method into work quantificaion and work timing was beneficial based on the available data and input for specialized planning software. The obtained work quantification models and work timing models resulting from the regression analysis and curve fitting analysis are applicable to establish the new engineering work scheduling forecasting method. Because a completely new data set is applied, quantified validation is limited.

This research concludes that the newly developed method divides the proposal engineering capacity schedule forecast into work quantification and work timing, for each of the 13 engineering work packages considered. Work quantification applies regression analysis to compose linear models that quantify work, while considering statistically significant project characteristics based on the historical engineering man-hour data. Work timing applies a start-finish relation analysis with the engineering throughput time and histogram fitting to establish normalized resource load curves that follow the trend of the historically spent data. The work quantification and work timing results are established in such a way that they can be applied into specialized planning software.

Preface

This thesis that lies in front of you is the result of a last phase to receive a masters degree in 'Maritime Technology' at the Technical University of Delft. Such a research tests the student's gained knowledge from prior years of study. The student is considered as a 'Master of Science' after successful execution of the research.

This research is executed at Royal IHC with the purpose of developing a new proposal engineering work scheduling method. IHC is a global market leader in the production of dredging and offshore marine vehicles. IHC's high production volume draws attention to the engineering process.

This research is divided into three main parts. The first part is an extensive introduction into the current problem to identify the root-cause of the problem. In the second part, literature is consulted on potential methods to create input for the defined problem. Thirdly, the most suitable methods are executed to compute all input for the new forecasting method. It is important to understand that the word 'method' is applied to mean two thing. This research establishes a new forecasting method for IHC. This i however done by investigating and execution (sub-)methods to compose all input for the forecasting method. This report aims to clearly distinct between the forecasting method and methods applied to compute input. Even though, caution must be present when interpreting the word 'method'. In the end, timing was short to work out the new forecasting method in appropriate software for application purposes. The quantification models and timing models are however ready for implementation with the corresponding limitations.

I would like to take this moment to thank everybody that has contributed to this research. Special thanks to J.M.G. Coenen as honorary representative & J.F.J. Pruyn as representatives from Delft Technical University for the extensive amount of feedback they offered throughout this research process. Also many thanks to I. Karimi, E. van Rijn and W. Zevenbergen as representatives from IHC for giving me the opportunity to execute this research at IHC and helping me during the execution.

Lastly, I would like to thank my mom, family and friends for always supporting, challenging and standing beside me through my career as a student and making this thesis possible.

Contents

List Of Abbreviations

CE	Concurrent engineering
ETO	Engineering to order
GA	General arrangement
MS	Microsoft
MaS	Master schedule
MLR	Multiple linear regression
MPS	Master Production Schedule
MSE	Mean squared error
SMLR	Stepwise multiple linear regression
PC	Project costs
PSE	Planning software export
TS	Technical specification
WP	Work package

1 Introduction

Preliminary to determine the research questions, a brief introduction is provided into the problem. This introduction provides key knowledge for the more in depth problem explanation in Chapter 2.

This chapter is divided into four sections. Section 1.1 provides a brief introduction into the shipbuilding market. Section 1.2 provides a brief introduction into engineering in a shipbuilding project. Section 1.3 explains the establishing of an engineering capacity schedule to identify imbalances by capturing project workload. Section 1.4 briefly shows discrepancies between the current capacity schedule and the current proposal engineering work forecast.

1.1. A brief introduction to the history of the shipbuilding market and its shift of bottlenecks

After the ending of World War II, the Asian shipbuilding industry expanded and took over most of the engineering and production of the high-volume, relatively non-complex ships (Coenen [7]). The Western European shipbuilding industry responded by shifting their market towards specialized, knowledge-intensive shipbuilding niches. This shift developed a specific product-knowledge within Western European shipyards, suppliers, research centers and universities (Hopman [16]) from which the market still benefits to this day.

In pursuit of maintaining its competitive market position, the Western European shipbuilding market started to outsource construction of ship hulls and systems to foreign (and most often cheaper) ship production facilities. Outsourcing created the possibility of building more and cheaper ships. Cooperation with foreign shipyards shifted the bottleneck from available building space on the slipway towards executability of engineering work. The amount of engineering work that could be executed by a company was however limited by the number of engineers that were employed by the company and not occupied by other projects. Engineering work as a bottleneck emphasized the importance of accurate engineering work forecasts to analyze if all future work was achievable. By creating insight into future engineering work for all projects, imbalances could be identified, from which decisions on hiring additional engineers or outsourcing engineering work could be made.

1.2. A brief introduction into engineering in shipbuilding projects

Engineering, which in this research is defined as "a process of transformation of specifications and requirements into a complete description of a physical product that matches its specification" (Nahm [25]), requires cooperation of many specialized engineers. All specialized engineers cooperate to transform project functions and requirements into systems and components and finally into a buildable design. Exchange of information is vital in this engineering process. Engineers are however limited to a specific work package [1] which lies within their field of expertise.

[1] Classification of a group of related tasks

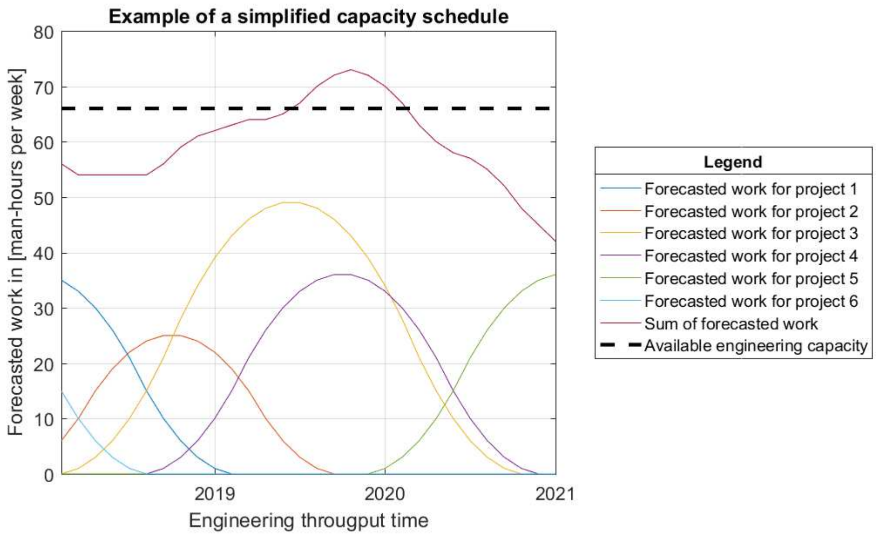


Figure 1.1: Example of a simplified work schedule forecast

IHC currently categorizes 21 different types of specialized engineers (also referred to as engineering resource). A set of activities for each engineering specialization is captured in 21 different engineering work packages. The amount of work for a specific work package and project is however different for each project. It is suspected that work for a specific work package is dependent on the project size and project complexity. Application of 21 different work packages requires 21 analysis of imbalances. Therefore, 21 independent work forecasts are required. The forecast is quantified in man-hours.

1.3. Establishment of a capacity schedule

An analysis of imbalance is executed in a so-called capacity schedule. A capacity schedule is established by: 1. forecasting a work schedule for each work package in a project; 2. taking the sum of all work forecasts from the same work package for all projects considered; 3. quantifying how many engineering man-hours are available over a forecasted period (also referred to as engineering capacity for each engineering specialization; 4. quantifying imbalances over time between the work schedule forecast from a specific work package and the associated available engineering capacity.

A fictive example of a capacity schedule for an example work package is shown in Figure 1.1. Each line, with the exception of 'Sum of forecasted work' and 'Available engineering capacity', is a forecast for the amount of work over a determined project throughput time. The 'Sum of forecasted work' is the summation of the individual work package forecasts. The dotted line represents the total available engineering capacity which are employed by the fictive company to execute all the work corresponding to the example work package. Whenever 'Sum of forecasted work' rises above 'Available engineering capacity', insufficient engineers are available to execute the work. Vice versa, insufficient work is available. Any imbalance between the two may cause unachievable deadlines or idle engineers which is generally estimated to result in 25% (Rouibah [28]) of the total consumed work for a project.

During the project proposal phase [2] an engineering work forecast is necessary to investigate if sufficient specialized engineers are available to actually execute the project before the project is acquired. The proposal work forecast is however fuzzy when: 1. there is limited project knowledge available to establish a proposal work forecast and; 2. the organization around engineering of the latest projects has been changed which creates fuzziness around 2.1; the application of current available forecasting models and 2.2; the application of available data.

[2] time when a client has interest in the build of a ship but it is not certain yet if the project will be executed by IHC

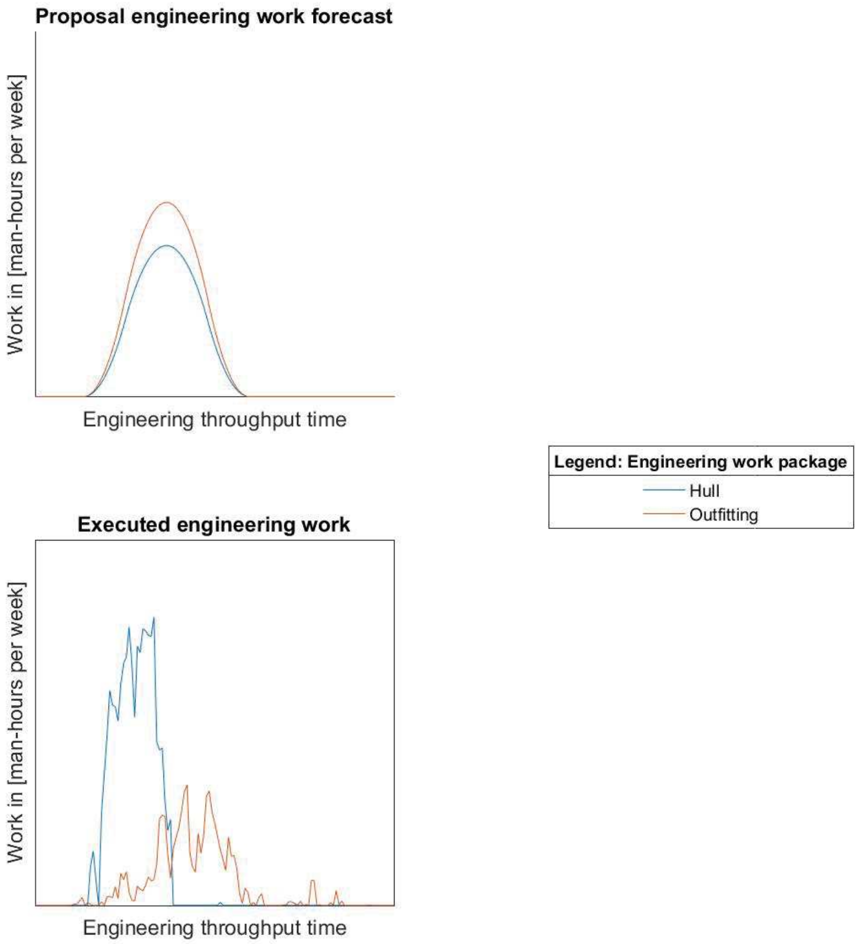


Figure 1.2: A comparison of engineering work forecast originating from the current method and executed engineering work

1.4. Problem definition

The current proposal engineering work forecasting method is experienced to not represent the current organizational structure which causes discrepancies between forecasted and spent man-hours.

An example of discrepancy between a proposal engineering work forecast and spent work for two work packages is shown in Figure 1.2. The figure shows that the forecasted work and spent work is not distributed similarly in time and quantity. This is noticeable by the timing and quantity of the peaks. IHC wishes for a new method that establishes a more accurate proposal engineering work forecast in current applied planning software in the required output.

2
Background

Preliminary to establishing a main research question, the potential improvements are further analyzed. The potential improvements are defined by investigating the origin of discrepancies between the current proposal engineering work schedule forecast, the differences between the forecast and spent work at IHC and literature. The answers from this analysis determine the 'problem(s)' to-be solved. The research questions that follow at the end of this chapter form the backbone of this research.

The following chapter is divided into seven sections covering three topics. Topic 1 provides the basic knowledge of a shipbuilding project and the contribution of engineering. This part lays the theoretical foundation for engineering. Topic 2 explains the current engineering capacity scheduling method at IHC and its limitations. This part compares the current situation with the obtained knowledge in Part 1. Topic 3 explains the research objective, research questions and research approach that follow from Topic 2.

Topic 1 consists of Section 2.1 which provides basic knowledge on the execution of a shipbuilding project and engineering. Topic 2 consists of Section 2.2 and Section 2.3. Section 2.2 explains how IHC currently composes the engineering capacity schedule. Section 2.3 explains the limitations of the method. Topic 3 is divided into Section 2.4, Section 2.5 and Section 2.6. Section 2.4 explains the research objective and scope. Section 2.5 translates the research objective into research questions. Section 2.6 explains the research approach. All elements in Topic 3 forms the basis for the remainder of this research.

2.1. Execution of a shipbuilding project

The following section provides basic knowledge on the phases of a shipbuilding project at IHC. This is done by explaining the general phases of a shipbuilding project and by explaining the engineering sub-phases in a shipbuilding project. Information is obtained from literature in combination with knowledge from IHC engineers. This section will also provide basic information on the work packages that are analyzed.

The following section is divided into two sub-sections. Sub-section 2.1.1 describes the general phases of a shipbuilding project. Sub-section 2.1.2 dives into the engineering phase by describing each corresponding sub-phase. A disclaimer about the proposed shipbuilding and engineering (sub-)phases is however necessary before continuing to the two sub-sections.

Disclaimer of the proposed phases

A shipbuilding project goes through different phases to transform a client's its wishes and requirements into a physical project. The number of phases and names applied to all phases are however blurred between companies and theory (Lamb [21]) which makes this matter for discussion. For this research, the process names of IHC are applied. Since it is not the scope to establish a definition of engineering for widely applicable usage, the following definitions do not necessary align with other researches than for application within IHC.

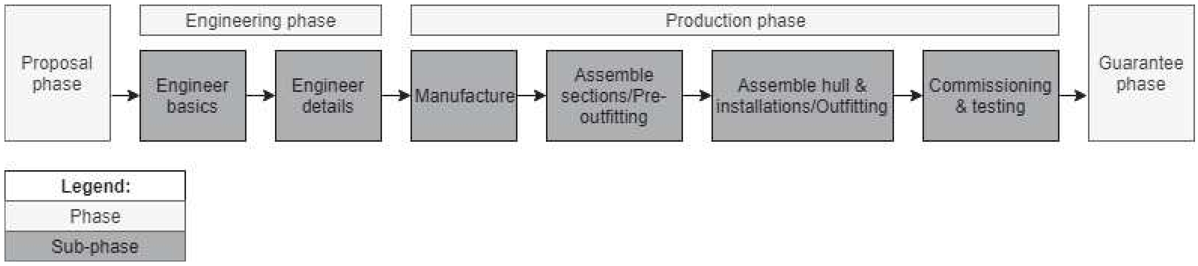


Figure 2.1: Flowchart of the shipbuilding phases and sub-phases at IHC

2.1.1. A general introduction into the phases of a shipbuilding project

In summary, a shipbuilding project goes through a proposal phase, engineering phase, production phase and guarantee phase. Some phases are on itself again split up into several sub-phases based on the nature of the work done. A flow chart of all phases and sub-phases at IHC is shown in Figure 2.1.

This section is divided into four paragraphs for each of the main phases. Paragraph A explains the proposal phase. Paragraph B explains the engineering phase. Paragraph C explains the production phase. Paragraph D explains the guarantee phase. This sub-section provides the basic knowledge to explain the engineering phase in more detail in Sub-section 2.1.2.

A. Proposal phase

Based on requests and requirements of a client, a 'proposal design' is established in the so-called proposal phase. The principal objective of this phase is to clarify the shipowner's required performance attributes and develop a proposal design, which satisfies the requirements, as well as a cost estimate and a risk assessment (Lamb [21]). This phase is necessary because many of the built ships are fully customized for the wishes of a client which is referred to as '*Engineered to Order*' (ETO) (Coenen [7]). This ETO characteristic and the customization that follows from is causes difficulty in establishing an engineering work schedule forecast. A milestone during the proposal phase at IHC is the so-called 80/80 phase where the client receives a General Arrangement (GA) [1], Technical Specification (TS) [2], project costs (PC) and Master Schedule (MaS). The term 80/80 phase is applied to point out the expectation that there is 80% chance that the client wishes to build the ship, and there is 80% chance that IHC will be the one to build the ship. Based on the GA, TS, PC and MaS, the client will proceed or decline further elaboration of the design. Preliminary to the 80/80 phase, the master schedule is consulted if sufficient engineers for each engineering work package are available to execute the project. It is the goal of this research to apply the engineering work schedule forecast here to investigate potential imbalances between engineering work and available engineering capacity.

For the remainder of this research, the term 80/80 phase is applied to refer to the timing that the new engineering work schedule forecasting method is applied.

When a client wishes to continue the project, the proposal design is further developed on for example definition of all sizing of major system components, establishment of simple diagrams, definition of building strategy and predicting the documented performance which are defined in the GA and TS. All design developments in the proposal phase contribute to the possibility of developing better estimates of product price, components and building process. Based on the established documentation which is referred to as the contract design, the contract with a client is potentially signed and the project is acquired.

B. Engineering phase

After the contract is acquired, the size of the engineering team takes a jump. The engineering phase takes on the developed ship design and continues with developing vessel's specifications. This is where the 21 engineering specializations start cooperating. Together they translate the contract design into a producible design. Development and exchange of information is critical in this translation process. Engineering is characterized by establishing a more detailed design as the project progresses. IHC Engineers explained based on their experience with the engineering process that the total engineering phase takes between 6 to 14 months

[1] A document containing the general layout of the ship
[2] A document containing all functional specifications of the ship

depending on the size of the project. Project size relates to the amount of necessary information to create a producible design which again relates to the amount of time necessary to obtain all information. The exact start of the engineering phase in the overall shipbuilding process is fuzzy. Engineering may start preliminary to the signing of the building contract when for example confidence in the contract is high or there is high pressure from simultaneously executed projects. The start of the engineering phase may also be delayed based on occupancy on other projects. The start of the engineering phase is however characterized as a big jump in the increase of the engineering team.

On the highest level, engineering is split up into basic engineering and detailed engineering. Basic engineering (or also referred to as technical engineering) (Coenen [7]) translates all functional matters from the GA and TS into systems, components and lay-outs. The associated work consists mainly of determining the right machinery, equipment and lay-outs. Detailed engineering translates the established design from basic engineering into a producible design. More on this matter is explained in Section 2.1.2. IHC Engineers explained based on their experience with the engineering process that there is a period of 4 to 6 months between the start of basic engineering and start of detailed engineering depending on the project size. When the ship design has sufficiently matured, the production phase starts to build the actual product. The engineering team decreases when all documents are established.

C. Production phase

Whilst some drawings may still require to be finished in the engineering phase, the first parts of the parts are fabricated and manufactured. The production phase starts with the manufacturing of parts, plates and profiles. During manufacturing, all ship parts are cut. All cut parts are assembled into panels and sub-sections in the assemble section/pre-outfitting stage. Sub-sections are combined to assemble sections and finally a hull. Together with the assembly of the hull, installations are outfitted and spaces are finished.

Generally, the production phase starts when space is available on the slipway. The ship is launched when the product is sufficiently finished. In the water, all systems, installations, components, etc, are checked and accepted by client and class. Technical and functional requirements are tested before the ship is handed over to the client.

D. Guarantee phase

Once the ship is handed over to the client, a shipyard's only importance is the satisfaction of the ship's owner. Any faults that may occur during operation are solved during the guarantee phase to satisfy the client.

2.1.2. The engineering phase in a shipbuilding project

The following section explains how engineering contributes to a shipbuilding project at IHC. Concluding from Sub-section 2.1.1, the engineering phase consists of basic engineering (or technical engineering) and detailed engineering. Both matters will be explained in more detail in the following paragraphs. Each phase will also explain the work packages that are applied by IHC. Before explaining the two engineering subphases, a definition is provided on engineering to explain the work done.

This sub-section is divided into three paragraphs. Paragraph A provides a general definition of engineering and content of work based on theory. Paragraph B explains what work is actually executed during basic engineering and which engineering resources are currently present at IHC. Paragraph C explains the executed work during detailed engineering and which engineering resources are currently present.

A. A general introduction into the engineering phase

Engineering at IHC is the key between the proposal design described in the TS and GA and documentation that satisfies all functions and requirements and is ready for production. As a definition: Engineering in this research is considered as a transformation of specifications and requirements into a complete description of a physical product that matches its specifications (Nahm [25]). This definition of engineering includes deciding of all technical matters, development and documentation of the design to enable its manufacture, which can be seen as 'designing' in stead of engineering (Lamb [21]). The design element is considered as part of the shipbuilding engineering process (Coenen [7]).

Transformation of specifications and requirements into a complete description of a physical product is accomplished by dividing the engineering process into two different phases based on the nature of the work done. This nature of the work done has to do with a decision making element, design skills required, the number of persons participating in the design effort, the level of detail of the design deliverables and other features of the design process that change over time as the design is develops (Lamb [21]). Engineering is divided into '*Basic engineering*' and '*Detailed engineering*'. The process of basic and detailed engineering and the associated work are explained in the following paragraphs. High-over: basic engineering is responsible for all diagrams, lay-outs and determining of equipment, detailed engineering is responsible for translating all diagrams, lay-outs and equipment into a producible design.

B. Basic engineering phase

During basic engineering, "the ship is designed in its entirety, on a system-by-system basis" (Lamb [21, p. 5-6]). This means that individual systems are defined, linked, integrated or otherwise combined to create a more complex system. Complex systems require a high level of system integration. A few examples of basic engineering tasks are the composing of diagrams for all systems that contribute to propulsion, heat and ventilation, fire fighting, fuel, etc, calculating the strength of a mid-ship section, calculation of resonance on the propeller shaft and establishing the hull shape. Because many of the specific systems require a high level of knowledge, specialized engineers are necessary to execute specific systems and components. The work associated with specific systems and components are categorized in a work package. Every work package is executed by a single engineering specialty. The high level of integration is only acquired by exchanging the right information at the right time between specialized engineers. This is also referred to as interdependency (Coenen, [7]. For example: The construction must be strengthened around mounting points of the main engine, pumps, generators etc. This means that construction engineers can only execute this work when layout engineers and equipment engineers are done. This interdependence between different systems requires iterations of a design. Engineering is characterized as an iterative process where each iteration is an elaboration of its predecessor. When reflecting this on the engineering throughput time and start of detailed engineering (As explained in Sub-section 2.1.1 Paragraph B, more iterations are necessary for a larger ship.

To reduce engineering time, different tasks are executed simultaneously by different engineers. This simultaneous execution of systems is also referred to as 'concurrent engineering' (Coenen, [7]). Concurrent engineering emphasizes correct timing of information exchange between engineers. This way, everybody has its information on time to elaborate the design and reduce throughput time.

IHC currently applies 21 different engineering work packages. The 12 basic engineering work packages are divided over maritime engineering and mechanical engineering. Furthermore, lead engineers are added to control the engineering process. The 12 basic engineering work packages and their associated tasks scope, divided over maritime, mechanical and lead engineering are:

Maritime engineering

- **Accommodation:** concerns all establishment of arrangements and layouts that are required for the crew accommodation, bridge and rescue equipment. This includes for example: establishing of safety plan, plan of doors, plan of floors and list of inventory.
- **Hydromechanics:** concerns all matter for the ship's stability calculations and tests, weight calculations, resistance calculations, launch calculations, stability booklets, and hydromechanical equipment such as rudders, propellers nozzles.
- **Construction plans:** concerns establishing of the arrangement of casco blocks and section plan. Construction plans is however highly related with the tasks for construction calculations which include the establishment of the complete construction plan, cross sections and specification of list of steel materials. More information on construction plans tasks are elaborated in the section on construction calculations.
- **Construction calculations:** concerns establishing of the construction plan, cross sections and specification of steel materials. This basically concerns the arrangement of frames, girders, and other hull work. This also includes the calculation of class requirements for most of the steel work.
- **Maritime equipment:** concerns establishing all equipment on the deck of the ship. These are boulders, safety equipment and sun tents.

Mechanical engineering

- **HVAC + FiFi:** concerns all climate systems, ventilation and fire fighting throughout the ship. This may also include cooling for LNG systems
- **Diagrams:** concerns establishing of arrangements for all on-board systems. This concerns merely the determination which systems are required to execute certain tasks. Examples of diagrams work are the diagrams for fuel system, lubrication system, grey water system, steam systems, pneumatics.
- **Hydraulics:** concerns all calculation on hydraulic systems on board. The extent of hydraulic systems on board is however different per ship. Hydraulics are used for the bottom doors and valves.
- **Mechanical layout:** concerns all, placement, connection and establishment of specifications and defining of auxiliaries in all technical rooms (engine room, pump room, etc). This includes for example the preliminary arrangement of the engine room, fore castle deck, exhaust system, etc.
- **Mechanical systems:** concerns all matters for the main propulsion system, propulsion of dredge pumps, propulsion for jetwater and generators. Work includes the placement of all systems, calculating all specifications, placement of gearboxes and executing of torsion and vibration calculations.

Lead engineering

- **Lead engineer maritime:** concerns the management of all maritime engineering work packages
- **Lead engineer mechanical:** concerns the management of all mechanical engineering work packages

C. Detailed engineering phase

When the basic design is sufficiently matured, detailed engineering complements the design by making it fit for production. A few examples of detailed engineering tasks are the placement of floors, pipelines, cable trays and brackets. Alike basic engineering, detailed engineering is highly interdependent. Problems in the basic design may be identified during the detailed engineering process. Any changes in the design during detailed engineering activities require a change of the basic design. Furthermore, certain detailed engineering tasks can only continue when specific tasks are done. For example, pipes can only be placed when all construction elements are placed. Outfitting can only place brackets brackets for all pipes when all pipes have been placed. IHC engineers mentioned that detailed engineering finishes about 20 weeks prior to the ship launch.

Detailed engineering consists of a total of 6 different work packages that are divided over maritime-, detailed and lead engineering:

Maritime engineering

- **Hull:** concerns all the translation of all structural arrangements into a producible design. Every frame, stiffeners, struts, girders, brackets, etc are modeled in 3D software where all connections are determined and made into producible designs which comply with class.
- **Outfitting:** concerns the placement of all small steel components. This includes the placing of floor, brackets for pipes, hatch covers, an brackets. All This includes for example the placement of brackets for all equipment in hull sections, consoles, floors, railings and detailed drawings of hatch covers, portholes, cranes etc.

Mechanical engineering

- **Routing:** concerns the placement of all required pipelines. All placed systems by mechanical layout are required to be connected as defined in the diagrams. Routing determines however how all pipes will actually 'run' through the ship. This is done by designing all pipelines in 3D software.

Lead engineering

- **Lead engineer detailed hull:** concerns the management of all Hull related tasks
- **Lead engineer detailed outfitting:** concerns the management of all Outfitting related tasks
- **Lead engineer detailed routing:** concerns the management of all Routing related tasks

D. Miscellaneous engineering phase

Besides the basic- and detailed engineering work packages, IHC also recognizes three miscellaneous work packages. The miscellaneous work packages are:

- **Dredging components:** concerns all matters around the systems required for dredging. This includes for example the establishment of arrangement for dredge pumps, bottom doors, suction pipes, filter installations.
- **Electrical & automation:** concerns all electrical matters on the ship. This includes for example the establishment of a power balance sheet, energy balance, switchboards, alarm installations and consoles.
- **Total lead engineering:** concerns the overall management of engineering

Dredging components is seen as an independent department and is therefore classified as 'other'. For the remainder of this research, dredging components shall be allocated to basic engineering. Electrical & automation is mainly executed by third parties and is therefore discarded from this research.

2.2. The current engineering capacity schedule at IHC

There are currently multiple potential improvements regarding the current engineering capacity schedule (see section 1.3 for a brief explanation of the capacity schedule) and the method that computes the necessary input. The origin of the potential improvements originate from the: 1. applied application to compose the engineering capacity schedule and; 2. the method to forecast work for custom built trailing suction hoppers. The following section will briefly explain both topics and the limitations that originate from it. This section forms the basis for determining a research objective, research questions and research approach.

This section is divided into two sub-sections. Sub-section 2.2.1 explains the current capacity scheduling application. Sub-section 2.2.2 explain the current engineering work forecasting method.

2.2.1. The current capacity scheduling application

The current engineering capacity scheduling is established in an Microsoft (MS) Excel based application that creates an overview of future work and available engineering capacity for each work package considered. This overview is similar to the example from Figure 1.1. This application is built and monitored by an IHC employee. The engineering capacity schedule requires a total amount of necessary work (in man-hours) which is on itself forecasted by a work forecasting method. This method is explained in Sub-section 2.2.2. Each work schedule forecast per individual project in the capacity schedule is established by submitting the following data items:

1. a forecasted amount of total necessary work (in man-hours)
2. a forecasted engineering throughput time (in months)
3. starting month
4. start of detailed engineering with respect to the start of the project

The application composes a capacity schedule by:

1. distributing the total amount of work (item 1) over basic- and detailed engineering by applying a fixed distribution
2. applying two bell shaped curves (one for basic engineering and one for detailed engineering) that time work over a throughput time (item 2) starting at the starting month (item 3) and detailed engineering start at the detailed engineering starting month (item 4)
3. distributing the work of bell shaped curves over all corresponding work packages with a fixed distribution.

The two bell-shaped curves (from Step 2) is shown in Figure 2.2. From the total necessary work [3] (Step1), 34,1% goes to all basic engineering work packages and 51,1% goes to all detailed engineering work packages. The remaining 14,8% goes to lead engineering work packages All lead engineering work packages are

[3] values have been changed in this public available thesis for confidentiality reasons

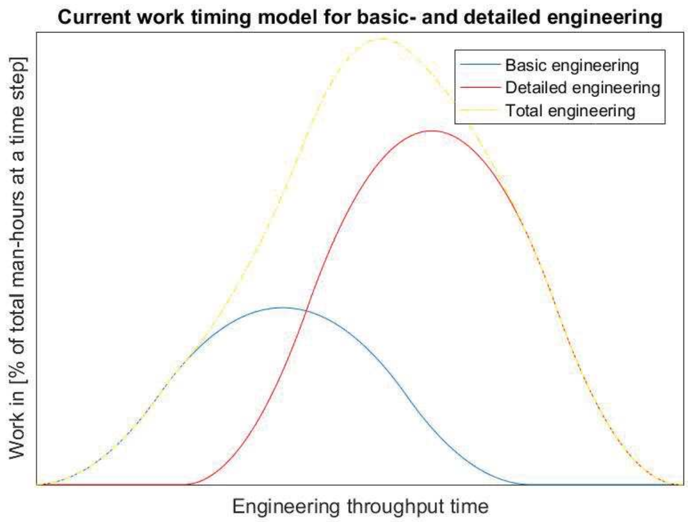


Figure 2.2: Timing of the basic and detailed engineering process over a throughput time

excluded from this forecast. Each basic or detailed engineering related work package is timed as a percentage part of one of two curves. The final engineering work forecast schedule containing all basic- and detailed engineering work packages is shown in Figure 2.3.

Reflecting on the theory of basic- and detailed engineering, the current applied engineering work schedule forecast shows that a part of basic engineering work is executed before detailed engineering starts. This is the result of the iterative nature of engineering. Furthermore, basic finishes earlier than detailed engineering which suggests that there is no rework at the end of detailed engineering. There are however several matters that raise questions. The forecast shows that work for a work package is determined with a fixed distribution. Theory says that work is dependent on size and complexity which shall affect the number of necessary man-hours for an individual work packages. The fixed distribution implies that work scales linearly to the total project man-hours. Theory mentions that engineering is an iterative process and certain work requires information from others. It is suspected that work may be required earlier for specific work packages. Lastly, all schedule forecasts are established with the explained method and can not be further updated with new project schedules once the project starts.

2.2.2. Work quantification

Currently, total necessary work (in man-hours) is quantified by extrapolation of historic project data based on experience from engineers and by applying two regression models. Both the experience from engineers and the regression models that link specific project characteristics to an amount of work so that a larger ship requires more engineering work.

In summary, the existing work quantification models at IHC apply a combination of simple linear regression models, simple non-linear regression models and multiple linear regression models. Both applications apply principal ship dimensions and functionalities like for example length, breadth, depth, number of crew, power of the main engines in the regression models to relate the product to man-hours. Over time, knowledge behind the establishment of regression models has become fuzzy. Furthermore, the regression models have not been updated with the latest project data. A detailed explanation of the regression models and the forecasting applications is provided in Appendix A.

2.3. Limitations of the current capacity scheduling method

There are several elements in the current proposal engineering capacity scheduling method that result in limitations. The limitations originate from the current applied engineering work scheduling application and the method to determine total necessary work. The following section summarizes each limitation. Each lim-

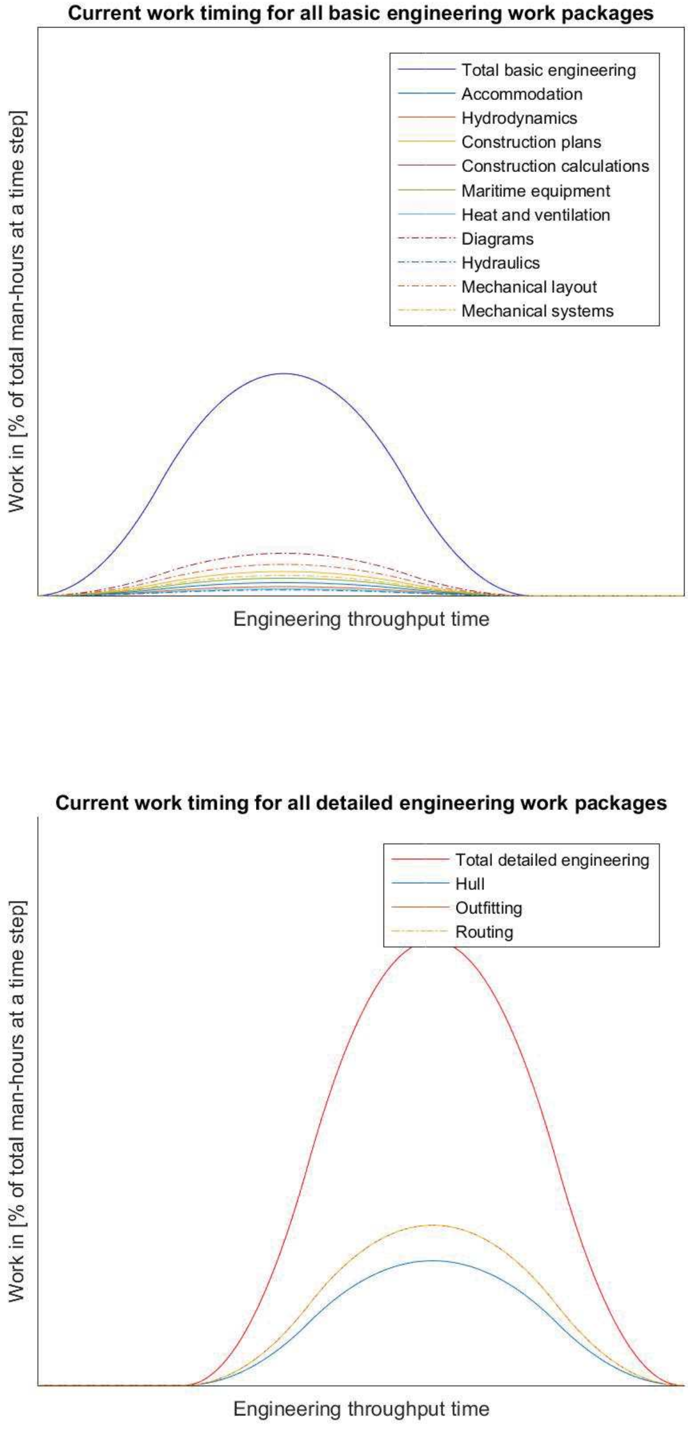


Figure 2.3: Timing of the basic and detailed engineering work packages over the engineering process

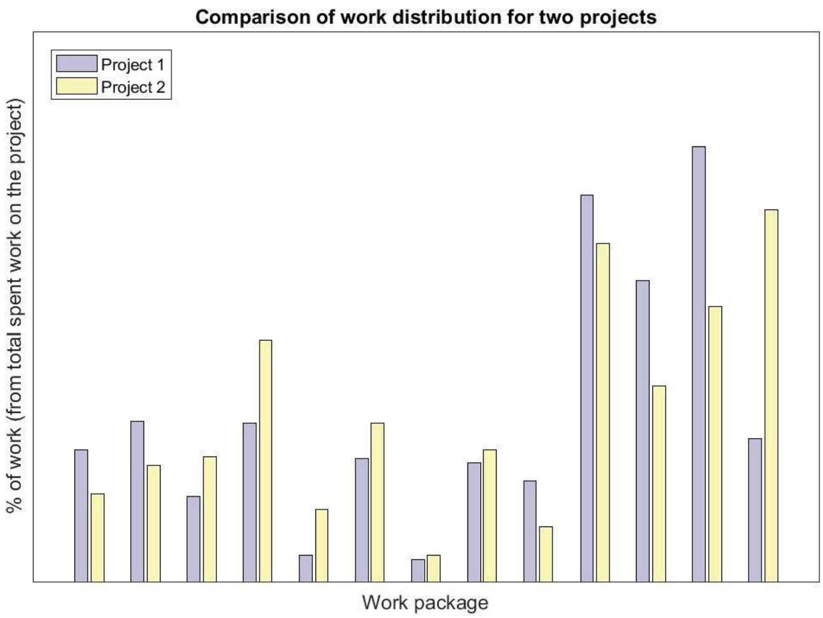


Figure 2.4: Distribution of work for two executed projects

itation is backed-up with experience from IHC engineers or figures from historical data. The historical data is applied in Figure 2.4, 2.5 and 2.6. The applied data is further explained in Chapter 3.

The limitations in the current method are:

- **Application of non-updatable project schedules in the MS Excel based capacity schedule application:** The current application establishes a capacity schedule in an MS Excel based application. All projects in this application are composed according to the forecasting method explained in Section 2.2. It is however not possible to update a project with the latest updated project schedules
- **Unknown basis of the regression models:** Knowledge around the work quantification models has bevcome fuzzy over time. It is unknown: 1. which data has been applied to establish the models and; 2. it is unknown why certain trade-offs have been made
- **Applying non-updatable regression models:** The work quantification models are applied as formulas with fixed estimates. The formulas are not updatable with the latest engineering man-hour project data.
- **Fuzziness around application of current historical man-hour data:** Due to organizational changes in engineering, a more comprehensive proposal engineering schedule is required. There is no knowledge on how to quantify historic man-hour data to the new organizational structure
- **Application of a fixed work distribution:** The applied fixed work distribution is composed from personal experience. This was necessary because there is fuzziness around the application of historical man-hour schedule data on the new engineering organizational structure. Furthermore, the current applied work distribution assumes that the work is distributed the same manner between projects. The current applied work distribution is provided in Appendix B. Application of a fixed distribution is however questionable when the work is assumed to be dependent on project size and complexity. When comparing two work distributions in Figure 2.4 it is shown that work is distributed differently between the projects. All work distributions from historical data are provided in Appendix G.1.
- **Neglecting encountered engineering problems in detailed engineering:** The current basic and detailed engineering timing curves assume that engineering work for basic engineering stops before detailed engineering stops. Theory clarifies however that engineering is an iterative process and problems

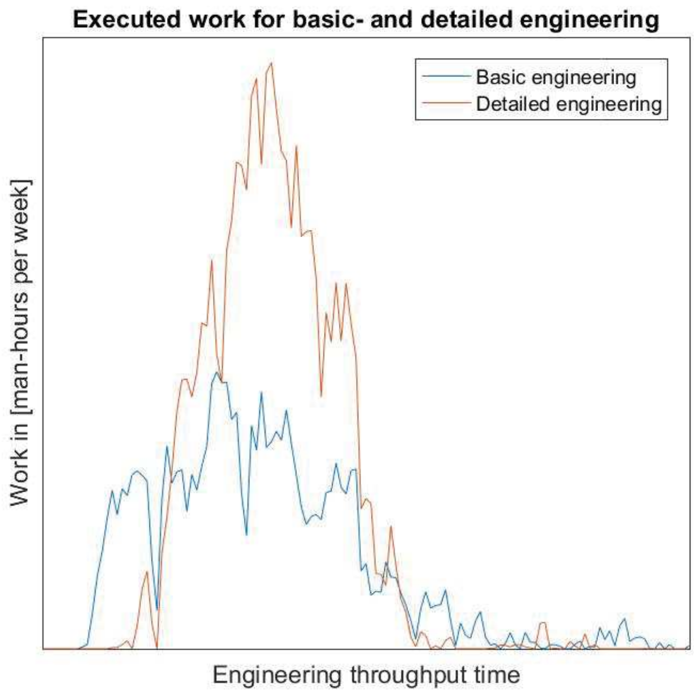


Figure 2.5: Example of executed basic and detailed engineering work

may be encountered during detailed engineering that require change in the basic designs. When comparing the work spending for basic- and detailed engineering work in Figure 2.5 it is shown that, for this example, basic engineering continues till the end of detailed engineering. All work spending figures for basic- and detailed engineering are provided in Appendix H.1.

- **Interdependency between engineering resources:** The current engineering work schedule assume that the work for basic- and detailed work packages start, finish and peak at the same time. This is contradictory to the explained matter around successive behavior of for example detailed engineering. When comparing the schedule forecast for detailed engineering and the spent work from a project in Figure 2.6, it is shown that work is executed differently than forecasted. All work spending figures for all detailed engineering work packages is provided in Appendix H.2.

2.4. Research objective and scope

The ultimate goal of this research is a new engineering work schedule forecasting method that is able to establish a proposal engineering work schedule in Primavera, for the 13 engineering work packages considered, for new custom built trailing suction hopper projects at Royal IHC.

The the resulting method potentially solves to following issues:

1. **Apply the latest, and most complete historical man-hour data set:** this ensures that there is knowledge on the applied data to establish the models
2. **Applies characteristics that represent size and/or complexity to quantify man-hours in a regression model:** this ensures that it is known how the regression models establish output
3. **Apply regression models that are updatable when new data becomes available:** this ensures that the regression models are always up to date
4. **Forecast a work schedule per engineering work package:** this potentially ensures the iterative behavior of work spending

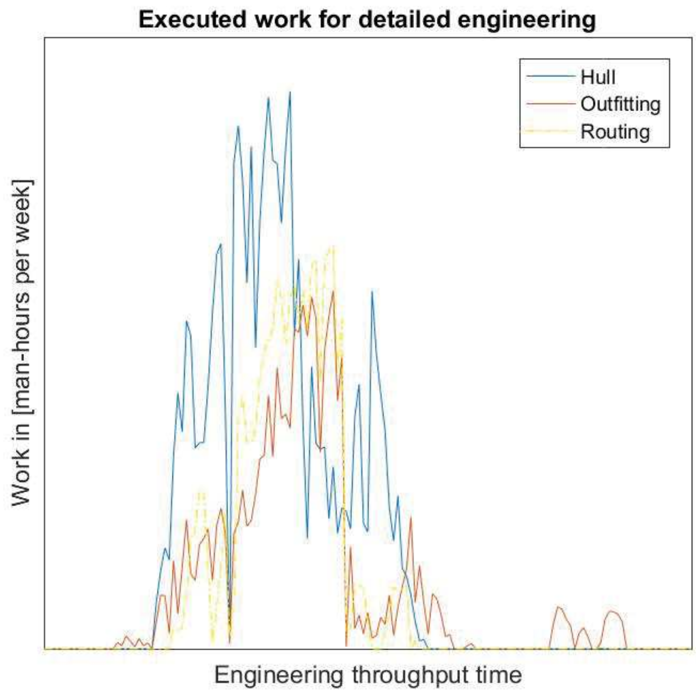


Figure 2.6: Example of executed work for all detailed engineering work packages

5. **Increase forecasting accuracy:** this ensures and validates if work can indeed be distributed with a fixed distribution
6. **Connecting the forecast output to Primavera:** this ensures that the engineering capacity schedule always applies the most up to date project schedules

This research is executed under two assumptions: 1. That a strong parametric relation exists between certain product parameters, like size and complexity of the ship and the process behavior and that the product dictates what kind of engineering activities are necessary and; 2. problems are solved in the same manner across projects.

The following matters are explicitly kept out of scope:

1. Lead engineering is neglected from this research
2. Engineering throughput time, start and finish of basic engineering and start and finish of detailed engineering are a given for the engineering work schedule

2.5. Research questions

The extent of the subject matter is solved by answering the following research questions with respect to the research scope; with the main question being:

> *How can IHC improve the work schedule forecast for basic- and detailed engineering work packages in the proposal phase?*

and sub-questions begin:

1. *What historic project man-hour schedule data is available at IHC, and how can these be applied for the purpose of this research?*
2. *What project characteristics are available in the* 80/80 *phase that quantify size and complexity of a project?*

3. *Which method is most suitable to quantify the relationship between historic project schedules and project characteristics?*

4. *What is the accuracy of the newly quantified relationship?*

2.6. Research approach

To give this report a structure, the content of the chapters are closely linked to the chronological order of the research questions. Each of the following sections provides a brief introduction into the chapter content. It is important to realize that this research develops a new method for IHC that establishes a proposal engineering work schedule forecast. The necessary input for this new method is however acquired by applying other methods that generate the input for the new proposal engineering work schedule forecast method. This report aims to clearly distinct between the methods that are applied to generate input and the general method that is developed for schedule forecasting. Even though, the reader must be cautious in interpreting the word 'method'.

Application of available data

As mentioned in the research objective, there is currently fuzziness in application of available man-hour data. This chapter investigates which data is available and usable for quantification of work per individual work packages. The availability and representation of data determines what is possible for the new forecasting method and what is not. The answer to the applicability of data and the possibilities for the new method is obtained by investigating the representation and application of the data. Knowledge on both matters is combined to determine how to manipulate and apply the available data to comply with Research objective 1 and 6.

Project quantification

It is the aim in this study to quantify relations between project characteristics and historical man-hour data. The result of this chapter is a set of project characteristics that are known in the 80/80 phase and potentially quantifies work that is brought forth from the project. At this point it is not yet known what the impact of characteristic is on work. Investigation and determination of project characteristics is done by investigating and quantifying engineering complexity. The term complexity is applied to appoint elements that contribute to an increase or decrease of engineering work. A list of project characteristics is acquired by: 1. consulting literature on elements that affect an engineering complexity; 2. consulting scientific research on project characteristics quantification methods and; 3. investigating available project characteristics that are available at IHC in the proposal phase that potentially quantify elements from the first step. The results that follow from this chapter are applied in succeeding chapters to select methods that is able to quantify the contribution of each project characteristic to the man-hour data. This chapter will comply with Research objective 2

Engineering work scheduling method development

This chapter investigates which method is most suitable to quantify relations between project characteristics and the man-hour data. The investigated methods are only used to obtain input for new forecasting method. The most suitable quantification methods are obtained from similar researches. The obtained quantification methods are tested for applicability by investigating compliance with Research objectives 1, 2, 3, 4, and 6. The most suitable method is executed in succeeding chapters to obtain input for the new engineering work schedule forecast method.

Obtain the input for the new engineering work schedule forecasting method

The defined method is executed to obtain all input for the new engineering work schedule forecasting method. The obtained results are tested for compliance with Research objective 4.

Conclusion and recommendations

Due to potential limitations in man-hour data, project characteristics and methods applied to obtain the input for the new method, conclusions and recommendations are necessary. Conclusions are made by answering the main- and sub-questions. General observations of remarkable results are also listed here. Lastly, a list is composed with elements that require further investigation for development and improvement of the proposed engineering work schedule forecast method.

3

Application of available data

The following chapter aims to answer Sub-question 1: *What historic project schedule data is available at IHC, and how can these be applied for the purpose of this research?* Answering this sub-question is done by investigating available data, necessary input to Primavera and the application of the usable data for establishing a proposal work schedule in Primavera. There is currently no documented knowledge available on historic work data and data applicability for an proposal engineering work schedule. This means that information can only be found with expertise from IHC employees and personal judgment. Knowledge on input into Primavera is obtained from the IHC schedulers. The answer to this sub-question are: 1. a list of historic man-hour data that is applied to compute input for the new work scheduling method and; 2. an approach to investigate methods that compose the input for the new work scheduling method.

This chapter is divided into four sections. Section 3.1 provides a summary of available man-hour schedule databases and investigates usability. Section 3.2 investigates and explains required input to establish an initial engineering capacity schedule in Primavera. Section 3.3 explains how the data is applied in the remainder of this research. Section 3.4 provides a summary of this chapter by answering Sub-question 1 and the contribution of this chapter to answering the main question.

3.1. Available data

Based on a search for available engineering work data, two databases containing a total of four different data structures was found. The data structures are numbered from 1 to 4 for ease of addressing and will be referred to as 'Data type' followed by the number for the remainder of this report. Data type 1 and 2 are currently applied by engineers to establish a forecast based on personal knowledge (as mentioned in Sub-section 2.2.2) and is therefore explicitly added. Data types 1 till 4 either represents: 1. *budget work* or *spent work*; 2. they are classified per *department, classification code* or *classification code & drawing number* and; 3. they provide data for the *total project* or provide data for the *total project on a weekly basis.* Any data that is structured by product group in Data type 3 and 4 is neglected from this research because lead engineering work is not divisible from the data. A detailed explanation of each database is provided in Appendix C. An overview of which data structure shows the data in which manner is shown in Table 3.1. A brief explanation of each terminology is provided below:

- **Budget work:** Represents an amount of work (in man-hours) which was determined preliminary to project execution. This is an amount of work which is expected to be spent
- **Spent work:** Represents an amount of work (in man-hours) which was actually spent by engineers. This data is composed from submitted data by engineers in work monitoring software
- **Project work:** Represents an amount of work (in man-hours) on a project
- **Project work per week:** Represents and amount of work (in man-hours) on a project on a weekly basis
- **Department:** Represents an engineering department

Table 3.1: Classification of available data types

	Department	Classification code	Classification code & drawing number
Budget work for total project	1		
Spent work for total project	2	3	
Budget work per week for a project			
Spent work per week for a project			4

- **Classification code:** Is a four digit code that represents a specific system, set of components or otherwise related tasks. An example is number 0334 which represents the arrangement of the accommodation
- **Classification code & drawing number**: Is a combination of the four digit classification code and a drawing number. The classification code and drawing number are divided by a dot. An example of this structure is number 0334.338 that represents the arrangement of accommodation on the main deck.

From each data type, a limited amount of historical project data is available. Without an investigation of project scope, 31 historical projects are available as Data type 1, 31 historical projects are available in Data type 2, 46 projects are available in Data type 3 and 13 projects are available in Data type 4. After further investigation of the projects, not all projects in the databases lie within the project scope. Some projects are: *technical project*, where a project is partially executed, *copy project*, where the project is based on an earlier established design or *not a custom built trailing suction hopper*, IHC also builds cutter dredgers or offshore vessels which are stored in the database. Within project scope, 18 projects are available as Data type 1, 18 as Data type 2, 19 as Data type 3 and 5 as Data type 4.

Based on discussions with IHC capacity forecasters, planners and engineers about the relation between engineering departments and engineering work packages, it became clear that department classified data is not usable for this research. According to the new project structure, some engineering departments execute multiple work packages. In summary, a forecast for a department is currently required in more detail. There is currently no knowledge available on the distribution of work from a department structure to work per work package in a top-down approach. An example of such a department is the Maritime engineering department. The Maritime engineering department executes the work packages Construction plans, Construction calculations, Hull and Outfitting. Furthermore, the data classified per department, type 1 and 2, contain lead engineering man-hours which are excluded from this research. Lastly, tasks between engineering departments have been exchanged. For example, The HVAC + FiFi work packages previously only was HVAC. It is not known how to quantify the changes from the department structured data. Based on these findings, Data type 1 and 2 are discarded for further use. Data type 3 and 4, containing work per classification code and work per classification code & drawing number can be made applicable to quantify work per work package with a bottom-up approach. A classification code, representing a set of ship systems or components, is generally produced by a single engineering resource. Since an engineering resource is linked to an engineering work package, classification codes are allocated to a work package. Successively the work package quantifies the amount necessary work and the resource quantifies the amount of available work. Application of Data type 3 and 4 requires an classification code-work package allocation list. Application of this allocation list makes it possible to increase available Data type 3 from 19 to 22 projects by neglecting the drawing number.

By only applying spent man-hour data from Data type 3 and 4 to establish a forecast, problems originating from the Student syndrome [1] and Parkinson's law [2] are present. It is a common knowledge within project management that a great amount of projects require at least the amount of time that is given which characterizes project management practice (Williams, [32]). This symptom requires feedback between a forecast from the developed method and the work that is brought forth. Further research is required into methods to establish a decent forecast with the purpose of ending up on the earlier defined work budget. Furthermore, by only applying Data type 3 and 4, some projects have less man-hours spent than was actually executed. This is the result from work outsourcing. All outsourced work has been added by hand in Data type 3. All

[1] one will only start to apply themselves to an assignment at the last possible moment before its deadline
[2] work expands so as to fill the time available for its completion

outsourced work is not included in Data type 4. This is considered as a general consequence of engineering and is neglected. However, an attempt is undertaken later in this research to potentially quantify rework. If it is not possible to allocate an increase or decrease as a result of outsourced work, a forecast shall be set up while considering the data as a 'normal project'. This will affect the resulting models and the forecast that is obtained from it.

Data type 3 and 4 are made applicable by applying 13 work packages for the 13 engineering resources considered. For now, each work package has the same name as the corresponding engineering resource. Work per work package is determined by applying the bottom-up approach by allocating a classification code to a work package. For example: all classification codes between 1200 and 1900 which represent construction drawings are executed by hull engineers and is added to the Hull work package. The earlier mentioned 0334 which represents the arrangement of the accommodation is executed by Accommodation. This classification-number-to-resource allocation can however only be applied under the assumption that a single classification code is executed by a single engineering resource is true. This is verified by IHC engineers in interviews and through a document referred to as 'Standard drawing list 2019-03-05'. The only exception is classification code 323 which is executed by construction plans engineers and construction calculations engineers. Based on experience from engineers $33.\frac{1}{3}\%$ of work is executed by construction plans engineers and $66.\frac{2}{3}\%$ of effort is executed by construction calculations engineers [3]. When reflecting the mapping hypothesis on Database 3 and 4: 1. Database 3 is directly convertible with the bottom up-approach and; 2. Database 4 is convertible with the bottom-up approach when neglecting the drawing numbers.

The complete list of man-hour data per engineering work package that follows from this mapping is provided in Appendix G. An example of the result from the mapping of Data type 3 is showing work per work package, for three projects is shown in Table 3.2. An example of the mapping of Data type 4 showing work for a work packages, per week, is shown in Table 3.3. Application of the mapping shows however that no work is mapped to Maritime equipment engineering. After further research, all work for Maritime equipment is classified under Mechanical equipment and Outfitting. This is considered as a limitation of the applied bottom-up approach. Maritime equipment is also neglected from this research. All data from the total database and Data type 4 is merely to great of size to add in the appendix.

The available data from Data Type 4 does not quantify the start and finish of the engineering phases with respect to all shipbuilding phases. Also throughput time is not quantified. Based on the gained knowledge in Chapter 2 it is suspected that the start of an engineering phase (or work in general) is noticeable as a quick increase or decrease of work spending. Exact quantification is however suspected to be fuzzy. Data on the exact data on start, finish and throughput time is not considered in this research. It is therefore assumed that the start, finish and throughput time for a new project is a given.

3.2. Engineering work schedule in Primavera

IHC currently applies Primavera as project portofoliomanagement (PPM) software. Primavera is applied to plan, schedule and control the project portfolio and individual projects. It is not the goal of this research to provide a detailed explanation of Primavera, It is only of interest how to set up a schedule in Primavera.

A schedule is established in Primavera by defining and connecting activities. Each individual activity in a schedule requires the following input:

1. **Activity start relation:** that defines when the activity starts
2. **Activity finish relation:** that defines when the activity finishes
3. **Resource load:** that defines how an engineering resource spends its workload over the activity duration (the resource load input is shown in Figure 3.1.
4. **Resource ID:** that defines which resource executes the activity
5. **Activity ID:** that defines what work package is executed

[3] values have been changed in this public available thesis for confidentiality reasons

Table 3.2: Example of mapping of database 3 [4]

Engineering resource	Project 1	Project 2	Project 3
Accommodation	183	154	228
Hydromechanics	353	140	378
Construction plans	128	103	928
Construction calculations	225	201	1,500
Maritime equipment	0	0	0
HVAC + FiFi	163	72	192
Diagrams	199	172	629
Hydraulics	43	32	111
Mechanical layout	143	183	609
Mechanical systems	319	163	302
Hull	903	488	2,827
Routing	706	381	1,721
Outfitting	1,380	805	2,801
Mission equipment	361	223	881

Table 3.3: Example of mapping from database 4 [5]

Year	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016
Resource / Week number	37	38	39	40	41	42	43	44	45	46
Mechanical layout	1	3	9	14	10	14	19	15	15	15

6. **Man-hours:** that defines how many man-hours are spent over the activity duration
7. **Project ID:** that defines which project executes the activity

The detail of the schedule is dependent on the number of activities and relations added in a schedule. Considering the available data, each of the 13 individual work packages gets its own activity start relation, activity finish relation, resource load, resource ID, activity ID man-hours and project ID. The work packages are: Accommodation, Hydromechanics, Construction plans, Construction calculations, Maritime equipment, HVAC + FiFi, Diagrams, Hydraulics, Mechanical layout, Mechanical systems, Hull, Outfitting, Routing and Dredging components. The new engineering work schedule forecasting method must supply an activity start, activity finish, resource load, resource ID, activity ID and man-hours for each individual work package.

On the highest level, IHC currently establishes a master schedule that defines the start and finish of each

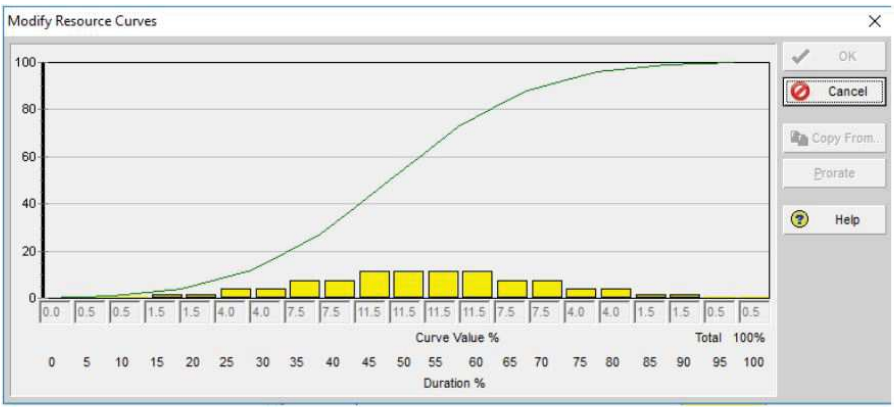


Figure 3.1: Resource load curve from Primavera

phase and sub-phase (as explained in Section 2.1) over the project execution. The scheduled activities that follow from this research are placed in the upcoming model. Relations shall be set-up between the start and finish of basic- and detailed engineering which are observable from Data type 4.

3.3. Application of available data

When reflecting necessary Primavera input on the representation of man-hour data, activity start relation, activity finish relation and resource loading for all work packages are only obtainable from Data type 4. Data is obtainable by comparing work spending of the work package with work spending in the associated engineering phase. This associated engineering phase is either basic- or detailed depending on the investigated work package. The lack of knowledge on the historic mile stones impedes establishment of recommendations for the master schedule itself. It is therefore assumed that the start and finish of basic and detailed engineering of the data is the same as in the master schedule. Furthermore, regression is a widely applied method to quantify relationships between a dependent variable and (a set of) independent variables. A regression approach between man-hours for a work package and project characteristics is executed on Data type 3 to establish work quantification models. Because there are many elements that affect the engineering work, this method must be able to compute if the characteristics actually contributed to the man-hours.

Based on the gained knowledge on available data an input to Primavera, the development of the method and the necessary input for the models shall be divided into two parts:

> Firstly work quantification models shall be applied to calculate work for a new project. For implementation purposes, the quantification models are made applicable by feeding them into MS Excel application. MS Excel is recommended to apply because there are skills and knowledge available within IHC. By importing project characteristics of a project into MS Excel, work for a new project, per work package is calculated. The results are then exportable to Primavera by applying an in-house available piece of software called Pexellent. This method of importing man-hours with Pexellent on a work schedule is generally applied within IHC.
>
> Successively, a template in Primavera shall be applied to distribute the work over a determined project duration from the Master schedule.

When reflecting on the quantity of available data, work quantification is based on 22 historic projects. This quantity makes a regression analysis possible. Based on the representation of usable data it is not possible to calculate if the new model is more accurate in calculating total project man-hours. It is possible to calculate the increase of accuracy of the newly established work distribution with respect to the fixed distribution in a confirmatory analysis. Work timing is based on 5 projects. The data availability complicates appointing of certain scheduling aspects to project characteristics. Furthermore it is suspected that the exact start, and finish is not exact quantifiable compared to the start and finish of basic- and detailed engineering. Milestones on basic engineering start, basic engineering finish, detailed engineering start, detailed engineering finish, start of production, launch of the ship, etc. from the historic applied master schedules are not considered in this research. Knowledge from engineers is combined with results from data to compose a final work timing model for each individual work package.

This division of input for the final model requires adjustment of the the research sub-questions. Sub-question 3 is divided into Sub-question 3.A: *Which regression method is most suitable to establish work quantification models?* and Sub-question 3.B: *Which method is most suitable to establish work timing models?*. Sub-question 4 is divided into Sub-question 4.A: *What is the accuracy of the established work quantification models that follow from the regression analysis?* and sub-question 4.B: *What are the similarities between the company knowledge and results from available data?*.

3.4. Summary

This chapter answers Sub-question 1 by identifying two data types that are applicable for the purpose of this research. The databases are referred to as Data type 3 and Data type 4. Both data types are made applicable by applying a bottom-up approach that allocates classification codes to a work package. By applying this bottom-up approach, 22 historic projects become available that quantify work (in man-hours) per work package and 5 historic projects become available that quantify work timing (in man-hours per week). The bottom-up approach is only applicable under the assumption that a classification code is classifiable under a single work package. Based on an analysis of available data the method input is composed by applying:

- Data type 3 in a regression approach to establish work quantification models that forecast man-hours per work package for new projects
- Data type 4 in a curve fitting approach to determine activity start, finish and resource load for each work package

This division is necessary to comply with Research Objective 1 ,4 and 6 . This division brings forth that Research question 3 and 4 can not be answered directly. Both research questions must be divided into a work quantification and work timing part.

Application of Data type 3 and 4 has its implications. The data is composed from spent data which means that effects from the student's syndrome and Parkinson's law are present. These symptoms require feedback between the forecast from this method and the work that is brought forth. Furthermore, allocation of classification codes is not does not allocate work to Maritime equipment. Further research is required to incorporate Maritime equipment into the forecasting method. The historically applied milestones of the master schedule are not taken into account to determine work timing. This limits recommendations for the current applied master schedule.

This chapter contributes to answering the main research question by supplying data to establish the input for the new engineering work schedule forecasting method. It is however necessary to divide further analysis into work quantification and work timing due to the availability of data and required input to Primavera. The application of the two databases complicates answering of the sub-questions by splitting the schedule into quantification and timing.

4

Project quantification

This chapter aims to answer Sub-question 2: *What project characteristics are available in the* 80/80 *phase that quantify size and complexity of a project?* The result of this chapter is a set of project characteristics that are known in the 80/80 phase and potentially quantify work that is brought forth from the project. This is done by investigating the matter around project complexity. The term complexity is applied to appoint elements that contribute to an increase or decrease of engineering work. This does also include size. A list of project characteristics is acquired by: 1. consulting literature on elements that affect an engineering project; 2. consulting literature on characteristic quantification methods and; 3. investigating available project characteristics at IHC in the 80/80 phase that potentially quantify elements from the first step in combination with the work scope. The list of characteristics that follows from this chapter are applied in Chapter 5 to investigate methods that forecasts work based on the project characteristics and data type 3 from Chapter 3.

The following chapter is divided into three sections. Section 4.1 investigates literature om complexity in engineering. This investigation results in a list of elements that are considered as contributing to complexity for IHC. Section 4.2 investigates different complexity quantification methods that were applied in similar researches. Section 4.3 investigates project characteristics that are available at IHC in the proposal phase, that apply a method from Section 4.2 and represent elements from Section 4.1. Section 4.4 provides a summary of this chapter by answering Sub-question 2 and the contribution of this chapter to answering the main question.

4.1. Consultation of literature

Investigating of complexity is done by consulting the complexity framework from Bosch-Rekveldt, ([5]). The general purpose of a complexity framework is to contribute to complexity assessment of engineering projects (Bosch-Rekveldt, [5]). It is assumed that an increase of complexity from any complexity element in the framework results in more spent work. The impact of complexity on work quantity remains at this point unknown. The complexity framework is composed by Bosch-Rekveldt from surveys with engineering managers and building upon empirical work. The complexity framework is split-up into three types based on their nature. This is organizational complexity, technological complexity and environmental complexity (Bosch-Rekveldt, [5]). The three types of complexity are assessed after the root-causes of complexity are addressed.

In summary, organizational, technological and environmental complexity is dependent on two aspects (Baccarini, [1]):

- **Differentiation:** The number of elements involved (*eg.* the number of frames in a hull construction)
- **Interdependence:** The way these elements are related (*eg.* the way the frames are connected to one another)

Differentiation and interdependence is present in different layers in organizational technological and environment (Harper, [13]). The layers are in:

- **Horizontal direction:** on a single hierarchic level (*eg.* connection of a frame to another frame)

- **Vertical direction:** on multiple hierarchic levels (*eg.* connection of frames to support the equipment)

As a result of differentiation or interdependence in horizontal or vertical direction, elements affect one another (Williams, [32]) in different relationships. The relationships are classified as:

- **Sequential relationship:** a change in one element affects the other element (*eg.* a change in rerouting a pipe requires replacement of a bracket)
- **Feedback relationship:** if alterations are made to an element, this has impact on the element itself, requiring further adjustments (*eg.* if a flange is changed, this may also require changes in the necessary connection weld on the drawing)
- **Pooled relationship:** each element gives a discrete contribution to the project, the contribution of several elements together influence another element. (*eg.* addition of a crane requires strengthening of the construction)
- **Reciprocal relationship:** a change in one element requires rework from other elements. (*eg.* a mistake in basic engineering that is uncovered during detailed engineering requires re-engineering of the basic design. This is also considered as rework)

Differentiation, interdependence, in horizontal or vertical direction that causes sequential, feedback, pooled or reciprocal relations are assumed to affect the engineering process in a shipbuilding project. These effects are expected to be present on complexity elements in the complexity framework. It is however possible that multiple elements in the complexity framework also affect one another. The following complexity elements are considered as affecting the engineering process of IHC. The list of composed from gained knowledge from IHC engineers:

Organizational complexity:

Size of the project team: The number of people that are involved in the engineering of a shipbuilding project.

Resource and skills availability: The right people are not always available to execute the right tasks. This may cause delays if the work is rescheduled or rework if the work is not executed by the right people.

Experience with parties involved: An increase in experience (potentially) with a party provides knowledge on the right communication to obtain the right output.

Interfaces between different disciplines: Different engineering specializations apply different specialized software. It is however not always possible to exchange all information due to software limitations. This may lead to more work or rework due to the application of outdated data

Contract type: The contract may not limit an amount of adjustments for a client. Adjustments requires rework.

Number of different nationalities: A different nationality potentially requires a different management style

Number of different languages: A different nationality potentially causes a boundary in languages where information transmission is impede.

Technological complexity:

Goal alignment: The contribution of multiple parties may cause mis-alignment of goals. For example: while one party its goal is to establish a design as quickly as possible, another party has the goal of spending as little money as possible on the design. This can be present on the highest level but also on drawing levels on for example disagreement of the translation of project functionality into equipment.

Clarity of goals: This is for example experienced with the client in the technical specification. The client may have a completely different view and interpretation of the technical specification than the shipyard. This fuzziness in goal clarity causes discussion and therefore discussion which leads to rework.

Scope largeness: Different clients require different extent of the subject matter. It is experienced that some clients wish very detailed documentation of all systems and components whilst others do not. Multiple engineers clarified that much time is spent on clients which require a larger scope

Uncertainty in scope: With some clients it is not known how detailed the documentation must be. This is also experienced with class. Uncertainty may cause rework because there is under-delivered. A change of requirements from the initial design may be encountered during project execution. This change of requirement trickles down to rework in other resources due to interdependency

Quality requirements: After drawings, diagrams and documents have been established, class needs to check for faults. This process of execution and checking may take time and may require rework

Number of tasks: Since every project is considered a unique project, new tasks require execution. To some extent the shipbuilding is considered a repetitive process. Based on interviews with engineers, the size of the vessel is expected to influence engineering capacity. Different sizes ...

Variety of tasks: This is the same matter as the number of tasks.

Dependency between tasks: Dependency between tasks is considered a great contributor to the amount of engineering work. As mentioned in Chapter 2, engineering is an iterative purpose. Engineering require each others information before they can continue. that dependency between tasks is a great contributor to engineering effort. It may occur that not all information is present due to this dependency. Assumptions must be made so that other tasks may continue. Assumptions may be wrong which requires rework

Interrelations between technical processes: Engineers require each others information to continue

Conflicting norms and standards: Whilst engineers wish to design something a specific way, this may be impede by other norms and standards from for example the client or class

Newness of technology: is a great contributor to engineering work because new technology must first be investigated before it can be implemented. Even though the requirements for new technology may be clear, interrelations and the effects on effort consumption is still unknown.

Experience with technology: When two or more ships are built from the same design, it is experienced that more engineering time is spent to not encounter problems more than two times.

Environmental complexity:

Variety of stakeholdes' perspective: Some clients are experienced to pursuit close control on the project by for example delivering own people to contribute to project control or requesting rework after drawings and documents have been submitted. Other clients are however easiliy pleased and do not have any remarks during project execution

Dependencies on other stakeholders: Alike the size of the project team, more stakeholders increase the number of elements and interrelations between stakeholders. This increases the complexity of other elements like for example experiences, norms and standards, interfaces and clarity of goals.

Internal strategic pressure: In some cases, a project is squeezed between two projects which increased deadline pressure. This high pressure made it possible to execute projects within the allocated time.

An aspect that is missing in this list is the experience of the project manager. Based on interviews with IHC engineers, it was experienced that the impact of the project managers and its relation to the project team and main client plays a big role in the success of a project.

4.2. Expressing complexity

Preliminary research (Bashir [2], Coenen [7], Gregory [10], Griffin [11], Huijgens [17], Kannapan [20], Norden [26], Zoutewelle [34]) attempted to quantify the relationship between work, costs or complexity with project and vessel characteristics. The researches either applied or proposed quantified project characteristics in an attempt to forecast work. None of the researches were able to quantify each element in the complexity framework and assumed that specific vessel or project characteristics represented specific complexity elements. In

Table 4.1: Summary of preliminary research on the application of project characteristics a forecast of project work or costs

Representation of complexity as:	Applied characteristics	Proposed characteristics
Principal dimensions	Coenen [7] Gregory [10] Zoutewelle [34]	
Principal dimensions & Interdependency factors	Huijgens [17]	
interdependency and differentiation in technological and organizational complexity		Baccarini [1]
Number of functions of systems and subsystems		Bashir [4] Griffin [11] Kannapan [20]

summary the following methods were applied to quantify a project in an attempt to relate this to work, costs or complexity:

- **Principal dimensions:** is considered as an overall dimension or magnitude of how big something is. This may represent a dimension in for example [meters], [kW] or a number of components.
- **Interdependencies and differentiation:** is considered as the number of connections between systems and components to interact with one another
- **Number of functions of systems and subsystems:** is considered as the functionalities that are required for a system.

An overview of the applied or proposed complexity quantification methods is provided in Table 4.1.

4.3. Available project documentation in the 80/80 phase

The following section investigates available project documentation and associated project characteristics that can potentially be applied to relate to man-hours. This is done by first investigating which documents are available in the 80/80 phase. Successively, the implementation possibilities are analyzed to link the available knowledge to a complexity quantification method.

This section is divided into two sub-sections. Sub-section 4.3.1 investigates the available documentation at IHC in the 80/80 phase. The result is a number of documents that are available and applicable. Sub-section 4.3.2 investigates applicable documentation to obtain project characteristics that potentially increase or decrease work.

4.3.1. Investigation of available documentation

Based on a document referred to as the 'Project deliverable flow' the following documents are considered as available in the 80/80 phase:

- **Technical specification:** A document containing all technical requirements of the project
- **General arrangement:** A general lay-out of the ship showing the location of rooms, equipment and large components

Based on interviews with IHC engineers, the following documents are considered as preliminary in the 80/80 phase:

- **Preliminary weight calculation:** a forecast of the construction weight
- **Preliminary component list:** a list of all necessary components
- **Preliminary cost calculation:** a forecast of the total project cost

Table 4.2: Principal dimensions from the general arrangement

Characteristic	Abbreviation	Unit
Length perpendicular	L_{pp}	**[m]**
Breadth	B	**[m]**
Depth	D	**[m]**
Loading volume	Vol	**[m^3]**
Complement	$Comp$	**[pers.]**

Table 4.3: Characteristics that quantify available space

Characteristic	Formula	Unit
Waterline area	$L_{pp} \cdot B$	[$\mathbf{m^2}$]
Longitudinal area	$L_{pp} \cdot D$	[$\mathbf{m^2}$]
Transversal area	$B \cdot D$	[$\mathbf{m^2}$]
Ship size	$L_{pp} \cdot B \cdot D$	[$\mathbf{m^3}$]
Ship size	$\left(L_{pp} \cdot B \cdot D\right)^{\frac{2}{3}}$	[$\mathbf{m^2}$]
Total deck area	$L_{pp} \cdot B \cdot No._{decks}$	[$\mathbf{m^2}$]

In pursuit of obtaining stable project characteristics (Coenen [7]), all projects from the preliminary documents list are discarded. It is suspected that the forecasts in the 80/80 phase deviate from the final resulting product. This is based on knowledge from the IHC engineers and is not backed up by a quantified study. More research is required in potential implementation and application of more preliminary documents.

4.3.2. Selecting of project characteristics

Project characteristics are chosen from the technical specification (TS) and general arrangement (GA). The technical specification contains all functional requirements of the to-be designed ship. The general arrangement shows the locations of large components in a general layout of the to-be designed ship. The TS and GA only quantify technical aspects of the ship. Currently no quantified documentation is available on historic, current of future organizational and environmental complexity elements. It is however possible to quantify the elements based on gut feeling. This shall results in biased project characteristics and is considered as no stable project characteristic. This limitation was tested by quantifying influence of the client for all projects. The addition of the characteristic resulted in inexplicable results from the analysis that is executed in Chapter 6. This limitation of organizational and environmental project characteristics results in a necessary assumption that organizational and environmental complexity is the same for each applied historical project. Furthermore, information within the TS is investigated on required accuracy level. Many of the project specifications have a very high level of detail. For example, is is suspected that, if the inside of the diameter of trailing suction pipe is 1400mm or each desk in a hut, do not largely affect engineering work considered to the number of elements and interrelations involved. As literature on the effect of project characteristics on engineering work is limited, knowledge is gained from the current engineering work forecasting applications and experience from IHC engineers.

As a basis, the applied project characteristics in current man-hour forecasting applications (See Appendix A) are bundled. These characteristics are: length perpendicular L_{pp}, breadth B, depth D, loading volume Vol, number of crew $Comp$. The characteristics, also generally referred to as principal dimensions are added in Table 4.4. Furthermore, combinations of the characteristics that quantify size as: $L_{pp}{\cdot}B{\cdot}D$, $L_{pp}{\cdot}B{\cdot}D^{\frac{2}{3}}$ and $B{\cdot}D$ from the forecasting applications are also added. From personal judgment also $L{\cdot}D$, $L{\cdot}B$ and $L_{pp}{\cdot}B{\cdot}No._{decks}$ are added. The characteristics are summarized in Table 4.3. By adding the mentioned project characteristics, number of tasks and dependency between tasks can be quantified. Based on the work from Huijgens ([17]) specifications of equipment are also added. From the current forecasting application, power of the main engine P is added.

According to IHC engineers, more project characteristics are currently experienced as causing an increase in complexity. The project characteristics are characterized as vessel functionalities and available space. The established list of vessel functionalities, mentioned by IHC engineers, are summarized in Table 4.5. It is as-

Table 4.4: Principal dimensions from the general arrangement

Characteristic	Abbreviation	Unit
Total power of propulsion engines	P	**[kW]**

Table 4.5: functional vessel characteristics from general arrangement

Characteristic	Options
Number of decks	2, 3, 4, 5, 6
Location of rooms	Accommodation Fore Pump room Aft Engine room Aft
	Accommodation Fore Pump room Fore Engine room Aft
	Accommodation Aft Pump room Fore Engine room Aft
Dredge pump propulsion	Connected to main engine Driven by electric engine Driven by diesel engine
Crankshaft connected to pump	Yes, No
Drive of jetwater	Diesel, Electric
Unusual systems	No Degassing system Gravel Oil recovery Barge unloading
Type of fuel	MDO, HFO, MDO & HFO
Type of drive train	Type 1, Type 2, Type 3, Type 4
Type of propulsion	Fixed pitch, controllable pitch
Number of suction pipes	1,2
Automated engine room	Yes, No
Discharge through suction pipes	Yes, No
Bulbous bow	Yes, No
Bow connection	Yes, No
Type of deck crane	Traveling, Fixed

sumed that the vessel functionalities affect the scope largeness, number of tasks, variety of tasks and dependency of tasks and interrelations between technical processes. There is however no detailed literature or data allowing thorough analysis of the aspects mentioned. This emphasizes the application of a quantification method that establishes models that actually show a contribution to man-hours.

Measures of vessel size are only obtainable from the earlier mentioned characteristics. Based on personal personal assessment the length/breadth ratio, length/depth ratio, breadth/depth ratio, Froude number, Speed-length ratio and Available volume are added. The characteristics are assumed to increase the dependency between tasks. The characteristics are summarized in Table 4.6.

Lastly, IHC engineers consistently mentioned that a basis for multiple ships and the stopping and restarting of a project also resulted in higher complexity. Therefore, based on historic knowledge, information was gathered on the matter. Also outsourcing of engineering is added here. The characteristics are summarized in Table 4.7.

Table 4.6: Characteristics that quantify available space

Characteristic	Formula	Unit
Length/breadth ratio	$\frac{L_{pp}}{B}$	$[-]$
Length/depth ratio	$\frac{L_{pp}}{D}$	$[-]$
Breadth/depth ratio	$\frac{B}{D}$	$[-]$
Froude number	$\frac{v_{trial}}{\sqrt{9.81 \cdot L_{pp}}}$	$[-]$
Speed-length ratio	$\frac{v_{trial}}{\sqrt{L_{pp}}}$	$[-]$
Available volume	$L_{pp} \cdot B \cdot D - Vol$	[**m^3**]
Trial speed	v_{trial}	**[knots]**

Table 4.7: Requirements from interviews with engineers

Characteristic	Options
Basis for series ship	Yes, No
Project stopped and restarted	Yes, No
Outsourced engineering	Yes, No

4.4. Summary

This chapter answers Sub-question 3 by establishing a list of 37 project characteristics that, are applied in current work forecasting methods or are experienced to affect differentiation and interdependency of engineering work for a custom built trailing suction hoppers at Royal IHC. Project characteristics are characterized as vessel characteristics, vessel functionalities, equipment size, vesel dimension ratios and project characteristics. All project characteristics are selected under the assumption that organizational and environmental complexity is the same for all historic projects.

This chapter contributed to answering the main question by identifying 38 project characteristics that affect project complexity. By quantifying complexity of a project, it is assumed that man-hours can be forecasted. The project characteristics from this chapter are applied in the following chapter to identify which project characteristics drive man-hours to successively quantify the relation between project characteristics and man-hours.

5
Engineering work scheduling method development

This chapter aims to answer sub-question 3: *Which method is most suitable to quantify the relationship between historic project schedules and project characteristics?* However, this sub-question is however slightly changed with the gained knowledge from Chapter 3. This chapter answers sub-question 3.A: *Which regression method is most suitable to compose work quantification models?* and sub-question 3.B: *Which method is most suitable to establish work timing models?* The answer to the sub-questions is established by investigating scientific literature on methods that study relations between: 1. historic man-hour data and project characteristics and; 2. Work timing. The most suitable method for this research is selected based on: 1. the objectives from Section 2.4; 2. available man-hour data from Chapter 3 and; 3. available project characteristics from Chapter 4. The results of this chapter are two methods that are applied in succeeding chapters to develop all input for the new proposal engineering work scheduling method.

This chapter is divided into three sections. Section 5.1 investigates and selects a most suitable method to establish work forecasting models. Section 5.2 investigates and selects a most suitable method to establish work timing models. Section 5.3 provides a summary of this chapter by answering Sub-question 3 and the contribution of this chapter to answering the main question.

5.1. Work quantification

Based on scientific literature, multiple different regression methods are applicable with the purpose of forecasting work or costs for new projects (Bashir [4], Coenen [7], Gregory [10], Huijgens [17], Hur [18], Jørgenson and Østvold [19], Liu [22], Norden [26], Taylor [29], Zoutewelle [34]). In summary, the methods are Simple linear regression, Simple non-linear regression, Multiple linear regression, Stepwise multiple linear regression, Neural networks and Classification and regression trees. An overview of the researches and corresponding applied methods is shown in Table 5.1. It is not the purpose of this research to extensively explain each research method. A brief introduction into each method is provided in Appendix J.

Based on the research objective from Section 2.4 in combination with the available project characteristics from Chapter 4, a list of criteria is established for the most suitable method. If applicable, the criteria will refer to its corresponding objective. in Section 2.6:

1. **Update the forecasting models with new data in MS Excel:** The forecast models require constant updating when new data becomes available. The regression models must be able to process the data in an MS Excel based application. This criteria complies with Objective 1 and 2
2. **Shows underlying concepts:** The forecasting models (and the forecast that is brought forth) must show how the model is developed. Showing the underlying models ensures that no knowledge is lost
3. **Can process interval, nominal and ordinal variables:** Project characteristics from Chapter 3 are available as interval, nominal or ordinal variables. The regression analysis must be able to establish a forecasting model with the three types of data.

Table 5.1: Summary of applied regression methods that quantified work or costs from scientific literature

Type of method	Research
Simple linear regression	Gregory [10] Liu [22] Zoutewelle [34]
Simple non-linear regression	Bashir [4] Coenen [7] Huijgens [17] Norden [26]
Multiple linear regression	Hur [18] Liu [22]
Stepwise multiple linear regression	Jørgenson and Østvold [19] Taylor [29]
Neural networks	Liu [22]
Classification and regression trees	Hur [18]

4. **Establish a forecast with multiple characteristics:** It is assumed that multiple characteristics affect engineering work. The regression analysis must be able to establish a forecast with multiple characteristics

5. **Calculate the impact of a characteristic:** It is assumed that not all affects of a project characteristic are noticable in the man-hour data. The regression analysis must be able to calculate which characteristic (or combination of) is most suitable to forecast work

Each applied regression technique has its benefits and limitations with regards to the selection criteria. The compliance of each regression analysis with respect to the criteria is shown in Table 5.2. An explanation of regression model compliance is provided in Appendix J. The table was established from gained knowledge from the mentioned scientific literature in Table 5.1, theory of each method from Appendix J and personal judgment.

From all analyzed methods, Multiple Linear Regression (MLR) analysis and Stepwise Multiple Linear Regression (SMLR) analysis show to comply with most of the selection criteria. However, neither of the two methods comply with all criteria. A SMLR analysis differs from MLR with the capability of analyzing the impact of a characteristic from a larger set. SMLR is however not easily implementable in MS Excel. It is possible to combine the two methods to obtain required results. The SMLR analysis is applied to calculate dependent variables which show a significant [1] correlation with the dependent variable. The obtained models from the SMLR analysis are, besides the calculation of significance, the same as the MLR analysis which generates the possibility to update the regression models in MS Excel when new data becomes available. A conversion of regression models from the applied software is however required. This method may only be used with the assumption that the obtained dependent variables from the SMLR remain to have the highest correlation with the dependent variable when new data becomes available.

There is however a draw-back on applying a linear regression based method. Different researches (Bashir [4], Coenen [7], Huijgens [17], Norden [26]) suggest the presence of non-linear relationships. This research will only apply a linear analysis which may result in less accuracy than a non-linear relationship. It is however possible to compensate project characteristics from linear to non-linear or vice versa for compensation (Hair, [12].

A drawback of applying a SMLR analysis is the encountering of multicollinearity (Hair [12]. As multicollinearity increases, it complicates the interpretation of the variate because it is more difficult to ascertain the effect of any single variable, owing to their interrelationships. Multicollinearity is however present by applying the project characteristics of Chapter 4. It suspected that deviations from multicollinearity relations cause an increase or decrease of work.

[1] Of influence on 95% of the population

Table 5.2: Compliance of a regression analysis and selection criteria

Type of method	Process new data in MS Excel	How is forecast established	Interval, nominal, ordinal, ratio variables	Multiple characteristics	Calculating impact
Simple linear regression	x	x			
Simple non-linear regression	x	x			
Multiple linear regression	x	x	x	x	
Stepwise multiple linear regression		x	x	x	x
Neural networks	x		x	x	x
Classification and regression trees	x				

An intersection is marked with an 'x' if the method complies with the criteria

Table 5.3: Additional added project characteristics based on non-linear project characteristics

Formula	Unit
$\sqrt{L_{pp} \cdot B}$	[**m**]
$\sqrt{L_{pp} \cdot D}$	[**m**]
$\sqrt{B \cdot D}$	[**m**]
$\sqrt[3]{L_{pp} \cdot B \cdot D - Vol}$	[**m**]
$\sqrt[3]{L_{pp} \cdot B \cdot D}$	[**m**]
$\sqrt{L_{pp} \cdot B \cdot No._{decks}}$	[**m**]
$\sqrt[3]{Vol}$	[**m**]

The SMLR analysis only calculates linear relationships between work and project characteristics. However, not all project characteristics scale linearly when increasing. Hair ([12]) recommends to transform variables. The extent of transformation can however be considered as a whole study. For the purposes of time, only non-linear project characteristics were transformed to linear. The added linearized project characteristics are shown in Table 5.3.

5.2. Work timing

Multiple different work timing methods have been applied with the purpose of establishing work load curves (Bashir [4], Norden [26], Vanhoucke [30], Vanhoucke [31]). However, methods that are Gantt-chart based (Vanhoucke [30], Vanhoucke [31]) are not applicable to obtain resource load curves with Data type 4. Also the remaining methods (Bashir [4], [26]) are established for the purpose of estimating time.

Based on the availability of data and required input into Primavera it is chosen to establish normalized resource load histograms that follow the general trend of work. Start relations, finish relations and resource loading results are established with the help of knowledge from engineers and backing them up with the available data. The result is a combination of both. The output of this method is a table as shown in Table 5.4 and a start-finish relations with regards to the engineering throughput time.

Table 5.4: Resource load example

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Normalized	[%]	0	0.5	0.5	1.5	1.5	4.0	4.0	7.5	7.5	11.5	11.5	11.5	11.5	7.5	7.5	4.0	4.0	1.5	1.5	0.5	0.5

5.3. Summary

This chapter answers sub-section 3.A and 3.B by selecting: 1. a combination of stepwise multiple linear regression (SMLR) to obtain significant relationships between project characteristics and manhours, and multiple linear regression (MLR) to keep the work quantification models up to date once this research is executed and; 2. curve fitting (CF) with predetermined templates to establish a start relation, finish relation and resource loading histogram. SMLR and MLR is applied on Data type 3. CF is applied on Data type 4.

This chapter contributed to answering the main question by selecting a SMLR and MLR analysis to establish work quantification models and curve fitting to establish work timing models.

6 Work quantification

This chapter aims to answer sub-question 4.A: *What is the accuracy of the established work quantification models models that follow from the stepwise multiple linear regression analysis?* The answer to this sub-question is obtained by applying the stepwise multiple linear regression analysis (SMLR) which is selected as most suitable technique in Chapter 5. Shortly summarized, the SMLR analysis calculates correlation between individual project characteristics from the total set from Chapter 4 and available data from Chapter 3. The SMLR analysis ads project characteristic that show the highest correlation into a work quantification model. This process is repeated until the work quantification model fulfills specific SMLR analysis requirements. The result of this analysis is a work quantification model that applies project characteristics to quantify work for each individual work package considered.

This chapter is divided into three sections. Section 6.1 explains the applied method. Section 6.2 executes the explained method. Section 6.3 provides a summary of this chapter by answering the sub-question and the contribution of this chapter to answering the main question. An explanation of a work quantification models is provided in Appendix K.

6.1. Explanation of the research method

The applied research method is inspired from Hair [12] and Heij [15] who developed practical methods for solving econometric questions in for example finance, marketing and economics. The method is tailored to the specific needs of this research. This tailoring is necessary in the selection of correct input variables and execution of the SMLR analysis. The following method forms the basis for execution in Section 6.2. The method broken down into three steps:

- ***Step 1* - Select the correct input variables:** It is given fact (Coenen [7]) that engineering work shows large variations between projects which are similar in size and complexity. Only representative projects must be applied to establish work quantification models. Furthermore, project characteristics must be applied that actually affect the work package considered. A SMLR analysis is known to calculate statistical significant characters which are mathematically correct but are not always explicable with common sense. This emphasizes the selection of the right input to ensures that the right man-hour data and project characteristics are applied to establish the linear regression model for each individual work package. Documented information is however limited. Therefore, the main source of information is obtained with knowledge from IHC engineers. Further more, a few tests are executed to develop suitable method to obtain explicable results
- ***Step 2* - Execute the stepwise multiple linear regression analysis:** This step establishes the algorithm for the SMLR analysis, executes the SMLR analysis and obtains results.
- ***Step 3* - Assess the results:** Each work quantification model for an individual work package is assessed on its result. Assessing is done for individual regression models and all combined. The main goal is to calculate accuracy of the model to answer Sub-question 4.A.

Each step is individually explained in the following sub-sections. Sub-section 6.1.1 explains Step 1. Sub-section 6.1.2 explains Step 2. Sub-section 6.1.3 explains Step 3.

6.1.1. *Step 1* - Select the correct input variables

The SMLR analysis is based on correlations between the man-hour data and project characteristics. Any non-representative data point may cause a non-representative result. A SMLR analysis is known for being highly volatile (Hair, [12]). This step ensures that the right input variables are defined to execute the SMLR analysis and obtain representative work quantification models. The necessary input consists of project characteristics and man-hour data.

Step 1 is divided into two sub-steps to individually select the correct dependent and independent variables [1]:

- *Sub-step* 1.1 - *Investigate knowledge from IHC engineers to identify elements that contribute to work for an individual work package to discard non-representative project characteristics:* Not all project characteristics quantify work for a specific work package. This step investigates which project characteristics are known to actually affect the work scope for each individual work package. A selection of project characteristics is established for each individual work package to test in the SMLR analysis. A list of project characteristics is established for testing with each individual work package

- *Sub-step* 1.2 - *Discard outlier projects:* Not all projects in database 3 lie within project scope or are representative for the general population. Some projects may have experienced budget overrun, or any other problem regarding complexity. Non-representative projects require exclusion from the stepwise multiple linear regression analysis since they may create biased results (Hair [12]). Knowledge on the matter is obtained from IHC engineers and potentially specific mathematical techniques.

6.1.2. *Step 2* - Execute the stepwise multiple linear regression analysis

Step 2 executes the SMLR analysis for each individual work packages. Information on execution of the SMRL are obtained from Hair ([12]) and Heij ([15]). Results are obtained by splitting this step into three sub-steps:

- *Sub-step* 2.1 - *Combine all necessary data from Step 1:* The right dependent and independent variables are be combined with applicable man-hour data for execution of the SMLR analysis. The combination method is dependent on the software applied.

- *Sub-step* 2.2 - *Compose the analysis model:* This sub-step establishes the SMLR analysis algorithm that obtains the work quantification models for individual work packages. This step also concerns the tuning of the model. Based on Hair ([12]) and Heij ([15]) the analysis shall calculate the following results per individual work package: a work quantification model, plot of model fit, plot of residuals, R^2, P and σ for each individual work package to assess the overall model fit. All regression analysis characteristics are briefly explained below:

  Work quantification model: is the work quantification model that shows a linear combination of project characteristics that are most suitable to forecast work for future projects

  Model fit: is a scatter plot showing the forecast from the obtained work quantification model compared to the observations. This plot shows an adjusted scale for the whole model on the x-axis and work (in man-hours) on the y-axis. The 95% confidence interval is also added.

  Plot of residuals: shows how much differences there is between the forecast and the observations. The x-axis represents the forecast. The y-axis represents the difference between forecast and applied data point.

  $\mathbf{R^2}$: is a goodness-of-fit measure for linear regression models. The value of R^2 is between 0 and 100. The higher the value, the better the fit. Even though a higher R^2 is a better fit, low R^2 can be perfectly good models. The R^2 does not indicate whether or not a regression model is adequate. Low R^2 are however problematic when reasonably precise predictions are required

  $\mathbf{P-value}$: or also referred to as the 'probability value' or 'null hypothesis', calculates the evidence that a project characteristic actually affects engineering effort. For a decent model fit, a P-value below 0.05 is widely applied (Hair [12]). The P-value must be below 0.05 for each established regression model

[1] For an explanation on the definition of dependent and independent variables, pleas consult Appendix J

σ : or also referred to as 'variance', calculates the average of how far observed values lie from the average of predicted values. The lower the variance, the more accurate the fit

- *Sub-step* 2.3 - *Obtain results:* Execute the established SMLR analysis algorithm from Sub-step 2.2 and obtain results for each individual work package.

6.1.3. *Step 3* - Analyze the linear regression models

As mentioned earlier, SMLR analysis are known to be highly volatile. To ensure a usable work quantification model, Hair [12] recommends to investigate the project characteristics in the obtained models. Furthermore, calculation of accuracy is also required with the purpose of answering the Sub-question 4.A. This step is divided into two sub steps where:

- *Sub-step* 3.1 - *Validate each individual work quantification model:* This analysis investigates which work quantification models are calculated for an individual work package. Two types of analysis are executed on each individual model. There will be an analysis on:

  A. Project characteristics & relationship: Investigates: 1. if the project characteristics in a linear regression model are explicable with reason and; 2. the relationship between project characteristics in the same work quantification model can be explained with reason.

  B. Confirmatory analysis: Executes a multiple linear regression analysis where two projects are excluded from the data-set. This way, the two excluded projects can be forecasted as being a newly established forecasts. The accuracy of the forecast can be identified by comparing the spent work from the database and the predicted work. This analysis is however only possible on the distribution of work, not on total forecasted work.

- *Sub-step* 3.2 - *Assess the total set of linear regression models:* This analysis investigates how the work distribution changes for different projects. This sub-step will answer if a fixed distribution is actually applicable. This step is executed by taking the total forecasted work from the confirmatory analysis in Step 3.1.B and analyzing the application of the fixed distribution and the confirmatory distribution. R^2 and Mean squared error will determine is the new forecasting method is more accurate.

6.2. Execution of the research method

The following section explains how Step 1 till 3 from Section 6.1 are executed. The required information is obtained from Hair ([12]), Heij [15]), knowledge from engineers and personal judgment. This chapter applies the same structure as applied in the previous section.

6.2.1. *Step 1:* Select the correct input variables

The following section explains how steps 1.1 and 1.2 are executed to obtain the SMLR model input.

Sub-step 1.1: Investigate knowledge from engineers to identify elements that contribute to work for an individual work package

Based on interviews with engineers, a list is established from all vessel characteristics that affect work for a work package. Initially this list contained 'basis for series ship' and project started and restarted'. However during generation of results, inconsistencies and non explicable results were obtained. It was chosen to discard the two project characteristics for further research. The list that results from this analysis is provided in Appendix M. The obtained knowledge per individual work package is:

Accommodation: Accommodation engineering is dependent on the vessel size, number of crew, location of the accommodation on the ship, number of galleries and mess rooms, level of luxury of the cabins, if the ship is classified under cargo or passenger class, noise levels are IMO or comfort class. The earlier defined parameters do not contain any of the mentioned characteristics other number of vessel size, number of crew, location of accommodation on the ship.

Hydromechanics: The GA and TS do not contain specific measures for hydrodynamics with the exception of a class and operational area. Only characteristics that quantify project size and size ratios (with the exclusion of v_{trial} are tested in the SMLR analysis.

Construction plans: Work on construction plans is dependent on the size of the ship and all interfaces between the construction and equipment. Equipment is for example fixed or moving cranes, winches, bottom doors, supporting engines, generators and gantry cranes. Every interface requires its own strengthening of the construction. The GA and TS contain information on the type of systems to be mounted but no characteristics which represent for example the number of components to mount or number of interrelations between components. However, no characteristic is available that quantifies the number of interfaces. Only type of deck crane and crankshaft connection to pump room are suspected to quantify an increase in interrelations. Furthermore, characteristics associated with vessel size, bulbous bow, bow connection and vessel ratios are tested.

Construction calculation: Work on construction calculations is assumed to be similar to that from construction plans.

HVAC + FiFi: HVAC and FiFi work mainly lies in the addition of a filter (which requires a significant amount of interrelations) and the addition of LNG. LNG requires extra safety measures like for example the heating of fuel input in the main engines to give the LNG the most optimal injection temperature. Examples of work are the arrangement and placement of all ventilation ducting in for example the engine room, pump room, fan room and AC room. An great factor of work is dependent on the type of system. For example: is a HVAC system is mounted with a general filter of carbon filter, more engineering effort is spent. Also with LNG, the HVAC system is more complex due to the placement of extra complex heating and cooling systems for the LNG. This characteristic was obtained in a later stadium than the execution of this analysis and is not considered in the list of vessel characteristics.

Diagrams: The amount of work is dependent on the number of systems that are on board. Systems are for example the lubrication, pneumatics, fuel, steam, etc. An increase in work lies in the class which for example affects the redundancy of systems. Ship size and systems and size of equipment are expected to cause work for Diagrams.

Hydraulics: Hydraulics are optional for the dredge pump drives and jet-water pump drives. Complexity lies in the number of hydraulic systems that are necessary on board. The characteristic associated is the dredge pump propulsion and drives of miscellaneous systems like for example jetwater pumps

Mechanical layout: Engineering for mechanical layout consists of the arrangement of all pipelines for all systems through the ship. It is suspected that the ship size and the number of systems on board affect the number of pipe components necessary. However, no detailed information is available on the number of systems that need to be connected. Therefore vessel size, vessel ratios and systems that require to be connected are tested.

Mechanical systems: Work for mechanical systems is mainly executed by the layout of the propulsion train and number of links in the drive train. This has mainly to do with the aligning of all propulsion systems when the system is in operation. Vessel size, vessel ratios, and all matters that quantify a part of the main engines are tested for influence.

Hull: Hull continues the work from Construction plans and Construction calculations. It is expected that Hull is affected by the same project characteristics.

Outfitting: Outfitting establishes all arrangements of equipment and small nautical gear. The extensiveness of work is of such a magnitude that this is not covered with the vessel functionalities. Only project size is tested to affects the work for Outfitting.

Routing: Routing places all pipelines throughout the ship. Any information on the quantity and interrelations is not known. Only vessel characteristics related to vessel size and available space are tested. Furthermore the power of propulsion engines is tested as representative quantity for the number of systems.

Dredging components: Work for dredging components is affected by the size of the ship and the number of functionalities of for dredging. Furthermore engineers mentioned that standard or custom components also require a significant amount of work. Unfortunately the stanardness of components is not known. Engineering work for dredging components is dependent on the ship size, miscellaneous dredging systems and dredge pump drive.

The gained knowledge is composed into a list of characteristics that affect an individual work package. The list is added in Appendix M.

Sub-step 1.2: **Discard outlier projects**
As a first step, all projects in the data set that are characterized as either a technical project or copy of an earlier developed project are discarded from this research. Furthermore, based on interviews with engineers, little knowledge was obtained from the experience with a project. The only projects that were consistently mentioned for budget overrun were the projects $CO1282$ and $CO1283$. The projects were the first project built by IHC that were equipped with an LNG propulsion system. New technology in combination with a high demanding client caused caused an increase in man-hours. Because newness of technology is not considered in this research, $CO1282$ and $CO1283$ are discarded from this research. Furthermore, in an attempt to investigate potential contribution of influence of the client as defined characteristic, certain projects were excluded from the research. These projects were not included in the establishment of new models when the characteristic of influence of the client was discarded for further use. The project should be reentered for further investigation. An overview of the applied projects per work package is added in Appendix L

6.2.2. *Step 2:* Execute the stepwise multiple linear regression analysis

The following section explains how Steps 2.1, 2.2 and 2.3 are executed to obtain the required model input. Execution of the SMLR analysis is done by applying mathematical software called 'Matlab' [2]. Matlab is a powerful mathematical tool with an automated SMLR analysis function. Furthermore, Matlab was chosen based on personal skills. Application of the built-in function simplifies the process of establishing the right algorithm and assures correct implementation of the underlying mathematical concepts (if at least rightly applied).

Sub-step 2.1: **Combine all necessary data from Step 1**
Matlab requires the input data as a matrix that contains all project characteristics to be tested and the man-hours for an individual work package. Equation 6.1 shows the required composition of the matrix.

$$\begin{bmatrix} A & | & \overline{B} \end{bmatrix} \tag{6.1}$$

where:

A is a matrix containing all project characteristics

B is a vector containing all man-hours per project for the work package considered

Matrix A is composed in such a way that each column represents a different project characteristic and each row represents a different project. Vector B is composed in such a way that each row represents work from a different project. Each project in a row in vector B corresponds to the same row in Matrix A. When a project is not applied in an SMLR analysis, the corresponding row is removed from matrix A and B. When a project characteristic is not applied in an individual SMLR analysis, the corresponding column is removed from matrix A.

A more elaborate version of Matrix 6.1 is shown in Matrix 6.2

$$\begin{bmatrix} Y_{1,1} & Y_{1,2} & Y_{1,3} & \dots & Y_{1,n} & | & R_{1,l} \\ Y_{2,1} & Y_{2,2} & Y_{2,3} & \dots & Y_{2,n} & | & R_{2,l} \\ \vdots & \vdots & \vdots & \ddots & \vdots & | & \vdots \\ Y_{p,1} & Y_{p,2} & Y_{p,3} & \dots & Y_{p,n} & | & R_{p,l} \end{bmatrix} \tag{6.2}$$

where:

R represents a quantity of work for a project work package

Y represents a project characteristic

l represents a work package

p represents a project that is included in the input

[2] https://www.mathworks.com

Sub-step 2.2 **Execute the stepwise multiple linear regression analysis**
The SMLR analysis is executed with a the function *stepwiselm()* in Mathworks software. Please consult ([9]) for a detailed explanation on the algorithm and corresponding mathematics. This Mathworks software is referred to as 'Matlab' [3]. Matlab is a software package that is specifically designed for numerical computing and is widely applied by engineers, scientists and economists. Matlab was selected because personal skills. Any other mathematical software package like for example 'R'[4] and 'Python'[5] are also possible for similar analysis. The math behind the algorithm is the same for all software.

The *stepwiselm()* rejects a project characteristic into the a model based on a R^2, P, F and T value in a forward and backward manner. For this research a significance level of 0.05 is applied. This significance level is a generally accepted term over all industries (Hair, [12]) and defines that the characteristic must be calculated as 95% significant.

A great disadvantage of a stepwise multiple linear regression analysis is that the method continues with adding project characteristics until the significance level decreases 95%. This may result in application of too many project characteristics in a final regression model (Hair [12]). This is called 'overfitting' (Hair [12]). Overfitting may be solved by changing the significance level. However, there is no knowledge on the application of certain significance levels in the shipbuilding industry. Overfitting is prevented in this research by terminating the analysis if more than two independent variables are applied in the regression model. Two was chosen based on scientific literature. Scientific literature (Hair, [12]) specifically claims that a minimum ratio of observations to variables is 5 : 1, but the preferred ratio is 15 : 1 or 20 : 1, which should be increased when stepwise estimation is used. Currently 23 observations are present. Because it is a known fact that variance is high, an attempt is undertaken to potentially identify the impact of at least two characteristics. Furthermore, the because size is considered as the main driver of complexity/work, the first value to add to the work quantification model must be a interval value. If a functionality is the first, the functionality is discarded for further analysis for that specific engineering work package. This last requirement is added based on personal judgment and experience from multiple trial runs. IHC currently has knowledge on the application of simple linear regression and simple non-linear regression. This research pursuits to exceed the current boundaries. Furthermore no knowledge is available on the application of a SMLR analysis in the shipbuilding industry.

Sub-step 2.3 **- Obtain results**
The following work quantification models, model fits, plot of residuals, R^2, $P-value$ and σ are obtained for each individual work package considered.

[3]https://www.mathworks.com/products/matlab.html
[4]https://www.r-project.org/
[5]https://www.python.org/

Accommodation

- The SMLR analysis calculates that Equation 6.3 is the most suitable work quantification model to forecast work for the Accommodation work package [6]
- The three statistics to evaluate the model fit are shown in Table 6.1
- The model fit and its residuals versus fitted values are shown in Figure 6.1.

$$Work = 97 + 0.008 \cdot (L_{pp} \cdot B \cdot D - Vol) \tag{6.3}$$

Table 6.1: Regression analysis results for Accommodation

Regression characteristic	Result
R^2	0.705
P	$5.40e-07$
σ	79

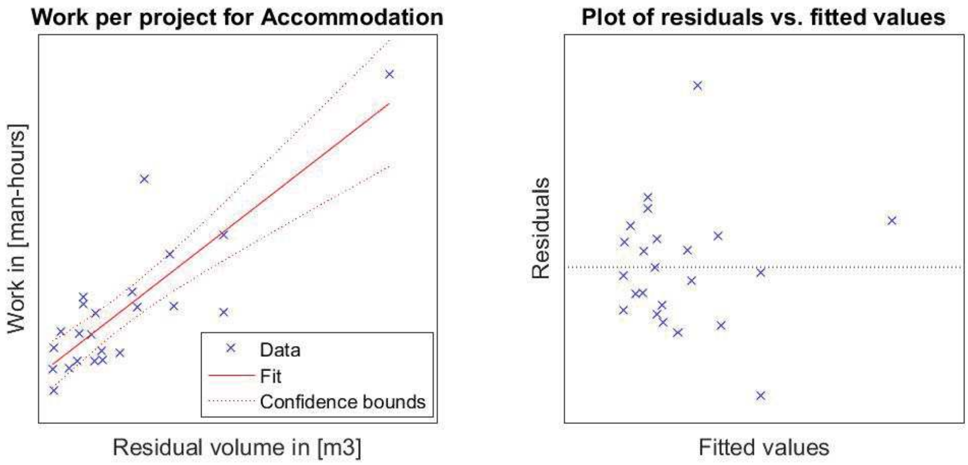


Figure 6.1: Result from the SMLR analysis for Accommodation

[6] values have been changed in this public available thesis for confidentiality reasons

Hydromechanics

- The SMLR analysis calculates that Equation 6.4 is the most suitable work quantification model to forecast work for the Hydromechanics work package [7]
- The three statistics to evaluate the model fit are shown in Table 6.2
- The model fit and its residuals versus fitted values is shown in Figure 6.2.

$$Work \quad = \quad 103 \quad + \quad 0.02 \cdot \left(L_{pp} \cdot B \cdot No._{decks}\right) \qquad (6.4)$$

Table 6.2: Regression analysis results for Hydromechanics

Regression characteristic	Result
R^2	0.718
P	$3.34e-07$
σ	78

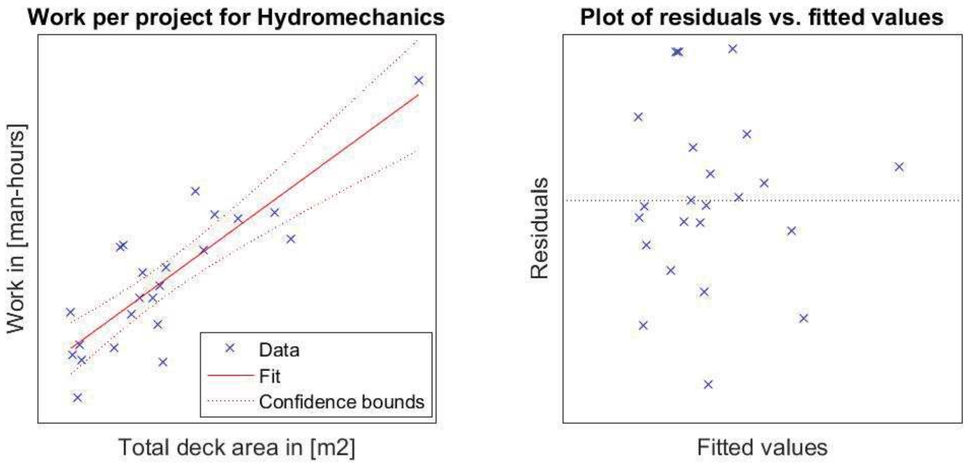


Figure 6.2: Result from the SMLR analysis for Hydromechanics

[7] values have been changed in this public available thesis for confidentiality reasons

Construction plans

- The SMLR analysis calculates that Equation 6.5 is the most suitable work quantification model to forecast work for the Construction plans work package [8]
- The three statistics to evaluate the model fit are shown in Table 6.3
- The model fit and its residuals versus fitted values is shown in Figure 6.3.

$$\begin{aligned} Work \quad = \quad -185 \quad + \quad 16 \cdot \sqrt[3]{(L_{pp} \cdot B \cdot D) - Vol} \\ [Traveling \quad deck \quad crane \quad : \quad - \quad 90] \end{aligned} \tag{6.5}$$

Table 6.3: Regression analysis results for Construction plans

Regression characteristic	Result
R^2	0.804
P	$9.6e-07$
σ	42

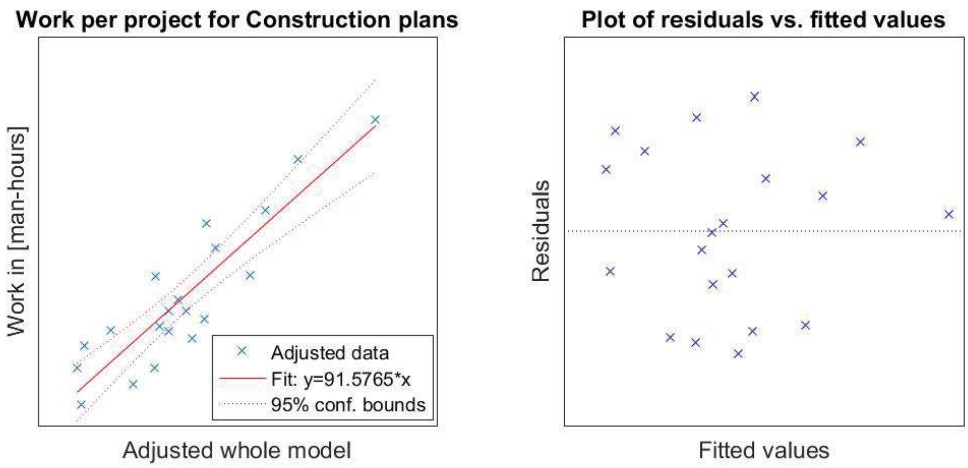


Figure 6.3: Result from the SMLR analysis for Structural plans

[8] values have been changed in this public available thesis for confidentiality reasons

Construction calculations

- The SMLR analysis calculates that Equation 6.6 is the most suitable work quantification model to forecast work for the Construction calculations work package [9]
- The three statistics to evaluate the model fit are shown in Table 6.4
- The model fit and its residuals versus fitted values is shown in Figure 6.4.

$$Work \quad = \quad 607 \quad + \quad 0.0075 \cdot L_{pp} \cdot B \cdot D \quad - \quad 105 \cdot \frac{L_{pp}}{B} \tag{6.6}$$

Table 6.4: Regression analysis results for Construction calculations

Regression characteristic	Result
R^2	0.907
P	$5.77e-09$
σ	48

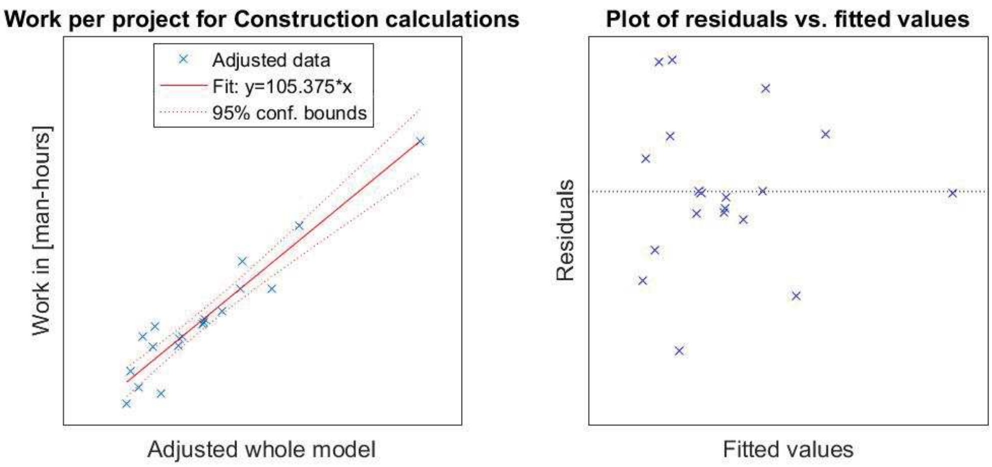


Figure 6.4: Result from the SMLR analysis for Structural calculations

[9] values have been changed in this public available thesis for confidentiality reasons

HVAC + FiFi

- The SMLR analysis calculates that Equation 6.7 is the most suitable work quantification model to forecast work for the HVAC + FiFi work package [10]
- The three statistics to evaluate the model fit are shown in Table 6.5
- The model fit and its residuals versus fitted values is shown in Figure 6.5

$$Work = -94 + 4.4 \cdot \sqrt{L_{pp} \cdot B} \tag{6.7}$$

Table 6.5: Regression analysis results for HVAC + FiFi

Regression characteristic	Result
R^2	0.663
P	$4.02e-06$
σ	40

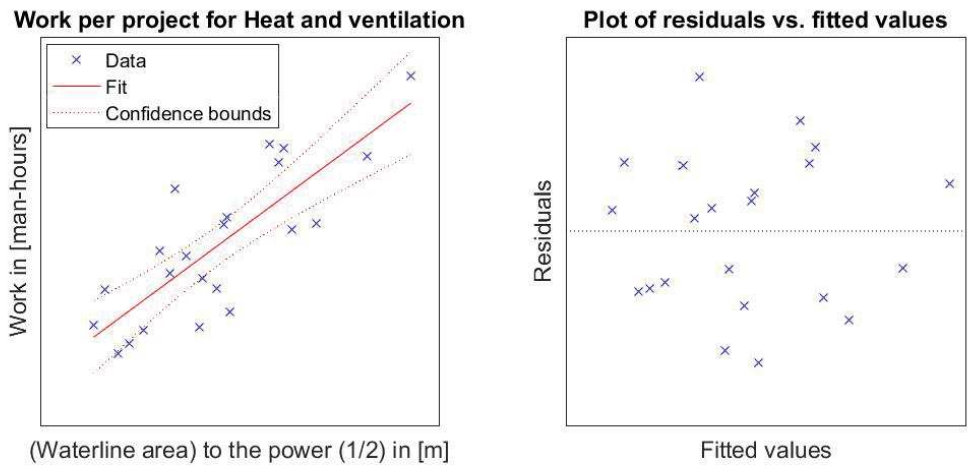


Figure 6.5: Result from the SMLR analysis for HVAC + FiFi

[10] values have been changed in this public available thesis for confidentiality reasons

Diagrams

- The SMLR analysis calculates that equation 6.8 is the most suitable work quantification model to forecast work for the Diagrams work package [11]
- The three statistics to evaluate the model fit are shown in Table 6.6
- The model fit and its residuals versus fitted values is shown in Figure 6.6

$$Work \quad = \quad -936 \quad + \quad 13 \cdot \sqrt{L_{pp} \cdot B} \quad + \quad 471 \cdot \frac{v_{trial}}{\sqrt{L_{pp}}} \tag{6.8}$$

Table 6.6: Regression analysis results for Diagrams

Regression characteristic	Result
R^2	0.853
P	$1.2e-08$
σ	68

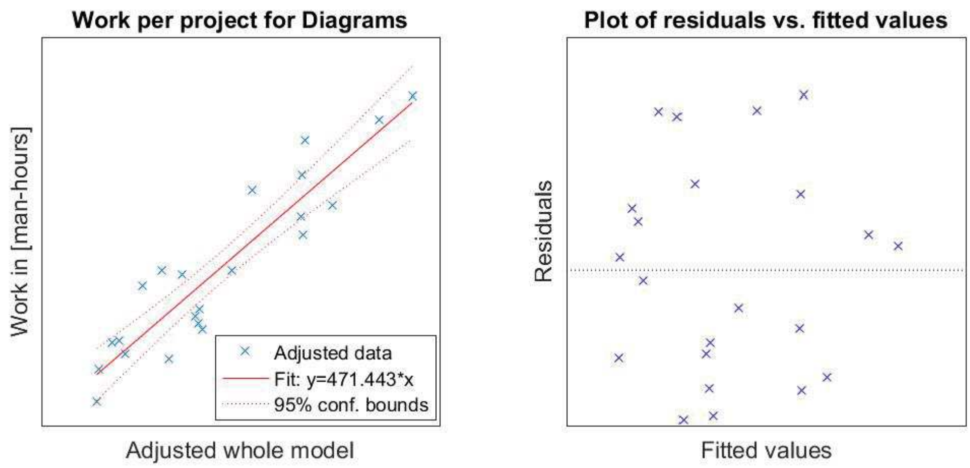


Figure 6.6: Result from the SMLR analysis for Diagrams

[11] values have been changed in this public available thesis for confidentiality reasons

Hydraulics

- The SMLR analysis calculates that Equation 6.9 is the most suitable work quantification model to forecast work for the Hydraulics work package [12]
- The three statistics to evaluate the model fit are shown in Table 6.7
- The model fit and its residuals versus fitted values is shown in Figure 6.7

$$Work = 22 + 0.005 \cdot P_{engines} \tag{6.9}$$

Table 6.7: Regression analysis results for Hydraulics

Regression characteristic	Result
R^2	0.59
P	$1.88e-05$
σ	30

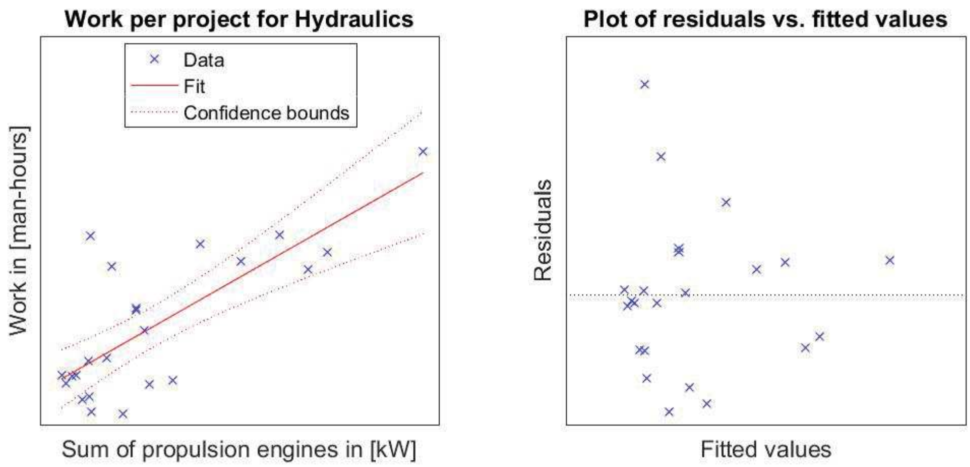


Figure 6.7: Result from the SMLR analysis for Hydraulics

[12] values have been changed in this public available thesis for confidentiality reasons

Mechanical layout

– The SMLR analysis calculates that Equation 6.10 is the most suitable work quantification model to forecast work for the Mechanical layout work package [13]

– The three statistics to evaluate the model fit are shown in Table 6.8

– The model fit and its residuals versus fitted values is shown in Figure 6.8

$$Work = -234 + 27 \cdot B \tag{6.10}$$

Table 6.8: Regression analysis results for Mechanical layout

Regression characteristic	Result
R^2	0.349
P	$3.81e-3$
σ	198

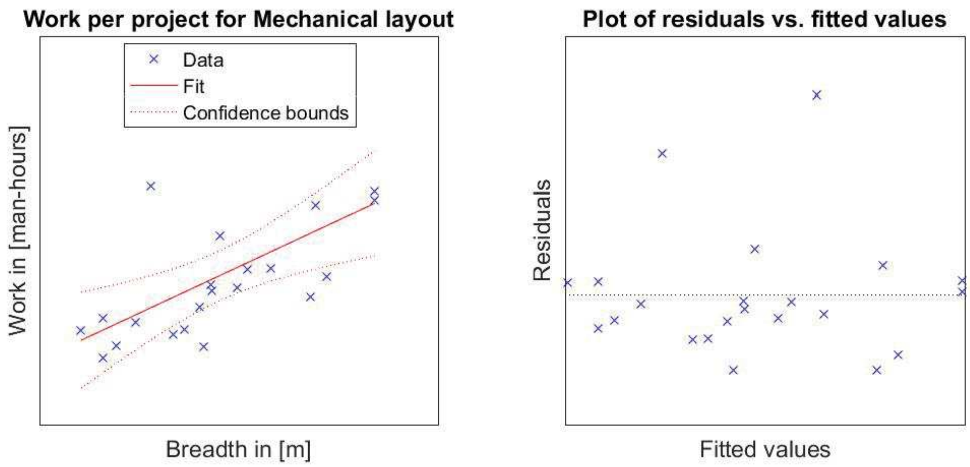


Figure 6.8: Result from the SMLR analysis for Mechanical layout

[13] values have been changed in this public available thesis for confidentiality reasons

Mechanical systems

- The SMLR analysis calculates that Equation 6.11 is the most suitable work quantification model to forecast work for the Mechanical system work package [14]
- The three statistics to evaluate the model fit are shown in Table 6.9
- The model fit and its residuals versus fitted values is shown in Figure 6.9

$$Work \quad = \quad -97 \quad + \quad 39 \cdot v_{trial} \quad - \quad 49 \cdot \frac{L_{pp}}{B} \tag{6.11}$$

Table 6.9: Regression analysis results for Mechanical systems

Regression characteristic	Result
R^2	0.637
P	$3.93e-05$
σ	54

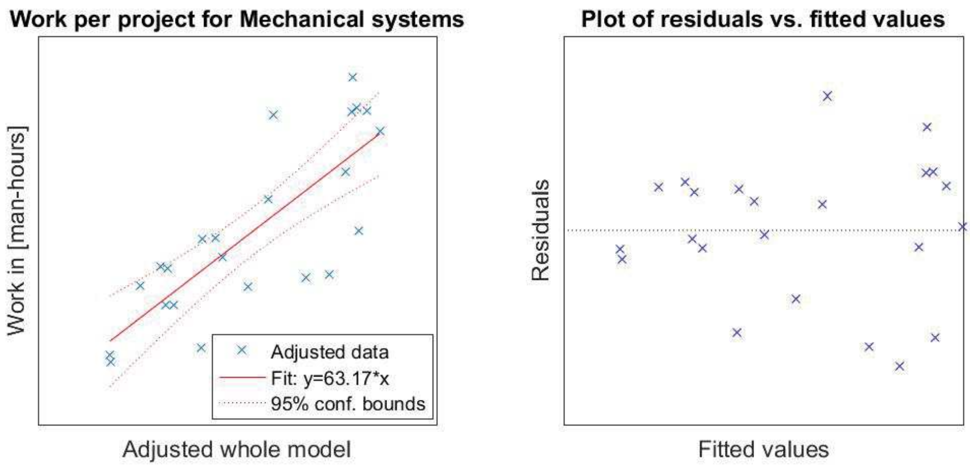


Figure 6.9: Result from the SMLR analysis for Mechanical systems

[14] values have been changed in this public available thesis for confidentiality reasons

Hull

- The SMLR analysis calculates that Equation 6.12 is most suitable work quantification model to forecast work for the Hull work package [15]
- The three statistics to evaluate the model fit are shown in Table 6.10
- The model fit and its residuals versus fitted values is shown in Figure 6.10

$$Work = 63 + 0.14 \cdot L_{pp} \cdot B \cdot No._{decks} \tag{6.12}$$

Table 6.10: Regression analysis results for Hull

Regression characteristic	Result
R^2	0.87
P	$9.4e-11$
σ	327

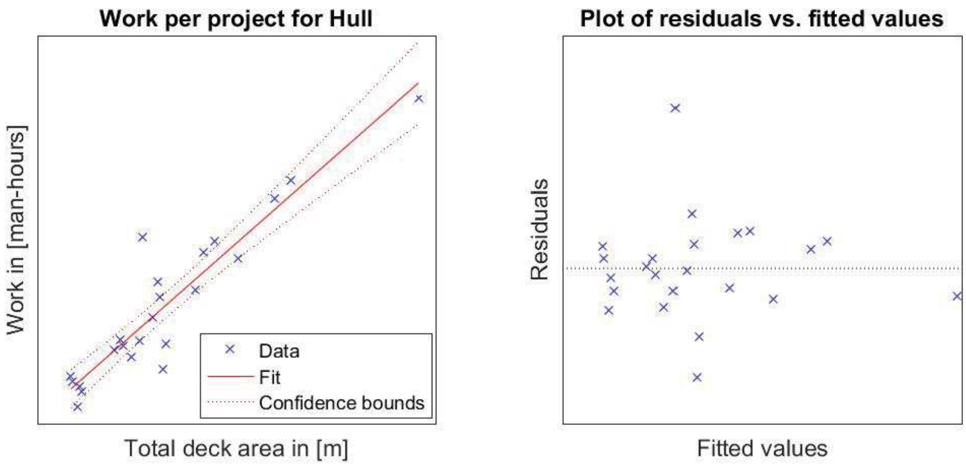


Figure 6.10: Result from the SMLR analysis for Hull

[15] values have been changed in this public available thesis for confidentiality reasons

Outfitting

- The SMLR analysis calculates that Equation 6.13 is the most suitable work quantification model to forecast work for the Outfitting work package [16]
- The three statistics to evaluate the model fit are shown in Table 6.11
- The model fit and its residuals versus fitted values is shown in Figure 6.11

$$Work = 305 + 0.065 \cdot Vol \tag{6.13}$$

Table 6.11: Regression analysis results for Outfitting

Regression characteristic	Result
R^2	0.773
P	$3.36e-08$
σ	255

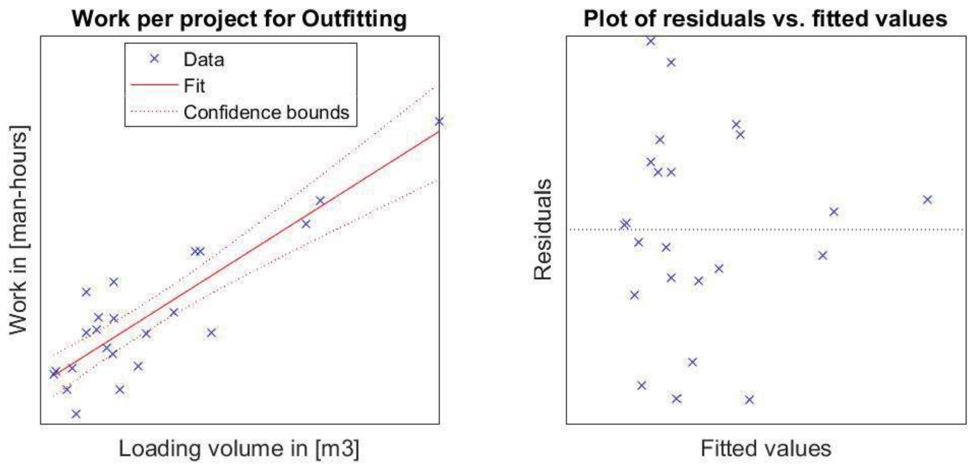


Figure 6.11: Result from the SMLR analysis for Outfitting

[16] values have been changed in this public available thesis for confidentiality reasons

Routing

- The SMLR analysis calculates that Equation 6.14 is the most suitable work quantification model to forecast work for the Routing work package [17]
- The three statistics to evaluate the model fit are shown in Table 6.12
- The model fit and its residuals versus fitted values is shown in Figure 6.12

$$Work \quad = \quad 2,695 \quad + \quad 0.12 \cdot L_{pp} \cdot B \cdot No._{decks} \quad - \quad 497 \cdot \frac{L_{pp}}{B} \tag{6.14}$$

Table 6.12: Regression analysis results for Routing

Regression characteristic	Result
R^2	0.839
P	$1.16e-08$
σ	307

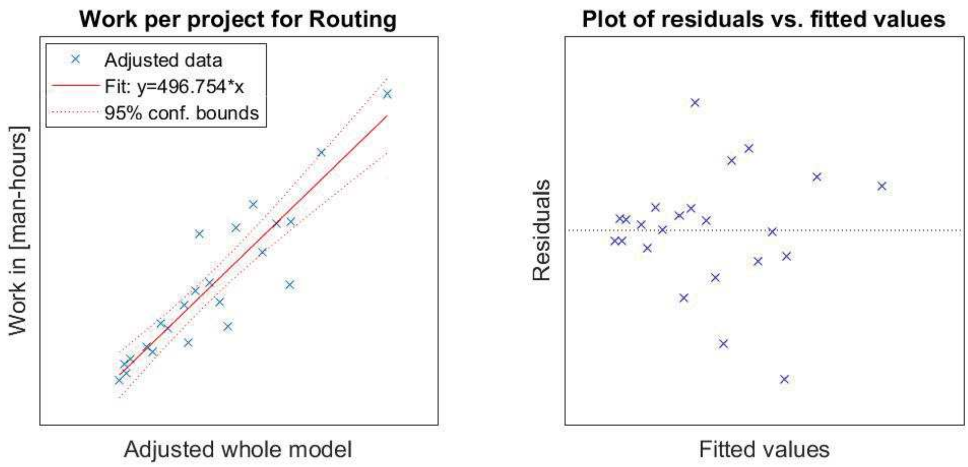


Figure 6.12: Result from the SMLR analysis for Routing

[17] values have been changed in this public available thesis for confidentiality reasons

Dredging components

- The SMLR analysis calculates that Equation 6.15 is the most suitable work quantification model to forecast work for the Dredging components work package [18]
- The three statistics to evaluate the model fit are shown in Table 6.13
- The model fit and its residuals versus fitted values is shown in Figure 6.13

The SMLR analysis of dredging components was subject to overfitting. Overfitting was tackled by discarding the last project characteristic that was added in the work quantification model until an explicable model was established. This resulted in discarding all earlier determined vessel characteristics except for $\sqrt[3]{L_{pp} \cdot B \cdot D - Vol}$.

$$Work = -421 + 36 \cdot \sqrt[3]{L_{pp} \cdot B \cdot D - Vol} \tag{6.15}$$

Table 6.13: Regression analysis results for Dredging components

Regression characteristic	Result
R^2	0.776
P	2,92e-08
σ	131

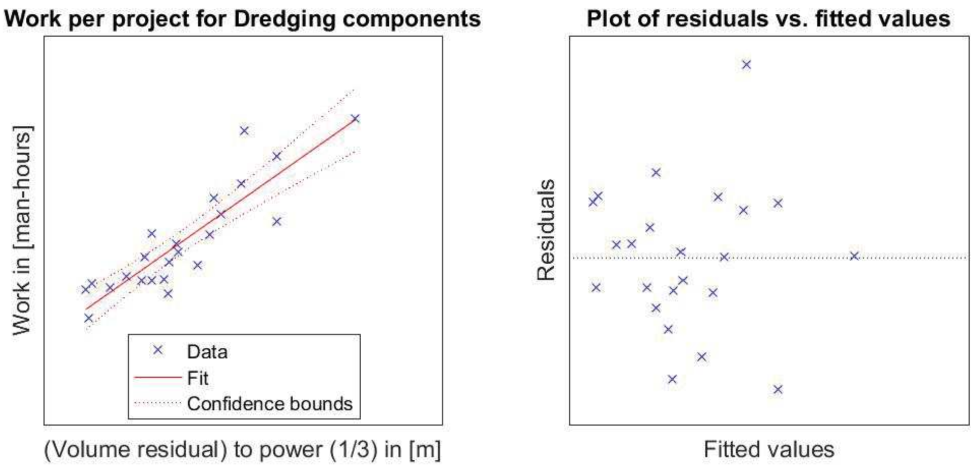


Figure 6.13: Result from the SMLR analysis for Dredging components

[18] values have been changed in this public available thesis for confidentiality reasons

6.2.3. *Step 3:* Analyze the linear regression models

The following section explains how Steps 3.1 and 3.2 are executed to validate each individual regression model and to assess the overall set of regression models.

Sub-step 3.1: Validate the individual regression model

This paragraph validates each individual linear regression models on its project characteristics, type of relationship, regression model characteristics, confirmatory analysis and discussion with engineers. A summary of all obtained work quantification models is added in Appendix N.

The following paragraph are divided into two sub-paragraphs. Sub-paragraph A analyzes project characteristics and relationships. Sub-paragraph B analyzes the accuracy of individual models.

A. Analysis of project characteristics & relationship

The following sub-paragraph analyzes the project characteristics and relationships. This is done by investigating and understanding the relation of each individual work quantification model and corresponding characteristics. A summary of each project characteristics in each regression models is provided in Table 6.14. A summary of all relationships in each regression model is shown in Table 6.15. The regression models from the confirmatory analysis are added in Appendix O. As a general fining, from all plot of residuals and the variance, it is observed that the variance is

Accommodation: Accommodation is linearly dependent on the fillable ship space in a simple linear relationship. No other parameters like number of passengers are experienced as influential in the stepwise multiple linear regression analysis. Application of this project characteristic suggest that the ship size relates to complexity of the accommodation.

Hydromechanics: Hydromechanics is linearly dependent on the available deck area in a simple linear regression. No other parameters like ship size or categorical ship size is experienced as influential in the stepwise multiple linear regression analysis. It is suspected that necessary work for the all calculations and booklets is a result of the available deck area. Based on personal judgment, variation is considered as high compared to the forecasts.

Construction plans: Construction plans is non-linearly dependent on the fillable ship space in combination with a traveling deck crane in a multiple linear relationship.

This non-linear relationship is the result of a decreasing complexity when the ship size increases. This characteristic of a non-linear relationship of ship size and work is currently known by IHC engineers. Engineers mentioned in interviews that the rounded hull shape in the bow and stern require a significant amount of work. The addition of a deck crane to the construction is not directly explicable. The deck crane: 1. may contribute to limitation of the design space which results in more interrelations; 2. Compensate for non-linearity in the term to drive down the man-hours from the larger ships (Mostly larger ships are outfitted with a traveling deck crane).

In an interview with engineers, questions were raised why the block coefficient was not incorporated into the analysis. Block coefficient is considered as a great contributor since a lower block coefficient is experienced as causing more rounding and therefore higher complexity in the construction elements. Also, $L \cdot B \cdot T \cdot C_b$ is considered as a more detailed measure of fillable ship volume compared to $L \cdot B \cdot T$. This was also considered to be true for construction calculations. These characteristics were not known at the time of this analysis and are recommended for investigation in further research.

Construction calculations: Construction calculations is dependent on the boxed volume of the ship in relation with the length-breadth ratio in a multiple linear relationship. Depth is only considered in one of the two variables which means that work mainly increases when depth increases. Breadth has a large effect on the engineering work since the breadth causes LBD to increase and the LB ratio to decrease. During an interview with engineers it was notified that a specific client (which also caused significant more work) requested ships have a lower L/B ratio than usual. It is suspected that the SMLR analysis identified this L/B ratio and applied this to quantify technological complexity from this specific client. This is also suspected to be true for Mechanical systems and Routing which apply the L/B ratio.

HVAC + FiFi: HVAC + FiFi has a non-linear relationship which is dependent on the waterline area of the ship. There is no other clarification other than that this characteristics merely provides the most accurate forecast.

Diagrams: Diagrams is linearly dependent on a combination of non-linear waterline area in relation with the speed-length ratio. The non-linear waterline area is suspected to quantify the best relation with differentiation and interdependency of the on-board systems. The addition of v_{trial} is suspected to represent the number of equipment and therefore systems and connections necessary.

Hydraulics: Hydraulics is linearly dependent on the total installed power of the main engines. This is however questionable considering that hydraulics work is mostly dependent on the number of hydraulic systems on board.

Mechanical layout: Mechanical layout is linearly dependent on the breadth of the ship. Breadth may represent the general population, but there is still a high variation. It is was suspected that more parameters like for example the addition of a specific system of the total installed power would be significant. For a future analysis it is advised to establish a general complexity factor to clarify and bring down the large spread from mechanical layout

Mechanical systems: Mechanical systems is linearly dependent on the trial speed and the LB ratio of the ship. Trial speed is suspected to affect the engine size which is in successively dependent on the ship size. Furthermore, a greater engine size (which results in a higher v_{trial} and requires a larger engine) causes work to increase due to the increase of systems and therefore interrelations. The LB ratio causes work to change when the ship length increases or the breadth decreases. It is suspected that this L/B ratio is caused by the increased level of complexity from a specific client (alike construction calculations).

Hull: Hull is linearly dependent with the deck area in a simple linear relationship. No other parameters like for example location of rooms or the addition of a bulb are calculated as influential. Because there is only one project characteristic in the linear relationship it is suspected that all elements that cause complexity are quantifiable as total deck area.

Outfitting: Outfitting is linearly dependent with the loading volume of the ship in a simple linear regression model. This is relation is however questionable. Loading volume is suspected as a general measure of all systems on board which trickles down to the amount of outfitting work.

Routing: Routing engineering is linearly dependent on the total deck area and L/B ratio in a multiple linear relationship. This is supposedly clarified that an extra deck causes significantly more equipment which requires more routing. Also the length is suspected as not contributing because more length just requires straight pipes and it is suspected that complexity lies in the establishment of the right bends. The L/B ratio may also be caused by the effect of the specific client.

Dredging components: Dredging components engineering is non-linearly dependent on the fillable ship volume in a simple non-linear relationship. Work for complexity of dredging components is suspected to be quantified by the available space in the ship. This model was the result of discarding project characteristics due to overfitting. The last remaining project characteristics was the fillable ship volume.

This relation however raises questions. This relationship calculates that, if LBT increases and the loading volume stays the same, work increases. This means that a larger fillable space causes more work. It is suspected that a larger fillable ship space results in the placement of more equipment and therefore more differentiation and interrelation.

An overview of all project characteristics and corresponding applied project characteristics is shown in Table 6.14. An overview of all relations is shown in Table 6.15.

Table 6.14: Summary of applied project characteristics per work package quantification model

Resource	B	v_{trial}	$Volume$	$P_{engines}$	$\sqrt{L_{pp}\cdot B}$	$\frac{L_{pp}}{B}$	$\frac{v_{trial}}{\sqrt{L_{pp}}}$	$L_{pp}\cdot B\cdot T$	$L_{pp}\cdot B\cdot No._{decks}$	$L_{pp}\cdot B\cdot T - Volume$	$\sqrt[3]{L_{pp}\cdot B\cdot T} - Volume$	Traveling deck crane
Accommodation										x		
Hydrodynamics									x			
Construction plans											x	x
Construction calculations						x		x				
Maritime equipment												
Heat and ventilation					x							
Diagrams					x		x					
Hydraulics				x								
Mechanical layout	x											
Mechanical systems		x				x						
Hull									x			
Outfitting			x									
Routing						x			x			
Dredging components											x	
Electrical & Automation												

Table 6.15: Summary of relationships of the resulting linear regression models

Resource	Simple LR	Multiple LR	MLR with Dummy
Accommodation	x		
Hydrodynamics	x		
Construction plans			x
Construction calculations		x	
HVAC + FiFi	x		
Diagrams		x	
Hydraulics	x		
Mechanical layout	x		
Mechanical systems		x	
Hull	x		
Outfitting	x		
Routing		x	
Dredging components	x		

Table 6.16: Summary of regression analysis results [20]

Resource	R^2	P	σ
Accommodation	0.705	$5.40 \cdot 10^{-07}$	79
Hydrodynamics	0.718	$3.34 \cdot 10^{-07}$	78
Construction plans	0.804	$9.60 \cdot 10^{-07}$	42
Construction calculations	0.907	$5.77 \cdot 10^{-09}$	48
HVAC + FiFi	0.663	$4.02 \cdot 10^{-06}$	40
Diagrams	0.852	$1.32 \cdot 10^{-08}$	68
Hydraulics	0.590	$1.88 \cdot 10^{-05}$	30
Mechanical layout	0.349	$3.81 \cdot 10^{-03}$	198
Mechanical systems	0.637	$3.93 \cdot 10^{-05}$	54
Hull	0.870	$9.40 \cdot 10^{-11}$	327
Outfitting	0.773	$3.36 \cdot 10^{-08}$	255
Routing	0.839	$1.16 \cdot 10^{-08}$	307
Dredging components	0.860	$2.88 \cdot 10^{-09}$	131

Reflecting on the SMLR analysis diagnostics, as shown in Table 6.16:

- it is not known if the R^2 are good or bad values. It can be noticed that Mechanical layout has a low goodness-of-fit and Construction calculations has a high goodness-of-fit. No hard statements can be made on this value.

- All P-values are below 0.05 which is mandatory

- Based on personal judgment, all variances seem high for the fitted values. When taking a random forecast data point from Mechanical systems, which is forecasted to spend 167 [19] man-hours, this value has a residual of 83 man-hours. This residual is 50% less than was actually spent on the project which is considered as not very accurate. The high variances is the result of the high variances in products that are similar in size and complexity. The forecasting models do provide a forecast for the general population.

B. Confirmatory analysis

A confirmatory analysis was executed to identify the accuracy of the obtained regression model. In this confirmatory analysis, two projects were randomly excluded from the regression model. New estimates were calculated for each work quantification model with the limited data set. This means that the same project characteristics are applied in each individual work quantification model. In this way, the excluded projects can be considered as 'new projects' because they haven't been used to compose the regression models. The resulting linear regression models from the confirmatory analysis are added in appendix O. The work from the historical project and work forecasted by the confirmatory regression models (which excluded the two projects) are shown in Table. 6.17.

The confirmatory analysis shows that the first project has a 5% deviation from the spent work. The second project also shows that the confirmatory analysis has a deviation of 5% with the executed work. There is currently no historical quantified data available to form a statement that this value is good or bad. However, the average deviation between spent work and historical budgets are on average 21% (which could be calculated from the Data types 1, 2, 3, 4. The comparison of the two values is however matter for discussion because it is not known how much work will be spent on the quantity that is issued from applying the proposed models. Further research is required into the work that is brought forth from the forecast.

[19] values have been changed in this public available thesis for confidentiality reasons

Table 6.17: Confirmatory analysis [21]

Resource	Example project 1		Example project 2	
	Spent work	Confirmatory work	Spent work	Confirmatory Work
Accommodation	109	122	269	248
Hydrodynamics	161	171	355	357
Construction plans	75	48	193	253
Construction calculations	138	117	349	438
HVAC + FiFi	40	33	187	150
Diagrams	148	202	394	466
Hydraulics	41	41	29	72
Mechanical layout	141	105	334	538
Mechanical systems	161	144	323	232
Hull	431	497	1,979	1,742
Outfitting	401	391	1,334	1,053
Routing	670	620	2,042	2,257
Dredging components	192	90	478	541
Total	2,703	2,579	8,265	8,345
(Total confirmatory divided by total spent) - 1		−5%		1%

***Sub-step 3.2:* Assess the total set of linear regression model**

This paragraph compares the distribution of work between the spent work distribution, confirmatory work distribution (which is obtained from Table 6.17 and the current applied fixed distribution. The three mentioned distributions for the two confirmatory projects considered are shown in Table 6.18. An increase or decrease between the fixed and confirmatory distribution is quantified by applying the R^2. For the confirmatory distribution a higher R^2 is required. Both confirmatory analysis have a higher R^2 value with respect to the fixed distribution. It can therefore be said that the new method forecast a more accurate work distribution that the fixed distribution.

Table 6.18: Work distribution analysis

	Example project 1			Example project 2		
Resource	Spent distribution	Confirmatory distribution	Fixed distribution	Spent distribution	Confirmatory distribution	Fixed distribution
Accommodation	4.0%	4.7%	2.5%	3.3%	3.0%	2.5%
Hydrodynamics	5.9%	6.6%	1.7%	4.3%	4.3%	1.7%
Construction plans	2.8%	1.8%	4.6%	2.3%	3.0%	4.6%
Construction calculations	5.1%	4.5%	3.4%	4.2%	5.3%	3.4%
Heat and ventilation	1.5%	1.3%	1.5%	2.3%	1.8%	1.5%
Diagrams	5.5%	7.8%	8.1%	4.8%	5.6%	8.1%
Hydraulics	1.5%	1.6%	1.1%	0.3%	0.9%	1.1%
Mechanical layout	5.2%	4.1%	6.0%	4.0%	6.5%	6.0%
Mechanical systems	5.9%	5.6%	3.9%	3.9%	2.8%	3.9%
Hull	15.9%	19.3%	17.8%	23.9%	20.9%	17.8%
Outfitting	14.8%	15.2%	22.9%	16.1%	12.6%	22.9%
Routing	24.8%	24.0%	22.9%	24.7%	27.1%	22.9%
Dredging components	7.1%	3.4%	3.7%	5.8%	6.5%	3.7%
R^2 between		0.9731	0.920		0.977	0.9251

6.3. Summary

This chapter answers sub-question 4.A by executing a stepwise multiple linear regression analysis. This analysis establishes linear regression models that will be applied to forecast work for an individual resource for a new project. The obtained linear regression models are summarized in appendix N. The availability of data limits the validating of accuracy. Only percentage distributions of work can be compared with one another. 22 Confirmatory analysis on work distributions calculate that the work distributions that follow from this method are more accurate than the current applied fixed distribution.

Application of the SMRM has been experienced as an extensive and complicated method. Furthermore, the regression models show high variance which questions the accuracy of forecasts. Lastly, when two project characteristics are applied in a model, multicollinearity complicates the interpretation of each project characteristics and its effect on the output. Therefore, more research is required in other methods to decrease variance and the application of combining project characteristics to forecast work.

This chapter contributes to answering the main question by establishing work quantification models that can be applied in the new proposal engineering work forecasting method. Available data and knowledge from IHC engineers clarified that work is distributed differently between projects. The application of this set of linear regression models results in a changing work distribution in the forecast that is more accurate than the current applied fixed distribution.

7

Work timing

This chapter aims to answer Sub-question 4.B: *What are the similarities between company knowledge and available data?* Answers to this sub-question are obtained by combining: 1. interviews with IHC engineers and; 2. applying the curve fitting analysis which was selected as most suitable technique in Chapter 5. The combination of two inputs is necessary because the data in Data type 4 is limited available and has been affected by complexity which means that the data shows a different situation than is (potentially) most suitable. Shortly summarized, this work timing analysis establishes for each of the 13 work packages considered: 1. a relation for activity start with respect to the basic- and detailed engineering throughput time; 2. a relation for activity finish with respect to the basic- and detailed engineering throughput time and; 3. a normalized histogram that follows resource loading over a project throughput time. These three items are referred to as '*WP timing*' for the remainder of this chapter.

This chapter is split up into three sections. Section 7.1 explains the work timing method. Section 7.2 explains execution of the work timing method. Section 7.3 provides a summary of this chapter by answering the sub-question and the contribution of this chapter to answering the main question.

7.1. Explanation of the work timing method

The work timing analysis is executed by following three steps for each individual work package considered. The method steps are:

- ***Step 1*** **- Determine the WP timing for individual work packages based on interviews:** There is currently no documented knowledge available on how work is spent over an engineering throughput time. This step investigates WP timing based on interviews with IHC engineers who execute work for specific work packages
- ***Step 2*** **- Determine the WP timing for individual work packages based on available data:** This investigates WP timing based on available data from Data type 4
- ***Step 3*** **- Compare the results and determine the final model:** This step combines the results from Step 1 and Step 2 by comparing WP-timing for each individual work package considered. Final work timing models are established for each individual work package considered.

Each step is individually explained in the following sub-sections. Sub-section 7.1.1 explains Step 1. Sub-section 7.1.2 explains Step 2. Sub-section 7.1.3 explains Step 3.

7.1.1. *Step 1* - Determine the WP timing for individual work packages based on interviews

There is currently no documented knowledge available within IHC on WP-timing. Information is acquired through interviews with engineers that are involved in the execution of work for specific work packages.

Engineers will however provide answers based on their view and experience on engineering, it is however preferred that there is uniform knowledge within IHC which complies with the available data. This step investigates two topics on work timing for each individual work package:

> *Start-finish relationship:* This step determines when a work package starts and finishes with respect to the basic engineering and detailed engineering throughput time
>
> *Resource loading:* This step determines which resource load histogram will be applied for each individual work package

All gained knowledge is composed in a table to create an overview.

7.1.2. *Step 2* - Determine the WP timing for individual work packages based on available data

This step investigates the start, finish and histogram of work from historical projects based on Data type 4 (See Chapter 3). Alike Step 1, knowledge is gained on:

> *Start-finish relationship:* This step determines when a work package starts and finished
>
> *Work loading:* This step determines which resource load histogram will be applied for each individual work package

However, resource load histograms must be established. This will be based on the knowledge from engineers.

7.1.3. *Step 3:* - Compare results from interviews and data

The identified WP timings from Step 1 and Step 2 are combined to establish suitable input for a Primavera activity template. It is however not possible to quantify the improvement from the new model. Therefore only the trend of individual work packages as combination of the whole are assessed.

7.2. Execution of the research method

The following section explains the results from Step 1 till 3. This section applies the same structure as Section 7.1.

7.2.1. *Step 1* - Determine the WP timing for individual work packages based on interview

The following section explains what information is obtained on WP timing based on knowledge from engineers. The general findings for each individual work package is provided in the following paragraphs.

Accommodation

> *Start-Finish:* Accommodation engineering starts between four to six weeks after the start of basic engineering and finishes at the end of basic engineering. This start relation is present because the hull shape and hull construction must be sufficiently matured before accommodation engineers start their work. The finish relation is present because the design must be finished so detailed engineering has sufficient information to start their work.
>
> *Resource loading:* Accommodation is generally executed by one engineer working that continuously develops designs. This one engineer divides its capacity over all projects which makes work timing rather dependent on resource and skills availability than on dependencies between tasks.

Hydromechanics

Start-Finish: Hydromechanics engineering starts at the start of basic engineering and finishes after the project has been handed over to the client. The work is divided into four stages where each stage has a specific start, finish and work loading. Each individual stage is explained by referring to them as stages:

- **Stage one:** starts at the start of basic engineering and finishes at the start of detailed engineering. Activities during this stage are: 1. establishing the hull shape, 2. preliminary stability calculations and; 3. preliminary resistance calculations. Many other work packages can can only continue when hydromechanics has established sufficient information. For example: accommodation requires a hull shape before it can continue and mechanical systems can only determine a main engine once they know the hull resistance. Work in this stage ends with a delivery of preliminary stability book to the class.
- **Stage two:** starts a few months prior to the ship launch. Executed tasks are updates on for example weight, stability and resistance calculations with newly obtained information from other work packages. This stage finishes at the end of the basic engineering with the delivery of the stability booklet.
- **Stage three:** starts prior to the launch of the ship and finishes after the launch. This stage executes launch calculations and inclining tests.
- **Stage four:** starts prior to the delivery of the ship where sea trials are executed.

Resource loading: There is little knowledge on resource loading for each individual stage other than that the work load increases to a peak to deliver all necessary documents and then decreases to zero again

Construction plans

Start-Finish: Construction plans engineering starts about two weeks after the start of basic engineering and finishes at the end of basic engineering. The start relation is the result from the maturity of design from Hydromechanics which determines the hull shape. The finish relation results from the transfer of information from basic engineering to detailed engineering.

Resource loading: The workload peak for construction plans is executed prior to the start of detailed engineering after which is gradually decreases. This relation is present because the design must be sufficient matured before detailed engineering work packages can take over the work. Most of the work for construction plans must be finished before the start of detailed engineering. After the peak, work gradually decreases until it stops at the end of basic engineering.

Construction calculations

Construction calculations follows the exact same patterns as construction plans.

HVAC + FiFi

Start-Finish: HVAC + FiFi engineering starts after about four to six weeks after the start of basic engineering and finishes at the end of basic engineering. The start relations originates from the maturity of design from Construction plans and Construction calculations. The finish relation results from information transfer to detailed engineering.

Resource loading: HVAC + Fifi engineering work is executed by one engineer that continuously develops designs. This one engineer divides its capacity over all projects which makes work timing rather dependent on resource and skills availability than on dependencies between tasks (similar to Accommodation).

Diagrams

Start-Finish: Diagrams engineering starts after about four weeks after the start of basic engineering and ends at the end of basic engineering. The start relation is present because information must be sufficiently matured before Diagrams can start its work. The finish relations results from information transfer to detailed engineering.

Resource loading: The workload increases until it reaches its peak prior to the start of detailed engineering. This characteristic is present because the design must be sufficient matured before detailed engineering work packages can take over the work. Work decreases till it reaches the end of basic engineering.

Hydraulics

Work for hydraulics is limited executed by IHC. Work spending is dependent on the availability of an engineer and the establishment of necessary documents. No knowledge on a clear start, finish or resource load is available.

Mechanical layout

Start-Finish: Mechanical layout engineering starts at the start of basic engineering and finishes at the end of basic engineering. This start relation is present because all other work packages require information from Mechanical layout. The design must be finished before detailed engineering takes over the work.

Resource loading: The resource load increases until it reaches its peak prior to the start of detailed engineering. This characteristic is present because the design must be sufficient matured before detailed engineering work can execute their work. Most of the work for Mechanical layout engineering must be finished before the start of detailed engineering. After the peak, workload decreases till the end of basic engineering.

Mechanical systems

Mechanical systems engineering follows the exact same patterns as Mechanical layout engineering.

Hull

Start-Finish: Hull engineering starts at the start of detailed engineering and finishes at the end of detailed engineering. This start relation is present because information is required from all basic engineering work packages.

Resource loading: Resource load increases until it reaches a peak. Resource load decreases after it reached its peak. This workload peak is skewed to the left. This left skewness is necessary because Routing engineering can only continue their work once it is clear how the construction will turn out.

Outfitting

Start-Finish: Outfitting engineering starts at the start of detailed engineering and finishes at the end of detailed engineering.

Resource loading: Resource load increases until it reaches its peak. Workload decreases after it reached its peak. The peak of work is skewed to the right. This right skewness is required because Outfitting continues with the work from Routing. Outfitting is dependent on the maturity of the design coming from Routing.

Routing

Start-Finish: Routing starts at the start of detailed engineering and finishes at the end of detailed engineering.

Table 7.1: Overview of WP timing results from interviews with IHC engineers

	Start relation			Finish relation	
Work package	Start of basic engineering	Late start	Start of detailed engineering	Finish of basic engineering	Finish of detailed engineering
Accommodation		4 – 6		x	
Hydrodynamics	x			x	
Construction plans		2		x	
Construction calculations		2		x	
HVAC + FiFi		4 – 6		x	
Diagrams		4		x	
Hydraulics					
Mechanical layout	x			x	
Mechanical systems	x			x	
Hull			x		x
Outfitting			x		x
Routing			x		x
Dredging components		2	x		

Resource loading: Resource load increases until it reaches its peak. Workload decreases after it reached its peak. The peak load of Routing is in the middle of the throughput time. This is present because Routing requires information from Hull. Outfitting continues with the work from Routing.

Dredging components

Start-Finish: Dredging components starts two weeks after the start of basic engineering and finishes at the end of basic engineering. This later start is present because Dredging components requires a hull and general layout to start fit its components. This finish relation is present because the design must be finished for detailed engineering to continue.

Resource loading: The most work for dredging components is prior to the start of detailed engineering. This characteristic is present because the design must be sufficient matured before detailed engineering work can execute their work. Most of the work for Dredging components engineering must be finished before the start of detailed engineering.

A summary of all acquired results is provided in Table 7.1

7.2.2. *Step 2* - Determine the WP timing for individual work packages based on available data

The following section reflects on the obtained results from available data. Shortly summarized, start and finish of work per individual work package are obtained from a plots that shows the spending of work for the work package. For all basic engineering work packages, work spending plots for total basic engineering and total detailed engineering are provided in Appendix H.3. Extra figures showing all detailed engineering work packages are provided in Appendix H.2. As mentioned in the theory, an engineering phase starts with a jump in the engineering team. It is suspected that this jump is noticeable

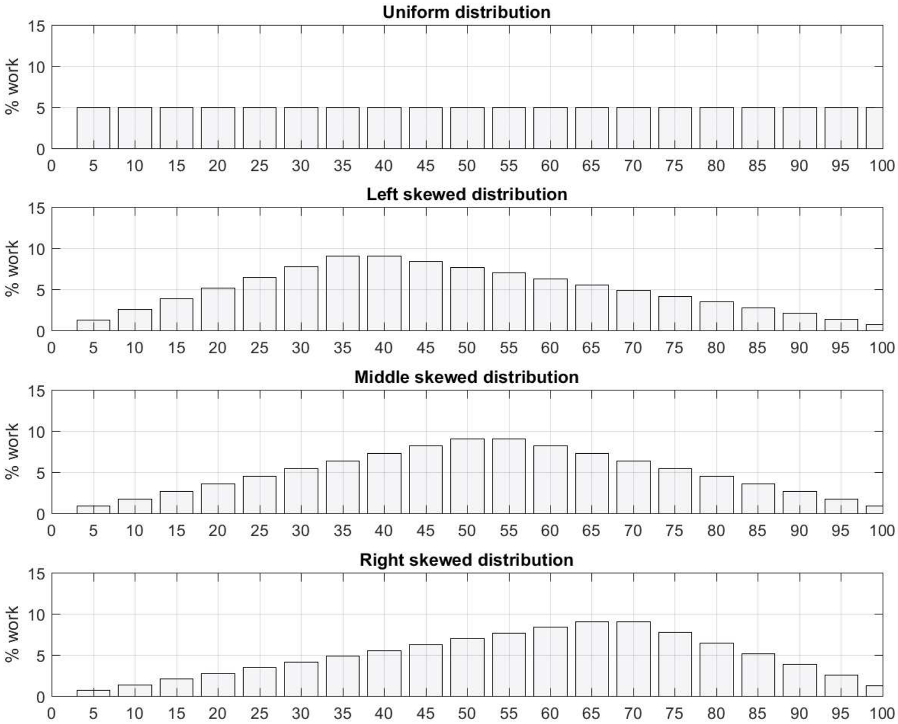


Figure 7.1: Applied histogram approximations

by a large increase in man-hours. The same yields for the end of detailed engineering. It is suspected that this is noticeable by a large decrease in man-hours. The exact starting and finishing dates remain however fuzzy. Hydraulics is neglected from this research

Four type of curves are applied to fit on work spending data. Because there is difficulty in obtaining curves from maths due to the high fluctuations in weekly man-hour spending, templates are established from gained knowledge from Step 1. A histogram approximation is either a uniform or triangular distribution. The triangular distribution is divided into a left skewed, middle skewed or right skewed triangular distribution. The peak is either located on $\frac{1}{3}$ of the throughput time, $\frac{1}{2}$ of the throughput time or $\frac{2}{3}$ of the throughput time. All histograms are shown in Figure 7.1. The histograms are quantified in Table 7.2. For the results in the following from here, a start and finish is determined based on personal judgment to merely visualize the resource load curve that follows from this research.

Table 7.2: Summary of resource load histograms

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Uniform	[%]	0.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Left skewed triangular	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4	0.7
Right skewed triangular	[%]	0.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.1	7.8	6.5	5.2	3.9	2.6	1.3
Middle skewed triangular	[%]	0.0	0.9	1.8	2.7	3.6	4.5	5.5	6.4	7.3	8.2	9.1	9.1	8.2	7.3	6.4	5.5	4.5	3.6	2.7	1.8	0.9

The general findings for each individual work package is provided in the following paragraphs. Each work package is backed up with a figure. All applied figures are added in appendix H.

Accommodation

Start-Finish: Work for Accommodation starts later than the start of basic engineering and finishes at the end of detailed engineering. An example of work spending with respect to basic and detailed engineering is shown in Figure 7.2.

Resource loading: Accommodation shows that man-hour spending is between about 0 and 40 man-hours per week. This confirms the obtained knowledge acquired in Step 1. Resource load is approximated as a uniform distribution. An example of Accommodation work consumption and its approximation with the uniform distribution is shown in Figure 7.3. The resource load histogram is quantified in Table 7.3.

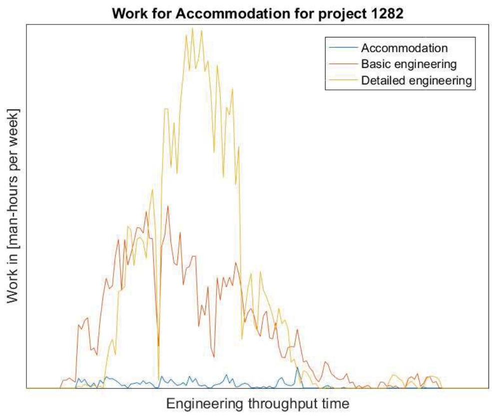


Figure 7.2: Work timing for Accommodation

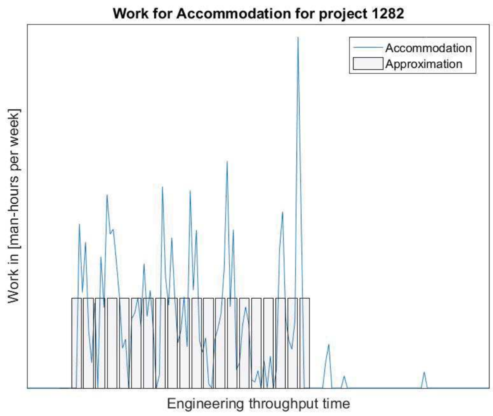


Figure 7.3: Resource load for Accommodation

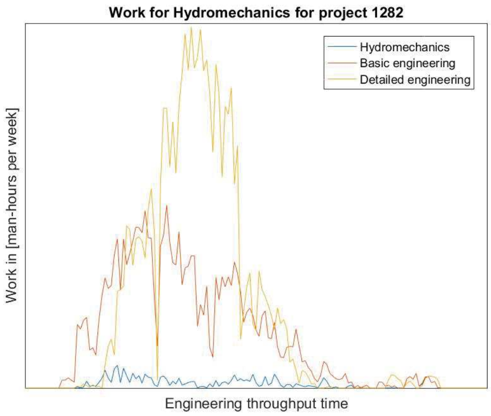
Table 7.3: Resource load histogram values for Accommodation

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Hydromechanics

Start-Finish: Hydromechanics starts at the start of basic engineering and finishes far after the end of detailed engineering. This finish relation is present because Hydrodyanmics is responsible for the launch and sea trials which are executed far later than the end of detailed engineering. An example of work spending is shown in Figure 7.4.

Resource loading: Application of a template is not recommended due to the four peaks of Hydrodynamics and further research is necessary.



set(gca,'ytick',[])

Figure 7.4: Work timing for Hydromechanics

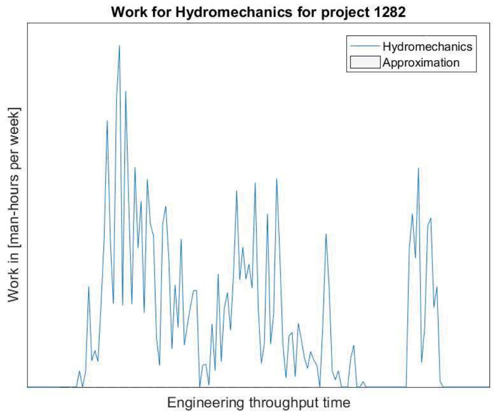


Figure 7.5: Resource load for Hydromechanics

Construction plans

Start-Finish: Work start shows a slight delay with respect to the start of basic engineering. Work is generally finished at the end of detailed engineering. An example of work spending for construction plans is shown in Figure 7.6.

Resource loading: Construction plans is utilized as a triangular shaped resource load curve with a left skewed peak. An example of Construction plans work consumption and its approximation with the left skewed triangular distribution is shown in Figure 7.7. The resource load histogram is quantified in Table 7.4.

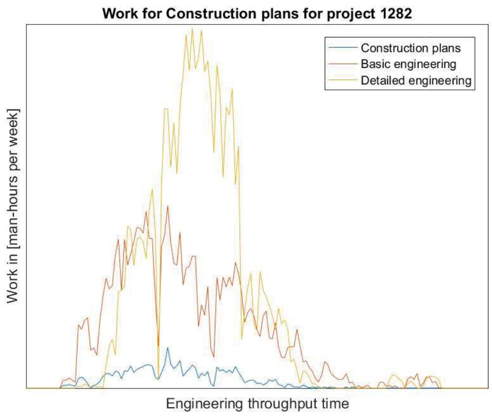


Figure 7.6: Work timing for Construction plans

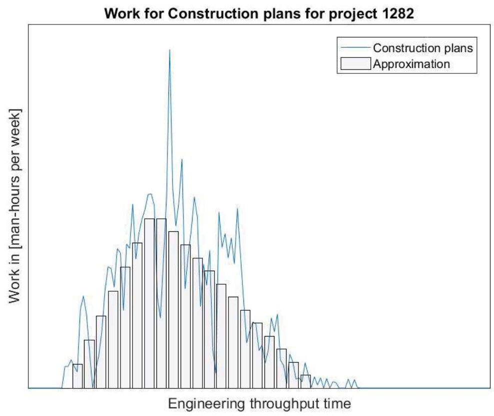


Figure 7.7: Resource load for Construction plans

Table 7.4: Resource load histogram values for Construction plans

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4	0.7

Construction calculation

Start-Finish: Alike Construction plans, Construction calculations work has a little delay with respect to the start of basic engineering and finishes at the end of detailed engineering. An example is shown in Figure 7.8.

Resource loading: Construction calculations is utilized as a triangular shaped resource load curve with a left skewed peak. An example of Construction calculations work consumption and its approximation with the left skewed triangular distribution is shown in Figure 7.9. The resource load histogram is quantified in Table 7.5.

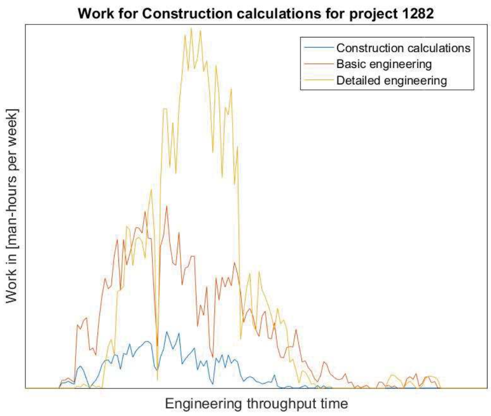


Figure 7.8: Work timing for Construction calculations

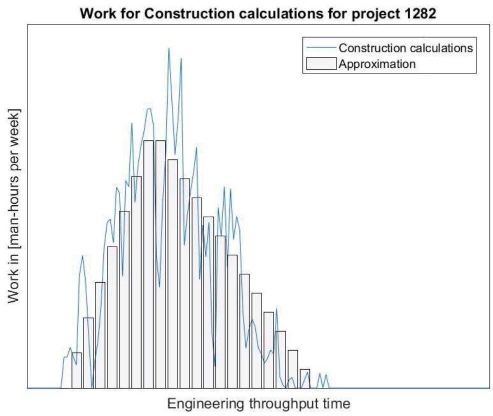


Figure 7.9: Resource load for Construction calculations

Table 7.5: Resource load histogram values for Construction calculations

Interval [%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height [%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4	0.7

HVAC + FiFi

Start-Finish: Work for HVAC + FiFi starts later than the start of basic engineering and finishes at the end of detailed engineering. An example of work spending with respect to basic and detailed engineering is shown in Figure 7.10.

Resource loading: Work spending shows that about 0 and 40 man-hours are spent per week. This confirms the obtained knowledge acquired in Step 1 that about one engineer executes all work. Resource load is approximated as a uniform distribution. An example of HVAC + FiFi work consumption and its approximation with the uniform distribution is shown in Figure 7.11. The resource load histogram is quantified in Table 7.6.

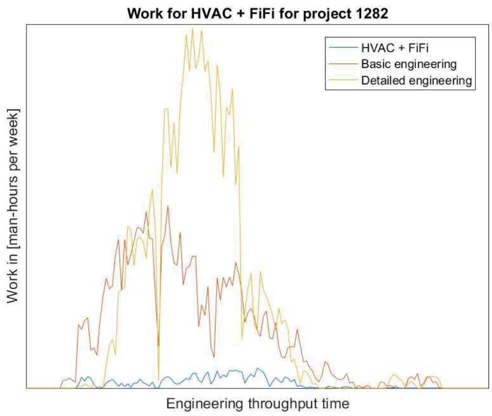


Figure 7.10: Work timing for Heat and ventilation

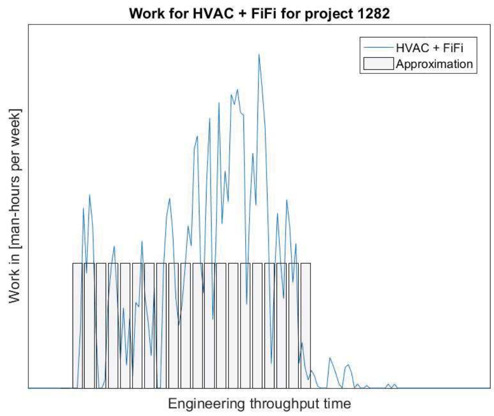


Figure 7.11: Resource load for Heat and ventilation

Table 7.6: Resource load histogram values for Heat and ventilation

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Diagrams

Start-Finish: The data shows that Diagrams has a later start than basic engineering and finishes at the end of detailed engineering. An example is shown in Figure 7.12.

Resource loading: Diagrams is approximated as a left skewed triangular distribution. An example of diagrams work consumption is shown in Figure 7.13. The resource load histogram is quantified in Table 7.7.

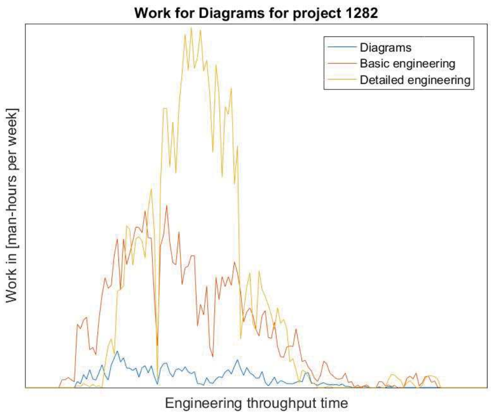


Figure 7.12: Work timing for Diagrams

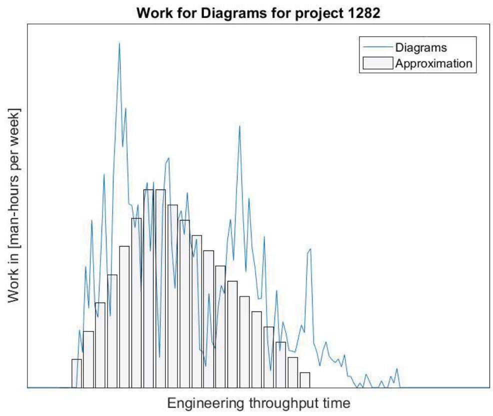


Figure 7.13: Resource load for Diagrams

Table 7.7: Resource load histogram values for Diagrams

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4	0.7

Mechanical layout

Start-Finish: No distinct start of mechanical layout can be obtained from the plots. Mechanical layout either start at the start of basic engineering or has a slight delay. Work finishes at the end of detailed engineering. An example of work spending is shown in Figure 7.14.

Resource loading: Mechanical layout approximated as left skewed triangular distribution. An example the approximation is shown in Figure 7.15. The resource load histogram is quantified in Table 7.8.

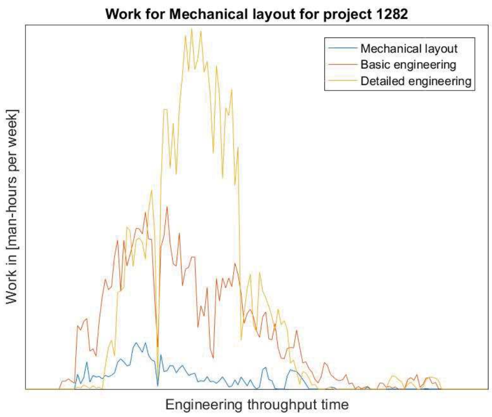


Figure 7.14: Work timing for Mechanical layout

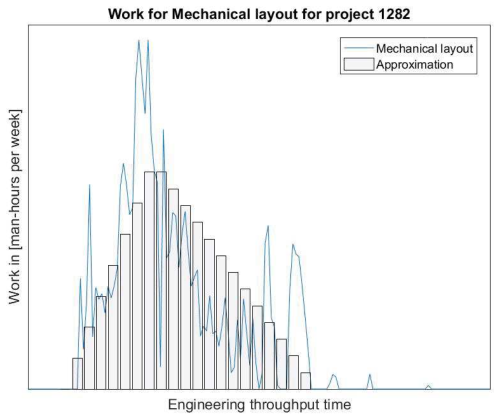


Figure 7.15: Resource load for Mechanical layout

Table 7.8: Resource load histogram values for Mechanical layout

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4
0.7																						

Mechanical systems

Start-Finish: Alike Mechanical layout, no distinct start of mechanical systems can be obtained from the plots. Mechanical systems either start at the start of basic engineering or has a slight delay. Work finishes at the end of detailed engineering. An example of work spending is shown in Figure 7.16

Resource loading: Mechanical systems consists of one triangular shaped distribution with the peak somewhat to the left of the middle. An approximation of mechanical systems shown in Figure 7.17. The resource load histogram is quantified in Table 7.9.

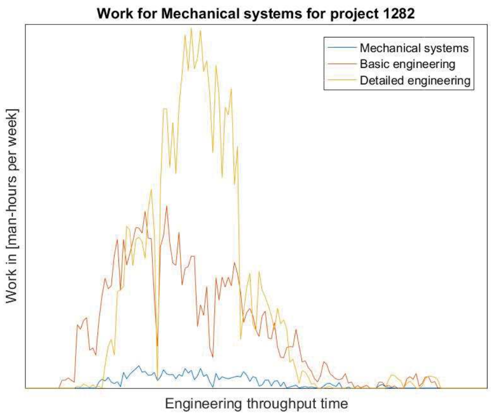


Figure 7.16: Work timing for Mechanical systems

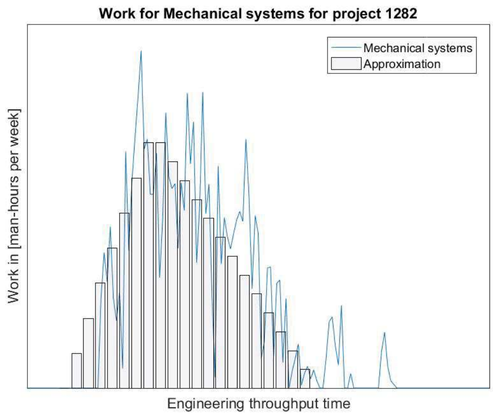


Figure 7.17: Resource load for Mechanical systems

Table 7.9: Resource load histogram values for Mechanical systems

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4
0.7																						

Hull

Start-Finish: Work starts at the start of detailed engineering and finishes at the end of detailed engineering. This confirms the acquired information from Step 1. An example of work spending for Hull is shown in Figure 7.18.

Resource loading: Hull consists of one left skewed triangular distribution. An example of a Resource load approximation is shown in Figure 7.19. The resource load histogram is quantified in Table 7.11.

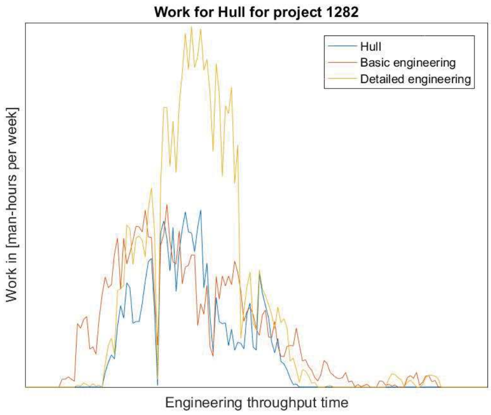


Figure 7.18: Work timing for Hull

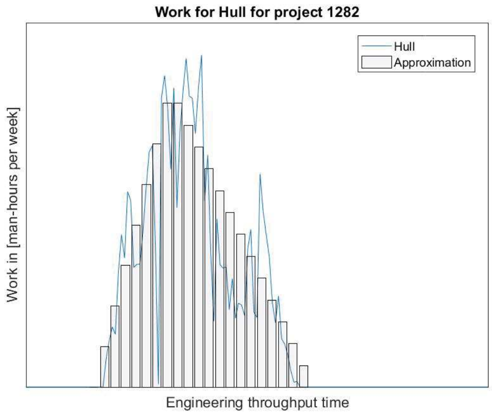


Figure 7.19: Resource load for Hull

Table 7.10: Resource load histogram values for Hull

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4
0.7																						

Outfitting

Start-Finish: Work starts at the start of detailed engineering and finishes at the end of detailed engineering. This confirms the acquired information from Step 1. An example of work spending for Outfitting is shown in Figure 7.20.

Resource loading: Outfitting consists of a triangular shaped distribution with the peak skewed to the right. The approximation of the Resource loading is shown in Figure 7.21. The histogram is quantified in Table 7.11.

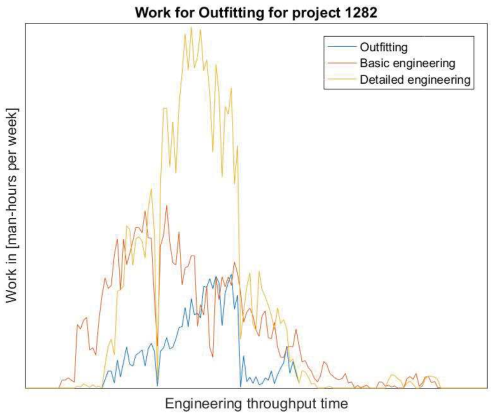


Figure 7.20: Work timing for Outfitting

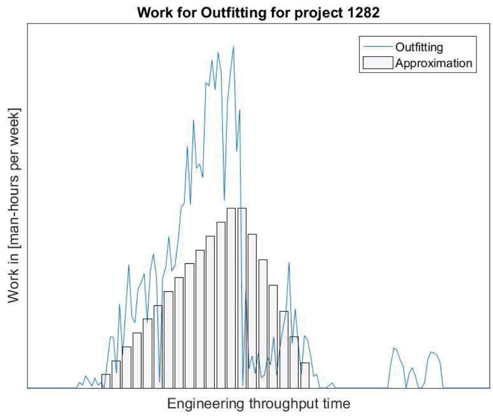


Figure 7.21: Resource load for Outfitting

Table 7.11: Resource load histogram values for Outfitting

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	0.7	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.1	9.1	7.8	6.5	5.2	3.9	2.6	1.3

Routing

Start-Finish: Work starts at the start of detailed engineering and finishes at the end of detailed engineering. This confirms the acquired information from Step 1. An example of work spending for Routing is shown in Figure 7.22.

Resource loading: Routing consists of a triangular shaped distribution with the peak in the middle. The approximation of Routing is shown in Figure 7.23. The histogram is quantified in Table 7.12.

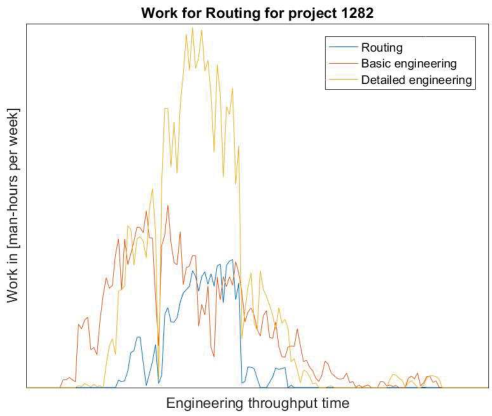


Figure 7.22: Work timing for Routing

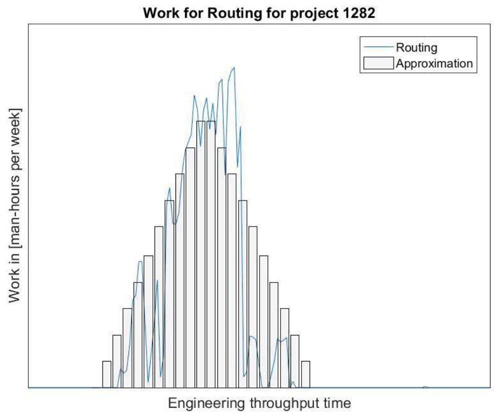


Figure 7.23: Resource load for Routing

Table 7.12: Resource load histogram values for Routing

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	0.9	1.8	2.7	3.6	4.5	5.5	6.4	7.3	8.2	9.1	9.1	8.2	7.3	6.4	5.5	4.5	3.6	2.7	1.8	0.9

Dredging components

Start-Finish: Work starts with a delay with respect to the start of basic engineering and finishes at the end of detailed engineering. An example is shown in Figure 7.24.

Resource loading: Dredging components consists of a triangular shaped distribution which is left skewed. An approximation of work spending is shown in Figure 7.25. The resource load histogram is quantified in Table 7.13.

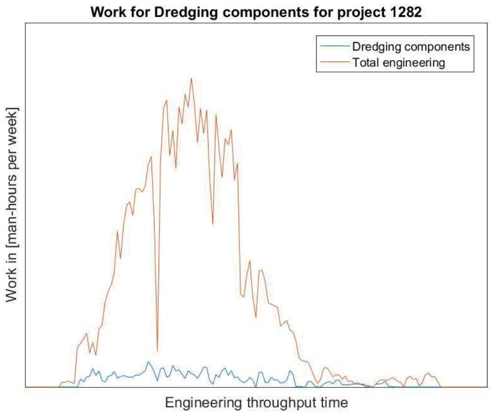


Figure 7.24: Work timing for Mission equipment

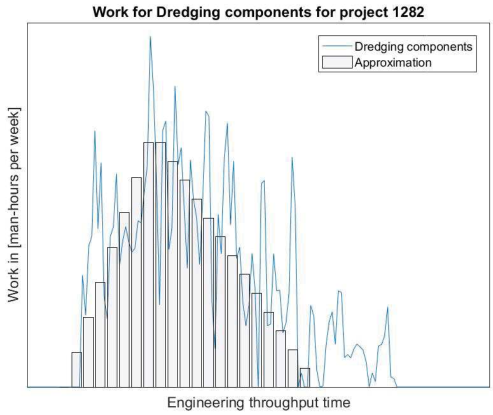


Figure 7.25: Resource load for Mission equipment

Table 7.13: Resource load histogram values for Dredging components

Interval	[%]	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
Height	[%]	0.0	1.3	2.6	3.9	5.2	6.5	7.8	9.1	9.1	8.4	7.7	7.0	6.3	5.6	4.9	4.2	3.5	2.8	2.1	1.4	0.7

Table 7.14: Overview of WP timing results from the data analysis

	Start relation			Finish relation		Distribution					
Work package	Start of basic engineering	Late start in weeks	Start of detailed engineering	Finish of basic engineering	Finish of detailed engineering	Uniform distribution	Triangular distribution	Left skewed	Middle skewed	Right skewed	Multiple triangular distributions
Accommodation	x				x	x					
Hydrodynamics	x				x		x				x
Construction plans		x			x		x	x			
Construction calculations		x			x		x	x			
Heat and ventilation		x			x	x					
Diagrams		x			x		x	x			x
Hydraulics											
Mechanical layout	x				x		x	x			
Mechanical systems	x				x		x	x			
Hull			x		x		x	x			
Outfitting			x		x		x				
Routing			x		x		x			x	
Dredging components		x			x		x	x			

A summary of all acquired results are provided in Table 7.14

7.2.3. *Step 3:* Compare results from interviews and data

The following step assess the obtained information from Step 1 and Step 2 to compose final utilization models for Primavera. Each resource is individually assessed in the following paragraphs. A summary of the result is shown in Table 7.15. It is generally observed the knowledge from engineers is different from the data. Only starting relations of work are experienced to be accurate. Even though engineers mention that the peak of resource load is located to the left of the start of detailed engineering, the figures show that this is not the case. Also work finish is not at the end of detailed engineering but at the end of detailed engineering.

Accommodation

Start-finish: The available data shows that Accommodation indeed starts later than the start of basic engineering. How much later is not obtainable from the data. The final model will apply a starts relation of 5 weeks (an average of 4 and 6) after the start of basic engineering. The available data shows work spending continues until the end of detailed engineering. This is potentially the work of reprise relations. The finish relation is linked to the end of the detailed engineering phase.

Resource loading: Work is spent over the total duration of the engineering phase in a uniform matter. A uniform resource load curve is applied.

Hydromechanics

Because Hydrodynamics has such a unique resource loading, start and finish relations this work packages requires further investigation with project milestones to establish a better work timing model

Table 7.15: Overview of WP timing results from interviews versus available data

Resource	Start relation			Finish relation		Distribution					
	Start of basic engineering	Late start in weeks	Start of detailed engineering	Finish of basic engineering	Finish of detailed engineering	Uniform distribution	Triangular distribution	Left skewed	Middle skewed	Right skewed	Multiple triangular distributions
Results obtained from interviews											
Accommodation		5		x							
Hydrodynamics	x			x							
Construction plans		2		x							
Construction calculations		2		x							
HVAC + FiFi		5		x							
Diagrams		4		x							
Mechanical layout	x			x							
Mechanical systems	x			x							
Hull			x		x						
Outfitting			x		x						
Routing			x		x						
Dredging components		2		x							
Results obtained from data											
Accommodation		x			x	x					
Hydrodynamics	x						x				x
Construction plans		x			x		x	x			
Construction calculations		x			x		x	x			
HVAC + FiFi		x			x	x					
Diagrams		x			x		x	x			x
Mechanical layout	x				x		x	x			
Mechanical systems	x				x		x	x			
Hull			x		x		x	x			
Outfitting			x		x		x				
Routing			x		x		x			x	
Dredging components		x			x		x	x			

Construction plans

Start-finish: The data shows that work starts a little later than the start of basic engineering. This complies with the gained knowledge from Step 1. Because an exact starting relation is not obtainable from the available data, 2 week is applied as start relation with respect to the start of basic engineering. The data shows that work finishes at the end of detailed engineering. The late finish is contradictory with the obtained information from engineers. This is potentially clarified by an amount of rework. The final model shall finish work at the finish of detailed engineering.

Work loading: Work is distributed with a right skewed triangular distribution.

Construction calculations

Start-finish: Alike construction plans, the data shows that work starts a little later than the start of basic engineering and ends at the end of detailed engineering. The later finish of engineering and is contradictory to the obtained information from engineers. Alike construction plans, this is also potentially clarified by an amount of rework. The activity shall start 2 weeks after the start of basic engineering and finishes at the end of detailed engineering.

Work loading: Construction calculations follows the same utilization curve as construction plans.

HVAC + FiFi

Start-finish: The data shows that HVAC + FiFi starts later than the start of basic engineering. This complies with the obtained data from Stage 1. The exact start is not obtainable from the data. The start relation from interviews is applied. Work continues till the end of detailed engineering. This is contradictory to Stage 1. Work shall finish at the end of detailed engineering.

Work loading: The data shows that work generally does not increase 40 hours on a weekly basis. A uniform distribution is applied.

Diagrams

Start-finish: The data does that diagrams starts a little later than the start of basic engineering. An exact number of weeks is not obtainable from the data. The start relation from Step 1 is applied. Work finishes at the end of detailed engineering. This is however contradictory to the obtained knowledge from Step 1. This relation is suspected to be present due to rework. The activity shall finish at the end of detailed engineering.

Work loading: The data shows that most of the work is spent on the left side of the throughput time. A left skewed triangular distribution is applied. This is in compliance with the knowledge from engineers.

Mechanical layout

Start-finish: The data does not show a trend in starting relation. Work either has a little delay or starts at the start of basic engineering. The start relation from Step 1 is applied. Work finishes at the end of detailed engineering. This is however contradictory to the obtained knowledge from Step 1. This relation is suspected to be present due to rework. The activity shall finish at the end of detailed engineering.

Work loading: The data shows that most of the work is spent on the left side of the throughput time. A left skewed triangular distribution is applied. This is in compliance with the knowledge from engineers.

Mechanical systems

Start-finish: Alike mechanical layout, the data does not show a trend in starting relation. Work either has a little delay or starts at the start of basic engineering. The start relation from Step 1 is applied. Work finishes at the end of detailed engineering. This is however contradictory to the obtained knowledge from Step 1. This relation is suspected to be present due to rework. The activity shall finish at the end of detailed engineering.

Work loading: The data shows that most of the work is spent on the left side of the throughput time. A left skewed triangular distribution is applied. This is in compliance with the knowledge from engineers.

Hull

Start-finish: The plots show that work starts at the start of detailed engineering and finishes at the end of detailed engineering. This is in compliance with the results from Step 1. The activity shall start at the start of detailed engineering and finish at the end of detailed engineering.

Work loading: As mentioned by engineers, the resource load curve is left skewed. This is confirmed with the available data. A left skewed triangular distribution is applied.

Outfitting

Start-finish: The result shows that work starts at the start of detailed engineering and finishes at the end of detailed engineering. This is in compliance with the results from Step 1. The activity shall start at the start of detailed engineering and finish at the end of detailed engineering.

Work loading: As mentioned by engineers, the resource load curve is right skewed. This is confirmed with the available data. A right skewed triangular distribution is applied.

Routing

Start-finish: The result shows that work starts at the start of detailed engineering and finishes at the end of detailed engineering. This is in compliance with the results from Step 1. The activity shall start at the start of detailed engineering and finish at the end of detailed engineering.

Work loading: The data shows that the peak of routing is skewed more to the right. This is contradictory with the obtained knowledge from Step 1. In an ideal situation, routing is middle skewed. Therefore a middle skewed triangular distribution is applied.

Dredging components

Start-finish: The available data shows no trend in start relation. The obtained start relation from Step 1 is obtained. The data shows that work is spent till the end of detailed engineering. The activity finishes at the end of detailed engineering.
Work loading: The data shows that the peak skewed to the left. This is confirmed in Step 1. A left skewed triangular distribution is applied.

The application of verifying knowledge from engineers and data shows that basic engineering continues its work until the end of detailed engineering. Furthermore, detailed engineering work peaks are successive. A summary of the final result is graphically represented in Table 7.16. A comparison of the current and the new work timing forecast for basic and detailed engineering is shown in Figure 7.27. A comparison of the current and the new work timing forecasts for all detailed engineering work packages is shown in Figure 7.27. The figures are merely added to show the difference between the current and the new work timing models. The values applied in the figures are based on the current fixed work

Table 7.16: Final applied WP timing for each individual work package

	Start relation			Finish relation		Distribution					
Resource	Start of basic engineering	Late start in weeks	Start of detailed engineering	Finish of basic engineering	Finish of detailed engineering	Uniform distribution	Triangular distribution	Left skewed	Middle skewed	Right skewed	Multiple triangular distributions
Accommodation		5			x	x					
Hydrodynamics	x										
Construction plans		2			x		x	x			
Construction calculations		2			x		x	x			
HVAC + FiFi		5			x	x					
Diagrams		4			x		x	x			x
Hydraulics											
Mechanical layout	x				x		x	x			
Mechanical systems	x				x		x	x			
Hull			x		x		x	x			
Outfitting			x		x		x				
Routing			x		x		x			x	
Dredging components		2			x		x	x			

distribution provided in Appendix B.

This recommendation is only provided under the assumption that the start and finish of basic and detailed engineering are known correctly. Further analysis is required in the start and finish of all resources with regards to the project milestones. This data was not applied in this research. Based on an analysis of the milestones with regards to the work spending, recommendations follow for the master schedule which follow in a (potentially) better proposal engineering work schedule forecast.

7.3. Summary

The chapter answers sub-question 4.B by verifying information from engineers with available data. The results are start-finish relations and work loading curves for each individual work package considered with respect to a predetermined basic engineering throughput time. The main difference with respect to the old work schedule is 1. the location of the peaks and 2. Longer execution of basic engineering.

Recommendations with respect to the current master schedule are is not possible because applicable milestones are not taken into account. Furthermore, the few projects available limit the possibility of characterizing specific project characteristics to the work schedule forecast.

This chapter contributes to answering the main question by applying histograms curves that are composed on historic situations. This can be done by assuming that problems are solved in a similar matter between projects. By applying utilization curves per resource, interdependency is taken into account. Available data and knowledge from engineers clarified that work per work package is distributed differently between resources. The application of this set of timing curves applies this effect in the initial engineering capacity schedule following form this research.

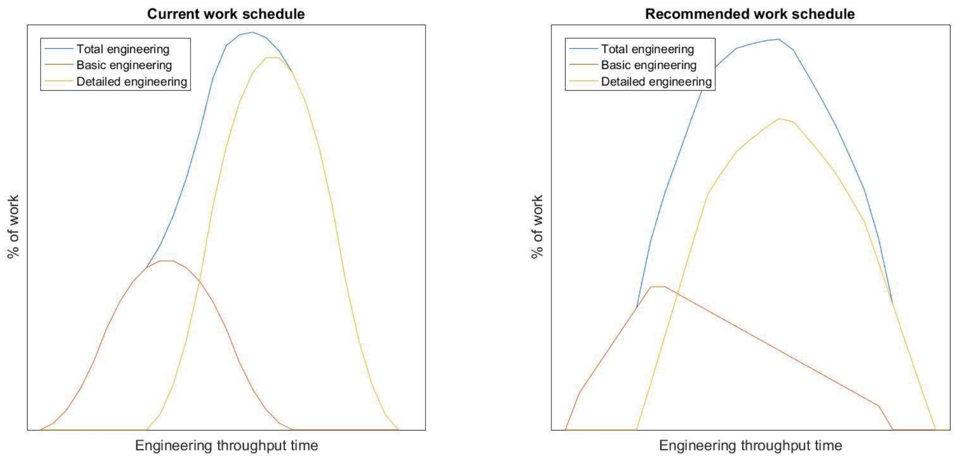


Figure 7.26: Comparison of the old and new activity effort utilization

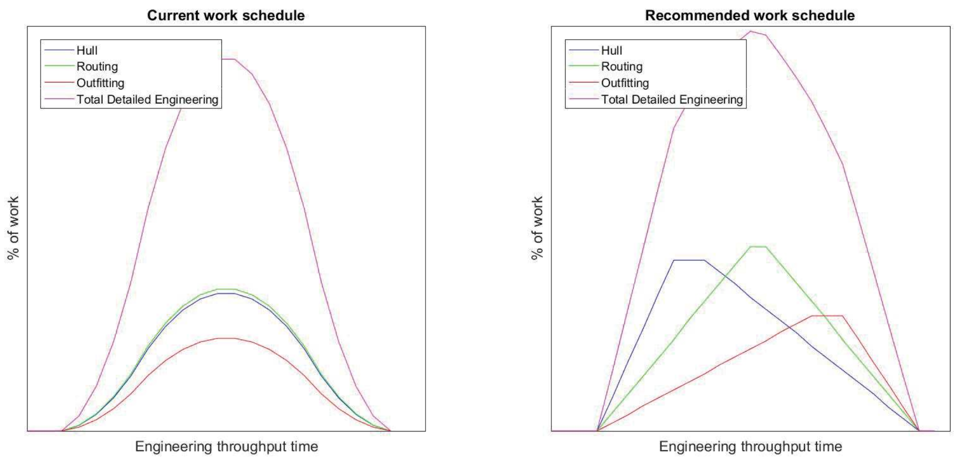


Figure 7.27: Comparison of the old and new activity effort utilization

8

Conclusions and recommendations

The following chapter provides conclusions and recommendations that follow from the development process of the new engineering work schedule forecasting method. The conclusions are presented by answering the main research question and sub-questions in Section 8.1. Successively, recommendations are listed for further research in Section 8.2.

8.1. Conclusions

The following section provides the conclusions from this research by answering the main question and sub-questions.

8.1.1. Answering the main question

How can IHC improve the work schedule forecast for basic- and detailed engineering work packages in the proposal phase?

IHC can improve the current engineering work schedule forecast for basic- and detailed engineering work packages in the proposal phase by dividing the work scheduling method into models that quantify work and models that time work. The models that quantify work are established with a stepwise multiple linear regression analysis that quantifies significant relationships between project characteristics and historic man-hours data. The models are kept up to date by applying a multiple linear regression analysis. Work timing models are established by combining knowledge from IHC engineers and available historical spent man-hour data in a curve fitting analysis.

8.1.2. Answering the sub questions:

1. What historic project schedule data is available at IHC, and how can these be applied for the purpose of this research?

Currently 22 historical projects are available that quantify work in total man-hours per workpackage and 5 historical projects are available that quantify work in weekly man-hours per workpackage. Based on the required input to Primavera, which will process the output of the new method developed in this research, the 22 projects are applied in a regression analysis to establish work quantification models that quantify work for future projects and the 5 projects are applied in a curve fitting analysis to schedule future work.

2. What project characteristics are available in the 80/80 *phase that quantify size and complexity for a project?*

In summary, there are four types of project characteristics available in the proposal phase that quantify size and/or complexity for a project. These are: vessel characteristics, vessel functionalities and vessel dimension ratios and requirements from interviews. Vessel characteristics are principal dimensions and combinations of principal dimensions. Functionalities are certain characteristics a ship has or has not, Vessel dimension ratios are ratios of vessel characteristics to quantify available space. Requirements from engineers are specific events that caused an increase or decrease of work. All project characteristics, with the exception of requirements from engineers' are obtainable from the general arrangement and technical specification which are the only documents that contain accurate project characteristics at the time that the proposal schedule is established. A total of 37 characteristics are defined.

3. Which method is most suitable to quantify the relationship between historical project data and project characteristics?

A stepwise multiple linear regression analysis is most suitable to quantify the relationship between project characteristics and man-hours and establish work quantification models as input for the new method. A curve fitting analysis is most suitable to establish work timing models that schedule work over a determined basic and detailed engineering throughput time.

4. What is the increased accuracy of the newly quantified relationship(s)?

Ability to measure the accuracy of the developed model is limited. This is a result of multiple problems that are solved simultaneously in this research. It can only be said that the accuracy of work distribution of all work packages has been shown to increase based on a confirmatory analysis.

8.2. Recommendations

Application of spent man-hour data:
Current work forecasts from the new method are fully based on spent man-hour data. It is however known that budget overruns are unavoidable from phenomenon such as Student's syndrome and Parkinson's law. It is therefore recommended to potentially communicate different work schedules with the engineers so that the final executed project ends on the forecasted budget. Furthermore, outsourced work is not retrievable from the data structure. Further research is required into univocal data.

Neglecting organizational and environmental complexity:
The application of the forecast in the 80/80 phase drastically limits available project data. A necessary measure is assuming that organizational and environmental complexity were the same for each historical project in the man-hour database. Therefore, further research is required in methods to quantify organizational and environmental complexity for historic, current and future projects.

Applying linear relationships:
The stepwise multiple linear regression analysis assumes that linear relationships are present between project characteristics and man-hour data. Even though the stepwise multiple linear regression analysis determines the most suitable linear relationships, non-linear regression techniques may result in better forecasts. Therefore research is required in the application of non-linearity in simple or multiple linear regression analysis to compare both results.

Project characteristics versus available data:
Some of the work quantification models contain two project characteristics in a linear relationship. Even though the relationship is calculated to be statistically significant, cautiousness is highly required during application of the models. This has to do with the complicates of interpretation due to multicollinearity. More research is required into the effect of specific project characteristics in relation to others.

High variance present:
Even though the most suitable predictor variables are applied, there is a relative high variance between the observations and forecasts. Further research is necessary into other methods to quantify relationships between historic project data and man-hours. A suggestion is to investigate forecasting possibilities on a lower level than work packages.

Not applying project milestones into work timing
The current work timing models are set up by combining knowledge from engineers and available data. It is however assumed that the start and finish of basic and detailed engineering are a given. Further research is required into timing of project milestones and the current master schedule template. Recommendations following from this analysis will result in a better fit of the established work timing models.

Appendix

List of Figures

List of Tables

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