Study of section & block outfitting to support production planning

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Master's thesis in industrial engineering

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Abstract:

This thesis focuses on providing more accurate and reliable data for production planning of section- and block outfitting in shipbuilding industry through specific installation time –measurements. Additionally, a current state analysis was conducted and process measurements were tested for future implementation. This work may interest readers, who want to know more about the challenges related to outfitting production and see these facts backed up by numbers. From a theoretical perspective, a heavy emphasis is on (key) performance indicators, waste and variation.

The methods for conducting the study are practical by nature but theory is used to explain results. Data has been collected through interviews with stakeholders and measurements have been performed to support the validity of the first mentioned.

The obtained installation times for section and block outfitting are by far the most valuable contribution since they have enabled predicting workloads much more accurately and thereby assisting production planning. All the future yard outfitting schedules are based on the installation times provided in this thesis. In addition, these have been utilized as the basis for calculating future investments. Otherwise, more insight is provided on reporting to information systems, detail design and variation within production.

Meyer Turku aims to double its production pace within the next five years. This study partly enables evaluating the sufficiency of existing development projects, i.e. gap plans. The area phase should be similarly studied, though, to gain a holistic understanding. For the body of existing knowledge on the topic, a new measurement technique: utilization of reference times, adds to practical examples for facilitating work analysis in highly manual circumstances with much variation e.g. metal workshops, in turn saving money.

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Preface

This thesis has been written for the Laboratory of Industrial Engineering within the Faculty of Science and Engineering at Åbo Akademi University in accordance with Meyer Turku –shipyard. The theory revolves heavily around the Lean-concept, most importantly including key performance indicators and the three types of wastes. In addition, effects of variation are considered. There are three major contributions for Meyer Turku: current state analysis on yard outfitting from a production point of view, installation times for most common components to support production planning and future proposal for viable performance metrics.

Ever since starting as a summer worker for outfitting development in 2017, I was intrigued by the shipbuilding industry and the complexity of it. I started out helping in a current state analysis for section outfitting by performing some simple measurements. The following year this evolved into a section outfitting pilot project, where I had the chance to develop key measurements for the project. After the project, I offered to take the analysis further by expanding to study and measure block outfitting. After making sure that no such study already existed, the green light was given. Finally, I am happy to be at this point after almost a year of work.

I am grateful to Meyer Turku for agreeing to conduct this study. I want to give special thanks to my supervisor Timo Aarnio who has not only given valuable advice during the thesis work but also guided me ever since I started working at Meyer Turku. I want to thank him for providing the opportunity to participate in educational seminars and training. Secondly, I want to give a big thank you to Jonas Spohr, who has supervised my thesis from the Laboratory of Industrial Engineering. Despite my wish to write a very practical thesis, he helped me understand the value of theory. After all, "There is nothing as practical as good theory – Kurt Lewin". Furthermore, I am grateful to my father, Jouko Saranki, who has helped me with matters related to detail design and still keeps doing so. Lastly, I want to thank everyone else who has been helping me by sharing knowledge of the shipyard. This is to all the colleagues, area managers, area responsible detail design coordinators, turnkey companies and subcontractors, who have been involved in my study. Thank you!

Toni Saranki 7.1.2020, Turku

Abbreviations

AHP	Analytical Hierarchy Process
BOM	Bill of Materials
COV	Coefficient of Variation
CSA	Current State Analysis
CT	Cycle time
EML	Outfitting during section assembly before painting (fi: *varustelu ennen maalausta lohkonkoonnin aikana*)
EMO	Outfitting during subsection assembly before painting (fi: *varustelu ennen maalausta osalohkonkoonnin aikana*)
EMS	Block outfitting before painting (fi: *varustelu suurlohkokoonnin aikana ennen maalausta*)
EMV	Section outfitting before painting (fi: *lohkovarustelu ennen maalausta*)
ERP	Enterprise Resourcing Planning
HVAC	Heating, Ventilation & Air Conditioning
JIT	Just-in-Time
JML	Section outfitting after painting (fi: *lohkovarustelu jälkeen maalauksen*)
JMS	Block outfitting after painting (fi: *suurlohkovarustelu maalauksen jälkeen*)
KPI	Key Performance Indicator
KRI	Key Result Indicator
PI	Performance Indicator
R	Rounded (spiral duct)
RI	Result indicator
RI	Rounded, Insulated (spiral duct)
SCV	Squared Coefficient of Variation
SOaaS	Section Outfitting as a Service
S&OP	Sales & Operations Planning
TH	Throughput
TK	Turnkey (-supplier)

TOC	Theory of Constraints
WIP	Work-In-Process
σ	Standard deviation
μ	Mean
c_a	Coefficient of variation for arrivals
c_e	Coefficient of variation for effective process time
C_{phase}	Completion percentage for phase
CT_q	Cycle time queue
D	Delay [hours]
T	Time [hours]
t_e	Effective process time
$t_{final,i}$	Final installation time for component i [hours]
$t_{ref,i}$	Reference time for component i [hours]
u	Utilization rate
x_i	Amount of component i [m, piece or kg]

1.0 Introduction

The modern setting of global competition in manufacturing industries is forcing companies to design new production methods to decrease lead times, reduce costs and produce higher-quality goods. Therefore, new development projects are launched in order to reach the future demands. To arrive there, a gap plan is needed between the current and future state. Creating a proper gap plan requires understanding of the company's current state, which is not always clearly known. That is why a company needs to analyze itself. This requires systematic measurements.

The significance of measurements within a company cannot be overstated. By measurements, all kinds of indicators are meant, which provide information about the company's activities, whether it be financial or production-related. One of the earliest measurement techniques was traditional management accounting, which was developed over a period of time from late nineteenth century until the 1920s and 1930s (Maskell, 1991, pp. 45-47). This focuses mainly on financial performance measurements, such as return on investment and cash flow. Due to increased demand on quality, schedule and cost effectiveness in modern business, it is no longer enough to focus solely on financial indicators. Instead, information is needed from the plant floor level to make sure that required quality and other demands can be met. New measurement techniques have been created such as balanced score card by Kaplan and Norton to include both financial and production-related metrics along with customer and learning & growth but there is no single all-around technique to cover the complexity of modern companies' production systems (Kaplan & Norton, 1992, pp. 71-79). According to the literature research done by M. Bourne et al. performance measurement literature is at a stage of identifying difficulties and pitfalls to be avoided based on experience from previous case studies (Bourne, Neely, Mills, & Platts, 2003, pp. 1-24). Therefore, measurements need to be implemented on a case-by-case basis for a company instead of forcing an existing solution.

There is an entire technological branch called knowledge management, which focuses on utilizing measured data from production processes in order to make best possible decisions (Girard & Girard , 2015, pp. 1-2). Data is crucial for planning effective processes. The best example comes from the car industry, where it is measured exactly how long each job takes. Having such data enables a company to understand their capabilities and future improvement needs.

Case: Meyer Turku – Problem formulation

The shipyard of Meyer Turku is in a similar position, where the current state is unclear but the future state is already decided. This is largely due to the strategy of outsourcing work through turnkey contracts, which has diminished the transparency of the process. The few existing measurements are not well maintained and they do not provide enough information for planning production accurately. For example, it is not known how long certain jobs are expected to take, which makes scheduling activities difficult. The shipyard lacks a systematic measurement system for production and currently there is no way to obtain numerical data from the plant floor level.

Meyer Turku needs to approximately double its production pace within the next five years due to the outstanding market situation. This requires investments among other projects. In order to invest in correct upgrades, though, information is needed. Moreover, without understanding the effort required to complete certain jobs, it is difficult to estimate the price of turnkey contracts even though it is subject to market economy i.e. the final price is decided by supply and demand.

Research objectives

To summarize, research objectives are listed below. They are explained more thoroughly in the following chapter “Scope of thesis”.

- Conduction of a current state analysis (CSA) for yard outfitting with a major focus on block outfitting
- Development and testing of process measurements for section and block outfitting including detailed description of the methods utilized
- Measuring installation time for most commonly used components during section- and block outfitting
- Proposal for future measurement process to make needed measurements a part of the production process

Scope of thesis

The first objective is to conduct a CSA on yard outfitting, which is a sub-process of shipbuilding consisting of section and block outfitting with the major focus being on the latter. The shipbuilding process is explained in chapter 3.1 along with outfitting and other shipbuilding terminology. The CSA concentrates on issues from a production perspective and possible causes of issues are studied. The depth of the study depends on whether the issue is internal, i.e. purely within the outfitting organization, or whether it is linked to another organization.

The second objective is to develop new process measurements for yard outfitting and test them. Additionally, the methods are described in detail so that they can be repeated later. This is about providing useful data for outfitting and backing up the CSA with numbers. Possibly of even greater importance is the concept of measurement and understanding which measurements are beneficial and how much effort they require to maintain. All measurements need not be done continuously, instead it might be enough to conduct them annually for a number of targets.

Even though the third objective is a measurement as well, it has been mentioned separately because of its importance. The purpose is to measure the installation times for the most used components in yard outfitting for both section- and block outfitting. Additionally, the ratio between installing components in section outfitting is compared to that of block outfitting. It is not known exactly, how much longer it takes to do the same jobs later in block outfitting for each component.

Finally, there is a proposal for the future measurement process based on the insights gained during the study. Recommendations for implementing the needed measurements as part of the production process are given. The benefits of recommended measurements are discussed and at the same time, the amount of effort required to maintain each measurement is explained.

Structure of thesis

In the introduction, the problem has been shortly described. All research objectives were already listed and they were explained more in depth. Additionally, there is a clarification of the thesis worker’s contribution regarding initial information for thesis. Before diving into the case, some beneficial theories have been introduced. Most importantly, Lean and variation theories are covered. After the theory in chapter 3, the shipbuilding process and useful terminology are explained for readers outside the shipyard. Then, current measurements are analyzed and the needs are identified. Chapter 4 focuses on explaining the measurement methods used along with detailed descriptions of the conduction of each measurement. The results for these are presented in chapter 5 and appendices. With the help of these results and interviews with stakeholders, a thorough CSA is presented about yard outfitting in chapter 6. Chapter 7 illustrates the progress made in production planning and the benefits of the thesis are analyzed there. The last research objective, future measurement process proposal is covered in chapter 8. Finally, there is a critical discussion about the credibility of the thesis and some recommendations for the future are given. The appendices contain all sensitive data from the point of view of Meyer Turku, including e.g. installation times. The version published by Åbo Akademi University does not contain this information. Therefore, the graphs and tables are presented without exact numbers, so that an understanding of the depth of the study can be achieved.

Clarification of the thesis worker's contribution

Originally, a current state analysis was conducted for section outfitting in 2017 with a consultant company and I was part of this project as well. Based on that, a section pilot project was done in the summer of 2018. During the pilot, I planned the measurement methods for obtaining data from the plant floor level. I made two major contributions. I invented a way to measure installation times for different components and, thus, was able to compare the efficiency of work between two different targets. After re-inventing the wheel so to speak, it was discovered that there installation times existed for section outfitting but their measurement methods were unknown, since these were done in the 1980s, 90s and early 2000s. The second contribution was measuring the time workers were able to spend in the section doing work and at the same measuring the amount of non-value adding work due to worksite circumstances.

After the section pilot project, I suggested that I could do a CSA for block outfitting and further improve the measurements I had invented. This started already at the end of August 2018 by discovering that no installation times were ever studied for block outfitting. It was understood from the pilot that work tended to slip forwards due to the challenges in outfitting production and I realized that potentially many unknown working hours were done in block outfitting. Officially, I started the thesis at the beginning of February 2019. The measurements have been designed, performed and analyzed solely be me. Moreover, I planned the measurable targets from scratch and sought out permissions for measuring as well. I have included a few of the section outfitting measurements from the pilot but they are my work, too. Additionally, my focus on CSA is on issues that did not become totally clear during the section pilot project. The pilot had much focus on work planning for section outfitting, while I concentrated more on issues from the point of view of production.

2.0 Theories

Beneficial theories that relate to the measurements and analyzes performed later are presented in this chapter. Firstly, current state analysis is explained and how it should be performed. Secondly, the theory for conducting measurements that help planning single measurements and entire measurement systems is covered. Additionally, the Lean philosophy is introduced in general but special focus is on flow, waste and Key Performance indicators. Variation is covered as well, including statistics for analyzing measurement results. Finally, the very basics of production planning are introduced.

2.1 Current State analysis

Current state analysis is a key business analysis activity which defines the “as-is” state of the business. A usual business analysis strategy consists of a three-phase approach, i.e. current state analysis, future state design and gap plan. Some organizations consider the CSA as a waste of time since the organization does not necessarily learn anything new from the results. However, a thoroughly done CSA helps identify root causes behind the symptoms. Analyzing numerical data from processes, provides quantitative information about the issues and, thus, a deeper understanding beyond the opinions can be reached. Creating a proper gap plan between the current state and future state is close to impossible if the business does not know its current capability. It would be difficult to define the pace of the improvement and, therefore, the set goals might be unreachable within the wanted time frame. The need for the CSA and its depth depends on the initial situation of the organization. (Villemez, 2017)

CSA should include both interviews and numerical data. Interviews are to be conducted with stakeholders who are familiar with either part of the process or the entire process. Therefore, they should be picked so that everyone, from plant floor workers to process owners, is interviewed (P.Nichols, 2015, pp. 2-7). At first, a holistic picture of the investigated process is to be formed. Thus, stakeholders can be recognized and the appropriate questions can be asked from each group, e.g. management or work supervisors. Through interviews, patterns start to form and minor issues can be identified from the major ones. The questions should be asked diplomatically, instead of accusing the person (Crosby, 2017). It is better to ask “What kinds of difficulties are you facing in your process?” rather than “Why can’t you keep up with the schedule?” After all, CSA is about solving the root causes, and not about trying to lay blame on individuals. Additionally, the initial questions should be open-ended, instead of trying to lead the interviewee to answer in a certain way. Again, it is better to ask “Are you facing any challenges in your work?” than “Is some of the material always late?” There could be unknown challenges that are not obvious to an observer at first glance which could lead to limited information. Afterwards, more detailed questions can be asked to help clarify the problem.

However, interviews alone are not enough for a thorough CSA, because people are usually biased one way or another. Instead, the CSA should be artifact-driven, meaning that existing data about the process should be collected and analyzed. This means looking at process designs, operational statistics etc. Even the fact that some critical data does not exist is a finding itself. In that case, it might be required to gather raw data through self-performed measurements. Data helps categorize issues to their right magnitude and that way the most important ones can be chosen for further study. As the CSA is about discovering process-limiting factors, a.k.a. bottlenecks, it is important to keep in mind that usually it is the fault of the process, not the people implementing it. That is why artifact-driven CSA is to be preferred, as it is also much deeper even if it does require more effort. (Villemez, 2017)

2.2 Performing measurements and planning measurement systems

Measurements have a crucial place in obtaining feedback from the production. Parmenter has listed several benefits of the measurements. They help people see progress and, therefore, motivate action; Measurements increase visibility; They facilitate feedback on how tasks are going, thereby providing early warning signals (Parmenter, 2015, p. xvii). In addition, Dean Spitzer has also stressed that employees actually like to be measured but they do not want to be judged subjectively (Spitzer, 2007, pp. 10-11).

Firstly, it is explained how data is actually used and its role in the information systems. Secondly, it is considered how measurement systems should be planned and maintained. Then, there are instruction for planning and executing a measurement.

Lastly, it is explained how data should be utilized, and understanding the importance of analyzing the holistic view.

Basic life cycle of data within a process

The output from performing measurements is data and obtaining data is a constant process. The basic life cycle of data is presented in Figure 1, which is based on Esa Rahiala's description of data in information systems. Raw data is collected on site by measuring workers and machines, or in some cases the machine provides its data automatically. Unfortunately, it is not always possible to gather all of the useful information and the risk for error exists, especially when measuring manual labor. Once gathered, the raw data is transferred to a computer and saved. It can be analyzed, e.g. in Excel or other statistical programs. Other measurements can be calculated from the raw data, i.e. the knowledge is processed further. The limiting factor is the effort required to do the processing. It is preferable to have the raw data inserted to a coded program, which does the processing automatically. Manual processing of data takes time and increases the risk for errors. The processed knowledge can be shared with the ones needing it. They can compare it with the organization's goal values and, thus, make decisions whether further actions are needed. The decisions made affect the original work on site and the cycle starts over. (Rahiala, 1985, p. 54)

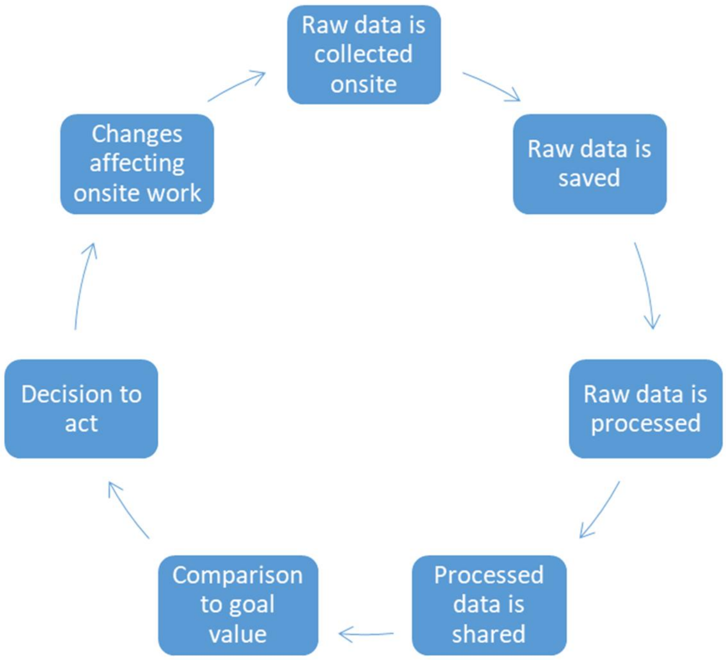

Figure 1: Basic life cycle of data in a process based on Esa Rahiala's description of data in information systems.

The role of the information systems

Larger organizations tend to use an enterprise resourcing planning (ERP) system, which is an information system combining the organization's different functions, e.g. production planning, inventory and accounting. The ERP is modified to fit the organization's processes. Data, e.g. the progress of activities, is periodically reported to the ERP which gives a better holistic view to the management. Accurately reporting the progress made is crucial, because the ERP is only as reliable as the information reported. Due to its integrated nature entering wrong data could have a negative domino effect. Additionally, the ERP requires for everyone to work within the system, not around it. Therefore, all old and informal reporting methods need to be discarded. This requires discipline from the ones reporting. (Umble, Haft, & Umble, 2003)

2.2.1 Planning of a measurement system

Planning a measurement system or otherwise performing a set of measurements needs to be aligned with the organization's goals. The practical implementation of a measurement system is based on the existing information systems and the key is to integrate the old useful data with the new necessary data. This is always company-specific. Companies need different sets of metrics and the practical measurement of these is often unique, i.e. the same metric can be measured differently in two companies.

According to Drucker, there are seven requirements for a measuring system (Drucker, 1974, pp. 340-346).

1. The system should be economical, i.e. only the necessary information is gathered and processed. Anything else is a waste only causing more harm than good.
2. The focus should be on matters that really affect the organization's result. Resources are not to be wasted on less important matters unless an unacceptable level is reached compared to goal value.
3. The measurements need to fit the target so that the data essentially helps decision-making.

4. The accuracy of the measurements needs to be on the right level. Sometimes it is enough to know only the direction of the change, not the exact value.
5. The measurements need to be conducted on a long enough period of time. Otherwise, there is a risk of not acquiring a holistic view.
6. The measurements need to be rather simple, so that anybody involved can understand them.
7. Measuring needs to be operative, meaning it really leads to something. There is no use to perform measurements unless the data is utilized later in decision-making. It is important that information flows to the right recipients, who have the power to make decisions.

Rahiala agrees with Drucker on the importance of focusing on what matters. He has summarized that the method, whether it is manual or computer-based, is of no importance. The simpler the measurements are, the better it is. He also mentions the time it takes to attain feedback and put it to use, i.e. how long it takes for the data life cycle to complete a lap in Figure 1. (Rahiala, 1985, p. 53)

Measurements can be divided into three categories by their focus: product-, customer- or organization-oriented. A measurement system can contain a combination of all three, or be focused on a single measurement category. Examples of the product-oriented measurements include a single product or an entire production volume. The scope can vary. Even the installation of a single component could be measured, or the entire product can be considered. The customer-oriented measurements focus on measuring issues from their perspective, e.g. their order or a part of the order. For example, a manufacturer could be interested in knowing how long it takes to deliver the goods from the start of receiving the order to being compensated. The organization-oriented measurements focus on monitoring the manufacturing, i.e. the use of machines and workers, instead of the goods that are produced. For example, measuring the amount of goods produced in a day by a factory production line is an organization-oriented measurement. (Rahiala, 1985, pp. 57-58) Interestingly, it seems that the product- and the customer-oriented measurements focus on measuring the flow, while organization-oriented measurements focus on measuring the resource efficiency.

Besides the three focuses, measurements can be divided into three time zones according to Parmenter: past, current and future. Past measurements give historic data.

Most of the measured data belongs to this category. For example, measuring the time it takes to do a certain job is this kind of a measurement. Current measurements are all about today. The idea is to be able to react to any situation immediately, e.g. comparison of the expected progress to the actual progress. In this case, the number of workers or machines could be adjusted to try and match the expected progress. Future measurements could be about tomorrow, next week or even the upcoming year. For example, predicting the needed capacity is a future measurement. (Parmenter, 2015, pp. 15-19)

2.2.2 Maintenance of a measuring system

Systematically measuring production requires a well-thought process of its own. The method for performing the measurements needs to be written down, so that they are always performed the same way and, thus, comparable. Rather than performing measurements occasionally, measurements should be performed periodically according to plans. If the measurement is an estimated value, e.g. the time it takes to do a certain job, its validity should be kept updated, so that the future scheduling is successful. If the measurement is critical enough, e.g. the progress of an activity, it has to be monitored continuously. (Rahiala, 1985, p. 59)

In case of a change to the measured process, new measurements need to be performed. Not only need the former values to be updated to match the new process, but possibly even the measurement techniques need to be modified. Possible changes could occur in the goals of production, production systems, organization's resourcing or design parameters. (Rahiala, 1985, pp. 59-60)

In order to make sure that data is collected and recorded approvingly, each measurement activity needs to have a responsible person. One person is responsible for collecting the data and recording, while the next person will analyze that data and pass it on to those who need it. On top of that, it would be beneficial to have a measurement manager, whose responsibility is to make sure that the measurements performed support the organization's goals. The measurement manager takes a more holistic approach to understand what combination of measurements are needed to help follow the production process and give critical information to the top management. (Parmenter, 2015, pp. 258-259)

2.2.3 Planning and execution of measurements

Rahiala has written instructions for planning and executing a measurement. There are five different aspects to consider. First, it needs to be decided what is actually measured and how the measurement is defined. The definition must be articulate. Whether something is included, or not, it must be mentioned. This way the future measurements can be conducted the same way by someone else and, thus, the results can be compared. (Rahiala, 1985, p. 59)

After defining the measurement, it is crucial to think about the execution. Essential questions such as: “How is the data collected?” and “Where can the required starting information be found?” need to be answered. Additionally, the process of calculating processed data from the raw data needs to be documented, so that calculations are done similarly. Another relevant matter is the accuracy of the measurements and the processed information. There is no use in trying to strive for a greater accuracy than the measured target allows. Finally, the effort of measuring needs to be considered. Is the benefit gained worth the required effort? (Rahiala, 1985, p. 59)

The way a measurement is performed directly affects the results, e.g. the timing of the measurement. For example, it is common that people work harder closer to the deadline, a.k.a. Student’s syndrome. Some days, workers are more productive which affects results more in a manually heavy labor. Some people get nervous when being watched closely and, therefore, perform worse while others work harder to try and show off. Additionally, the number of workers doing the same job, or otherwise working in the same area, has an effect on the working efficiency. This is known as production function theory (Solow, 1957).

Processes include different amounts of variation. The causes for variation, inside and outside the measured process, need to be documented (Piirainen, Aikavaihtelu, 2014, pp. 9-10). Ideally, the effect of each cause is identified but determining the exact impact of each cause separately, requires significant effort. Besides, it might be almost impossible if circumstances around the measured targets keep changing. If there are permanent changes to the process, the measurements need to be updated to match the changed circumstances.

Lastly, it needs to be decided, who are to receive the information and in what kind of format. Additionally, the time it takes to distribute the processed data to those who need it, could be of importance, especially if direct action needs to be taken. Reporting needs to serve the purpose of enabling controlled production but, at the same time, it needs to be as light as possible so that only the necessary information is distributed. (Rahiala, 1985, pp. 62-67)

2.2.4 Using the measured data correctly

Often, an organization has set itself a target value, i.e. a future state, which they try to reach by making changes in the production. Rahiala has mentioned that measurements can serve a different purpose. Striving to keep the measured target between two parameters at all times would be an example of a controlling measurement, which has a pre-determined allowed variation range. As long as the measurement stays between the two desired parameters, no action needs to be taken. Depending on the measurement, it could also be an estimate, which validity is being tested and improved over time, e.g. measuring the time it takes to do a certain job and, then, using the average as a planning parameter. In this case, monitoring would be focused on how close the current average is compared to the actual working time. Also, the deviation from the estimate could be monitored so that further statistical analysis could be performed. (Rahiala, 1985, p. 63)

Sub-optimization is a real danger if the impact on the entire process is not understood. The same applies to using the measurements for decision-making. Usually, more than one measurement is needed, because one indicator might not tell the whole truth. The connections between the indicators need to be understood, since each indicator only tells part of the story. In the worst case, if a company focuses solely on improving one metric and rewards employees for reaching it, this could encourage gaming of the particular metric. James P. Ignizio criticizes this approach in his book, *Optimizing Factory Performance*. He has written a fictive case in every chapter of his book and one of them is about maximizing the utilization rate of workers and machines in a factory. In its entirety, this is a very counter-productive action. As a result, the cycle times increase and the work-in-progress grows beyond control. It has been shown that no real factory can be operated at a 100% utilization rate due to variation (Piirainen, Vaihtelu, 2014, pp. 84-91). In order to keep all the employees busy at all times, enough material needs to be available for everyone to work with. In the end, the results were catastrophic for this factory, since orders could not be finished in time and the factory ran out of space. (Ignizio, 2009, pp. 208-217)

2.3 Lean

Lean's popularity as a concept has skyrocketed during this millennium, even though it has received criticism for its image as a cost cutting philosophy. In the end, it is up to the organization to find the correct way to utilize Lean. Lean offers some ready-made principles and methods, but the final adaptation between the theory and the practical operations is often troublesome, since the solutions that fit Toyota in the past might not fit other companies without modifying the methods. (Modig & Åhlström, 2013, pp. 145-146)

Firstly, Lean is defined and a general overview is provided through its four abstract levels. One of Lean's core principles, flow, is examined closer. Then, two Lean methods, Waste and Key Performance indicators, are discussed. At the end, correct implementation of Lean is discussed and an example of wrongful implementation is presented.

Lean definition

There is no single definition for Lean which is proofed by Jaiprakash Bhamu's and Kuldip Singh Sangwan's literature review, who reviewed 209 research papers written about Lean manufacturing (Bhamu & Sangwan, 2014, pp. 876-882). Generally, Lean revolves around prioritizing flow and eliminating waste. The right amount of goods are to be processed at the right time with the right quality and with minimal stocks. The depth of the definition varies, i.e. some see it as a philosophy and a culture, while others regard Lean as a means to an end.

2.3.1 Lean pyramid – the four abstract levels of Lean

According to Nicklas Modig and Per Åhlström, Lean should be divided into four abstract levels: values, principles, methods and tools & activities. Together they form a pyramid, where the values are at the top and the tools & activities are the bottom. Figure 2 is re-drawn based on the Lean pyramid from their book, "This is Lean". Examples of each level have been added to the figure.

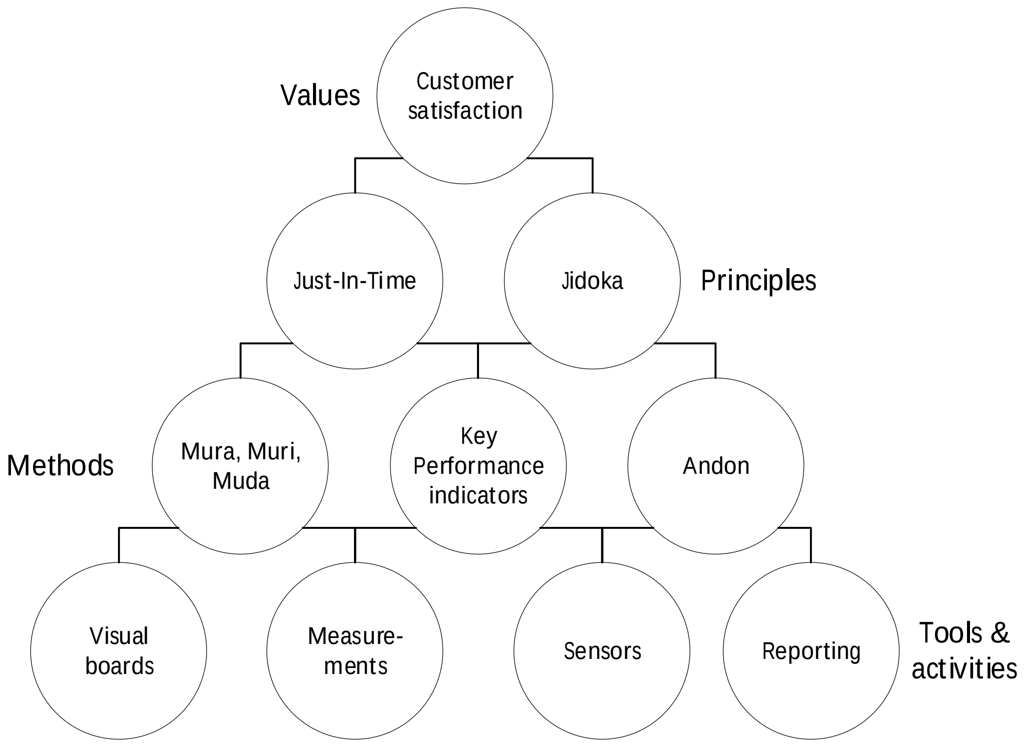

Figure 2: Lean pyramid showing the four abstract levels and examples of each level.

Values define how an organization should act regardless of the situation. They help to create the organization's culture and they are the very foundation of it. For example, Toyota Motor Corporation's most important value is the satisfaction of customer needs, and all the decisions made within the organization have to support these values. In order to define the organization's values, it needs to be decided, what are the most important concepts. It is possible to have more than one value but the values cannot be conflicting.

To make sure that all activity supports the organization's values, principles are needed to help in the decision-making. They decide what the organization should prioritize. Figure 2 shows Just-in-time and Jidoka, which are principles created by Toyota. JIT is about delivering the right amount of product at the right time and, thus, creating flow inside the process. Jidoka supports JIT by creating a more transparent organization. Everyone should see the bigger picture and, thus, be able to make decisions supporting the entire process instead of sub-optimizing a part of it. Originally, Womack and Jones introduced the five principles of Lean manufacturing in their book “Lean-thinking: Banish Waste and Create Wealth in your Organization”. By identifying the customers and specifying value, the manufacturer knows to produce goods of right quality, i.e. the value that the customer is willing to pay. Mapping the value stream helps to divide the activities into three categories: value adding, non-value adding but necessary, non-value adding and unnecessary. The last one can be targeted for removal. Creating flow through the elimination of waste helps dispose excess processes that do not add value to the customer. Responding to the customer pull enables to produce the right amount of goods at the right time. The last of the five principles is pursuing perfection. Lean is about continuous improvement and the goal is to establish such organizational culture becoming “just the way things are done”. (Womack & Jones, 1997), (Ciarniene & Vienazindiene, 2012, pp. 726-731)

Methods, in turn, are needed to implement the principles. They describe what to do while trying to act according to the principles. Methods are a result of identifying patterns within the production. Probably the most important method is standardization, which helps reduce variation (reducing variation is a principle). There are over 30 methods related to Lean. Some of them are: Muda, Andon, Key Performance Indicators (KPIs) etc. Usually, a combination of them is used to reinforce the desired principle. It is important to choose the methods fitting the process. It is a common mistake to try and force a method on a problem, instead of the other way around.

Tools & activities are at the lowest level of the pyramid. They execute the methods. An example of a tools includes visual boards above production lines, while updating the board is an activity. That is a rather simple example of implementing Andon, a method for visualizing the production process for workers on the plant floor. The visual board could show information to workers, such as the status of production and possible stoppages.

Implementing the Lean philosophy starts from the top by identifying the organization’s values. The principles make sure that organization’s values can be upheld when making decisions. The methods describe how to reinforce the principle by using the best practices. Finally, the methods are put to use through tools & activities. Implementing Lean takes time. Philosophically, it is a never-ending process, since the idea is to do things better than yesterday. An organization does not become Lean when a project is finished and the set goal is achieved. Instead, it has to keep reaching for the star, even though it can never be reached completely. (Modig & Åhlström, 2013, pp. 99-107)

2.3.2 Lean principle: flow

Concentrating on the flow means following a product through the process and trying to maximize the value added time, i.e. the product does not wait to be processed for long periods of time (Melton, 2005). There are three laws that explain, why it is difficult to increase the flow. These are Little’s law, Theory of Constraints (ToC) and variation. Variation is covered separately in chapter 2.3.

Little’s law

Little’s law is an equation for relating throughput (TH), work in process (WIP) and cycle time (CT). Little’s law can be written as follows.

$$WIP = CT * TH \qquad (1)$$

Throughput is the number of products produced in a certain time, e.g. [products per hour]; Work in process is the number of products under processing, e.g. [products]; Cycle time is the average time it takes for one product to be processed, e.g. [hours]. For example, if the goal is to double the throughput, then the cycle time needs to be halved, so that the work in process would stay the same. (Piirainen, Vaihtelu, 2014, pp. 84-85)

Theory of Constraints

The second law limiting the flow is the Theory of Constraints, which refers to a bottleneck in a process. A bottleneck slows the flow and that way the entire process is slowed down. The process is as fast as its slowest part. Two characteristics define a bottleneck. Firstly, a queue forms before the bottleneck and, secondly, the workstations after the bottleneck need to wait for more work to come from the downstream. It is to be noted that there is always a bottleneck present in a process, which keeps limiting the flow. By investing to the current bottleneck, a new one appears somewhere else, since, then, that is the slowest part of the process. There are two reasons for the forming of bottlenecks. Firstly, a process usually needs to be done in a certain order, e.g. painting of a surface cannot be done before it is polished. The second reason is variation. (Modig & Åhlström, 2013, pp. 37-39)

Resource efficiency vs flow efficiency

Originally, organizations have focused on maintaining a high resource efficiency, and they believe that by using resources effectively, they can come to the best results. However, this is not always true, because production optimized by resource efficiency usually leads to lengthy throughput times which, in turn, result in large amounts of WIP (work-in-process). The inventories are large and, thus, a lot of capital is invested. Lean is about shortening the process time through using enough capacity to complete the tasks quickly which leads to better customer satisfaction (they get their products/services faster) and smaller WIP. Once the flow efficiency is deemed good enough, resource efficiency can be optimized to fit the new, faster flowing process. The change from a resource efficient company to a Lean abiding company is illustrated in Figure 3.

There are four areas: Wasteland (low resource efficiency, low flow efficiency), Efficient islands (high resource efficiency, low flow efficiency), Efficient ocean (low resource efficiency, high flow efficiency) and Lean, the perfect state (high resource efficiency, high flow efficiency). The star in the chart marks the perfect spot, which is the goal but can never be reached due to variation in the process. Every process has variation either from outside or inside and most likely both. The arrows in the figure show how the transformation from high resource efficiency / low resource efficiency must go through the Efficient ocean first (Modig & Åhlström, 2013, pp. 99-107).

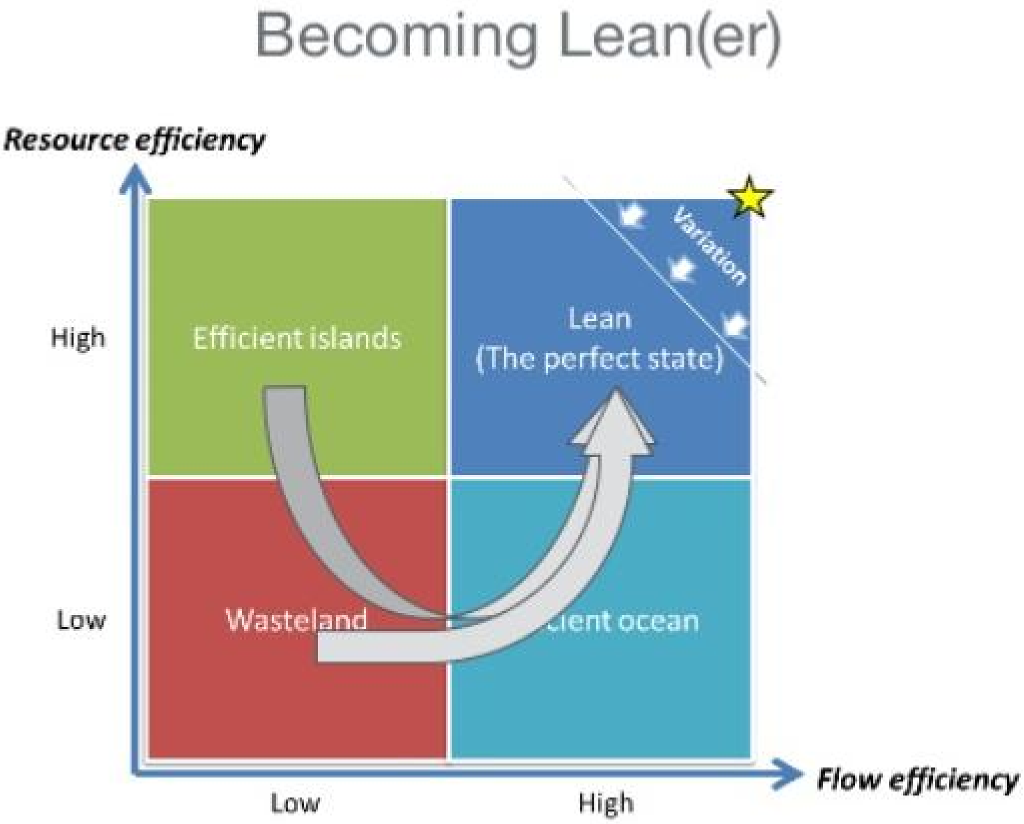

Figure 3: The journey from a traditional, resource efficient organization to a Lean organization.

2.3.3 Lean method: three types of waste – Muda, Muri and Mura

The elimination of waste is one of the most important principles in Lean manufacturing. In order to eliminate waste from processes, it has to be recognized first, which is not as simple as it sounds. It helps to categorize waste into three different types: Muda, Muri and Mura. By understanding the connections between these, it is possible to eliminate waste both on the factory floor and prevent it in the first place. (Pienkowski, 2014, pp. 1-16)

Muda is the easiest type of waste to detect. It means activities that do not add value to a process, i.e. anything that the customer is not willing to pay for. Although, there are activities that are necessary for the process, e.g. periodical maintenance which simply cannot be eliminated. Originally, Taiichi Ohno defined the seven types of Muda in his book "Toyota Production System – Beyond Large-Scale Production" (Ohno, 1988):

1. Overproduction – producing more than needed is waste
2. Excessive inventory – strains warehouse operations
3. Inappropriate or non-value added processing - eliminate needless operations, use best practices
4. Waiting – time and resources are wasted
5. Transportation – unnecessary material movement is waste
6. Unnecessary motion – redundant movement by operators, everything should be close at hand
7. Defects – cause significant harm and the need to re-do the work

There is also an 8th source of Muda which is untapped employee creativity. Often, the ones doing the work at factory floor have the best ideas about improving the process. To not utilize that free knowledge inside the organization, is pure waste. (Pienkowski, 2014)

Muri means overburden or unreasonableness and it is tied to the improper use of capacity. It goes both ways, i.e. workers and machines can have either too much or too little to do. Both are bad, and result in Muda. On one hand, not having enough work to do leads to idle time or waiting, one of the seven types of Muda. On the other hand, not having enough capacity leads to other types of Muda. This causes, for example, extra stress for machines and workers, reducing their ability to perform. Skipping maintenances will lead to breakdown of a machine. Repairing the damage will cause idle time for workers and it will cost extra funds, which are both unnecessary. There are three main causes of Muri: poorly organized workstation, lack of standard work and Mura, variation in the production volume. (Pienkowski, 2014)

Mura means variation or unevenness in the production volume. There are two different forms of it, variation in the production scheduling and uneven production workload. As mentioned earlier, variation hinders efficient manufacturing. Mura is the most difficult type of waste to detect. It is usually the root cause for other types of waste. Mura needs to be taken into account already when designing or modifying a process.

Pienkowski stresses the importance of recognizing waste not only as Muda, but also as Mura and Muri, because they are all connected. Ignoring the other two is like firefighting. Reducing Mura leads to a reduction of Muri and, thus, Muda. This is illustrated in Figure 4.

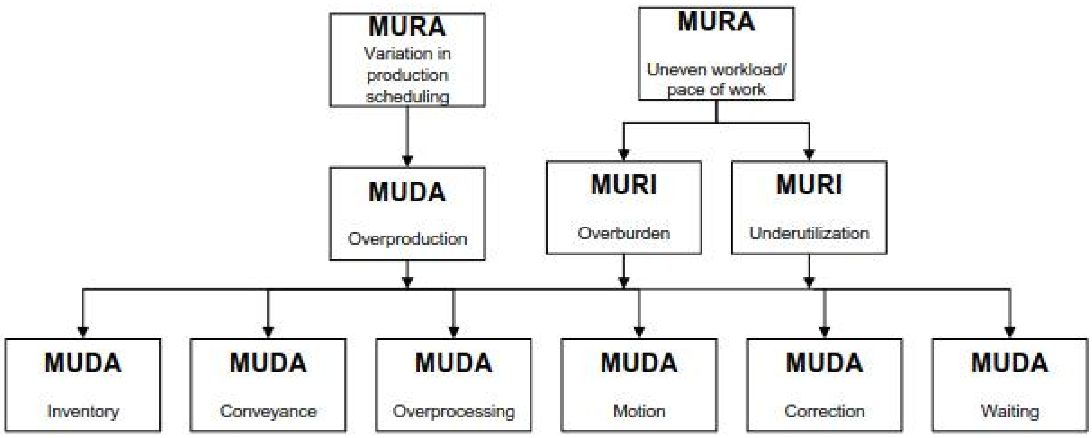

Figure 4: The connections between Mura, Muri and Muda.

2.3.4 Lean method: Key Performance Indicators

There is a considerable link between the KPIs and knowledge management. There exists a few methods for choosing the KPIs. The Balanced Scorecard was already mentioned in the introduction. Another one is AHP-SMART approach which combines analytical hierarchy process (AHP) with SMART-criteria for measurements developed by Shasin & Mahbod (Shasin & Mahbod, 2007). SMART stands for goals that are: Specific, Measurable, Attainable, Realistic and Time-sensitive. The selection of right KPIs enables successful knowledge management.

Four types of performance measurements

It is a common misconception to say that all measurable targets are key performance indicators (KPIs). There are also performance indicators (PIs), key result indicators (KRIs) and result indicators (RIs). The main difference between the key result indicators and the key performance indicators is that the KPIs are non-financial. The KRIs usually measure financial numbers but are not limited to them, such as customer satisfaction. For example, profit is a result of many factors. One cannot pinpoint the cause to exactly one reason or one team, unlike KPIs. The KRIs could show that the profit is negative, but they do not tell wherein the reason lies. The difference between the KPIs and the PIs is that the first mentioned is critical for the organization, while the latter should not be completely ignored though. (Parmenter, 2015, pp. 3-8)

Lead and lag indicators

Often, lead and lag indicators are linked to the KPIs. The Lead indicators are about predicting the future, while the lag indicators look at the past performance. Generally, it is better to focus on the lead indicators, i.e. future measurements, since they enable prevention of harmful effects through giving time to react. Then again, the lag indicators are closer to the result indicators, since financial measurements are past-oriented. However, Parmenter is of the opinion that the lead and lag indicators are not a useful way of defining KPIs, because a measurement can be both. He provides an example of a late plane arriving to airport that needs to depart for the next flight. The fact that the plane is arriving late is a lag indicator but at the same time it is a lead indicator for the airport staff, since the tighter schedule will cause problems for them. (Parmenter, 2015, pp. 8-10, 15-18)

The seven characteristics of KPIs

The key performance indicators and the performance indicators are designed to measure the production process. By monitoring them, it is possible to say why the profit was negative. It could be the cause of bad efficiency or poor quality management. David Parmenter has excessively researched KPIs and presents the seven characteristics of KPIs in his book, “Developing, implementing and using winning KPIs” (Parmenter, 2015, pp. 11-14).

1. Non-financial measures – Converting a measurement to money makes it a KRI
2. Timely – Measured frequently (24/7, daily, weekly)
3. CEO focus – Acted upon by management when deviations occur
4. Simple – Everyone is able to understand the measurements and possibly come up with way to improve
5. Team based – Responsibility and instructions can be tied down to a team or a group of teams
6. Significant impact – impacts more than one critical success factor
7. Limited dark side – Poorly thought out measures can lead to dysfunctional behavior

The last characteristic is considered deeper, since, often, KPIs are misused as part of a rewarding system. Ignizio agrees with Parmenter about the limited dark side. KPIs should never be used as a basis for a rewarding system. This encourages employees to focus on the said metric and ignore the holistic view. Even worse, the gaming of metrics likely occurs so that the reward is earned (Ignizio, 2009, pp. 215-217). Dean Spitzer has presented many examples regarding this and one of them is shortly described. A fast food restaurant manager wanted to win an award for having zero wastage of chicken. To achieve this, he told the staff to start cooking the chicken once the customer had ordered it. He won the award but customers disappeared due to the long waiting times. (Spitzer, 2007, p. 24)

Performance measurement template

Parmenter has introduced performance measurements in a template, where all the important information for the measurement is listed: frequency of measurement, time zone, teams that would use the measurement, strength, feasibility and sector(s) that would use the measurement. The strength is stated at a scale from one to five, where "5" is strong and "1" is weak. The feasibility is given at a similar scale. "5" is very easy to implement; "3" requires additional actions so that data can be gathered and "1" means that the data is very difficult to gather. An example of the template is shown in Figure 5. Note that this figure has been re-drawn without the exact measures listed. (Parmenter, 2015, pp. 351-360)

Measure	Frequency of measurement	Time Zone	Strength	Feasibility (effort required)	Teams that woul use the measurement	Sector(s) that would use the measurement

Figure 5: David Parmenter's performance measurement -template.

2.3.5 Implementing Lean

The definition of Lean has created a lot of confusion and it is understood wrongly quite often. Lean is about much more than implementing a single method. It is a production philosophy. Many companies have tried to implement the Lean-philosophy in their processes, but according to Bhasin and Burcher, only 10 percent or less have succeeded. This is mostly due to trying to implement some of the Lean methods without understanding the holistic view, which could lead to sub-optimization, and possibly do more harm than good. Cost cutting is usually a part of trying to get rid of waste. However, cutting costs in wrong parts of the process may cause significant damage. (Bhasin & Burcher, 2006, pp. 56-72)

Besides technical requirements, e.g. the correct use of multiple Lean methods, another important aspect is the organization's culture according to Bhasin & Burcher. Without everyone's embracement, especially the senior and middle level managers, the implementation of Lean is doomed to fail. Lean forces the organization to re-design their entire processes and only a few organizations are ready to face such a challenge. Getting the re-designed processes to run smoothly takes time which might initially put the organization in a bad position. That is why Lean is regarded with skepticism in many organizations. However, Modig & Åhlström are more of the opinion that the organization does not need to implement Lean on all four abstract levels. Instead, the organization might only choose to implement a few of the Lean methods. According to them, the reduction of variation is the most important goal. An organization should use the methods that fit their needs the best. (Modig & Åhlström, 2013, pp. 155-157)

2.4 Variation

The obstacle for reaching perfection in a manufacturing process is variation, and it is always present. There is variation from both inside and outside the system. Firstly, the manufacturing system's "formal reason" is explained. Secondly, terms *accuracy* and *precision* are covered which can be used to analyze variation in the measurement results. Then, two types of variation are discussed, random and non-random variation. Additionally, some helpful statistics are introduced, e.g. empirical rule. Finally, possible methods for dealing with variation are briefly explained.

2.4.1 Manufacturing system's "formal reason"

No matter the process, there are always two critical elements: *demand* and *transformation*. Demand means the need of an inner or outer customer. A customer wants a certain product with a certain quality and within a certain time frame. In turn, transformation means converting starting capital to a product or a service by adding value to it. *Value* is defined as a characteristic that the customer is willing to pay for more than producing it costs. It is estimated that only 0.1 – 10.0% is value adding work, and the rest is wasted due to variation. Additionally, two primitive elements are needed: *flow* and *stock*. Flow is the motion of material or resources through the transformation process. Stock presents materials or resources that are waiting for the transformation. In a perfect world, demand and transformation are fully compatible, i.e. transformation fulfills the demand exactly without any waste. Therefore, no stocks would be needed and the utilization rate would be 100%. However, this is never truly possible, because there is always some waiting. It is either the customer, material or workers, who has to wait. (Piirainen, Vaihtelu, 2014, pp. 9-12), (Ignizio, 2009, pp. 127-131)

2.4.2 Sources of variation – Accuracy and precision

The sources of variation can be divided into two different categories: *accuracy* and *precision*. Accuracy means the deviation from the average target value. Respectively, precision means the deviation within a group of measurements, i.e. consistency. This is useful for analyzing possible errors in the measurement results. For example, having accurate but imprecise measurement results means that the average target value is good but the process includes much variation. On the contrary, having inaccurate but precise measurement results means that the original average target value is incorrectly estimated but luckily, the process includes little variation. This is illustrated in Figure 6. (Piirainen, Vaihtelu, 2014, pp. 79-80)

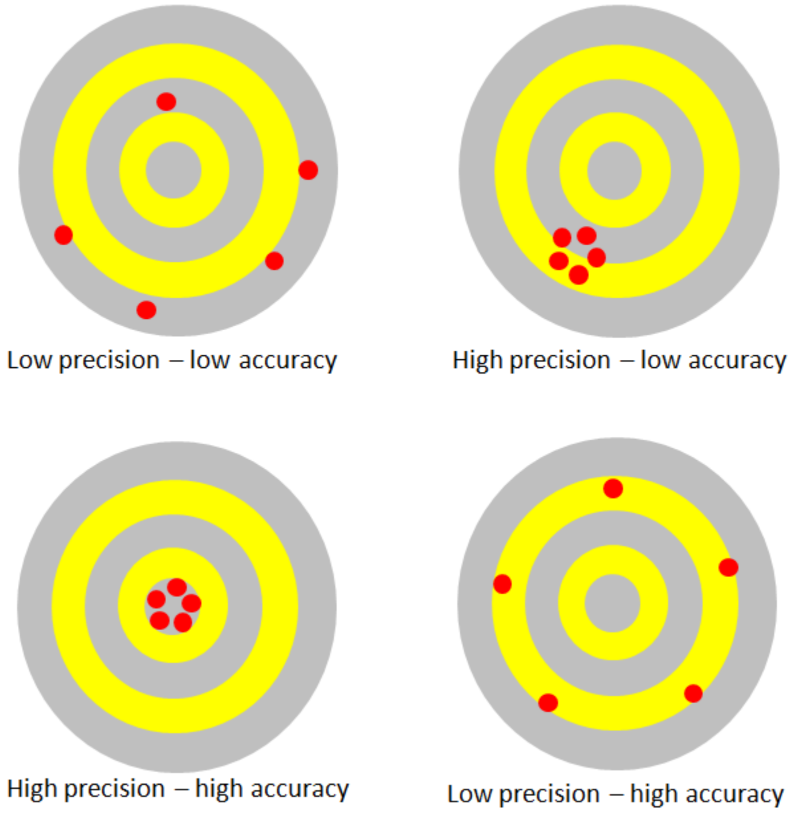

Figure 6: Terms *accuracy* and *precision* illustrated.

2.4.3 Random and non-random variation

Variation can be divided into *random* and *non-random variation*. Random variation is also known as “Noise”, “Natural Pattern” or “Non-assignable cause”. This occurs in systems, where several variables are dependent on each other in different circumstances, but the effect of each variable is impossible to determine. For example, manual labor always includes some random variation, since workers have different sets of skills, and daily motivation varies. Random variation is smaller than non-random variation, i.e. the standard deviation is smaller. When a process includes only random variation, it is predictable according to the empirical rule.

Non-random variation is known as “Unnatural Pattern” or “Signal”. It happens, when there is an observation which deviates considerably from the average, and there is a single reason behind it. For example, an unexpected breakdown of a machine could be the cause of this. Therefore, the standard deviation is bigger. The processes including non-random variation are unpredictable. Samples deviating more than 3σ are very likely affected by non-random variation. (Piirainen, Aikavaihtelu, 2014, p. 57)

Wheeler has created a process for dealing with both types of variation. Firstly, the type of variation needs to be recognized. If the variation is non-random, the reason needs to be studied and the process needs to be stabilized. This is a matter of problem solving. However, if the variation is random, it must be determined if the outcome is acceptable. In case it is not so, the process needs to be possibly re-designed and investments made. The latter is a matter of improvement. (Wheeler, 2010)

2.4.4 Statistics

Empirical rule

The *Empirical rule* is a statistical rule which states that almost all data is within three standard deviations of the mean. This is also known as three-sigma-rule or as 68-95-99.7 –rule. It is only applicable if data is assumed to be normally distributed or as more commonly referred to Gaussian by its developer. According to the *Central Limit Theorem*, a sample size of 30 is often enough to say that data follows normal distribution. The bigger the sample size, the better it will imitate normal distribution (Chase & Bown, 2000). *Standard deviation* is usually marked with a σ-symbol. The empirical rule has defined that 68.27% of measurement results fall within a +/- 1σ–range, 95.45% within a +/- 2σ–range and 99.73% within a +/- 3σ–range. Additionally, there are probabilities defined for +/- 4, 5 and 6σ but 3σ is almost always enough. The empirical rule and its probability thresholds are illustrated in Figure 7. The equation for normal distribution is shown in equation 2, where μ is the mean and σ is the standard deviation. (Piirainen, Vaihtelu, 2014, pp. 51-53)

$$f(x) = \frac{e^{-(x-\mu)^2/(2\sigma)^2}}{\sigma\sqrt{2\pi}} \quad (2)$$

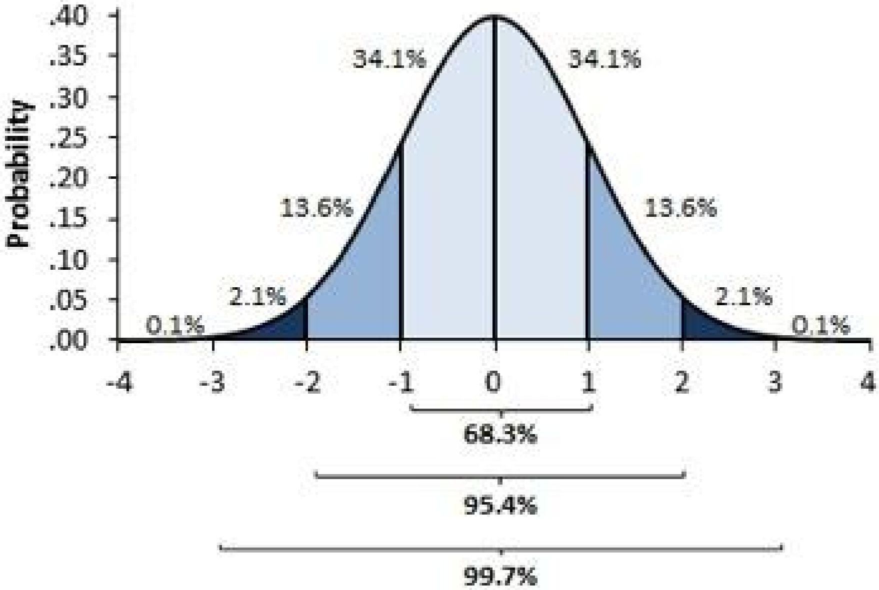

Figure 7: Empirical rule and Sigma's probability thresholds.

Coefficient of variation

The *coefficient of variation* (COV) describes the proportionality of the standard deviation and the mean. This is shown in equation 3. It is better to analyze the relative deviation than the absolute deviation. Another possibility is to use the *squared coefficient of variation* (SCV) but COV is often utilized. Equation 4 shows how to calculate the SCV. (Piirainen, Vaihtelu, 2014, p. 52)

$$COV = \frac{\sigma}{\mu} \quad (3)$$

$$SCV = \frac{\sigma^2}{\mu^2} \quad (4)$$

2.4.5 Kingman's formula

Kingman's formula, a.k.a. the VUT-equation, describes the relation of cycle time in queue, variation, utilization rate and process time. It is shown in equation 5, where CT_q is the cycle time in queue, c_a is the coefficient of variation for arrivals, c_e is the COV for the effective process time, u is the utilization rate and t_e is the effective process time. V is the variation component, U is the utilization rate component and T is time component. It is important to realize that changing any of the components has an effect on the cycle time (Kingman & Taylor, 1966).

$$CT_q = \left(\frac{c_a^2+c_e^2}{2}\right) * \left(\frac{1}{1-u}\right) * t_e = VUT \tag{5}$$

For example, if the utilization rate is raised from 70% to 95%, the cycle time would increase 7.14 fold. Firstly, U-components are calculated for both rates: $U(70\%) = \frac{0.70}{1-0.70} = 2.3$ and $U(95\%) = \frac{0.95}{1-0.95} = 19$. Then, dividing U(95%) by U(70%) gives 7.14. Kingman's formula proves that increasing the utilization rate raises the cycle time even more unless variation can be reduced. (Piirainen, Vaihtelu, 2014, pp. 76-77)

2.4.6 Dealing with variation

There are two methods for dealing with variation. Preferably, variation is to be reduced, because the other option, utilizing *buffers*, requires extra funds. Unfortunately, reducing variation is not simple and may require redesigning of entire processes. The simplest method for reducing variation is to set up tolerances, i.e. the value may vary between two parameters. When the tolerance is crossed, the reason is hunted down and corrections are made. However, this has limited utility according to Shewhart since deviations tend to increase despite trying to fix them (Shewhart, 1939). Secondly, *statistical process control* (SPC) has been utilized to identify random variation, which is based on utilizing the empirical rule. Then, non-random variation can be identified in case the measurement is outside of the 3σ-range. The latest advances have taken place in *Lean Six Sigma*, which focuses on reducing random variation through design experiments.

There are three kinds of buffers: additional time, stock and capacity. Utilizing time as a buffer means that the customer or material waits. Investing in additional capacity means that the utilization rate decreases, since there is more idle time for workers and machines. Lastly, increasing stock size means that more space is needed and more capital is tied to WIP. Choosing to utilize correct buffer(s) is important. For example, if business is time-sensitive, both additional stock and capacity can be used. Trying to increase productivity through increasing the utilization rate would be a very bad move, since there would be even more WIP. (Piirainen, Aikavaihtelu, 2014)

As was seen in Figure 3, optimizing resource efficiency minimizes flow efficiency and vice versa. Therefore, Piirainen has concluded that it is not sufficient to optimize one or the other, instead an optimal balance should be found between the two parameters. However, reducing variation enables a potentially higher productivity, i.e. it is possible to get closer to the star. (Piirainen, Vaihtelu, 2014, pp. 132-136)

2.5 Production planning

The purpose of production planning is to plan and manage the need of material and capacity based on customer demand, so that production can satisfy the customer's needs with quality and efficiency. Basically, there are three levels to this: sales and operations planning (SOP), production planning and shop floor control. The purpose of SOP is to fit demand with production through utilizing information from customer orders, forecasts and market information. This can take place even 12-18 months before production start (45th Anniversary seminarium for Suomen Tuotannon Ohjaus -yhdistys, 2019).

Based on the demand plan, a production plan, a.k.a. master production plan, can be made. This includes both material and capacity requirements. Existing material in stocks and incoming material should be considered as well. Capacity refers to the number of needed workers and machines, but it could also include logistics capacity. Finally, a production order is made based on these two to the company's information systems.

The last level of production planning consists of ordering material. Moreover, a fine level plan is made, which includes a final schedule. This could be at an accuracy of one day or even a work shift. Finally, production is controlled at shop floor level with either visual tools, supervision, information systems or a combination of these. The production planning process is depicted in Figure 8. (Jacobs, Berry, Whybark, & Vollman, 2009)

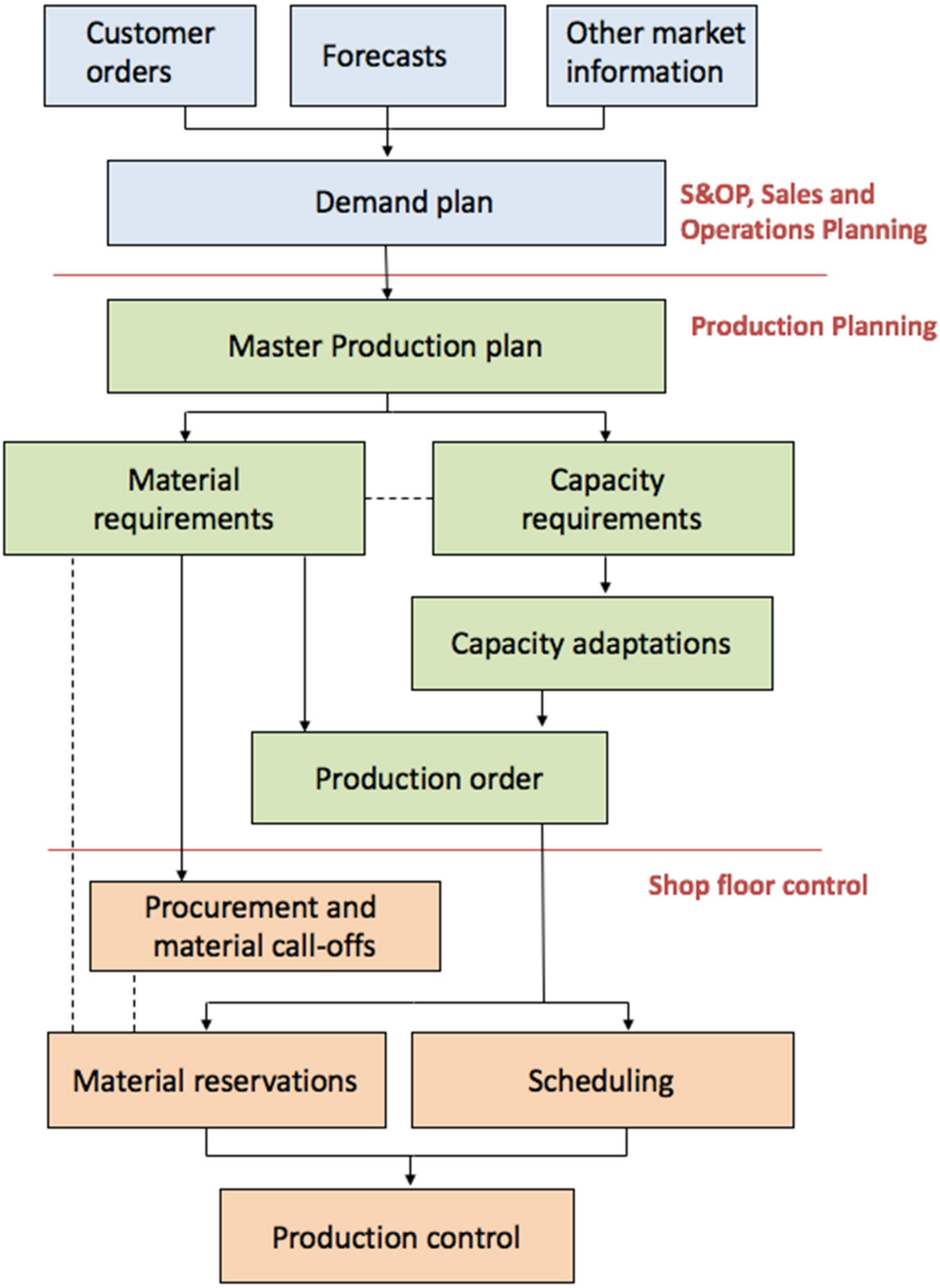

Figure 8: Production planning –process.

3.0 Current and needed process measurements for yard outfitting

Firstly, some shipbuilding terminology is explained. Then, the current measurements from shipyard's information systems are analyzed. Afterwards, needed measurements are covered and finally, the information users are discussed.

3.1 Overview of shipbuilding and Meyer Turku

Firstly, the shipyard of Meyer Turku is introduced and then some crucial terminology for shipbuilding is explained. The following terms are explained with necessary detail: outfitting, areas, turnkey suppliers, background outfitting process, outfitting phases and outfitting building method.

Meyer Turku

Meyer Turku is a shipyard located in southwestern Finland and it has been family-owned by Meyer family since 2013. The original Turku shipyard was founded already back in 1737. Nowadays, Meyer Turku specializes in building highly complex, innovative and environmentally friendly cruise ships, car-passenger ferries and special vessels, e.g. icebreakers. It is one the Europe's leading cruise ship builders with a turnover of 969.7 million euros in 2018. Due to the growing amount of cruise ship passengers, the market for shipbuilding is in a state, where demand is larger than capacity. Cruises are constantly sold out and the demand for cruising has increased by 20.5% over the past five years. In 2017, there were a record 25.8 million passengers globally (2018 CRUISE INDUSTRY OVERVIEW). That is why Meyer Turku's order book is full for the upcoming years.

Hull and Outfitting

Today, modular way of construction is vital in the shipbuilding business. Ships are pre-fabricated in small parts called sections. Sections are then combined to a larger unit called a block and these blocks are finally lifted to the dry dock for eventual hull assembly by welding. Hull production is responsible for construction of the hull while Outfitting takes care of installing HVAC, electricity, insulation material and all other equipment and systems. Outfitting is divided further to visual and background work. Visual work is done after background work and it includes e.g. draping. Background work is done after section assembly, during block assembly, after block assembly and onboard.

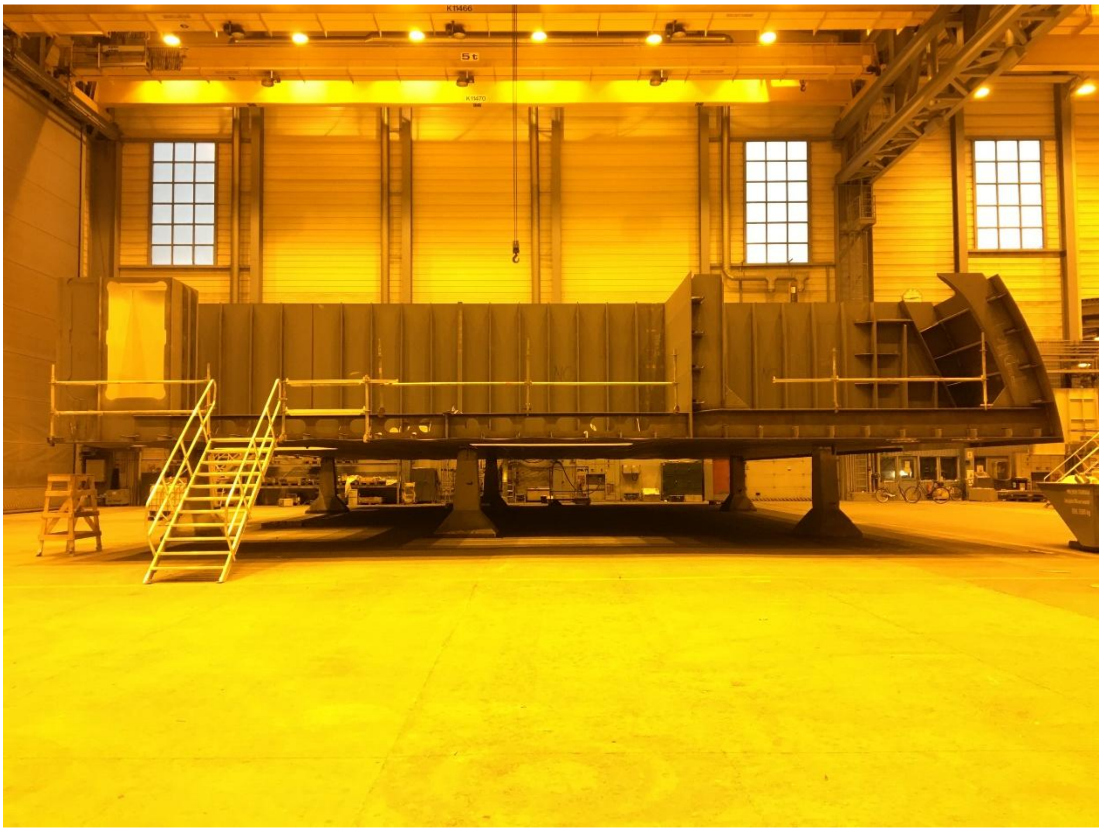

Figure 9: A section upside-down in EMV-outfitting.

Figure 10: An assembled block in EMS.

Figure 11: Blocks are lifted to dry dock for assembly, where area outfitting starts.

Areas

On the contrary to the hull production, outfitting has divided the ship into different areas instead of sections and blocks. An area is a small part of the ship, e.g. a restaurant or a single AC-room. The areas are shown in a ship project's area partition drawing which is a rough level blueprint of the layout including each deck. The areas are not synchronized to the sections, i.e. an area can be divided into several sections or, the other way around, an area can only be a small part of the section. There are six area groups: cabin, machinery, deck, technical, service and public areas. Additionally, there are about 30 area types, e.g. lifts, staircases, crew cabins and pantries. Altogether, a ship can have as many as 400 areas.

Supply chain for outfitting

Meyer Turku has decided to follow a strategy of buying turnkey deliveries from companies specialized in outfitting certain area types of the ship. This strategy was implemented by one of the previous shipyard owners. Meyer Turku has decided to mainly focus on machinery areas and navigation bridges. This means that about 80 percent of outfitting is done by turnkey suppliers (TK suppliers). They are responsible for everything between the detail design and the final delivery of the area. TK suppliers have often outsourced work further to subcontractors. This may include detail design, and installation work is almost always outsourced. It is not uncommon to have a subcontractor outsource part of the work even further.

Description of the background outfitting process

The background outfitting process starts with basic design the purpose of which is to design the types of piping, cable trays, ventilation etc. After the basic design, detail design designs the routing of the components and makes the final installation drawings along with pre-fabricate drawings for certain materials. Outfitting takes place in squares which are work sites for sections and blocks. The components are to be installed in different phases according to the building method. There are four pre-requisites for the outfitting installation work: section or block, drawings, materials and workforce. Without any of these, work cannot proceed. There are drawings separately for the section, block and area phases. The materials are ordered by the purchasing department and they are delivered next to the squares by a logistics company. The workforce is generally subcontracted.

Outfitting phases

Currently, there are seven possible outfitting phases which are presented in Table 1. It is assumed that EMO, EML, EMV and JML all have the same efficiency, since the section is upside down. This is the first part of the "1-3-5 myth". However, no EMO phases were studied, because they are rarely utilized due to them taking place in double bottom sections, i.e. at the bottom of the ship. After the section outfitting, the section is turned the right way and it is assembled to a block. Similarly, EMS and JMS are expected to have the same efficiency, since the work takes place mostly upwards. This is the second part of the myth. Between EMS and JMS, there is block painting. The last phase, area phase, has its own efficiency. This is the last part of the myth, but that is not studied. Area phase starts after the block is lifted to the dry dock.

Table 1: The outfitting phases in starting order

Outfitting phases:	Short for Finnish:	English translation:
EMO	ennen maalausta osalohkokoonnin aikana	before painting during subsection assembly
EML	ennen maalausta lohkokoonnin aikana	before painting during section assembly
EMV	ennen maalaista lohkovarustelun aikana	before painting during section outfitting
JML	jälkeen maalauksen lohkovarustelun aikana	after painting section outfitting
EMS	ennen maalausta suurlohkokoonnin aikana	before painting during block assembly
JMS	jälkeen maalauksen suurlohkokoonnin aikana	after painting during block outfitting
Area	aluevaihe	area phase

Outfitting Building method

There is an outfitting building method for each TK supplier. This document lists all the areas, blocks and sections belonging to the turnkey delivery. There are instructions for both the background and visual work. The document gives information about what to install in each of the outfitting phases. Additionally, the responsible party for each activity is mentioned. For example, hull production will cut all the openings and install the stiffeners as long as outfitting is able to give opening information in time. The approximate timeline for the delivery and the main milestones are listed as well.

3.2 Current data collected from the yard outfitting process

Meyer Turku utilizes an ERP system called Safran, where most of the information is reported. An entire ship project consists of thousands of activities which are at least partly divided under areas. Each outfitting area manager is responsible for reporting his or her area's progress to Safran. There is a number of information, a.k.a. attributes, for each activity. Out of the available attributes, 35 of them are related to a measurement. 3 of these are for completion percentage reporting; 27 are for reporting either planned, expended or current working hours with different names and, finally, the last 4 are forecast measurements. Table 2 presents these.

Having 27 different names for basically three different types of working hours measurements is absurd. It is frustrating to differentiate between these. As Rahiala and Drucker mentioned, measurements should be simple and easy-to-understand (see chapter 2.2.1). It would be better to have only a few to start with. Additionally, the current reporting interval is once every two weeks which could be a problem for measuring anything related to current situation. In other words, it is not possible to have any daily reporting of activity and, thus, such measurements cannot be implemented with shipyard's information systems unless reporting interval is changed. As Parmenter pointed out, the purpose of the measurements is to increase visibility and enable making adjustments during the production (see chapter 2.2).

Table 2: Existing measurements found within shipyard's information system

Column:	Completion %	Working hours	Forecast
Completion %	x		
Actual %	x		
Baseline Cost		x	
Baseline Planned progress		x	
Baseline planned QTY		x	
Baseline QTY (CSH)		x	
Baseline QTY Cost		x	
Baseline Total Cost		x	
Calculated % Complete (CPC)	x		
Current Planned Progress		x	
Current Planned QTY		x	
Current QTY		x	
Current QTY (RSH)		x	
Current QTY Cost		x	
Current Total Cost		x	
Progress BL		x	
Progress CU		x	
Expended Cost		x	
Expended QTY		x	
Expended QTY Cost		x	
Expended QTY Total Cost		x	
Forecast Duration			x
Forecast Finish			x
Forecast QTY			x
Forecast Start			x
Delay (h)		x	
Original QTY		x	
Planned Cost		x	
Planned Qty		x	
Planned QTY Cost		x	
Planned Total Cost		x	
Revised QTY		x	
Unfinished CU		x	
Total QTY (TSH)		x	
Remaining working days			x

Inaccurate reporting

A disturbing trend was noticed in reporting. First of all, the reports including spent working hours were exactly the same whether it be planned, expended or current working hours. Understandably, there is no way for Meyer Turku to know the exact working hours spent because of the outsourcing. The second issue is the reporting of completion percentage. Almost exclusively, all activities are reported to 100% when the activity is over time-wise, even if some of the planned work was not completed. There are many cases, often EML and EMS, where the activity was reported as 100% but no work was done. These two issues create a falsified understanding of the bigger picture. For these reasons, the people closer to the action have become suspicious of information systems, even rightly so. There is little value in an ERP system that does not reflect the truth. This has even led to people having personal Excel-files to do their real job, while shipyard’s information system is a fancy façade. As Umble mentioned (see chapter 2.2), an ERP system filled with faulty data is detrimental.

Completion percentage and planned working hours

Even if the reporting percentage would be completely accurate for yard outfitting, it would not tell the whole truth. Just by considering the outfitting activity, e.g. EMV, there is no way to know how much work is expected to take place in reality. Supposing that outfitting is done according to the building method would be a good start but, unfortunately, it is not followed precisely. Additionally, the exact amount of material, e.g. piping, varies in each section / block leading to different amounts of work. The completion percentage should be tied to either a semi-accurate planned estimate or the expended working hours. Currently, the planned working hours estimate is based on the previous ship projects but it does not consider the material that is about to be installed for this specific phase. Instead, it is a percentage oriented division based on the total expected working hours for the area.

It is unclear how accurate this current estimation method is for the big picture but based on the section pilot project, it is safe to say that it does not work at individual activity level. Moreover, it needs to be known in a rough manner which component groups were installed. Without the first criteria, semi-accurate planned hours, reporting of the completion percentage does not mean anything, because it lacks context. Again, the measurement needs to be easy enough to understand as Drucker listed (see chapter 2.2). Perhaps in the future, the planned hours could be updated once the detail design is finished, because all components are known then. As a conclusion, there are measurements that are very inaccurate or non-existing because of the lack of transparency due to the long subcontractor chain. At least, it should be possible to do better at Meyer's own areas.

3.3 Needed data

The needed data from the outfitting process can be divided into two categories. There is data critical for running the processes, e.g. an estimate of planned working hours, and, then, there is data that is equally important to help determine the future improvement needs, e.g. the need for investments. The first category includes improvement of the planned hours, spent working hours and reporting of the completion percentage. The second category is mostly capacity related, but also the generated working hours from work slipping further are considered.

3.3.1 Required data for controlling the processes

Improvement of planned hours

The planned hours need to be updated to match the reality somewhat sensibly with a known error margin. It is impossible to get rid of the estimation error entirely due to the variation within the process because of workers being individuals. However, the best estimate can be given by knowing what jobs are to be done and how long each job takes on average. The jobs are already known, since each component is in Cadmatic, a 3D drawing tool. Also, their characteristics are shown there. Additionally, there are some jobs that are not in Cadmatic, e.g. installation of insulation pins. However, this is not a problem as long it is known approximately how much time is required for it. However, a much more difficult challenge is knowing how long it takes to do certain jobs. Due to the TK contracts, there is no follow-up on the actual installation work and, thus, installation times are not accurately known.

Knowing the expended working hours

In order to obtain feedback of how processes are doing, the expended working hours need to be known. Production planning needs this information to compare how well the estimates are doing, and it helps the procurement organization to estimate how good the deals were in reality. Currently, there is no way to get this data. Due to the lack of transparency and the long supply chain, only the subcontractor writes down the expended working hours. Even the TK suppliers do not know this data. The collection of working hours and their reporting should be made part of the outfitting process. The benefits are far greater than the effort required. Due to the way how current contracts are done, subcontractors do not need to report their working hours to anyone. Understandably, this is also a business secret, so the issue needs to be approached carefully.

Reporting the completion percentage

Besides accurately reporting the completion percentage for each activity, it would be beneficial to know what component groups are installed. This makes it easier to understand the progress and where possible delays exist. The TK suppliers keep track of the last mentioned but such reporting function does not exist in Meyer's information system. The completion percentage for a component group was not measured due to the need for an area phase study. The completion percentage is given for each activity, though.

3.3.2 Required data for future improvement needs

Shipyard capacity measurements

One of the limiting factors capacity-wise is the number of outfitting squares. Theoretically, there cannot be more sections and blocks as WIP at the yard than there are available squares. Even though the purpose is not to sub-optimize the square utilization rate, it is important to know how current capacity is utilized. The capacity can be calculated from Meyer's information systems but it is based on how long the sections and blocks are staying in the square. This was taken deeper by studying the proportional time of work taking place in the square. The following data were measured: the number of days work took place and the average number of workers. The purpose of this measurement is to find out how actively work takes place during the phases compared to the available square time, i.e. how much capacity subcontractors utilized to get the job done.

The cost of work slipping further

Some more light was shed to the myth of “1-3-5” for the installation times at section, block and area phase by studying the first part “1-3” for each component group. Based on this data, it is possible to calculate what is the potential cost of working hours when outfitting work slips further. Moreover, it is easy to notice what kind of work is more critical to do already during the section outfitting. Even though this cost does not directly affect Meyer Turku because of the TK contracts, in the end, it will do so. It should be within the shipyard’s interest to make sure that pre-requirements are in order for the TK suppliers and subcontractors. This data is processed so that it can be shown how much extra work the subcontractors are forced to do, for which they will surely charge for, one way or another. As a result, the subcontractors will ask initially for more compensation, because they realize that there might be challenges along the way that are not of their fault. In turn, the TK supplier needs to ask for more compensation because the cost of work increases which finally comes back to bite the ship yard.

3.4 Information users

Albeit only mentioning purchasing and production planning, there are likely others who can benefit from parts of the information, such as area managers and work supervisors. Generally, the purpose of these measurements is to provide numbers for backing up the opinions of stakeholders, and helping to identify the magnitude of challenges as part of an artefact-driven CSA. Hopefully, the measured data results in new development projects, or at least helps solidifying the direction of existing ones.

3.4.1 Production planning

First and foremost, this thesis is written with production planning in mind, whose function is to plan all schedules including the yard outfitting. There are schedules with different accuracies. The first schedules are rougher compared to the final schedules. Basically, there are three different levels to scheduling in outfitting: rough planning, mid-level planning and fine planning.

Rough planning, a.k.a. coarse planning, is based on the previous ship projects and can take place as soon as the general arrangement is ready, which is more than a year before production start. This level is the same as the demand planning shown earlier in Figure 8. In this case, the demand planning is only affected by the customer orders, i.e. the upcoming ship projects due to it being several years long at the moment.

At the mid-level planning, more is known due to completed basic design but some information is still missing. This should take place once basic design allows, which is roughly 2 to 7 months before the production start. In fine planning, each component is known exactly due to the detail design being completed. This takes place approximately 4 weeks before the production start. These two make up the production planning in Figure 8.

The measurement of installation times enables calculating the workloads for each phase, both for a single area or an entire block in production planning. Looking back to Figure 8, the workload calculation is based on the material requirements, which come from basic and detail design. When the workload is known, a feasible amount of outfitting time can be given by supposing that the subcontractor uses a certain number of workers on average. This is the capacity requirement and the final adaptation is up to the subcontractor on the plant floor level. Ideally, this process is implemented to ERP, so that the needed outfitting times are calculated automatically, and then reviewed by production planners. As a reminder, jobs that are not shown in Cadmatic have to also be considered in some way. The last part of Figure 8, the shop floor control, is mostly up to the area builders.

Besides utilizing the installation times for fine/medium planning, coarse planning gets some benefits as well. In coarse planning, the sizes of two similar type of areas are compared to one another. For example, it can be estimated from the previous ship project how many hours of work did section outfitting take for a certain type of an area. It has to be supposed that the work took place according to plans, because reality is, of course, not known. By knowing the average installation times, it can be estimated how many hours of section outfitting is required per square meter. Finally, a new, rough estimate can be calculated by using the size ratio between these two areas and multiplying it with the workload from the previous ship project. A simplified production planning process illustrating the significance of the installation times is shown in Figure 12.

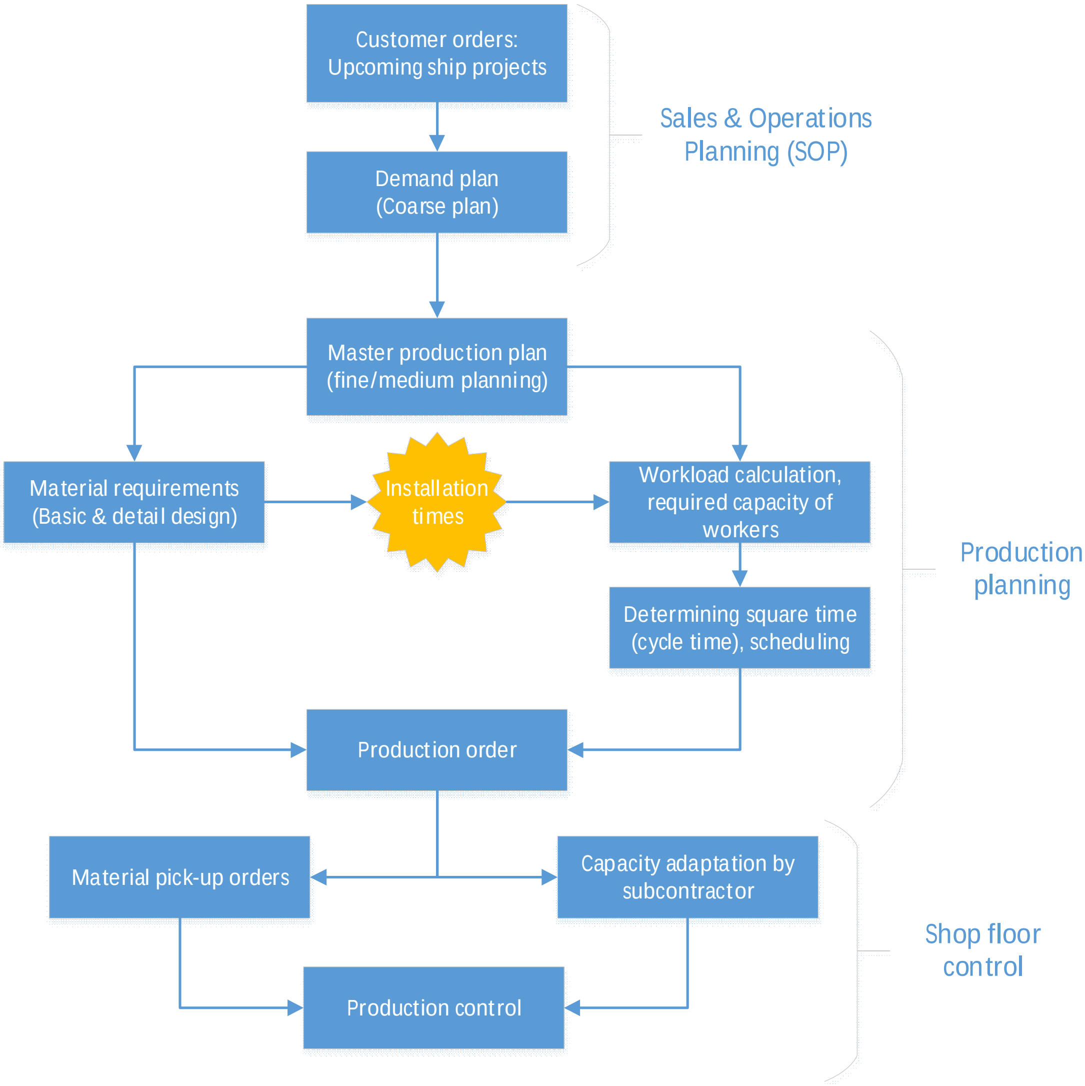

Figure 12: Simplified production planning process for yard outfitting.

3.4.2 Procurement

Procurement differs greatly depending whether the area belongs to Meyer Turku or a TK supplier. There is generally much more control in the first mentioned. Additionally, the background and visual work could be procured from different sources but only the background work is covered here.

Procurement in Meyer's own areas is possibly divided into smaller pieces compared to the areas outsourced to TK suppliers. There could even be separate deals for the yard outfitting and area phase background work. Yet, some lack of transparency still exists because further sub-contracting occurs. On a positive note, the contracts are done much closer to the production start, even as late as a month prior to it. This is due to waiting to have the detail design drawings ready, so that the exact amount of material is known. Because of these two factors, there is much more available information when trying to determine the value of the contract. Of course, the final price may not be the same as the estimated price, since it depends on the market price as well, i.e. how many contractors are offering and what their idea is about the value of the contract. This is due to the information asymmetry, because both sides have different amounts of information available. Although, getting feedback on the expended working hours would enable the possibility to calculate how good the contracts were in reality. Currently, there is no way of knowing this for sure. However, the estimation of the contracts is not covered in this thesis.

On the contrary, TK contracts are sold as large lump sums. Therefore, estimating these is much more difficult. Besides, the timing is usually more than a year before the production start and, currently, no feedback is available from their production regarding the expended working hours. In order to estimate the value of the contracts more accurately, a complete understanding of the background work including the installation times is needed. Even then, the estimates are according to the rough planning and it has not been studied how big of a potential difference there exists compared to the fine planning. At least, the value of section and block outfitting work can be predicted more accurately if Meyer Turku were to split the current TK contracts into smaller pieces.

4.0 Description of the process measurements

Firstly, the approach to the measurements has been described, since they were planned from scratch. The planning of the measurements required much effort, including what to measure and how. Some of the challenges are discussed as well. Then, all of the measurements are defined and their execution is explained in a detailed enough level, so that anyone could perform the measurements similarly and, thus, receive comparable results. Lastly, there is a discussion about the accuracy of the measurements and the quality of the raw data.

4.1 Justifying the approach to thesis measurements

In this chapter, the approach to planning and execution of the measurements is explained, including target orientation, the principles behind choosing the areas, the schedule for performing measurements and the methods for gathering the information in the production. In general, much work went to preparing and performing the empirical study.

Area-oriented measuring

There were realistically two possible choices for a starting point, an area-oriented or a block-oriented measurement. Each had merits but, in the end, the area-oriented one was chosen. The third choice according to Rahiala (see chapter 2.2.1) would have been customer-oriented measurement but that does not fit the yard outfitting since most interactions with the customer are in the area outfitting. Generally, outfitting is focused on areas, so it made sense to follow the product (or a part of it) through the value stream. The chosen areas were followed from section outfitting all the way to the end of the storage phase with a few exceptions, i.e. some of the section outfitting phases could not be followed entirely due to their early production start. The other option, block-oriented measurement, would have focused on processes, e.g. EMS and JMS. This would have been a somewhat viable choice as well. However, the scope would have been larger in this case, because a block may contain up to 30 areas with different area types involved. Some of these areas can be tiny, so there would have been much to monitor. Instead, it was decided to choose sections/blocks with mostly one large area. This way there was more work per area to follow which made measuring easier. Additionally, permission needed to be sought out for the measurements, so it was much easier to do this for nine areas compared to possibly 50 areas.

One shortcoming of the area-oriented measurement is that the areas within a block can have a totally different completion percentage. To illustrate this, one block was measured entirely to show how the completion percentage varies greatly. However, considering a block as a product from the point of view of outfitting is not ideal, since each area has possibly unique challenges and different subcontractors. Additionally, the idea is to be able to measure the partly unfinished work from section outfitting and the rest of it in block outfitting. This way measuring of "1-3" would be very realistic since the workers are same.

Choosing the targets and the schedule

In this case, a target means the combination of an area and a block. An area is always on a single deck with the exception of shafts, and it may cover both P- and S-sides in section outfitting. There were a few principles for choosing the targets. It was critical to be able to study both EMS and JMS at least. The possibility to observe section outfitting, as well, was a bonus. Secondly, it was optimal to have targets so that a single area would take most of the section's space. Viable targets were sorted through choosing them from the general arrangement and, then, checking their production schedule from the shipyard's information systems. To be safe, more areas were chosen than could realistically be measured to make sure that there was enough sampling in case there were any unexpected challenges. Finally, the results were obtained from 9 different areas and 13 targets, whereupon 4 of the areas were followed in two different blocks. Areas including shafts, e.g. lifts and AC-shafts, were left out on purpose, because work differs greatly from that of public spaces, cabins and technical accommodations.

The measurements started at the end of February 2019 and lasted all the way to the beginning of August 2019, which is a total of over five months of daily field study. Planning and executing the field study has easily required about 600 hours of work. On top of choosing the targets, much work went to analyzing the detail design drawings, Gemba walks and performing the measurements. The schedules for the measurable targets are included in Appendix A. The first Gantt chart was made already back in August 2018, the second in February 2019 and the last in May 2019. Three different schedules were needed because the production schedule kept changing. The last Gantt chart shows the real schedule according to the section/block transfers. This is shown in Appendix A.

Obtaining raw data on site

The general guidelines for the measurements are discussed, which apply for all of them, while intricacies of specific indicators are covered later. The measurements have been performed Monday through Friday but, often, subcontractors work on Saturdays as well, but rarely on Sundays. The weekend working hours have been asked from the workers or their supervisors. The reported hours have been compared to the progress made by checking the detail design drawing. This precaution was done to make sure that the reported hours were sensible. Fortunately, there were no issues regarding trustworthiness of these during the study. Additionally, the workers were asked for information regarding possible challenges or otherwise anything irregular.

The targets were visited at least once a day during the study but often even up to three times, depending on how predictably work occurred. Sometimes, the workers change worksites during the day due to finishing their job at the first site. Additional visits were mostly needed while obtaining allocated working hours, in order to calculate the installation times.

It could be said that the measurements have been performed under “reactive mode”, i.e. it was not possible to dictate any of the circumstances in the production. When performing truly academically correct measurements, only one factor should be changed at a time. Because of more than one factor kept changing between the targets, it is impossible to analyze the effect of a single factor accurately. Most of these factors were caused by random variation.

4.2 Installation times for section and block outfitting

The concept of installation times is explained, including the holistic approach for calculating the final values, and the reference time approach, which is used to simplify the data gathering part of the process. Additionally, all of the measured component groups are briefly introduced and their percentage of all yard outfitting material is illustrated. Then, the exact method for the calculation is explained. Some components require the knowledge of reference times while others do not. Finally, the factors affecting the installation times are considered.

4.2.1 Definition: Installation times for section and block outfitting

The purpose of this measurement is to find out how long does it take to install different components in section and block outfitting. Most of these components belong to HVAC but there are other jobs, e.g. insulation of the ceiling and bulkheads, as well. There are separate installation times for most component groups in section and block outfitting but some components, e.g. penetrations, take equal amount of time to install. The so-called "1-3 myth" applies to components installed to the ceiling. Vertical work to the bulkheads should take the same amount of time, regardless of the fact whether the section is upside down, or not. The studied work included very little vertical work and, thus, it has not been separated from the studied work, since it would not have been practical. In the end, the margin for error is negligible.

Two kinds of installation time measurements are needed, so that the most realistic approximations can be made. Firstly, it needs to be measured how many hours a certain job, e.g. installation of spiral ducts, takes in total. The installation time can be calculated by dividing the spent working hours on a component by the amount of component, resulting in hours per component. Some component groups are not that simple, though, because there are components with different units included. For example, spiral ducts include straight pipe (hours per meter), parts and silencers (both hours per piece). However, due to the selected measurement method, it is impossible to record the time spent for these three separately, but it is known that their installation times are not entirely same. Therefore, a second measurement is needed where the effective time spent installing a certain component is recorded. This serves as an initial reference time which purpose is to find the correct ratio between 1 meter of straight spiral duct and a single spiral duct part, e.g. a bend. By calculating a theoretical installation time for all the material with the reference times, it can be compared to the real working hours and dividing the real time by the theoretical time, a ratio between them is found. Lastly, this ratio is multiplied with the original reference times, which is the final installation time. Blücher reference times have been recorded during the thesis measurements, but thin sheet ducts (except duct insulation) and spiral ducts are taken from the 2018's section pilot. The exact formulas for calculating the installation times are presented in chapter 4.2.2.

The first measurement takes a more holistic approach, where a worker's entire workday is considered with the exception of lunch. Everything else, e.g. coffee breaks, material pick-ups and work planning onsite, is included. The purpose is not to differentiate between the value adding and non-value adding work because of the amount of variation between the circumstances. In the current situation, this holistic approach gives a more useful estimation. In fact, Meyer Turku's production planners wanted to have the installation times in this format, because measuring the effective time does not yield good raw data for production planning due to the unknown gap between the total working time and the efficient working time. Besides, measuring the efficient working time is very time consuming. The second type of measurements for the reference times are not to be mixed with the final installation times. They are only utilized to calculate the ratio between the theoretical and the real time. These reference times are not the same as effective time, but they contain less non-value adding activities, i.e. the worker has been on site during the recorded time. The reference times are given in Appendix B.

Three different units are used depending on the component: hours per meter, hours per piece or hours per kilogram. The appropriate unit is listed next to each component in Table 3 which lists all the studied components. The unit was chosen based on the format it is in Cadmatic, the 3D drawing software. This was done in order to make it easier to automate the workload calculations for future needs without needing to make manual conversions in between. Due to some challenges in trying to get the Cadmatic material data to match the measured data, some simplifications have been done. For example, the installation time of multilayer piping's parts has been included to the straight pipes. This way, there exists only an installation time for the straight multilayer pipes and all parts are zero. All the components are briefly described below and possible simplifications regarding the calculations are included. It is to be noted that all parts in a component group are considered to have the same installation time with the exception of small connection pieces that have installation time equal to zero.

The most common yard outfitting material

All of the most common outfitting components are described below and pictures are presented as well.

- *Thin sheet ducts* are used in the ventilation systems. There are standard components, e.g. straight 1500 mm parts and bends. Silencers are also standard components but they take slightly longer to install. Additionally, there are pre-fabricates which are made from thin plate. Depending on the system, thin sheet ducts can be insulated, which needs to be considered as well.
- *Spiral ducts* are also used in the ventilation systems but there are no pre-fabricates. There are two kinds of spiral ducts, R (rounded) and RI (rounded and insulated). Additionally, there are silencers, which have their own installation time.
- *Thick sheet ducts* are used for the ventilation but they are much sturdier than thin sheet ducts. They are always pre-fabricates. Unfortunately, no sampling was obtained for the thick sheet ducts.
- *Blücher piping* is used mostly for grey water systems. There are both straight pieces and parts, which are considered separately. There are four different diameter sizes for blücher piping but the size difference is negligible in terms of installation time.
- *Pre-fabricated pipes* were not measured because they require more accurate study than the method used. Additionally, diameter sizes vary from DN50 to even DN700 and there are different methods for jointing the pipes.
- *Plastic piping* had little sampling due to many times it being planned to the area phase. Plastic pipes have both straight pieces and parts but parts are not counted due to the simplification. Plastic pipes include many materials, e.g. PB, PE-X and PVC.

- *Cable trays* are mostly straight, standard pieces. There are five kinds, LZCT (light galvanized cable tray), NCT (normal cable tray), HZCT (heavy galvanized cable tray), WFCT (wire frame cable tray) and SMCT (sheet metal cable tray). The last mentioned is not included to regular installation times, since it takes more time to install than the previous four types.
- *Penetrations* are used for connecting lines between the deck plates or bulkheads. There are ventilation, cable tray and piping penetrations. Additionally, scuppers are under this category, which are part of grey water systems.
- *Insulation (space)* is drawn to basic design scheme and, thus, it is not seen in the material listing for detail design. There are three main types of insulation, fire, thermal and sound. The estimation for insulation is rougher, because there is no easy way to obtain the area of insulated square meters automatically per section.

Table 3: Measured components and their unit for installation time

Component group	Component	Unit
Thin sheet ducts	std. straight part 1500 mm	h/piece
	std. parts	h/piece
	silencers	h/piece
	pre-fabricated plates	h/kg
	duct insulation	h/piece
Spiral ducts	spiral duct R	h/m
	spiral duct RI	h/m
	spiral duct part (R&RI)	h/piece
	spiral duct silencers	h/piece
Thick sheet ducts	thick sheet plate	h/kg
Blücher-piping	blücher pipe	h/m
	blücher part	h/piece
Plastic piping	pipe straight	h/m
Cable trays	LZCT, NCT, HZCT, WFC	h/m
	SMCT	h/m
Penetrations	thin sheet penetration	h/piece
	spiral duct penetration	h/piece
	piping penetration	h/piece
	cable tray penetration	h/piece
	scuppers	h/piece

Having the installation times for all of the materials listed in Table 3 would cover 86% of all yard outfitting material, excluding insulation, and, thus, only 14% would be unknown. Studying the pre-fabricated pipes could potentially bring this up to 95%. In any case, obtaining measuring results for 20 components or 7 component groups already accounts for much. This is a prime example of measuring what matters as Parmenter has instructed (see chapter 2.3.4). It seems that there is most work for spiral ducts, followed by thin sheet ducts and cable trays. The unknown materials include, for example, different types of valves. The data is presented in Figure 13.

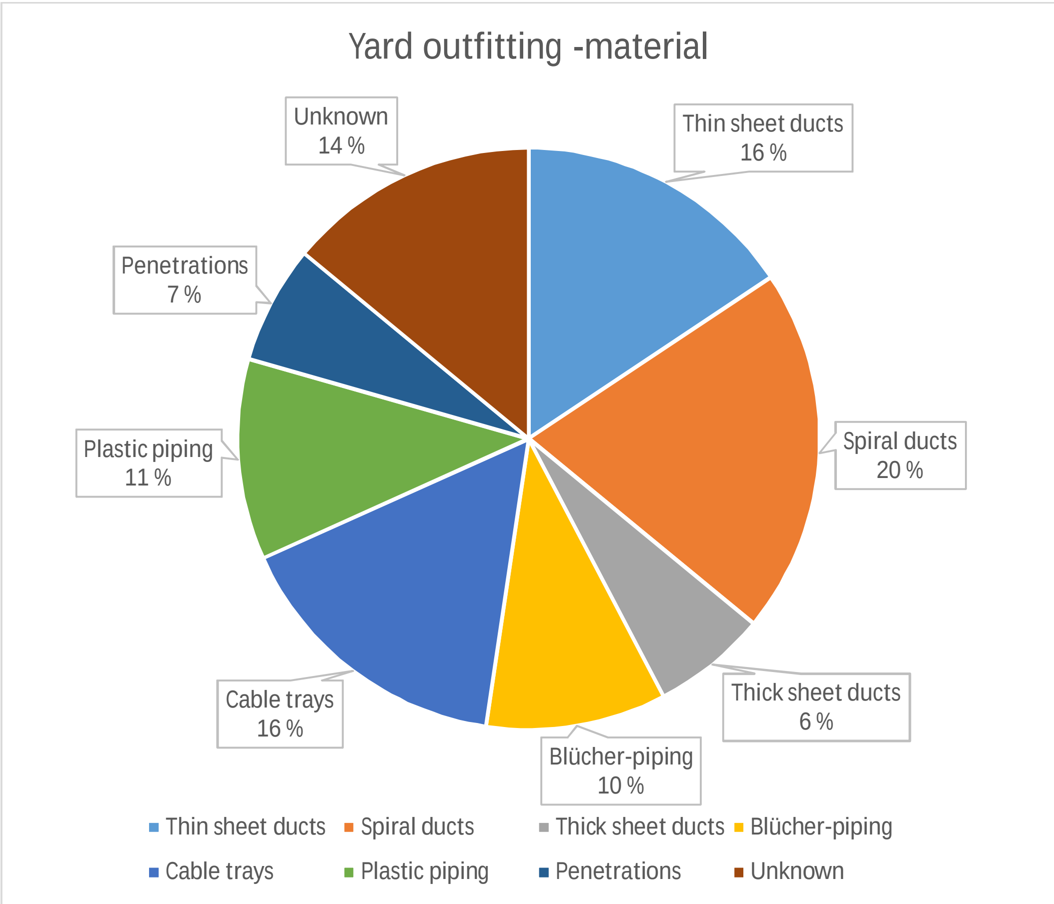

Figure 13: Yard outfitting material pie chart.

Figure 14: Thin sheet ducts: standard 1500 mm in the front, pre-fabricated thin sheet plate at the back.

Figure 15: Spiral ducts R and RI.

Figure 16: Thick sheet ducts.

Figure 17: Blucher-piping, support brackets and insulation.

Figure 18: Cable tray (LZCT) installed in EMV.

Figure 19: Rectangular duct penetrations and a spiral duct penetration.

Figure 20: Pre-fabricated zinc pipes at the front, fiberglass piping at the back.

4.2.2 Execution: Installation times for section and block outfitting

This measurement is easily the most demanding compared to others due to the need for very detailed raw data. Essentially, the allocated working hours per component group are needed along with the number of installed components. Collecting the allocated working hours requires between one to three daily visits to the target depending on how predictable the work is. The most difficult task is to keep track of the welders who keep welding between different component groups. Generally, workers have 10-hour workdays Monday through Friday and Saturdays are either 6 or 8 hours. Sundays are very rarely working days, but the working hours depend on the subcontractor. Workers were regularly asked for these. The allocated working hours are collected at an accuracy of 1 hour each day. Moreover, the reference times are recorded at an accuracy of one minute.

Secondly, the progress was tracked daily on detail design drawings, which helped confirming the reported hours. A material listing from Cadmatic for yard outfitting was very useful, since the materials could be sorted out for each target. Only the unfinished components needed to be subtracted from this listing. When calculating the installation times, it is assumed that a negligible error comes from determining the installed components. With the help of these two and the reference times, the installation times can be calculated. Note that, reference times are not needed for all components, mainly for thin sheet ducts, spiral ducts and blücher piping. An example is given in Appendix C.

Calculating installation times for components with reference times

The installation times for components with reference times are calculated with the following steps:

1. The length of straights (m) or number of parts (pieces) are summed up from the drawing or sorted out from the material listing. This is $\Sigma x_{tot,i}$, where x is the amount of component, index *tot* means total and *i* is an index for a component, e.g. straight or part.
2. If all of the components are not installed, their dimensions need to be subtracted.

$$\Sigma x_{tot,i} - \Sigma x_{uninstalled,i} = \Sigma x_{installed,i} \tag{6}$$

3. A theoretical time, T_{theory}, for the component group is calculated by utilizing the reference times $t_{ref,i}$, i.e. the installed amount of parts multiplied by its reference time.

$$T_{theory} = \Sigma x_{installed,i} * t_{ref,i} \tag{7}$$

4. The real working hours, T_{real}, are compared to the theoretical time. A ratio, R, is calculated between the two by dividing the real hours with the theoretical hours.

$$R = \frac{T_{real}}{T_{theory}} \tag{8}$$

5. Finally, the reference times are multiplied with the earlier calculated ratio from step 4 to obtain the final installation time, t_{final}.

$$t_{final,i} = t_{ref,i} * R \tag{9}$$

Calculating installation times for other components

1. All that needs to be done is to divide the real working hours by the dimension of the installed components.

$$t_{final,i} = \frac{T_{real}}{\Sigma x_{installed,i}} \tag{10}$$

This holistic approach covers the most usual components, e.g. thin sheet ducts and spiral ducts, very well, since the number of working hours is usually large and, therefore, the margin of error is smaller. However, utilizing the above described approach on measuring smaller jobs, e.g. installation of a single pipeline, is not ideal, because the margin for error increases, since the installation work is not being constantly watched. That is why pre-fabricated pipes were not measured.

4.2.3 Factors affecting installation times

Due to the nature of manual work, natural variation exists between workers' skills. Moreover, some workers are specialized in installing certain component groups, e.g. piping, while some workers could be considered more "Jacks of all trades". The specialized workers have likely a slight edge over the other group when considering purely the installation time. Having all around capable workers has other benefits though. It is likely easier to utilize these on all occasions rather than have them wait around.

According to production function theory, work efficiency decreases when more workers are added to the same space. There are also jobs that require two or more people, e.g. installing heavy components. In these cases, the installation time might seem high because it includes some waiting time during some parts of the process. Unfortunately, it was not possible to try and estimate this factor's effect. Generally, a small number of workers were on site at a time during the study.

Insulation is part of the outfitting work, which should be installed in JMS according to the current building method. Quite often, it is installed too early during section outfitting, complicating installation of other components. Some of the insulation material is vulnerable and workers cannot stand on said material. This requires extra carefulness while moving inside the section. However, some parts of the section must be insulated since large components such as thin sheet pre-fabricates may block that space. This affects only section outfitting since during block outfitting the insulation is under the roof.

There are also differences in subcontractors and TK-suppliers prepare the worksite for workers. Sometimes, TK-suppliers or work supervisors take care of lifting material pallets up to the right deck in block outfitting. Otherwise, workers are forced to either lift the materials himself or carry them through stairs. Depending on the work supervisor, he might even do most of the material pick-ups themselves so that workers can focus on installing. There are also occasions when workers are forced to move long distances to obtain the needed tools or supporting material. However, the installation time includes all this waste and, therefore, some workers could have better results by being able to spend more time onsite.

4.3 Working hours spent for each phase

Working hours are collected separately for each phase: EMV, JML, EMS, JMS and storage. Note that the hours are only collected for the studied area, even if there were more than the studied area within the section or block's deck. Additionally, it is only workers' hours that are considered, not those of supervisors even if they brought material to site or supervised lifting operations. The time needed for preparation of the worksite e.g. setting up equipment is also included along with cleaning in the end. Similarly to the allocated working hours needed for installation times, the entire work day is included with the exception of lunch. Again, working hours are collected at an accuracy of one hour for each worker. However, this is easier to measure since working hours do not need to be allocated. For this measure, one daily visit to the target is enough.

Rarely, some preparative work has been done in advance that did not take place onsite. For example, thin sheet ducts can be partly insulated except the space between the joints. Fortunately, the insulation of thin sheet ducts did take place onsite but this is not always the case. Same applies for pre-fabricated pipes that need to be polished at the end before welding.

4.4 Completion percentage for yard outfitting after each phase

There are a few different options for determining the completion percentage. The easiest way is to just look at the detail design drawings and based on installed components to estimate the readiness approximately. There is certainly some room for error if done this way, but it could be that this is already accurate enough in some cases. Another method would be calculating the percentage of material rows installed vs. all material rows when each installed component is known. While certainly more accurate than pure perception, this method does not consider that materials take different amount of time to install and materials outside of detail design drawings are not considered, e.g. insulation. The most accurate results could be reached by utilizing the installation times with the exact material listing and adding a rough estimate for material outside of Cadmatic.

Basically, the completion percentage aims to give an idea of how well the work is progressing proportionally to the finished task. As already mentioned, it needs to be linked to either spent or planned working hours to give it some sort of context. That is why the measurement is tied to planned working hours according to the detail designer's drawings, i.e. the utilized installation time (section or block) depends on the phase, where the detail designer has planned the component to be installed. For example, section outfitting material (according to current building method) drawn to block outfitting drawings utilize block outfitting installation times. The exception to this is plastic pipes, which are left out entirely due to half of them being drawn to area phase drawings. Unfortunately, it was not possible to obtain material listing for area phase material the same way as for yard outfitting material. Insulation and support rail brackets are included, even though they do not appear in this material listing and, therefore, their estimate is rougher. Material on block border is included in order to simplify calculations due to block border material not being defined separately in the drawing even though it is area phase work.

The completion percentage is calculated after section outfitting, EMS and JMS & storage. The last two have been combined because quite little took place during JMS alone. It is to be noted that the completion percentage after storage is the same as the completion percentage after yard outfitting. Finally, the proportion of unfinished yard outfitting work can be calculated. In addition, it is possible to calculate a theoretical time for delay, i.e. how many working hours the said target is lagging behind.

Calculating completion percentage instructions

1. A theoretical total time for yard outfitting T_{yard} is calculated for all of the components. This is done by adding the theoretical installation times for all components. Materials designed to section outfitting utilize section outfitting installation times $t_{avg,i,section}$ while block outfitting utilizes its installation times $t_{avg,i,block}$. Indices i and k present possible components that can be installed. Additionally, an estimation for other material T_{other}, e.g. insulation, is added.

$$T_{section} = \sum_i^k (x_{tot,i} * t_{avg,i,section}) \tag{11}$$

$$T_{block} = \sum_i^k (x_{tot,i} * t_{avg,i,block}) \tag{12}$$

$$T_{other} = T_{insulation} + T_{support\ rail\ brackets} \tag{13}$$

$$T_{yard} = T_{section} + T_{block} + T_{other} \tag{14}$$

2. Similarly, a theoretical time can be calculated for installed components after each phase.

$$T_{EMV} = \sum_i^k (x_{installed,EMV,i} * t_{avg,i,section}) \tag{15}$$

$$T_{EMS} = \sum_i^k (x_{installed,EMS,i} * t_{avg,i,block}) \tag{16}$$

$$T_{JMS\&Storage} = \sum_i^k (x_{installed,JMS\&Storage,i} * t_{avg,i,block}) \tag{17}$$

3. The completion percentage C can be calculated for each phase with the following equations:

$$C_{EMV} = \frac{T_{EMV}}{T_{yard}} \tag{18}$$

$$C_{EMS} = \frac{T_{EMV} + T_{EMS}}{T_{yard}} \tag{19}$$

$$C_{JMS\&Storage} = \frac{T_{EMV}+T_{EMS}+T_{JMS\&Storage}}{T_{yard}} \quad (20)$$

4. The percentage of unfinished yard outfitting work after storage $C_{unfinished}$ can be calculated by subtracting the completion percentage after storage from 100%.

$$C_{unfinished} = 100\% - C_{JMS\&Storage} \quad (21)$$

5. Unfinished working hours after yard outfitting, $T_{unfinished}$, are calculated by subtracting the theoretical time of installed components from the theoretical time of all installed components.

$$T_{unfinished} = T_{yard} - (T_{EMV} + T_{EMS} + T_{JMS\&Storage}) \quad (22)$$

4.5 Yard outfitting capacity measurements

The purpose of these measurements is to illustrate how the subcontractor's worker capacity is utilized in conjunction with Meyer's outfitting squares. Square utilization rate has been calculated by comparing the available networking days with the number of days work took place. Officially, network days are Monday through Friday but work took place often also on Saturdays, which have been counted to utilized working days. Therefore, square utilization rate is slightly higher compared to the scenario where Saturdays were not included. This is a good indicator for section outfitting, since the targets were chosen so that one area would cover almost the entire section. However, for block outfitting this is not a viable measurement because there are multiple areas on different decks. Instead, the measurement should be considered as how well the available outfitting time was used for that particular area. Additionally, EMS is not analyzed at all, only JMS and storage. The average number of workers are calculated both for the entire outfitting time (network days) and utilized working days.

Calculating square utilization rate for section outfitting and utilized outfitting rate for JMS/storage

1. The available outfitting time is the time between arrival of the section/block and its leaving. This data can be found from the shipyard's information

systems by looking at the transfer dates. From these dates, only network days are considered, i.e. Monday through Friday.

2. The number of utilized working days are recorded onsite by visiting it daily and presence on weekends is asked for. Weekend working days are included.
3. The utilization rate is finally calculated by dividing utilized working days from step 2 by available outfitting time from step 1.

$$Square\ utilization\ rate = \frac{Days\ work\ done}{Available\ network\ days} \tag{23}$$

Calculating average number of workers for available outfitting time

In order to calculate this, spent working hours and number of available outfitting days need to be known. Additionally, it is presumed that a worker has a 10-hour working day. Only the studied area is considered even if there are more than one area on the same deck in a block. The formula is:

$$\frac{Spent\ working\ hours}{(number\ of\ available\ outfitting\ days * 10\ hour\ workday)} \tag{24}$$

Calculating average number of workers for utilized working days

This is similar compared to previous calculation except utilized working days are used instead of available working days. The formula is:

$$\frac{Spent\ working\ hours}{(number\ of\ utilized\ working\ days * 10\ hour\ workday)} \tag{25}$$

4.6 Accuracy of the measurement results

Gathering working hours onsite

Gathering the allocated working hours for the installation times is by far the most demanding task and it includes some margin of error. This margin is slimmer when the workers are working only on one component group for several days. The possible error comes when the workers switch tasks since the exact timing is not known but the error between switching the tasks should not be more than two hours. Additionally, if the worker changes working site, the exact timing is difficult to determine. The workers were interviewed, though, when these kinds of situations occurred. The last factor contributing to a possible error is that work often took place on Saturdays as well. These working hours were asked for and the worker's answer was compared to the progress on the drawings to check the validity. There are observations up to several hundred hours, where the margin of error is approximately 1-5%. Observations that are somewhere between 20 and 50 hours have a slightly bigger margin of error, approximately 5-10%. Observations that were less than 20 hours have not been utilized in calculations due to their higher uncertainty. Similar challenges exist for collecting the total spent working hours but this is easier due to not needing to allocate the hours. The error for marking up installed/uninstalled components is assumed to be negligible.

Calculations

In case there are observations that can be classed as outliers, they are not included in the calculations. These occasions are mentioned separately in chapter 5. The allocated working hours actually have a large effect on most of the measurements. They have an impact on the installation times, completion percentages and generated working hours. The second factor is the utilized reference times, which have an equal impact on blücher piping, spiral ducts and thin sheet ducts. Reference times for the blücher piping were studied but not those of spiral ducts and rectangular ducts, with the exception of its insulation. Having incorrect reference times distorts the ratio of installing components in the same component group. For example, the difference between installing spiral duct R and spiral duct RI could be larger. However, it could be faster than thought to install spiral duct silencers. The effect is illustrated in Figure 21. The green box means that allocated working hours are raw data that should be collected; Blue boxes describe thesis measurements; orange sun describes the final goal of providing accurate raw data for the production planning and grey boxes are component groups. In any case, the results of other measurements or production planning estimates are only as accurate as the original raw data and reference times. Therefore, it is extremely important to focus on these first.

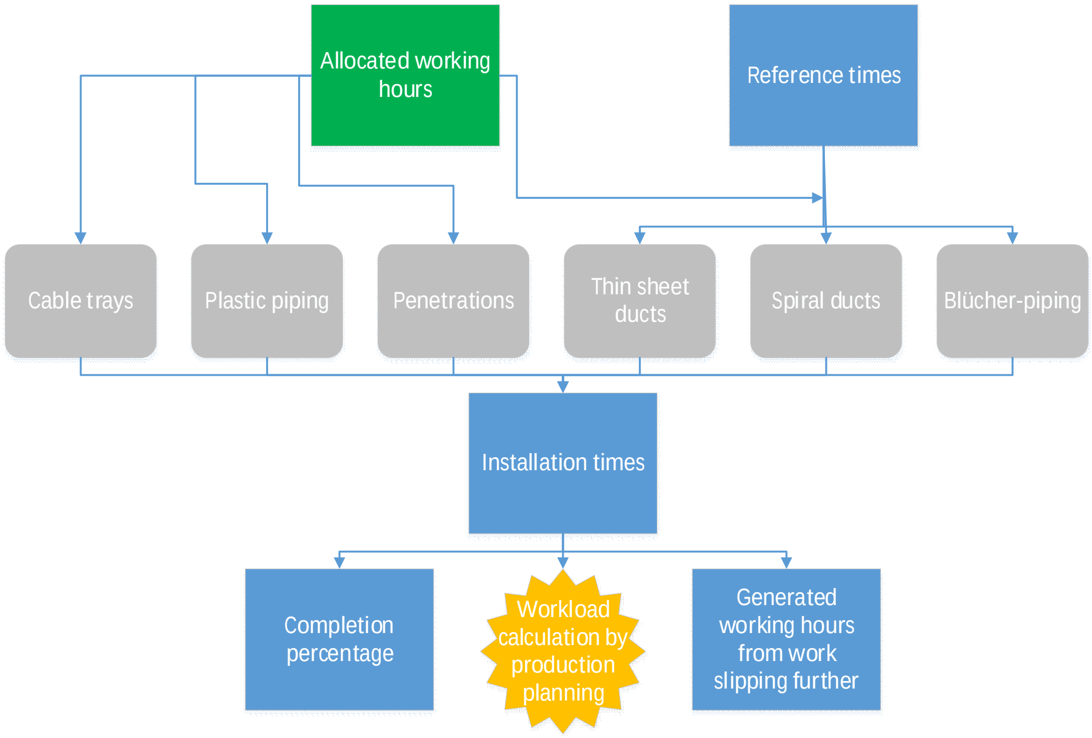

Figure 21: Impact of allocated working hours and reference times on measurements.

5.0 Results of the process measurements

Some of the results are shown here in chapter 5.0 but all sensitive data can be found in Appendices. The results for installation times, spent working hours, completion percentages and capacity measurements are covered. Although all data is not available for readers, some percentage-wise comparisons are shown, so that the significance of the measurements can be understood.

5.1 Installation times for section and block outfitting

The installation times are considered as sensitive information for Meyer Turku, so they are presented in Appendix C. This includes the current averages used by Meyer Turku's production planners, the measurement averages (installation times), the standard deviation for measurements and the 2σ-range based on standard deviation. Additionally, there are graphs illustrating each component. The suggested values for plastic pipes and penetrations are shown in Appendix E, even though a complete analysis could not be made of them due to a low sampling size.

Therefore, some limited information is given that does not reveal the exact values. Following information has been given: sample size, the difference between the current and new estimate in percentages and the coefficient of variance. Moreover, an average for COVs is calculated (see formula 3). Lastly, an example is given, where the magnitude of variation based on the measurement's standard deviation is illustrated on a fictional workload of 100 hours. This illustration similarly utilizes the 2σ-region. Additionally, some interesting points are commented from this information.

Lastly, the recommended values are given for production planners, which are in the Appendix as well. Based on these recommended values, the myth of "1-3" is unraveled, and possible explanations for the results are discussed.

5.1.1 Installation times for section outfitting

Due to the same measurement method, results from the section outfitting pilot project have been partly included. The installation times from the reference sections have been utilized here but not the ones from pilot sections. The reason for not utilizing the pilot sections is that the circumstances were slightly different and these results do not directly correspond to TK suppliers' way of doing things. The reference sections are marked separately.

A few interesting facts are pointed out from Table 4. Firstly, there is a difference of 150% between the current and the new installation time for pre-fabricated thin sheet plates. This is due to them not having their own installation time earlier, except they used the same one as thick sheet ducts. Secondly, the estimate for spiral ducts diminished greatly, about 60%. Spiral ducts were the most utilized component according to Figure 13. This has certainly a large effect on planned working hours. Additionally, the installation time for blücher piping diminished as well. The original value for blücher parts was far off from the measured value. The ratio of installing straight pipe vs parts is much bigger than previously thought. Installing 1 meter of blücher pipe took on average 10 times more time than installing a single part. The original ratio was close to 4:1. Most likely, this has to do with the fact that pipes need supports and they need to be cut to right length while parts can simply be glued together.

Table 4: Limited information of section outfitting installation times

Section outfitting					
Thin sheet ducts					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Std. straight part	5	-6 %	31 %	34 %	32h - 168h
Std. part	6	1 %	32 %		
Silencer	5	2 %	35 %		
Pre-fabricated plate	5	150 %	40 %		
Spiral ducts					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Spiral duct R	7	-61 %	26 %	28 %	44h - 156h
Spiral duct RI	7	-62 %	28 %		
Spiral duct part R&RI	7	-60 %	26 %		
Silencer	3	-57 %	33 %		
Cable trays					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
LZCT, NCT, HZCT, WFCT	5	-36 %	27 %	27 %	46h - 154h
Blücher-piping					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Blücher pipe	4	-48 %	16 %	16 %	68h - 132h
Blücher part	4	-81 %	16 %		

5.1.2 Installation times for block outfitting

Similarly, limited information of the block outfitting results is shown in Table 5. Sample size is roughly five for each component group, which is slightly less than for section outfitting. It seems that the current estimate for section outfitting is actually rather close to the block installation time measurements. Spiral ducts require slightly more time but, on the contrary, cable tray has been installed faster upwards than current estimate for downwards. Blücher piping required some more time again. Secondly, the amount of variance in thin sheet duct and spiral duct samplings is huge, which is easiest to see in the 100-hour job examples. There were two samplings, where work was done much more efficiently. The worker worked mostly alone and he was working under his own company name, which surely provided more than average motivation. However, the observations are included to show the enormous effect of natural variation, even though circumstances were favorable otherwise as well. Lastly, cable trays were installed even quicker than in section outfitting, even if not by much. On a positive note, the variation was small even though the circumstances between the observations varied.

Table 5: Limited information for block outfitting installation times

Block outfitting					
Thin sheet ducts					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Std. straight part	6	0 %	51 %	40 %	20h - 180h
Std. part	5	-14 %	48 %		
Silencer	4	-21 %	55 %		
Pre-fabricated plate	3	14 %	8 %		
Spiral ducts					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Spiral duct R	4	11 %	68 %	69 %	0h - 238h
Spiral duct RI	4	12 %	69 %		
Spiral duct part R&RI	4	10 %	70 %		
Silencer	4	12 %	69 %		
Cable trays					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
LZCT, NCT, HZCT, WFCT	4	-44 %	8 %	8 %	84h - 116h
Blücher-piping					
Component	Sample size	Difference from current estimate (%)	COV (%)	Average COV (%)	100-hour job example with +/- 2σ
Blücher pipe	5	24 %	31 %	32 %	36h - 164h
Blücher part	5	-54 %	33 %		

5.1.3 Comparison of section & block outfitting installation times and recommended values

The comparison has been done by using the recommended installation times, which are the averages of observations with the exception of thin sheet ducts' average. The two samples measured from the worker with his own company name, have been left out due to them distorting the average too much. Normally, such data manipulation should not be done but it felt justified here. In any case, this should even out in the future when a larger sampling is collected. The recommended values are shown similarly in Appendix E.

Apparently, there is some truth to the myth of "1-3", even though the results are mixed. The "block vs. section factor" is calculated with the following formula: $factor = \frac{t_{block,i}}{t_{section,i}}$. It is peculiar that the factor varies so much between the component groups. Thin sheet ducts and cable trays are much closer. In fact, cable tray was installed even faster upwards. On the contrary, installing spiral ducts and blücher piping required much more time. The fact that makes the results peculiar, is that thin sheet ducts weight the most out of these component groups. Cable trays and blücher piping is quite light, and spiral ducts do not weight much more either. Installing spiral ducts and blücher piping requires more planning and measuring from the worker due to the need to cut the pieces to the right length. Therefore, the worker spends more time between climbing up and down the ladder. More study onsite is required to be able to explain the result completely.

Based on the results, it can be said that there is no notable difference in installing cable tray downwards or upwards. Therefore, it was decided to present all observations for this in one graph and calculate a new recommended average value. This is in Appendix E as well.

Table 6: Comparison of section and block outfitting installation times per component

Thin sheet ducts	
Component	Block vs. section -factor
Std. straight part	1,21
Std. part	1,14
Silencer	1,10
Pre-fabricated plate	1,33
Average	1,20
Spiral ducts	
Component	Block vs. section -factor
Spiral duct R	2,82
Spiral duct RI	2,91
Spiral duct part R&RI	2,75
Silencer	2,61
Average	2,77
Cable trays	
Component	Block vs. section -factor
LZCT, NCT, HZCT, WFCT	0,89
Blücher-piping	
Component	Block vs. section -factor
Blücher pipe	2,38
Blücher part	2,40
Average	2,39

5.2 Expended working hours per target

Expended working hours are presented for all of the measured targets by phase: section outfitting (EMV/JML), EMS, JMS and storage. These are presented in Appendix F.

Total expended working hours are listed first and after that the allocated working hours are shown. This measurement is about the total expended working hours but the allocated hours are shown because they were utilized in calculating the installation times. Some additional notes are included in Appendix F about the allocated working hours as well.

5.3 Completion percentage

The completion percentage has been studied from two different angles. Firstly, all of the studied areas, which are scattered in different blocks, have been analyzed. The completion percentage has been studied after each phase and the measured installation times have been utilized to calculate the percentages as accurately as possible. Secondly, there is another measurement, where an entire block's major areas were checked. The purpose is to show that the completion percentage varies greatly even within the same block.

5.3.1 Completion percentages for studied targets

Completion percentages for yard outfitting are calculated with the help of installation times. The exact calculations are shown in Appendix G. Additionally, theoretical delayed working hours have been calculated based on this data as well. From these calculations, it can be seen what components were not installed and vice versa. Figure 22 illustrates the separate completion percentages for section, EMS, JMS & storage and the percentage of unfinished yard outfitting work. Only one of the targets managed to complete all yard outfitting work while the lowest completion percentage was 11. On average, the completion percentage is 65% for this sampling. The average for work taking place in section outfitting is 30%, EMS 6% and JMS & storage 29%. Table 7 shows the completion percentages after yard outfitting.

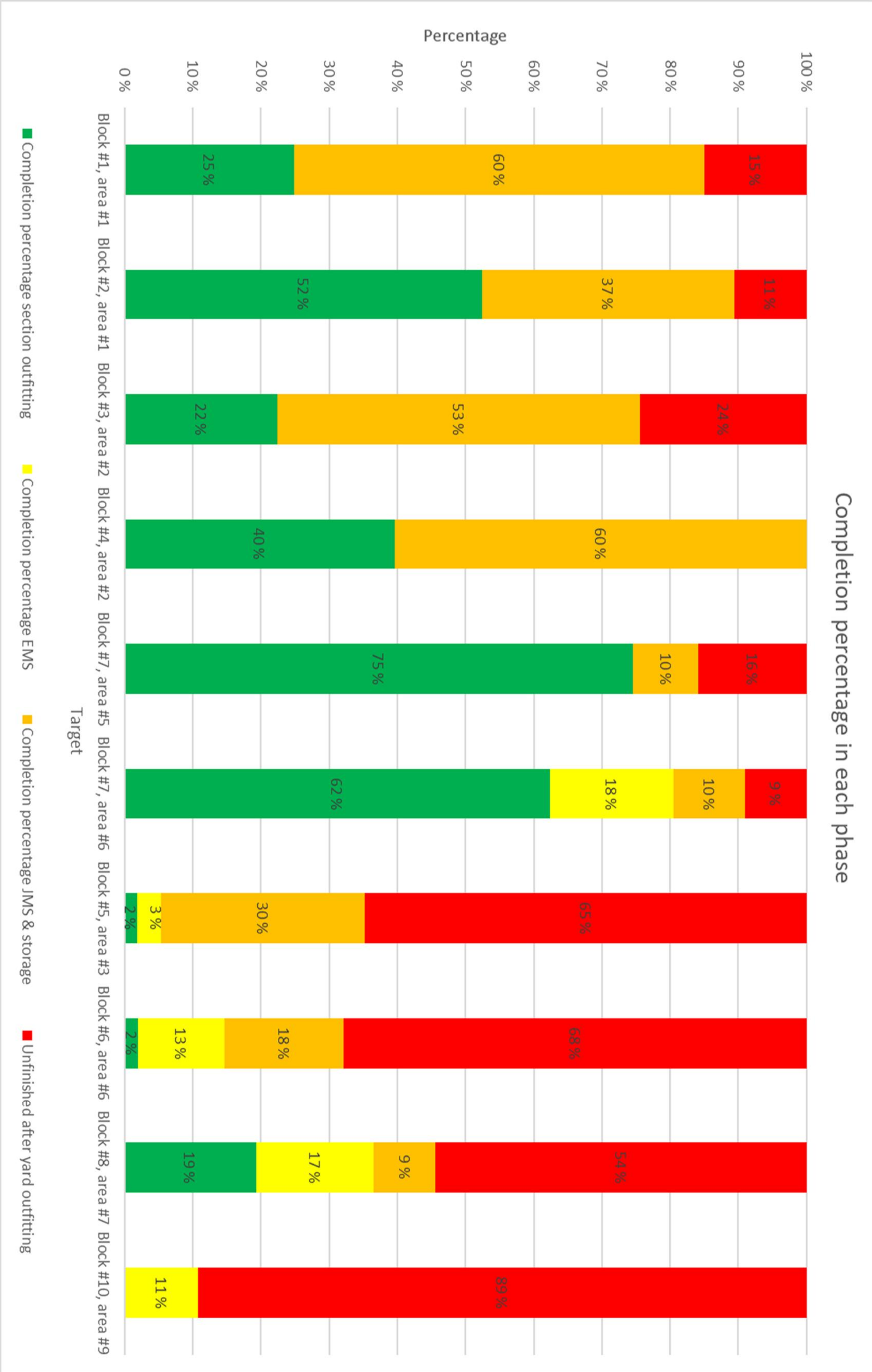

Figure 22: Completion percentages for section, EMS, JMS & storage and percentage of unfinished yard outfitting work.

Table 7: Completion percentage after yard outfitting for studied targets

Completion percentage after yard outfitting	
Target	Completion percentage
Block #1, area #1	85 %
Block #2, area #1	89 %
Block #3, area #2	76 %
Block #4, area #2	100 %
Block #7, area #5	84 %
Block #7, area #6	91 %
Block #5, area #3	35 %
Block #6, area #6	32 %
Block #8, area #7	46 %
Block #10, area #9	11 %

5.3.2 Completion percentages after yard outfitting for each area within a block

This measurement was performed to show that areas within the same block can have totally different progress because each area has its own responsible TK-supplier with their own challenges. Block #1 includes four ceilings, which have been named decks A, B, C and D. Additionally, there is a shaft that spanned the entire block vertically. It is to be noted that deck A has no floor to stand on since it is part of another block. This measurement has been simplified from the previous one. Installation times have not been utilized; instead, the progress has been estimated based on a combination of marked drawings and perception. Additionally, only the larger areas have been included. The data is presented in Table 8.

Again, there is much variation between the completion percentages of the areas after yard outfitting. The average for these areas is 55% but it does not mean that the block's completion percentage is the same. Some areas contained more work than others. Two of the areas, "A2" and "A3", had no work done while "A1" was very close to complete even though they were on the same deck. Working without having the floor to stand on is certainly more difficult and, as a result, deck-to-ceiling connections cannot be made. It could be that "A1" had most of the outfitting work already done in section outfitting. Anyway, it is difficult to look at the completion percentage of an entire block from point of view of the outfitting due to the fragmented nature of area-focused working.

Table 8: Completion percentages within Block #1 for all major areas

Target: Block #1		
Deck:	Area:	Approximate completion
A	A1	95 %
	A2	0 %
	A3	0 %
B	B4	80 %
	B5	65 %
C	C6	20 %
	C7	40 %
D	area #1	85 %
	C8	75 %
Shaft	S9	90 %

5.4 Ship yard capacity –measurements

These measurements focus on figuring out the capacity utilized by subcontractors on average and its range of variation. Firstly, the studied targets are observed both during section outfitting and JMS & storage. Additionally, a process-oriented measurement is presented for an entire block, where capacity utilization was studied for each deck.

5.4.1 Capacity measurements for section outfitting

Four targets were analyzed from section outfitting. Sections where next to no work took place are not listed because they lacked prerequisites, e.g. drawings, instead of only being limited by the subcontractor's capacity. In addition, some of the targets started their production earlier than the measurements began. However, the point is to illustrate how the subcontractor tends to utilize most of the section outfitting time but uses a low number of workers. This held true for the section pilot project as well. The average number of workers is 1.7 when compared to available square time and 2.0 when compared to number of days work took place. The number of workers depends totally on the subcontractor since they are able to decide themselves how many to use. On the contrary, there are also occasions when section outfitting is heavily utilized if there are critical jobs from the subcontractor's perspective. Generally, subcontractors do want to utilize the section outfitting but, unfortunately, they are not able to do so due to the ship yard's challenges and their own limited capacity. The data for section outfitting capacity measurements is presented in Table 9. The calculations include working hours, square time and number of days work done and these are presented in Appendix H.

Table 9: Section outfitting capacity -measurements

Target	Square utilization rate	Average number of workers	Average number of workers (days work done)
Section #1	75 %	1,4	1,9
Section #2	100 %	2,9	2,9
Section #3	67 %	1,0	1,6
Section #4	100 %	1,6	1,6

5.4.2 Capacity measurements for JMS and storage

There were eleven targets, i.e. an area inside a block with varying amounts of work done. The data is presented in Table 10. The raw data for calculations: working hours, JMS & storage length in network days (Monday – Friday) and number of days work done, are shown in Appendix H. Note that targets "Block #8, area #7", "Block #10, area #9" and "Block #9, area #8" did not have a storage phase. Column "Working days vs network days -ratio" has a large variation. There are targets where work was done more, e.g. "Block #1, area #1", whereas barely any work was done in some targets. For example, in "Block #7" much of the work was already done in the section outfitting while in the former mentioned, much of the work took place specifically during JMS & storage. On average, there was some work done in the studied area with a probability of 44%. In any case, the column "Average number of workers (days work done)" shows again that subcontractors tend to use a rather low number of workers simultaneously. On average, subcontractors used 1.6 workers during JMS & storage when working. Additionally, this number drops to half, 0.8, when considering the length of the entire phase.

Table 10: Combined JMS and storage phase outfitting capacity -measurements

Target	Working days vs network days ratio	Average number of workers (phase length)	Average number of workers (days work done)
Block #1, area #1	0,80	1,2	1,4
Block #2, area #1	0,52	0,9	1,8
Block #3, area #2	0,65	1,3	2,0
Block #4, area #2	0,63	1,4	2,2
Block #5, area #3	0,24	0,4	1,6
Block #6, area #3	0,26	0,3	1,2
Block #8, area #7	0,61	1,2	2,0
Block #10, area #9	0,17	0,2	1,0
Block #7, area #5	0,04	0,0	1,0
Block #7, area #6	0,04	0,0	1,0
Block #9, area #8	0,86	2,1	2,4

5.4.3 Capacity measurement of an entire block

Since measuring a single area inside a block consisting of multiple decks, does not give a holistic picture of the JMS and the storage outfitting, "block #1" was measured entirely to help understand the entity from a process point of view. The working hours were collected for each deck (not area) and, additionally, the shaft was recorded separately due to its special nature of work. Weekend working hours were not collected, so the measurement is limited to the network days. Therefore, the actual working hours including weekends are likely slightly greater than the measured ones. The working hours for "block #1" JMS and storage phase are presented in Appendix H, as well as the total working hours based on it.

The shaft took 47.1% of the total working hours in "block #1". This has been separated due to it being very different work compared to more common work, e.g. public spaces and cabins. The focus is on analyzing the decks more accurately. Deck E contains only the floor and, thus, there were less potential components to be installed, e.g. railings and penetrations. On the contrary, the lowest deck, A, contains the ceiling and the bulkheads but no floor. Arguably, much of the outfitting material is installed to the ceiling but, in this case, little work took place. Additionally, the ceiling is higher up than on the other decks because the block is placed on large supports. Decks B, C and D could be said to be ordinary block outfitting work, since the floor and the ceiling are both available.

Even if the shaft is filtered out from the data, work took place on some deck of the block on 31 out of 35 days, so there was often someone who was utilizing the square. The average number of workers in the block was 3.4 excluding the shaft and 7.2 when included.

The analysis is taken a step further by looking at decks B, C and D separately. These decks included several areas with different subcontractors. The data for these decks' capacity measurements is in Table 11. Again, the raw data, the number of days work done and the number of network days, is in Appendix H. The average number of workers is a bit higher than in Table 10, but still quite close. This provides further proof on the limited use of capacity by the subcontractors, and their desire to focus on optimizing their resource efficiency.

Table 11: Capacity measurements for decks B, C and D

Deck	Utilization rate	Average number of workers (network days)	Average number of workers (days work done)
B	0,48	1,2	2,4
C	0,33	0,8	2,5
D	0,60	1,2	1,9

6.0 Current State analysis

Firstly, the boundaries of the analysis and the methods for information gathering are explained. Major topics include the current building method, EMS outfitting, JMS/storage outfitting, reasons for work slipping further, variation within the yard outfitting process, sources of waste and analyzation of resource/flow efficiency. Backed up by the data from chapter 5, the CSA gives a thorough overview of the yard outfitting production from the point of view of the area.

6.1 Boundaries of the analysis and information gathering

The analysis is limited to the yard outfitting with a major focus on the block outfitting due to the section outfitting been studied previously. However, it is partly included, especially in the measurements, to provide a more holistic picture of the entire yard outfitting. Besides, section and block outfitting face partly similar challenges, and the work is almost the same except for the installation direction. The yard outfitting process is studied from the point of view of production, i.e. much focus has been set on issues taking place on site and, then, discovering the causes for the challenges there. Detail design, one of the pre-requirements for successful outfitting, has been partly included because of its significant impact. The existing reports in Safran regarding the studied processes are analyzed and compared to reality. However, the warehouse and logistic operations have been scoped out. In case of material shortages, they are only recorded.

The CSA includes both interviews with stakeholders and measurements on site, as Villemez recommends (see chapter 2.1). The latter is done to obtain evidence of some of the stakeholders' opinions and help understand the challenges in their correct magnitude. Additionally, the measurements are shown to some of the stakeholders (their own work), so that they can explain the possible reasons for the results. As Nichols suggests, the stakeholders were chosen so that the entire yard outfitting process was covered from most perspectives (see chapter 2.1). From Meyer Turku, this included mostly area managers but some other personal as well, e.g. detail design coordinators were interviewed. The point of view of the TK suppliers was studied, too, through interviews with project managers and work supervisors. Finally, subcontractors' workers and work supervisors were interviewed during their work along with one of their managers and a few detail designers. This enabled a comprehensive analysis including all the important perspectives, so that all sides could be understood. A map showing the organizations and the interviewed employees is in Figure 23. The last two groups, subcontractors' workers and their supervisors, are marked with green due to most information coming from onsite. The circles depict personnel while the rectangles are organizations.

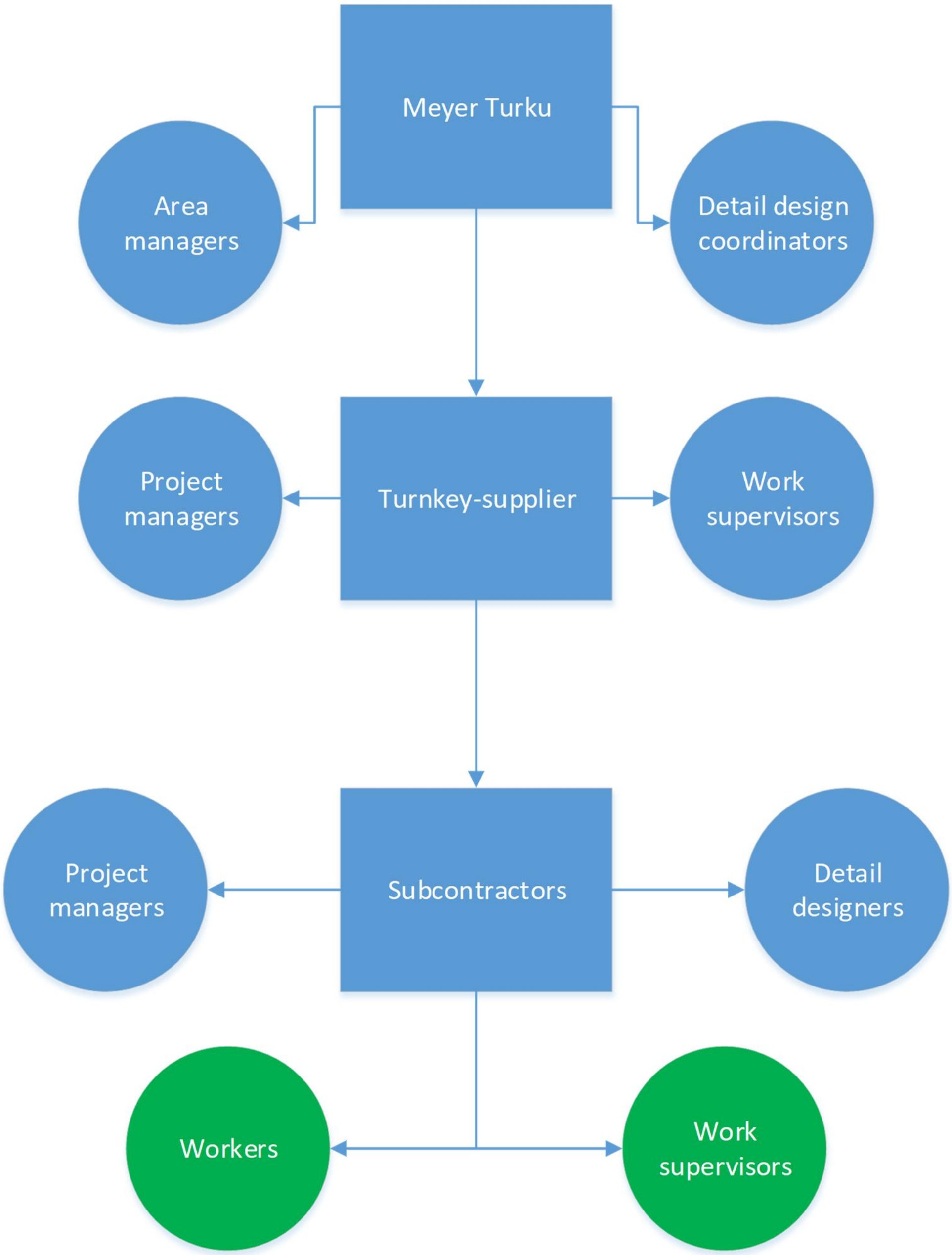

Figure 23: Interviewed employees from Meyer Turku, TK-suppliers and subcontractors.

Besides providing quantitative data for the stakeholders' claims, the measurements were performed in order to estimate the yard outfitting's current capabilities, e.g. the completion percentage after yard outfitting. The measurements were done in section outfitting for EMV and JML phases but not before those. In block outfitting, the storage period has been included, because much work took place there. The measurements are limited to pastime, i.e. no immediate corrections were made for the measured targets. Instead, possible adjustments are made to the future plans. The majority of the measurements are product-oriented, but there are a few process-oriented ones. The measurements are solely focused on work on site. This was intentional, since the biggest lack of information lays there.

6.2 The current building method for yard outfitting

In this chapter, the current building method for yard outfitting is examined through comparisons between the detail design and the actual installation work. Additionally, there is a suggestion for an improved yard outfitting building method by creating a working order for components to eliminate unnecessary work. Lastly, there are three improvement suggestions for detail design to help the work on site.

6.2.1 Comparison of the current building method vs detail design drawings

Each TK supplier has a separate building method document for their procured entity, i.e. all the areas included in this entity follow the same document, which is sensible, since the areas usually belong to the same area group. The contents of the documents were compared between different TK suppliers and area groups but they were exactly same regarding what to do in each yard outfitting phase, at least for the studied area groups, i.e. technical accommodations, public spaces and cabins.

Turnkey suppliers are responsible for their area's detail design and according to the policies, drawings must be ready and delivered to the subcontractors two weeks prior to the production start. There are three possible drawing phases for outfitting. The section outfitting installation drawings are marked X16, where X is a number depending on the area group. This does not distinguish itself between EML, EMV or

JML. The block outfitting installation drawings are marked X26, and similarly there is no distinction between EMS and JMS. The area phase drawings are marked X36, respectively. This is valid for ship projects before the Icon-series, i.e. Icon is the name of a ship series type.

Figure 24 illustrates how well the building method was followed by different areas' detail designers. On the left side is Meyer Turku's building method for the ship project, L-396. According to it, deck- and bulkhead penetrations should be installed in EML, while HVAC should be installed in EMV with the exception of plastic pipes which should be done in EMS. Additionally, insulation should be done in JMS. In this figure, "section" covers all three section outfitting phases and "block" includes both EMS and JMS.

The most significant deviations can be seen in ventilation, i.e. thin sheet ducts and spiral ducts. Even 5 out of 8 detail designers have decided to deviate from the building method with the spiral ducts and 4 out of 7 with the thin sheet ducts. When asked about this, a number of reasons were given. TK suppliers were of the opinion that they did not want to install the ventilation before the block painting due to a risk of components getting damaged during the shot blasting. In addition, the lack of time during EMV was mentioned and, optimally, ventilation should be installed after all the intensive fire work is finished. Blücher piping was included 3 out of 6 times in the section outfitting drawings. Similar reasons were cited for this. Most importantly, intensive fire work should be finished before the blücher installation. The material can easily be damaged through "spark showers" leading to corrosion over time unless properly protected. Plastic pipes should be installed during block outfitting but only 3 out of 8 detail designers followed the building method. One designer decided to time them already to the section outfitting, while four of them timed the plastic pipes to the area phase. Generally, these should be installed towards the end due to the material being light and rather vulnerable. Another interesting observation is that the support rail brackets are always included in steel outfitting drawings which are section outfitting drawings but do not contain HVAC-material. This is actually very sensible, since their purpose is to ease outfitting work, especially ceiling lining work, later in block and area outfitting.

Not having drawings available or not including material obviously limits workers' potential in section outfitting. Currently, the work keeps slipping further to block outfitting and this starts from the fact that detail designers do not or cannot follow the current building method. The impact is significant. In L-394 ship project, the number of estimated working hours based on detail designers' way of timing components was approximately 3.5 times higher compared to if the work had been planned purely according to the building method. This is no surprise, since in Figure 24 half of the key activities were timed to block outfitting. Some of the TK suppliers mentioned that they did not want to be too early with their drawings due to possible changes coming from the buyer. This last claim has not been investigated, though, and it is out of scope.

Building method vs. detail design -matrix

Component group:	Building method:	Area #1	Area #2	Area #3	Area #4	Area #5	Area #6	Area #7	Area #9
Penetrations on bulkheads	EML	section	section	section	section	section	section	section	section
Deck penetrations, scuppers	EML	block	section	section	section	section	section	section	section
Bottom plates for draught and fire stops	EML			section					
Steel plate ducts (thick sheet)	EMV		section					area	
Air ducts (thin sheet)	EMV	block	block	block	section	section	section	area	
Spiral ducts	EMV	block	block	block	section	section	section	area	block
Pre-fabricated pipes	EMV	section	section	section	section	section	section	area	section
Cable trays	EMV	section	block	section	section	section	section	area	section
Blücher-piping	EMV	block		area	section	section	section	area	
Support rail brackets	EMS	section	section	section	section	section	section	section	section
Plastic pipes	EMS	area	block	area	area	block	section	area	block

Color explanations:

- Detail design much later than building method
- Detail design later than building method
- Detail design earlier than building method
- Detail design according to building method
- None of these components were designed to area

Figure 24: Comparison of current building method vs. detail design.

6.2.2 Comparison of the current building method vs completed work

To highlight the difference between the reality (actual installation work) and the detail design (planned work), another comparison is made, where the building method is compared to the actual installation taking place. Moreover, insulation and its pins have been added to this comparison, because insulation is part of basic design and, thus, not shown in detail design. Figure 25 illustrates when components were installed in the studied areas and their correctness regarding the current building method. Sometimes, the installation has happened during two different phases, e.g. JMS and storage. In these cases, the phase where most of the work happened, has been chosen. This comparison is slightly similar to the completion percentages shown in chapter 5.3.1 but the difference is that the duration of the activities has not been taken into consideration here. Therefore, focus in on the number of deviating activities, not the number of working hours.

Generally, work is done later than the building method suggests. In fact, only 38.6% (51 out of 132) is done according to the building method and even as much as 49.2% (65 out of 132) is done later. 12.1% (16 out of 132) of work has been done earlier, but that is not necessarily good because doing, for example, insulation too early hinders other work. The worst thing is that on average 9.1% of the yard outfitting work were left to area phase. These percentages are calculated from Figure 25. It is to be noted that these are averages for the combined activities of studied areas. As it was already seen earlier, the completion percentage varies greatly between the areas.

According to the building method, most of the work should take place in section outfitting. In this study, only 47.4% (46 out of 97) activities did that. The rest were completed during the block outfitting or storage, and some section outfitting work moved on to the area phase. The storage phase is not an official outfitting phase and, in the future, it cannot be counted on when the schedules are tightened. According to the study, 14.4% (19 out of 132) of activities took place during the storage phase. Of course, it is better to do work there than not at all. Considering the issue from the point of view of a worker, it makes no difference, because the block stays usually in the same square and the circumstances do not change. However, due to the faulty reporting to Meyer’s information systems, it is not known whether work happens in storage or not. For example, JMS could be three weeks long and after it 6 weeks of storage could follow. Supposing that the work took 6 weeks to do, it could be completed because of the extra buffer. Then, in the next ship project, a similar block is given 3 weeks of JMS time, again, but due to the tightened schedule, no storage exists. In this case, work cannot not be finished during JMS. Planning thought that three weeks would be enough because nobody complained about the lack of time the last time. This is why the block scheduling needs to be more accurate.

The most difficulties were with the thin sheet ducts and the spiral ducts. Only 16.7% (2 out of 12) of the areas managed to install the ventilation in section outfitting. In the earlier comparison, it was already noticed that many designers have decided to stage the ventilation to block outfitting, partly explaining this. Other reasons include short section outfitting times, material shortages and workers being busy with the previous ship project.

The support rail brackets were installed during EMV with one exception, even though the building method suggests it to be done during EMS. This is positive. As mentioned previously, the current building method is illogical in this case. On a less positive note, insulation was installed early 41.7% (5 out of 12) of the time. This is a complicated issue, since the insulation material needs to be closest to the deck plate below all other material but it slows down other work if done first in section outfitting. Moreover, there are also spots under large components, e.g. pre-fabricated thin sheet ducts, which need to be insulated, too.

Building method vs. actual work -matrix		Area, block											
Component group:	Building method:	A#2, B#3	A#2, B#4	A#1, B#1	A#1, B#2	A#5, B#7	A#6, B#7	A#3, B#5	A#3, B#6	A#4, B#5	A#4, B#6	A#7, B#8	A#9, B#10
Deck penetrations, scuppers	EML	EMV	EMV	JMS	EMV		EMS	EMS	EMS			EMS	EMS
Bottom plates for draught & fire stop	EML							JMS					
Ventilation penetrations	EML	EMV	EMV	JMS		EMV	EMV				EMS	EMS	
Piping penetrations on bulkheads	EML	EMV	EMV					EMS	EMS	EMV		EMS	
Insulation pins	EMV	EMV	EMV	EMV	EMV	EMV		EMV	EMV	EMV	JMS	EMV	
Thick sheet ducts	EMV		EMV									EMS	
Thin sheet ducts	EMV	Storage	Storage	JMS	Storage	EMV	EMV	Storage	Storage		Storage	Area	Area
Spiral ducts	EMV	Area	Storage	Storage	Storage	EMV	EMV	Storage	Storage	Storage	Storage	Area	Area
Pre-fabricated pipes	EMV	EMV	EMV	EMV	EMV	EMV		Storage	EMS	EMV	EMV	EMS	EMS
Cable trays	EMV	JMS	EMV	EMV	EMV	EMV	EMV	JMS	EMS	EMV	EMS	EMV	Area
Cable penetrations	EMV	EMV	EMV	EMV	EMV			JMS	EMS	EMV	EMS	EMV	
Blücher piping	EMV			JMS	EMV	EMV	EMS	Storage		EMS		EMS	
Support rail brackets	EMS	EMV	EMV	EMV	EMV	EMV		EMV	EMV	EMV	EMV	EMV	
Multilayer / plastic pipes	EMS	Area	EMV	Area	Area	Area	Area	Area	Area			Area	Area
Section border outfitting	EMS	JMS	JMS										
Vertical outfitting (pipes)	EMS	JMS											
Insulation	JMS	EMV	EMV	EMV	EMV	Storage	Storage	JMS	Storage	JMS	Storage	EMV	Area

Color explanations:	
(dark green)	Work completed correctly according to building method
(light green)	Work completed correctly either during section or block outfitting but in different phase
(yellow)	Work completed earlier than building method suggests but good
(orange)	Work completed earlier than building method suggests but bad
(red)	Work completed in a later phase than building method suggests or in storage
(dark red)	Work is left to area phase even if it should have been completed during yard outfitting

Figure 25: Comparison of current building method vs. actual work.

6.2.3 Validity of the current building method and future improvement

Looking back to the two comparisons, it can be said that the current building method is not followed properly. It is seen more as a supporting document, instead of being strictly enforced. TK suppliers can do things differently as long as they complete the work before the final deadline, i.e. the delivery of the area. These documents are often copied from previous ship projects and, sometimes, there are errors regarding block numbers. The sections including the designated area are not even mentioned, even though the information should be written there.

The biggest issue is a lack of working order within the phases. For now, workers or their supervisors may decide themselves what to install first. Although, they have the knowledge to make the correct decisions, they have other considerations, e.g. their own resource efficiency, which easily leads to sub-optimization. This is rather common because work within the same area can be outsourced to different subcontractors, meaning one company is responsible for insulation while another for ventilation. Both of these companies must consider what is the easiest way for them to complete their work. The insulation company would gladly do the insulation first if they have available workers. By updating the current building method to include the optimal working order and enforcing it, sub-optimization within work can be lessened. On a positive note, if the work is outsourced to a single subcontractor, they want to do the entire section outfitting as efficiently as possible. In this case, sub-optimization is not a problem.

There are several matters to consider when deciding the optimal working order, and there may be variation depending on the block. For this purpose, it is taken for granted that all pre-requirements, drawings, material, section/block and workers, are available. A good starting point is to do the most critical work first. Installing heavy components, e.g. thick sheet ducts and pre-fabricated pipes, later is much more time-consuming than lighter ones. Weight is not the only critical issue. Some components, e.g. penetrations and scuppers, are starting points for ventilation systems and pipelines. These could be called enablers of a sort because they enable installation of other components. Additionally, any unnecessary non-value adding work should be eliminated. There is a risk of intense firework damaging the more vulnerable components, e.g. bluchers. If any welding is done close to blücher piping, they need to be protected properly. If these vulnerable components are installed after fire working, no such protection is needed. Lastly, all the bigger module lifts should be planned into the building method, so that the risk of failure is minimal. Occasionally, there are large modules that need to be lifted inside the block during EMS before the next section is lifted on top. The time frame is usually less than a week in these cases.

An improved building method has been suggested in Figure 26 based on the observations and conversations with work supervisors. It is a decent start but before putting it to use, it would be beneficial to obtain feedback from area managers and supervisors, so that its validity can be confirmed to fit the different areas. Special cases such as blocks to go through inner shell shot blasting, need to be investigated more thoroughly. EMV is divided into five different phases. Phase I is actually the old EML phase, which includes mainly installation of penetrations. Phase II is for installations including intense firework while phase III is for ventilation, blücher-piping and cable trays. Then, steel outfitting and possibly plastic piping are to be done at phase IV. Lastly, the rest of the insulation should be done at phase V.

No work has been planned to EMS with the exception of lifting modules. Instead, it should be used as a buffer for section outfitting work. It should not be relied on too heavily, though. Besides, there exists JMS and even possibly storage afterwards. Section border outfitting between the P- and S-sides should be done there along with vertical work and bulkhead insulation. Additionally, the material could be lifted to the block in advance for the upcoming area phase in order to ease lifting operations around dry dock.

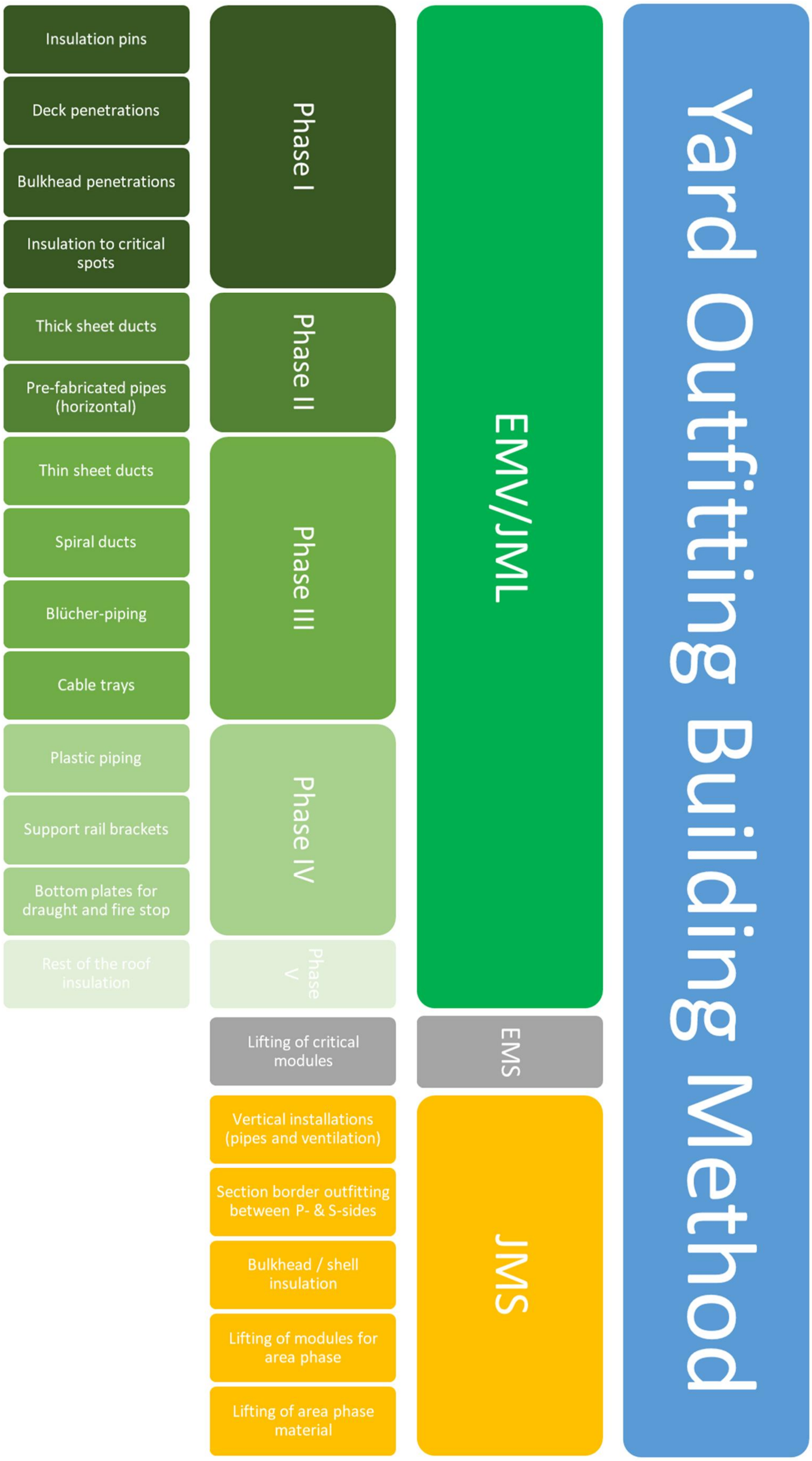

Figure 26: Suggested new building method for yard outfitting including working order.

6.2.4 Detail design improvement considerations to ease the section outfitting

Detail design drawings are mostly drawn in "top view under deck X" style, even for the section outfitting. Since the section is upside down during this time, the drawing needs to be interpreted like a mirror image. This requires more skill from the workers and, definitively, takes more time. Moreover, the risk for errors increases. The workers are already responsible for installing the supports without the help of the drawings, since their places are not designed. Additionally, the workers need to know the different regulations by heart, e.g. how close to a T-frame one is allowed to weld a cable tray support. It would be beneficial to have the drawings available in "bottom view for section outfitting" style. After all, most of the yard outfitting work is supposed to happen already during the section outfitting. Some areas have already implemented this, mainly machinery areas. A valid concern for this idea is that there is a risk for incorrect work if the bottom view drawing is used during the block outfitting due to not being able to complete all work in the section outfitting. To answer this concern, it would be good to have the same drawing both the correct way and upside down. In order not to increase the workload of detail designers, there would need to be a tool in Cadmatic that can turn the drawing upside down. According to a detail designer, 3D drawings, a.k.a. "axial views", can easily be turned upside down but unfortunately the same function does not exist for the 2D drawings. The labels cannot be reversed this way and, therefore, the work is almost the same as doing a new drawing. This would require more thought from the detail design and the production responsible persons, so that a viable solution is found considering future processes, especially SOaaS (Section Outfitting as a Service), which aims to increase the section outfitting capability. It would definitively help the installation work, particularly the more novice workers at shipyard.

Most drawings utilize a system to mark some of the standard components, e.g. thin sheet duct bends, with numbers. Note that these are not to be mixed up with pre-fabricated material's spool numbers. The idea is good but, unfortunately, the execution leaves room for improvement. Firstly, some of the drawings actually lack the explanation for what component the particular number represents. Additionally, these numbers tend to vary depending on the detail designer or the company. A more standardized marking system would be beneficial so that all detail designers use the same numbers for certain components.

The last suggestion, adding the lengths of standard pipes to drawings, was met with controversy among the detail designers but the workers, on the contrary, approved. For now, the length of straight standard materials is not marked to the drawings. This includes, for example, straight spiral ducts and blücher pipes. The workers need to measure the needed length themselves and, then, they can cut the appropriate length piece. The lengths of these parts are already known in Cadmatic but they are not marked to the drawings. On a positive note, this would save some time during the section outfitting. However, there are some cons as well. There is a risk for the drawings to become less readable if too much information is squeezed to fit on top of the existing necessary data, such as dimensions, line numbers etc. This would probably require component group based drawings, i.e. one drawings includes only blücher piping and nothing else. Another concern is the final benefit. The workers are not able to install at an accuracy of 1 mm, so some adjustments are always necessary. It is difficult to say if this is worth the effort.

6.3 Outfitting in EMS

After the section outfitting, the section is turned the right way and, then, it is lifted to the block assembly. During the block assembly, the hull production is responsible for attaching the sections together. First, the respective portside and starboard sections are welded together and after that the next sections can be stacked on top. Additionally, the hull production performs fairing which purpose is to straighten the deck plate and bulkheads due to the tendency for the metal to try and resort back to its original form. Usually, no more than four sections are stacked on top each other, i.e. eight sections altogether in a block. It is also possible to have smaller blocks with fewer sections. Block assembly and EMS outfitting could be said to be concurrent activities, since they take place simultaneously.

The sections are stacked on top of each other in roughly less than a week apart and, usually, the block assembly process takes about 4 to 5 weeks. However, the real EMS time varies according to the section. The first floor gets roughly 4 weeks outfitting time; the second floor gets 3 weeks etc. It is possible that the last floor gets no outfitting time because the block moves on to the painting after the hull production is ready with their work. The available EMS time depends, of course, on when the sections are lifted. Meyer's information system shows the EMS activity for each area separately but they all have the same time period despite being on different decks. Therein lies a risk of imagining that it is possible to do equal amount of work during EMS on the bottom and the top deck. This is more of an issue when looking at the process from a bigger picture during the production planning. Therefore, the EMS activities for different areas in the same block should be planned per deck.

Moreover, the planned working hours, i.e. the Planned QTY column in Safran, were compared to the real working hours during the EMS phases. The comparison can be found in Appendix I. The planned estimates based on the old ship projects did not do very well, quite the opposite. For example, it was estimated that EMS would take 1000 hours for blocks #3 and #4 in area #2 but in reality, no work was done at all. As a conclusion, it seems that the Safran estimates for working hours cannot be trusted at this level. Generally, quite little work was done during EMS, except in block #8. Even according to Meyer Turku's current building method, there should not be much work planned, except the outfitting of the section border between the P- and S-side.

Principally, the hull production has a more crucial role during this phase. Therefore, the outfitting workers should give way to the hull production if working close by. Working simultaneously with the hull production, certainly, slows down work slightly but it cannot be said by exactly how much. By no means is it impossible to work, though, if the situation requires it. Ideally, the hull production would work one floor at a time from the bottom to the top with the outfitting following suit but, in reality, they might be working in two or three floors simultaneously. This is due to wanting to keep the individual workers efficient by not placing too many workers on the same deck. The lack of synchronized planning between the outfitting and the hull production has led to a rather disorganized block assembly / block outfitting process. It does not help that a block can easily contain over 20 different areas and, thus, even more operators. Simple issues, e.g. removal of outfitting materials before hull production, can become difficult. For example, a rather common situation is that some area has stacked loads of material within the block and they need to be transferred because the hull production needs to perform fairing. The hull production worker would call directly to the block's outfitting contact person who asks which area is concerned. However, the hull production does not consider areas so they need to figure it out first. Then, the responsible TK supplier is contacted which, in turn, contacts the possible subcontractor to go and perform the task. For the information to flow to the right person, at least three phone calls are needed, likely even more.

This has partly led to the subcontractors skipping the EMS outfitting and instead completing the work during JMS / storage phase when in relative peace. From Figure 25, it can be seen that 7 out of 12 (58.3%) targets utilized their EMS time. Usually, outfitting workers have continued doing section outfitting work that could not be completed during EMV/JML. The results for each component group are shown in Table 12. Deck penetrations and scuppers were most commonly installed but other penetrations as well. Note that the result for thick sheet ducts is ignored due to a low sampling. Otherwise, some piping and cable trays were installed too.

Table 12: Component groups installed in EMS

Components installed in EMS		
Component group	Installed in EMS	Percentage
Thick sheet ducts	1 of 2	50,0 %
Blücher piping	3 of 7	42,9 %
Deck penetrations, scuppers	5 of 12	41,7 %
Piping penetrations on bulkheads	3 of 12	25,0 %
Pre-fabricated pipes	3 of 12	25,0 %
Ventilation penetrations	2 of 12	16,7 %
Cable trays	2 of 12	16,7 %
Cable penetrations	2 of 12	16,7 %

Because of the uncertainty regarding the EMS time, it would be better to consider it as a buffer time for the section outfitting, instead of planning much new work there. While preferably wanting to finish all section outfitting work during EMV / JML, it would be possible to utilize EMS to catch up without affecting the ship yard's timelines at all, i.e. no section would need to be delayed if little work could not be done for any reason, e.g. material missing. The lifting of critical modules and machines should be done but, otherwise, there is not much anything else as important. Vertical pipes could be installed along with the section borders but that is why JMS exists.

6.4 Outfitting in JMS and storage

After EMS, the block goes to the painting for about two weeks. The outer shells are always painted and possibly the inner shells as well. This all depends on the block. Then, JMS begins in either outside squares or inside in one of the production halls. Usually, it takes place in the first mentioned. In this case, the welding gases and the electricity need to be brought to the site. The lifting of the components into the blocks happens with the help of forklifts or crane vehicles. The working conditions are the same as in EMS, except the hull production should have completed their work. Minor fixes and replacements were done to the openings during the study but normally JMS is solely for outfitting purposes. After JMS, there might be a storage period depending on the lifting schedule to the dry dock. From the point of view of the worker, storage is exactly the same as JMS and, therefore, storage phase is strongly utilized to catch up with work. The block even stays in the same square at least if outside.

Earlier in Figure 25, 19 out of 132 (14.4%) activities took place during the storage phase. However, this value is slightly misleading, since the activities require different amounts of time. The installation of rectangular ducts can take even as much as 500 hours due to having so many components but, sometimes, there is only 50 hours of work. To illustrate this better, a comparison between the JMS and the storage working hours is presented in Figure 27. Due to the secrecy reasons, the hours are not revealed. Note that area #4 was left out from this comparison due to not being able to follow working hours accurately enough during the JMS and the storage. Technically, quite little work is done during the JMS compared to the storage phase. This is actually explained by comparing the lengths of these two phases in networking days. The comparison is shown in Figure 28.

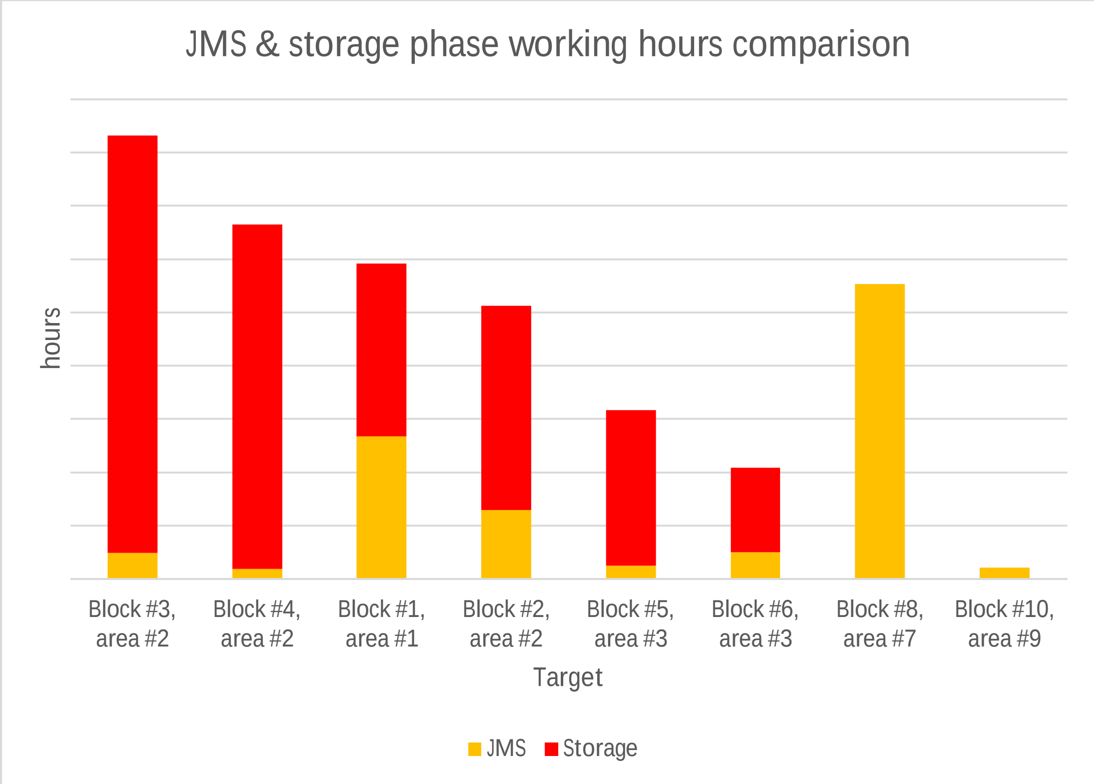

Figure 27: Comparison of JMS and storage actual working hours.

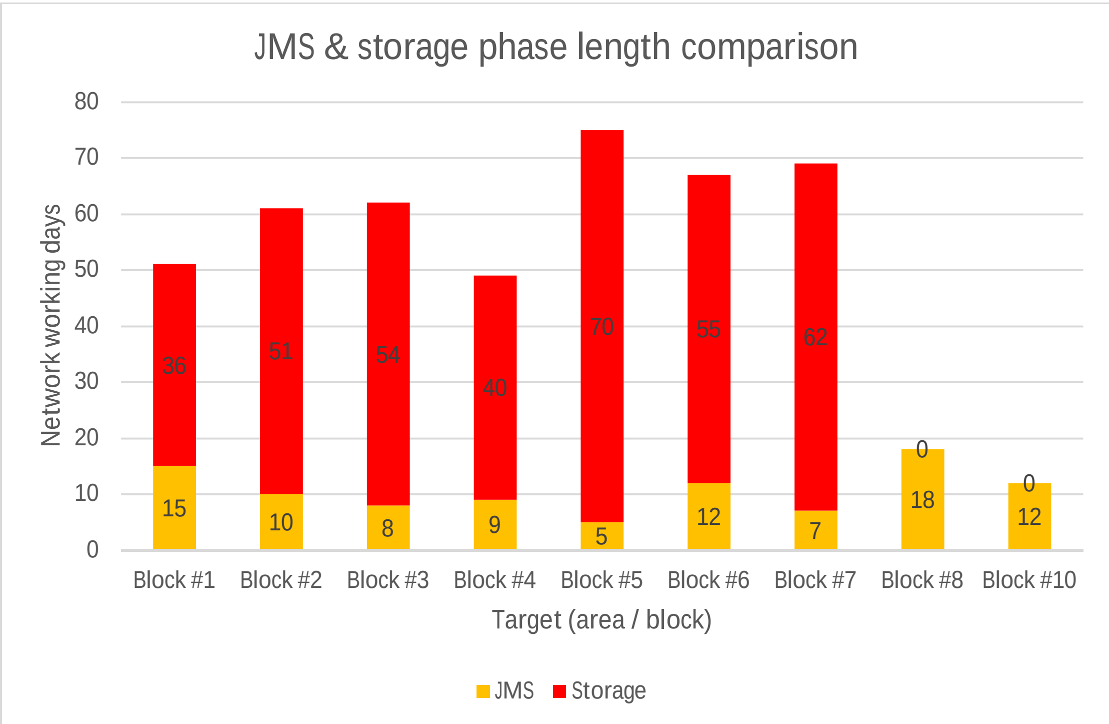

Figure 28: Comparison of JMS and storage phase lengths.

According to Meyer Turku's current building method, insulation should be done during the JMS, which held true 50% of the time. Multilayer and plastic pipes are supposed to be installed already during the EMS but only 1 out of 10 managed to complete these before the area period. Most notably, over half of the ventilation and blücher piping has been done during JMS and storage. Some TK suppliers purposefully left these jobs to be done after the block painting for fear of the shot blasting damaging these. In addition, there were some material shortages regarding the pre-fabricated thin sheet ducts. The installed component groups in JMS and storage are shown in Table 13.

Table 13: Component groups installed in JMS and storage

Components installed in JMS / storage		
Component group	Installed in JMS	Percentage
Thin sheet ducts	7 of 12	58,3 %
Spiral ducts	7 of 12	58,3 %
Blücher-piping	4 of 7	57,1 %
Insulation	6 of 12	50,0 %
Cable trays	2 of 12	16,7 %
Deck penetrations, scuppers	1 of 12	8,3 %
Ventilation penetrations	1 of 12	8,3 %
Cable penetrations	1 of 12	8,3 %

At the moment, the TK suppliers are able to utilize the storage phase in order to catch up with the section outfitting work. In the future, these might be considerably shorter and more blocks might not have it at all. In any case, planning needs to take into consideration the possibility for a storage phase, i.e. check the planned lifting schedule. Currently, the storage period is a buffer for the hull production before lifting the blocks to the dry dock. "Storage phase working" phenomenon originates from an operative choice in running the entire ship project process. The section production starts about 6 to 8 months before the first block is lifted to the dry dock. The hull production keeps manufacturing blocks at an even pace and just before the dry dock phase begins, the yard is full of blocks waiting to be lifted. This waiting period is storage phase for outfitting. According to the process, no work should be done there, because no work has been planned. I am not saying that the storage period should not be utilized but due to inaccurate reporting it is easy to get a false picture of things going according to plan. Planning does not get feedback that the JMS time given was too short if a long enough storage phase exists behind it in order to compensate.

6.5 Reasons for work slipping further

There are several reasons for work slipping further, and some of them have been mentioned already but they are presented in this chapter in a structured manner. They can be divided into two categories: general reasons that are not dependent on any phase and phase-specific reasons that are only present in certain outfitting phases. Moreover, it is analyzed how these reasons cause a sort of a chain reaction and how far reaching the effects are.

6.5.1 General reasons

Previous ship project

It seems that it is not only students who suffer from the syndrome that is infamously named after them, i.e. leaving work close to deadline. Ship projects are not much different. In the beginning, the deadline is so far away and it does not matter if all planned tasks could not be completed, since there is plenty of time to catch up later and there is so much else to do. Generally, this means that yard outfitting work keeps slipping to the area phase and a chain reaction begins. During the final months, a big push is done to catch up, so that the deadline is held. Most of the focus is on the ship floating next to the outfitting pier, lessening needed resources from the ship project that has started manufacturing sections and blocks. Most crucially, this forced prioritization consumes people’s energy as they are barely surviving and, thus, a ship project whose deadline is a year away does not receive the needed attention. While everyone realizes this is by no means ideal, it is difficult to break the vicious circle. This would likely need a strategic decision to increase capacity for a time period to catch up and, then, make sure that it does not happen again by completing work as close to planned as possible.

Design

Another critical reason is the delayed detail design, which has three effects on the outfitting production. Sometimes, the detail design drawings are not completely ready before the section outfitting start, even though they should be delivered to the workforce two weeks prior. Working with an incomplete drawing increases the risk for re-doing work later due to the possible design errors. Additionally, the detail designers need to draw the pre-fabricate drawings and they need to be sent out to the manufacturers. If these drawings are sent out too late, it is possible that the needed pre-fabricates do not arrive in time. Thirdly, the detail designers give opening info to the hull production, so that they can cut the needed holes to the metal sheets even before the section assembly. If the opening info cannot be given for any reason, the outfitting workers are forced to cut the wholes themselves, which counts as extra work. When asking for reasons to these delays, all of the interviewed detail designers mentioned that they lack the proper pre-requirements in order to successfully complete their job within the planned deadlines. Typical challenges mentioned were incomplete or otherwise faulty basic design, penetrations missing from bulkhead responsible (cannot start the drawing if one does not know where to end the lines) and late changes to the design from the buyer. These are some of the reasons for detail design being late but it is to be noted that the root causes may lay somewhere deeper but they are out of scope for this study.

Availability of work force

Often, the subcontractors doing the outfitting do not simply have the workers to do all of the jobs at once. This is partly tied to the first reason, the previous ship project, but that does not explain it entirely. To understand the issue better, the point of view of the subcontractor is considered. A subcontractor has a certain number of workers hired. The company wants to keep that number stable, since it is expensive to vary capacity between short periods of time. To make sure that the needed capacity stays the same, the company needs an even workload. On the contrary, the yard outfitting process occurs in spikes. There is intensive work for a few weeks at times and, then, there are long pauses between these spikes. To combat this, the subcontractors try to balance their workload through having enough different areas whose spikes occur at different times. The storage after JMS is actually a blessing for their way of working, since they get more buffer time. As mentioned in theory, buffers are one way to combat variation. This is why subcontractors are usually doing work with only a few workers to complete the most critical jobs as was shown in the capacity measurements. On top of that, they are thinking about the resource efficiency. There are always choices to be made, e.g. which are the most critical areas, because sometimes these spikes go on top of each other. The outfitting process contains so much variation that predicting the spikes accurately is impossible.

Material shortages

In addition to the pre-fabricated material, e.g. certain thin sheet ducts and all thick sheet ducts, there is also "bulk material", e.g. spiral ducts and cable trays, which the ship yard orders in large quantities. The TK suppliers are responsible for procuring the pre-fabricated material but the "bulk material" is delivered by Meyer Turku. Some of these logistics and warehouse operations have been outsourced to other companies. The shortages regarding the pre-fabricated material could be the fault of late pre-fabricate drawings, or the manufacturer not being able to keep up with the deadline. On the contrary, the shortages regarding the "bulk material" originate from a lack of co-operation between outfitting, purchasing and logistics. During the section pilot project, there were severe problems getting all of the material in time for the section outfitting. The solution was to order material early enough, so that it was definitively available when needed. However, this is an inadequate approach, because it strains the warehouse operations and ties more capital by having large inventories.

It is vital to have all of the needed material. The difference between having most of the material and all of the material, could be the difference for starting the work or not. For example, having all of the straight spiral ducts but no bends means that no spiral ducts can be installed. Additionally, there is the valid working order to consider. It is not advised to install more vulnerable components before the intensive fire working is finished. For example, if thick sheet ducts are missing, no other ventilation should be installed either.

6.5.2 Phase specific reasons

EML

This phase takes place towards the end of the section assembly in the hull production facilities. At this point, the hull production is even busier than during the block assembly and, therefore, they have possibly more than five welders assembling the section. This means that there is little space for outfitting, and assembling the section is, of course, the priority. After the section assembly is complete, the section needs to be approved by the buyer. Before the approval, no big components can be installed, so that the buyer can check all of the welding work. When the approval from the buyer is received, the section is transferred onwards to either the section outfitting or the painting. Therefore, the time period to do outfitting is very short. Additionally, outfitting needs permission from the hull production if they can come start the outfitting work in the first place. Due to these challenging circumstances, it is no wonder why many decide to skip this phase entirely.

EMV

There is variation in the section assembly, as well. This results in sections coming to EMV either slightly later or earlier than planned. There were quite big challenges during the pilot project due to the hull production investments, and at that time sections came much later than planned. Even though the arrival time varies, the sections should leave according to the plans, which causes variation to the available section outfitting time. In some cases, the section outfitting times ended up being very short. The missed outfitting days were not compensated, instead the original timeline was kept if the block assembly could receive the section.

The amount of outfitting work in an area depends on the type of the area. Section outfitting time is given according to the type of the area within the section. Currently, machinery rooms are to receive at least 3 weeks while all other sections should make do with 2 weeks. This is not abiding but serves as a general guideline. In any case, the section outfitting time is not decided by a section’s exact workload. For example, a public space section with loads of ventilation might receive the same amount of time as a passenger cabin section, even though the first one requires roughly 3 times more time. For some sections that are not machinery rooms, 2 weeks is simply not enough.

These critical sections should be defined in advance and the appropriate measures taken.

As mentioned earlier, a section may contain several areas while some are larger than others. Some of the smaller areas might not even start their work at all before the block outfitting. A common phrase heard was: "There is so little work, only bulkhead penetrations. We don't want to bother establishing a work site for that. We'll do it later". However, these penetrations might be crucial for a neighbor area. Penetrations are either starting points or ending points for lines. The same applies to deck penetrations. Unfortunately, they are even more problematic. When the section is upside down in EMV / JML, the deck is actually part of the area above in the general arrangement. In other words, an area's ceiling and bulkheads are in one section but the deck belongs to another one. It is much handier to install deck penetrations in block outfitting when these are together except for the bottom section. In any case, skipping work because there is so little of it may be sensible for the subcontractor but it likely hinders someone else's work even more, causing sub-optimization, yet again.

EMS

This was already covered for the most part in EMS outfitting in chapter 6.3 but the key points are repeated here. Block assembly is the first priority and outfitting gives way. Additionally, working is likely a bit slower due to more people within the same space. The hull production does not necessarily work one floor at a time from the bottom to the top so that outfitting could follow suit. Lastly, communication between the outfitting and the hull production is challenging at times. For these reasons, the subcontractors prefer working in JMS and storage.

JMS

Again, these were already mentioned in chapter 6.4 JMS and storage outfitting. The biggest reason is the possible existence of storage phase after JMS, which could last for even 2 months depending on the lifting schedule.

Painting

The shot blasting has been mentioned earlier and the fear of it damaging the more vulnerable components. Before the painting, surface treatment does shot blasting to smooth out the plate so that painting is easier, which practically means that the plate is shot with tiny steel balls. In case these steel balls hit outfitting components, there is a risk for them getting damaged. The paintable surfaces depend on the placement of the section regarding the ship and this can vary between ship projects. Sections under the waterline are completely painted; Sections below the boat deck have their outer shells painted from both inside and outside; Sections above the boat deck have their outer shell painted only from outside. Additionally, all AC rooms and electrical spaces are painted from the inside. The magnitude of this risk is currently unknown, even by surface treatment organization. There are many opinions regarding the matter but no clear instructions. It needs to be studied how the shot blasting affects the yard outfitting process. This is crucial knowledge before the SOaaS is launched. Several questions need to be answered, such as "Can we install ventilation and blücher piping or not?" or "How much space needs to be reserved as a precaution so that the components do not get damaged?". A new development project is strongly recommend to be launched with the surface treatment organization so that the issue can be solved.

6.5.3 Chain reaction of reasons and their effect

The reasons mentioned in the previous chapters and their connection to one another are illustrated in Figure 29, a chain reaction chart for work slipping further. Under "General reasons", there are four root causes, previous ship project, incomplete basic design, other work sites and bulk material shortages, which start this chain reaction for work generally slipping further. They are marked with a shape of a golden oval. For lack of better wording, term *root cause* is used but it should be noted that there might exist even deeper reasons. These affect outfitting's pre-requirements: detail design, work force and material. They are marked with grey rectangles. The blue rectangles describe lesser reasons, which are found within the processes. There can be several of these lesser reasons in a row leading to the final symptom. For example, late pre-fabricate drawings leading to late pre-fabricate materials and, therefore, to incomplete material packages. The ship yard's processes are marked with a green rectangle.

It is no wonder that a significant amount of work takes place during the storage phase when there are so many challenges within the yard outfitting process. The chances for successfully completing the yard outfitting jobs according to the plans are not good at the moment. So many things can go astray. Besides general reasons (which are represent at all times), the snowball starts from skipping the EML. Most of the yard outfitting work should be completed during EMV/JML but this is difficult due to the lacking pre-requirements. After the section is turned the right away, the installation gets more time-consuming and logistics are more challenging, too. The EMS is used to catch up with some of the section outfitting work but not all, especially ventilation and blücher piping. Therefore, lots of work is left to the JMS but the true outfitting time depends on the lifting schedule. Taking into consideration the limited work force capacity used by the subcontractors, it is no wonder some of the work slips onboard. By the time storage starts, all of the pre-requirements should be in check with the exception of the unknown work force capacity. The detail design should be ready; materials should be available and there could be plenty of time during the storage. This way all of the work slowly slips forwards, because the earlier work is not finished. Finally, the ship project is in its current state at the outfitting pier.

The outfitting process from the point of view of Meyer Turku is in a precarious position. Firstly, fixing the pre-requirements, such as material shortages and incomplete basic design, requires a combined effort from all the involved organizations, not just the outfitting. The vicious circle involving the final “push” needs to be broken, so that enough attention can be given to the yard outfitting. Due to the way the turnkey contracts are signed, Meyer Turku cannot force the subcontractors to do work according to the plans, so the limited work force challenges will possibly continue to exist. Additionally, there exists an attitude that it is okay for work to slip further without hunting down the reasons why the work slipped further. The turnkey contracts are partly to be blamed for this, because it creates room for thoughts such as “As long as the area is ready before the final deadline”.

Even though the pre-requirements are certainly less than ideal, the outfitting has room for improvement as well. The current state of affairs should not be accepted. At the moment, the risks are transferred to the TK suppliers, who, in turn, transfer it on to the subcontractors. Therefore, it is difficult to differentiate the symptoms from the root causes when no one has a clear view of the big picture. This whole TK network with current contracts is an easy but insufficient solution. Instead of doing what is easy, we should focus on doing what is right. It will certainly require more effort but it will pay back in the long run. As long as the supply chain network keeps running the process in their own sub-optimized ways, it will cause additional costs for Meyer Turku. These companies are not operating without a profit for sure. The change starts from actively following the yard outfitting and really knowing our own production processes, so that we know in what direction to go.

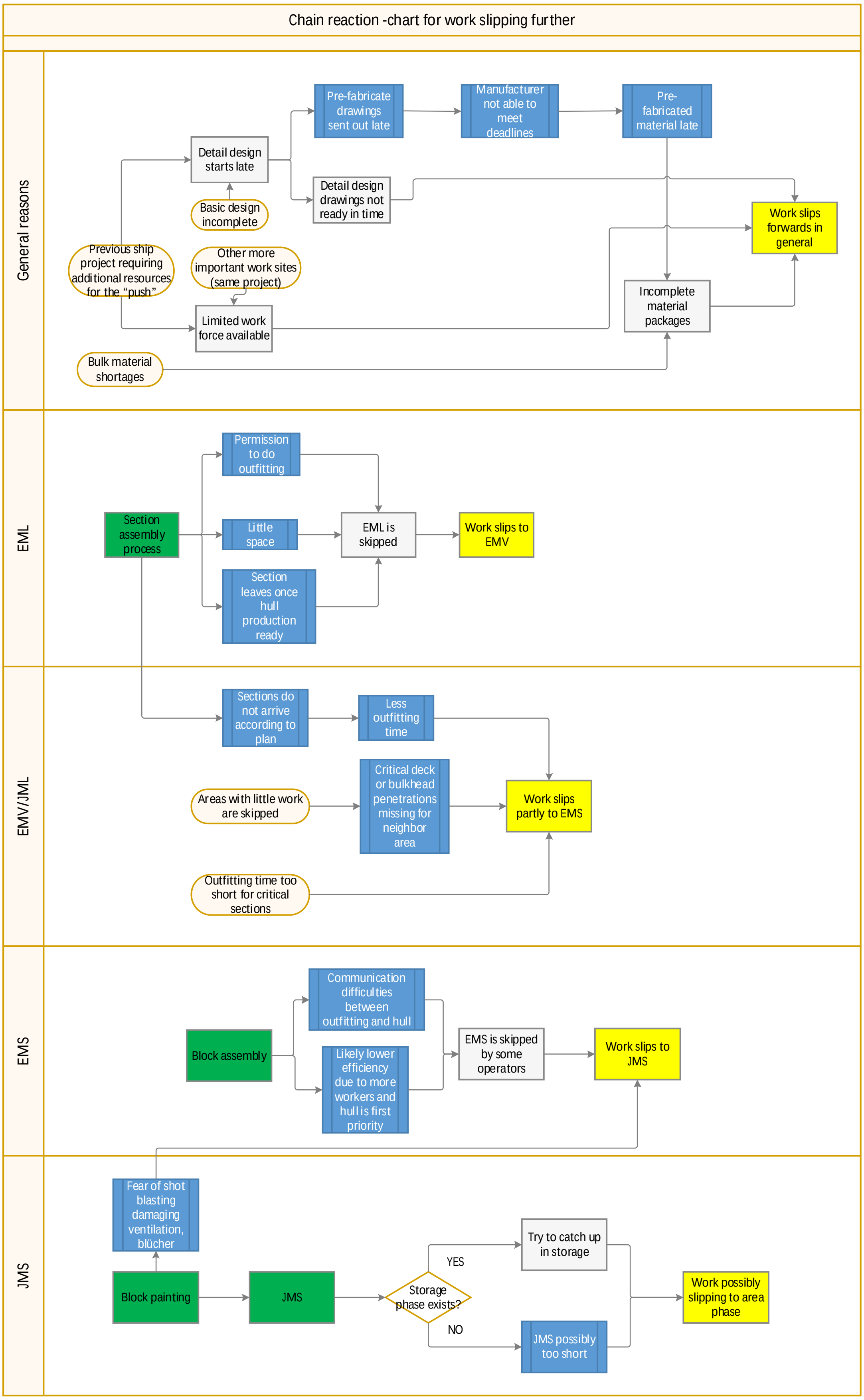

Figure 29: A chart showing the reasons and their connections for work slipping further

6.6 Variation and its impact on the outfitting process

As shown in the Kingman's equation (formula 5), there is variation both from outside and inside the process. Variation from outside is analyzed with limited focus and variation in existence of pre-requirements is not touched upon. Instead, it is analyzed how current scheduling, which does not take into consideration the needed outfitting time, leads to a need for large capacity changes within short periods of time. However, variation from inside is mostly due to the nature of manual labor. Additionally, the accuracy and precision of the installation times are discussed as Piirainen suggests (see chapter 2.4.2).

Need for capacity adjustments due to an uneven production schedule

It is inevitable that the workload varies between each section due to sections including different kind of areas. However, this should be taken into consideration much better when planning the production schedules. As mentioned earlier, scheduling is not based on the outfitting's planned hours, which creates situations where there is either too much or too little time. In Table 14, the required daily worker capacity is shown for the studied sections. The data for the calculations is found in Appendix including the section outfitting time and the planned hours. In the calculations, it has been supposed that workers have a 10-hour workday and the work takes place Monday through Friday.

The required capacity varies between 1.3 and 9.6 workers for this sampling, which is an enormous range. The average capacity required is 5.5. The fact that the work might progress either slower of faster than planned is not considered here but that adds extra variation to the required capacity. It was already mentioned that the subcontractors wanted to have a balanced workload in order to keep their efficiency up. Since adjusting the capacity at a short notice is difficult, the only realistic method is to use buffers, i.e. do work later in the storage. Having such uneven workload is considered Mura but that is covered later in chapter 6.7.

Table 14: Required capacity for completing all of the planned work in section outfitting

Coded name	Required capacity (workers)
Section #1	4,5
Section #2	8,8
Section #3	7,4
Section #4	9,6
Section #5	7,3
Section #6	2,8
Section #7	3,8
Section #8	4,9
Section #9	4,3
Section #10	1,3

Variation in installation times

As it was seen in the installation time measurements, there was variation between the installation times for a component within the same phase. The factors (a worker's skill, the number of workers on site, insulation for section outfitting and other preparations) effecting them were already discussed in chapter 4.2.3. It is impossible to get rid of the random variation caused by a worker's skill and motivation. However, non-random variation, such as extra jobs, should be eliminated. Other preparations, e.g. the work supervisors' participation through getting material is also random variation, as well as the existence of untimely insulation in the section outfitting.

Looking at all of the installation time graphs in Appendices, it is easy to notice that the samples can deviate from the average quite much to both directions, i.e. the standard deviation is large. This means that the installation times can be considered as imprecise according to Figure 6. This was similarly seen in the "100-hour job examples", where the 2σ-range was given. In order to get less imprecise results, the process should be more standardized. For example, standardizing the working order like in Figure 26 would help.

The accuracy of the installation times is more difficult to analyze, since the real average is not known and it will never be exactly known. However, through performing a sufficient number of measurements an accurate enough level can be reached. Piirainen's suggestion of 30 samples should be good enough for this. Despite the smaller than optimal sampling, it was noticed in Table 5 that the former installation estimate for cable trays deviated quite much from the thesis estimate.

6.7 Sources of waste within the production

Waste has been categorized to Mura, Muri and Muda as Pienkowski suggests (see chapter 2.3.3), so that the connection between these is easier to understand. Firstly, the sources of Mura are exposed and, then, Muri is discussed which originates from the first one. Lastly, Muda is analyzed which is seen daily in the production.

Mura in yard outfitting

There are two kinds of Mura, uneven workload and variation in the production scheduling. Unfortunately, both are present in the yard outfitting process. The first type of Mura was already presented in Table 14, where it was shown how the needed capacity keeps changing on a wide scale. Such uneven workload is problematic for the subcontractors. In order to fix this, the square time in the section outfitting needs to be given in a standard manner, for example, by assuming that work takes place with 6 workers and 10 hours a day. The second type of Mura has not been analyzed in this thesis but its existence was already confirmed during the section pilot project. Sections kept arriving to EMV/JML later than planned. What is worse, the arrival date changed just a few days before, leaving very little time to react. This puts unnecessary stress on the subcontractors, since they want to keep a high utilization rate. The only way to make sure that there is always some work is to increase their WIP, which leads to the current predicament of long throughput times.

Muri in yard outfitting

Muri, the second category of waste, is a consequence of uneven workload. The two forms of Muri are: under-utilization and overburden. As it was seen in the capacity measurements, work tended to happen with a low number of workers. Sections and blocks with relatively little outfitting work received similar square time as targets with more work. Therefore, there is under-utilization when there is little work and overburden when there is too much work, respectively.

Table 15 shows the difference between the actual duration and the needed duration for 6 workers. In the worst case, the section #3 has 5 days too little time while the section #10 has extra 10 days. Taking the average of all sections, gives 1 day as extra in total, which seems fine. However, this is very deceiving and one should absolutely not analyze it that way. On one hand, assuming that the maximal capacity is 6 workers, there are 14 days too little time for sections #2, #3, #4 and #5. This leads to 14 days of delay. On the other hand, the 15 positive days are under-utilized and they do not make up for the negative ones. This is why variation is so dangerous. The only way to fix this is through adding buffers for the needed sections and reducing the actual duration for others.

Table 15: Calculating actual duration minus needed duration for 6 workers

Duration	Actual duration - needed duration for 6 workers
Section #1	2
Section #2	-4
Section #3	-2
Section #4	-5
Section #5	-3
Section #6	2
Section #7	3
Section #8	3
Section #9	5
Section #10	7

Muda in yard outfitting

As mentioned, Taichi Ohno has categorized Muda into seven types (see chapter 2.2.3). Three of these could be found within the yard outfitting: inappropriate or non-value added processing, unnecessary (worker) motion and transportation (material). It has already been shown that much of the work keeps slipping further from section to block outfitting. Due to the lesser efficiency when installing upwards, more working hours are generated. This is simply pure Muda. Additionally, the building method document is not followed. Therefore, there exists a risk for sub-optimization, when there are different subcontractors operating within the same area. The installation of insulation is a common case.

The second Muda, unnecessary worker motion, is more of a problem in block outfitting. This is due to the worksites being rather far away from the subcontractors' quarters. The block outfitting squares are practically on the other side of the ship yard compared to subcontractors' quarters, which is almost a kilometer away. These quarters include subcontractors' social premises and private warehouses. Additionally, bulk material, such as screws and angle bars, are located in the section outfitting hall, which has a more central location but some distance exists, though. Anyway, the workers are forced to move long distances when the need arises. In order to get a better understanding of the magnitude of the problem, value added time should be measured and non-value added activities categorized as well. This was already done back in the section pilot project to test whether the retrieval of bulk material is an issue, or not. However, the distances were very short compared to the block outfitting circumstances, so more research in the future is needed to test this out.

The last observed Muda is the unnecessary transportation of materials. Material is delivered to the section outfitting squares next to the section but due to the existing challenges all of it cannot always be installed. In these cases, either two things happen: the material is sent to the subcontractor's private warehouse or the workers might even sport-weld some of the heavier components, e.g. pre-fabricated pipes, to bulkheads for storage. The secondly mentioned should not even be done due to it possibly complicating the painting process. In any case, both lead to Muda. It would be better to have only necessary material on site to lessen this.

6.8 Analysis on flow of yard outfitting

In this chapter, two important concepts related to the flow are analyzed. Firstly, Little's law is applied to section outfitting, and the effect of doubling the production output is considered. Secondly, the subcontractors' focus on high resource efficiency is discussed along with its drawbacks.

Little's law in yard outfitting

As introduced in the theory, Little's law is an equation (formula 1) relating Work-In-Process, throughput and cycle time. WIP is the amount of sections or blocks in the squares; TH is the number of finished sections and blocks; CT is the average time it takes to do the work (see chapter 2.3.2). Because of the way scheduling is done, i.e. the yard outfitting scheduling is mostly done with the hull production in mind, it is difficult to increase the available square time. The reason for this is that the hull production needs the section for the block assembly. Therefore, it is not possible to increase the cycle time in the section outfitting. Since the section outfitting needs to keep feeding sections to the block assembly, the throughput will stay the same even if all of the section outfitting could not be completed. The last factor in the equation, WIP, is limited to the number of existing worksites.

However, there is a need to effectively double the production pace so that the future ship projects can be delivered on time. In order to accomplish this, there are theoretically three options for doubling the throughput: double WIP, cut cycle time in half or a combination of these doing a bit of both. The first option would mean investing in more worksites. This way the subcontractors could keep working the way they are. However, this is not viable due to the size of the investment. The second option is to cut the cycle time to half. This has certainly potential, since work tends to happen with much less than 6 workers but the challenge is to get the subcontractors onboard. The last option, a combination of both, is probably most viable, since this way some stock buffer could be achieved, so that there is less stress on the subcontractors. By increasing the WIP a little, the cycle times need not be as strict. This depends on the amount of added buffer, of course.

High resource efficiency – low flow efficiency

Considering the way that the subcontractors have multiple worksites available and the workers are always busy, one could say that a high resource efficiency is utilized. However, this does not mean that the way of working is very high up in efficient islands like in Figure 3. Even though everyone is busy, all of the activities are not value adding or the best practices are not used. The best example is the way the yard outfitting currently takes place. As it was shown in Figure 22, the completion percentages after the section outfitting were rather low compared to the planned work. Moreover, it was shown in Table 6 that installing upwards definitively takes up more time than downwards for all components, except cable trays. With these two facts as evidence, it is easy to say that work is not as efficient as formerly thought.

Due to the significance of the section outfitting as a process, it would be better to focus on raising its outfitting completion percentage. Even though, the section installation times are likely to be a little slower due to the increased number of workers and the added risk for some idle time, the overall efficiency will be better than the current way of operation. It is better to utilize some extra capacity in the section outfitting rather than working very hard later to catch up. This could be related to the Efficient ocean situation given by Moody and Åhlström (see chapter 2.3.2), where resource efficiency is not so good, since extra capacity is utilized to make sure that all work can be completed faster. The most importantly, more work accomplished before the area phase reduces stress later.

It is necessary to remind, though, that the current situation is not completely the fault of the subcontractors. Most of the fault lies at the lacking pre-requirements which need to be fixed before the process can be expected to run smoothly. What is positive, is the fact that workers are generally rather skillful in their work as shown in the installation times, which are in reality better than previously thought. Through re-engineering parts of the processes related to the yard outfitting, it is certainly possible to reach Meyer Turku's goal of doubling the throughput.

7.0 Production planning accuracy and improvement from earlier methods

To better understand the progress that has been made regarding the production planning, the development of the installation time concept has been covered. Secondly, the planned estimates from Meyer's information system and the current production planning estimates are compared to the new yard outfitting estimates based on the thesis' installation times. Finally, there is a comparison between the actual working hours and the planned estimates. This illustrates the fact that the actual progress rarely follows the planned estimate leading to either more or less needed working hours.

7.1 Development of the installation times

As already mentioned in chapter 4, the planned estimates are only as good as the initial raw data, i.e. the installation times. In order to illustrate the growth that has taken place, all of the phases included in this process are covered briefly along with their key developments.

Installation times from the past

Measuring the time it takes to do different jobs is not a new invention per se but the measurements needed to be re-performed in a standardized way. There existed some installation times for the section outfitting even before the section pilot project. Unfortunately, their measuring methods were not known. For example, it is not known if only the value added time has been measured when workers are present at the worksite or if the whole workday has been included with the exception of lunch. It is even possible that the values have been gathered through different methods, or that some of them are simply guesses based on considerable experience. Besides the unknown measurement methods, it is difficult to say, which value is more correct, since there are approximately between one to four values for each component. These values landed on a rather large interval in general, which made the task of deciding "which is the correct value" very difficult. There is no way to review the calculations or even know the sample size because the average value is the only thing listed. In some cases, there were even different units for components, e.g. someone had estimated thick sheet ducts to be installed with [h/m] while others used [h/kg].

Installation times from section pilot project

After the re-invention of the installation times for this project, in order to compare pilot sections to reference sections, a standardized way for calculating the installation times was created. This has been already explained in chapters 4.2.1 and 4.2.2, both the calculations and the method for obtaining the raw data. After the project, the measurement results were obtained for specific sections and these could be compared in order to calculate a new average to be used by the production planning. The section pilot project provided reliable installation times for section outfitting with the exception of pre-fabricated pipes. The sample sizes for components varied between 3 and 10. The current planning estimates for outfitting are mostly based on these installation times. Due to the total lack of installation times for block outfitting, these values have even been utilized there without applying any kind of correction factor.

Installation times from thesis measurements

The major contributions are the completely new installation times for block outfitting, including thin sheet ducts, spiral ducts, cable trays and blücher piping. The change to the current estimates based on the section pilot project, are bound to change considerably for the block outfitting. Additionally, some new samplings were measured for section outfitting, which was combined with the previous reference samplings to calculate even more accurate installation times. There were between one to four new samplings obtained. On top of obtaining new and better installation times, the effect of variation has been analyzed. It was really eye-opening to realize the amount of standard deviation in the calculations. This was shown as the 2σ-range. Even though the production planning will keep doing the estimates according to the averages, it would be important to consider impact of variation when designing the buffers or doing daily management.

Future development for installation times

Although, there has been good progress with the development of the installation times, the job is not done yet. Firstly, more sampling is still needed for both the section and block outfitting to help verify the existing results. Since the sample size is somewhere between five and ten for each component, there exists some unknown but likely small error depending on the sampling. The best way to illustrate the problem is a Gaussian curve just like one in Figure 7. First of all, the difference between thesis' average and the actual average, i.e. the real average of limitless number of samplings, is unknown. Therefore, the top of the Gaussian curve is likely slightly wrongly placed. The real installation time is either a bit smaller or higher. Secondly, variation affects the shape of the curve. Having little variation makes a slimmer but higher curve, since most of the samplings land close to the average. Then again, having much variation creates a wider but lower curve, since some samplings are distributed further from the average. The current sampling is very limited when analyzing variance but it is safe to say that there is quite much of it as it was shown in chapter 5.1.3. However, Piirainen suggest a sample size of 30 to be sure. So in essence, it is possible to get the top of the Gaussian curve very close to the reality with enough measurements and, additionally, the shape of the curve (variation) will be known more accurately.

7.2 Yard outfitting planned workload comparison

The best way to illustrate the development of the installation times and, therefore, the production planning estimates is to compare the available data. As already mentioned in chapter 3, there is a planned hour estimate in Meyer's information system, Safran. This estimate is the sum of all the yard outfitting activities: EML, EMV/JML, EMS and JMS. Additionally, the production planning has provided their insight through utilizing the section outfitting installation times for all material in Cadmatic. Finally, there is an estimate based on the installation times measured during the thesis for both the section and the block outfitting. Also, an estimate for insulation and support rail brackets are included, which are materials not found in Cadmatic. The full comparison including the planned hours is in Appendix J. The difference between the thesis and the other two planned hours have been calculated. Based on the difference, a deviation percentage from the thesis estimate has been calculated, which is shown for each studied target in Table 16. The benchmarking was done to the thesis values due to it being the best available data.

The first column shows Safran's deviation from the thesis estimate. The deviation percentages range between -99% and +146%, which is a very wide interval. In addition, only two of the targets are somewhat close (-13% and -29%). Another interesting observation is that for this sampling, the Safran estimates are smaller than the thesis estimates 8 out of 10 times. It is clear that the Safran estimates for the yard outfitting are unfit to be relied on even when considering the entire yard outfitting, instead of only single phases.

Respectively, the second column shows the production planning's estimate after the data from the section pilot project. This estimate does not include the planned hours for the non-Cadmatic material. Additionally, the material in the block outfitting utilized the section outfitting installation times. These are the two differences between these estimates. In this case, the deviation is much less compared to Safran. The deviation percentages range between -36% and +47%. Also, there are 5 estimates that are within +/- 30% range. It is interesting that only 6 out of 10 targets' deviation was negative, since the planned hours generally increased due to the addition of insulation estimate and the block outfitting installation times being higher than the section outfitting installation times. Then again, section installation times for cable trays and spiral ducts decreased. Additionally, the estimate for the penetration installations were decreased by a lot.

Table 16: Percentage of deviation from current production planning –estimate for Safran and thesis' installation times

Coded target	Safran's deviation from Thesis	Production planning's deviation from Thesis
block #1, area #1	-74 %	6 %
block #2, area #1	-58 %	-17 %
block #3, area #2	85 %	-13 %
block #4, area #2	146 %	-36 %
block #5, area #3	-42 %	-28 %
block #6, area #3	-43 %	-33 %
block #7, area #5	-87 %	33 %
block #7, area #6	-29 %	38 %
block #8, area #7	-99 %	-20 %
block #10, area #9	-13 %	47 %

7.3 Comparing workload estimations vs. actual hours

The purpose of this particular study is to find out how close the actual working hours for yard outfitting are compared to the theoretical estimations based on the thesis installation times. This way an understanding can be reached about the variation between the planned and the real hours, since the actual progress rarely matches the planned progress exactly. It could be seen in Table 4 and Table 5 that the component groups have different coefficients of variation. Here, the idea is to analyze the combined variance, which also takes into consideration that targets have relatively different amounts of each component. The deviation percentage is calculated through the following formula: $deviation\% = \frac{actual - theoretical}{theoretical}$. The data is presented in Appendix J but the deviation percentages are shown in Table 17.

On average, the actual hours have been 11% higher than the planned hours, even though it is not always the best method for analyzing data. In 5 out of 9 cases, the deviation has been less than +/- 10%. However, there are two worse cases, especially the last target in the table, where the actual work took 90% more time than on average. The reason for the first target, block #1, being much faster than the average is due to a very skillful ventilation worker. Then again, target block #8 had much more challenging working circumstances. Without a doubt, there will be some targets with bigger deviations in the future but it seems that, generally, the average installation times give unexpectedly good planning estimates. It must be admitted that this illustration is partly biased, since the averages are calculated from the same data. Instead, the installation times should be tested on new targets in the future. It is important to note that the planning accuracy can only be taken up to a certain accuracy level because of manual work always containing a certain amount of random variation. In order to better understand the potential ceiling for the planning accuracy, the standard deviation of each component group should be studied more, which means getting a higher sample size in the first place.

Table 17: Percentage of deviation for theoretical installation time and actual working hours

Target	Deviation %
block #1, area #1	-47 %
block #2, area #1	2 %
block #3, area #2	7 %
block #4, area #2	1 %
block #5, area #3	16 %
block #6, area #3	31 %
block #7, area #5	-7 %
block #7, area #6	8 %
block #8, area #7	90 %

8.0 Proposed future measurements for yard outfitting

In total, seven indicators are recommended for yard outfitting: three KPIs and four PIs. The KPIs are about gaining a realistic understanding of the progress achieved while the PIs are more focused on helping planning and controlling. The indicators are summarized in a measurement matrix, which shows each indicator's strength, feasibility etc. Parmenter's suggested matrix from Figure 5 has been modified to fit the shipyard's needs. Lastly, there are recommended process descriptions for implementing the measurements. The suggestions are made based on Drucker's seven requirements for a measuring system (see chapter 2.2.1) and the sorting of indicators to KPIs and PIs according to Parmenter's seven characteristics of KPIs (see chapter 2.3.4).

8.1 Proposed KPIs and reasons for their selection

Three KPIs are recommended for the shipyard to measure in the yard outfitting: completion percentage for component groups within drawings and two different indicators for delayed hours: actual delayed hours and delayed hours to be earned. These are critical from the point of view of the area, and they help the area manager to keep better track of progress in production. Depending on the point of view, KPIs might vary. For example, considering the issue from the point of view of the process would give more importance to the number of needed squares, cycle time and throughput. However, only the product, area, is considered here, instead of the process. Interestingly, all KPIs are related to following the progress of the areas. This is logical since Meyer Turku cannot interfere too much in TK suppliers' doings. Due to the TK contract, it is enough to know the progress accurately. Anything else is secondary. Additionally, the KPIs are designed so that it leaves little room for gaming as Ignizio has suggested (see chapter 2.2.4).

KPI - Completion percentage for component groups within drawings

The current way of reporting the completion percentage for an activity is not ideal, since the real work scope is unclear. This is due to the usage of budgeted hours and the exact work to be accomplished is not defined. Having a planned estimate for the activity's working hours based on the installation times would solve part of the issue. This requires a bill of materials of all the planned components to be installed, which is derived from the drawings. What makes the matter complicated is the fact that only part of the materials included in the drawings are installed in a specific phase. For example, penetrations should be installed in EML and blücher piping in EMV. To make matters worse, designers do not always follow the building method. For example, ventilation was often drawn to block outfitting HVAC drawing, instead of the section outfitting variant. Therefore, it is impossible to know what the activity, e.g. EMV, includes without looking up the related drawings and understanding the building method. The reported activities should be easy-to-understand and leave no grey area.

That is why the best solution would be to divide the current process-based activities into more specific activities, e.g. EMV ventilation installation and EMV pre-fabricated pipes installation. This way, it is instantly clear which component groups are concerned. It will be difficult to game the metric without being caught by planning work to later stages. Then, the area manager can ask the important question: "Why could we not install this component group?" The purpose is to obtain as accurate picture of the progression as possible, which is not possible with the current way of reporting and the existing Safran activities.

KPIs – Actual delayed hours and delayed hours to be earned

Due to the tendency for work to slip further, the delay should be monitored extremely closely. This is probably the most important measure along with the completion percentage. By adding up the delayed hours from separate activities, it is possible to detect how many hours a certain area or even the entire ship project is lagging behind. Noticing the delay earlier gives potentially more time to catch up. Obviously, it is much easier and cheaper to compensate for the delay over a longer period of time rather than going all-in shortly before the deadline.

One important aspect needs to be considered, though. From the point of view of the production, the delayed hours need to be reported, so that the additional generated working hours are taken into consideration while planning the needed worker capacity in the next phase. However, the problem is how to keep the earned hours, i.e. completion percentage, reporting in check. This creates a mismatch situation between the two kinds of hours. My suggestion is to keep these two separate and report both, since neither can be dismissed. To clarify, the actual delayed hours are for production, so that it is known approximately how many hours are needed to catch up in reality. Then again, the “delayed hours to be earned” indicator tells how many percent the area is lagging behind.

The planned estimates calculated from the installation times should serve as a guideline for these, instead of expended hours as was the case for calculating the completion percentages. In fact, the “delayed hours to be earned” is the left over when the installed, theoretical hours are subtracted from the total theoretical hours, i.e. the planned estimate. See Appendix G for the completion percentage calculations. When calculating the actual delayed hours, the unfinished materials should be multiplied by the next phase’s installation times, so that the upcoming workload considers the generated hours as well. Now, it is possible to obtain very accurate estimates for work slipping further from section to block outfitting due to knowing the latter’s installation times. Unfortunately, due to the unknown area outfitting installation times, the delay from block to area phase cannot be accurately calculated. What is positive, reporting these requires very little extra effort if the first KPI is reported because of their link in the calculations.

8.2 Proposed PIs and reasons for their selection

The following PIs are recommended for the shipyard: expended working hours, installation times for section and block outfitting, average daily capacity required by the subcontractor to finish planned work and additional working hours outside of the contract. These support mostly the production planning.

PI - Expended working hours

As already mentioned in chapter 3.4, there are two information users for the collected expended working hours, procurement and production planning. The size of the deals varies from entire TK entities to a single component group installation within a section.

At first, it is easier to implement the knowledge of the expended hours to a simpler purchased work scope, e.g. installation of thick sheet ducts in a section. In time, the goal should be to measure the entire area building process from EML to the final delivery. Optimally, when all the expended hours for the area are known, it will be possible to make more accurate turnkey deals. Ultimately, this would hopefully lead to one set of numbers, which means that the budget hours are almost equal to the planned hours.

The production planning utilizes the expended hours as a feedback for comparing them to the planned hours. This way, the amount of variation can be identified over time, which enables a better buffer planning. Additionally, it would be interesting to know when there is non-random variation and, then, discover the cause. This would also reveal the combined validity of the installation times, whether they are too low or high.

The reason for choosing this as a PI is because the data cannot be used to affect the on-going work. The indicator has lots of potential but requires much work before it will truly be a powerful boon. The measuring of the expended hours should be considered as a long time investment into better production planning and procurement deals.

PI - Installation times for section and block outfitting

All three KPIs are based on the utilization of the installation times, which obviously makes this indicator very important. In addition, installation times are the key ingredient in the workload calculations. The reason for this being a PI is merely a technicality. As earlier stated by Parmenter, all KPIs should be timely, i.e. they are measured constantly. Due to the enormous effort required to accomplish this measurement, there is no sense in measuring every target in the production. Besides, after obtaining a sufficient sample size, little benefit is achieved. The measuring should be accomplished as minor projects focusing on few aspects of the installation times at a time. Possible future minor projects include: reference times study, installation time measurement in vertical areas, steel outfitting installation times and study of insulation.

PI - Average daily capacity required by the subcontractor to finish planned work

As it was shown in Table 14, sections are not receiving outfitting time according to the planned estimate which forces the subcontractors to vary the number of workers. This would be a rather easy measurement to implement, since the planned estimates are needed anyways, and the square time is decided as well. Simply, the planned estimate needs to be divided by the expected daily working hours in order to obtain the number of workers needed. The measurement serves two purposes. Firstly, the uneven planning of workload, Mura, should be exposed while planning the production. Secondly, TK suppliers or their subcontractor should be notified of the average number of workers needed. This way they can prepare better and, optimally, more work is accomplished. In order to implement the measurement, a new column needs to be added to Safran for reporting the needed daily capacity. The calculation should be done by a production planner, who calculates the workload.

PI – Additional working hours outside of the contract

Sometimes, the subcontractors are forced to do more than stated in the original contract due to unexpected work turning up. For example, cutting openings for penetrations is considered additional work, or there might be a need to re-do work for reasons that are not of the subcontractor's fault. This should be measured because it affects the budget for the area. Additionally, the reasons for additional work should be studied and potentially eliminated. The subcontractor tells the area manager of the expended hours and he should be the one to report them to shipyard's information system. The only thing needed is to add a new column to Safran for reporting the extra hours. This works better in Meyer's own areas, since the contract is directly between Meyer and the subcontractor. For TK areas, it is not relevant to measure this, since this should not affect the original contract between Meyer Turku and the TK supplier.

8.3 Measurement matrix for yard outfitting

All of the indicators are summarized in a measurement matrix in Figure 30. For each measurement the unit, frequency of measurement, target, time zone, strength, feasibility, requirements, beneficiary and responsible person are given. As a reminder, the feasibility (effort required) is given at a scale from 1 to 5, where 1 means that much effort is required and 5 is very easy to implement. Obviously, all KPIs have a high strength rating but their implementation requires some effort, though. The PIs are more varied. Measuring the actual working hours and installation times takes significant effort, the latter more than the first. The other two PIs, average daily capacity required to finish planned work and additional working hours outside of contract, are easy to implement but their strength is not as high either.

Six of the measurements are past-oriented and one is future-oriented but there are no measurements reflecting the current time zone. There would be one very viable measurement for the last category, comparing the planned progress to the actual progress. If implemented, it would be possible to react during the phase if work is progressing slower than planned. In this case, workers could be added so that all planned work can be completed. However, this falls under the daily management and, currently, it is not within the sphere of Meyer's influence, i.e. Meyer does not have the power to manage subcontractors' workers, only suggest advice. Perhaps, this could be implemented in SOaaS when Meyer Turku takes more control of the section outfitting. In addition, it must be considered, whether Safran reporting is kept at a weekly level and daily reporting is possible done is some other application.

The studied capacity or the square utilization rate have not been suggested, since they were more useful as a one-time study as part of the CSA. There is no point in constantly measuring them, since it is up to the subcontractor to decide the final capacity utilization. The point about the low number of workers being utilized was already proven with this amount of sampling, both in the section and the block outfitting.

Most of the tasks should be reported by the area manager, which is logical since he/she is the overseer for the area. However, it does not mean that he/she is responsible for gathering the data on site. Work supervisors and subcontractors can be asked to provide the information. In the end, the area manager is liable for the truthfulness of the data and, therefore, he/she needs to know the real progress well enough. The measurements lose their value if the data reported is faulty.

Measure	Unit	KPI or PI	Frequency of measurement	Target	Time Zone	Strength	Feasibility (effort required)	Requirements	Who benefits from the information?	Responsible
Completion percentage for component groups within drawings	%	KPI	weekly	All areas	past	5	3	installation times	Area manager, top management	Area manager
Actual delayed hours	h	KPI	end of phase	All areas	past	5	3	installation times	Area manager, top management	Area manager
Delayed hours to be earned	h	KPI	end of phase	All areas	past	5	3	installation times	Area manager, top management	Area manager
Actual working hours in section and block outfitting	h	PI	end of phase	Meyer's areas	past	4	2		Production planning, purchasing	Area manager
Installation times for section and block outfitting	h/m, h/piece, h/kg	PI	5-10 times per ship project	Specifically selected	past	5	1		Production planning, purchasing	Outfitting development
Average daily capacity required by subcontractor to finish planned work	workers	PI	before EMV/JML	All areas	future	3	5	installation times	Production planning, subcontractors	Production planning
Additional working hours outside of contract	h	PI	end of phase	Meyer's areas	past	2	5		Area manager, controlling	Area manager

Figure 30: Measurement matrix for yard outfitting

8.4 Future measurement process proposal

There is a unified description for all KPIs, since they are linked. Additionally, the process for obtaining the expended working hours in Meyer's areas is included. The PI, future measurement of installation times, has been divided to three separate parts. There are no description for the final two PIs, average daily capacity required by subcontractor to finish planned work and additional working hours outside of contract, since it is enough to only add two columns to Safran. The responsible person is always mentioned and any possible help to him/her, as well.

Future measurement of completion percentage and delayed hours

All three KPIs go hand-in-hand, since the delayed hours are the same as the unfinished material multiplied by the installation times. When calculating the "delayed hours to be earned" measurement, the multiplication happens with the section outfitting installation times. Respectively, calculating the actual delay is done by multiplying with the block outfitting installation times. This is clarified with the formulas below. $C_{i,EMV}$ is the completion percentage for component *i* in EMV; T is the theoretical installation time, which is calculated by multiplying the number of components with their installation time. For more details on calculating T, see chapter 4.4. *D* means delay and it is the sum of all components.

$$C_{i,EMV} = \frac{T_{i,installed,EMV}}{T_{i,total,EMV}} \qquad (26)$$

$$D_{actual} = \sum_i^k \left(x_{i,unfinished,EMV} * t_{i,block}\right) \qquad (27)$$

$$D_{earned} = \sum_i^k \left(x_{i,unfinished,EMV} * t_{i,section}\right) \qquad (28)$$

The critical information needed is a list of all installed components from the BOM. TK suppliers should deliver the list in Excel format, while the area manager confirms the validity of the list at a general level by visiting the target at the end of the phase. In Meyer's own areas, it should be up to the work supervisor to check the installed components and mark them to the BOM.

The next step, calculation, should be automatized. It should be enough to insert the BOM and the installed materials to a coded program, e.g. ready-made Excel, which automatically calculates all three. Then the area manager can easily report to Safran. This way, the effort of reporting does not increase by much for the area manager.

Future measurement of expended working hours

This is a more demanding measure than the three KPIs, since daily visits to the site are required. The information should come directly from the subcontractor but there needs to be a validation by a Meyer employer, e.g. a work supervisor. The area manager will do the reporting to Safran after confirming the validity of the given hours from his/her work supervisor. Additionally, there should be a clause in the contracts between Meyer Turku and the subcontractors, which says that they are required to report their working hours weekly. Without the clause, there is a risk of not obtaining the actual hours. This applies to both SOaaS and in Meyer's own areas. Unfortunately, the situation is more difficult with the TK areas due to the limited visibility. Even if the TK supplier would request the actual working hours from their subcontractors, there is no guarantee that the information given is correct. Meyer does not simply have enough employees on the TK areas to supervise the process at a daily level.

Future measurement of installation times

This consists of three parts. Firstly, the reference times should be studied, followed by a push to create a comprehensive collection of them. Lastly, the installation times need to be updated in case there are any notable changes in the ways of working.

Future measurement of reference times

The reference times define the installation ratios between components within the same group, e.g. straight blücher pipe and blücher part. In addition, the reference times are utilized for thin sheet ducts and spiral ducts. In the future, it would be beneficial to study the pre-fabricated pipes in more detail, since their weight and diameter vary leading to different installation times. It would be good to record at least 5 samplings for each component, and measure no more than one component per same worker. In order to succeed in recording the reference times, the measurer must understand or be supervised about the component's included work stages. For example, installing straight blücher pipe includes installing supports to deck (approximately one support for each meter) and gluing the pipes together. On the contrary, the blücher parts do not need supports. The reference times should be measured by a member of the development department. This would be approximately a full-time project of few weeks. Afterwards, there is not a need for updates unless something changes drastically about the installation of the component, e.g. new kind of technology or change in the frequency of supports to be used.

Future push for creating a comprehensive installation time collection

As mentioned in chapter 7.1, the installation times studied in this thesis are a good start but there is room for improvement. Therefore, I suggest doing a large push after the reference time study to increase the sample size for the already known installation times and, on top of that, to study the less known work: vertical areas, steel outfitting and insulation.

There would be a quite easy implementation possibility in Meyer's own areas in case the subcontractors' hours are reported by the component group. The only raw data needed is the expended hours and the installed components. The latter needs to be done anyway, since it is required for all KPIs. The task becomes much more time-consuming if the expended hours need to be collected on site, since one to three daily visits will be required to obtain high quality raw data. To make validation of working hours slightly easier, a good communication with the observed subcontractor is helpful. See chapter 4.2 for exact information on completing the calculations and the guidelines for obtaining the expended working hours.

The calculations should be done by the development department based on the instructions given here. It does not really matter who collects the raw data but the data quality must be ensured. Having one person to do both the raw data collection and the installation time calculations would be the safest approach, although not the most efficient. In the TK areas, the expended hours need to be collected by an employer of Meyer Turku due to not receiving expended working hours from the TK supplier's subcontractors.

Future maintenance of installation times

The third part, the maintenance of the installation times, is listed in the measurement matrix because it is a never-ending process, while the previous two parts are one-time projects. In case, the planned hour estimates are doing very well, the amount of maintenance may be lessened. The resources could be utilized on studying the area phase instead. The methods are exactly the same for this as for the previous part and, similarly, this task should be completed by the development department with help from Meyer’s own work supervisors.

9.0 Discussion

Firstly, all the key results are listed and their significance is discussed. Then, the limitations of the study are presented and, lastly, the most pressing issues for future improvement are given.

9.1 Key results and their significance

Below, all the key results and observations from the thesis are pointed out. Firstly, it is explained why the specific result or observation is important. Secondly, the significance and future impact on shipyard is considered.

Improved installation times for section outfitting and new ones for block outfitting

The measured installation times are by far the most significant contribution of the thesis. Even though only seven component groups were measured: thin sheet ducts, spiral ducts, thick sheet ducts, blücher piping, plastic piping (limited sampling), cable trays and penetrations (limited sampling), it is possible to predict 86% of all HVAC outfitting in yard outfitting. In addition, the myth of “1-3” was unraveled. As expected, the difference in the installation times was not as large. In fact, cable trays took approximately equal time to install. Surprisingly, installing spiral ducts took on average 2.77 more time in block outfitting but, on the contrary, thin sheet ducts were installed only 1.20 times slower. In any case, it is clear that the section outfitting should be prioritized, since it is wasteful to complete the same work later with greater effort. The installation times have been put to wide use already within Meyer Turku. All production planning related to the yard outfitting is done with these. In addition, future multi-million yard outfitting capacity investments are based on the installation times when the future workloads were predicted.

Besides understanding the wasted potential, installation times are the key ingredient in production planning. By multiplying the contents of the material list, BOM, with the installation times, the planned hours are received. This is extremely useful for section outfitting, since almost all of the work is about HVAC, the exception being insulation and some steel outfitting. However, the last two contain much less work in general.

While block outfitting benefits from the installation times, as well, there are other factors to be counted, e.g. shafts. Estimating the needed square time is more complicated for a block, since there exists more of non-HVAC work. In any case, the idea is to figure out the most work-containing part of the block. It can be one of the decks or possibly the shaft. Unfortunately, the shafts were not studied properly. Therefore, the installation times can be utilized to calculate the most work-containing deck and give square time according to that.

Reliable method for calculating yard outfitting completion percentage and unfinished work

The study of installation times has made it possible to calculate the yard outfitting completion percentage with great accuracy. While requiring some effort, since all of the installed components need to be known, the end result is much better than an educated guess. In order to obtain a realistic understanding of the progress, this is the only viable method. Sadly, the total completion percentage of the entire area is still out of grasp due to not knowing the installation times for area outfitting. However, work remains to be done regarding the accuracy of the yard outfitting reporting. Even though the unfinished working hours are known, the current reporting format does not make it possible to report which components were installed.

It is very alarming that only 1 out of 10 targets managed to complete all the planned yard outfitting work. On average, the completion percentage was 65%. However, the completion percentage varied between 11% and 100%, which shows the level of variation between different areas. It is to be noted that the previous ship project in outfitting quay had a large impact on this phenomenon of work slipping further.

Limited use of capacity in yard outfitting and working during storage phase

According to the measurements, work took place on average with 1.7 workers during the section outfitting, which is a very low number considering the shipyard’s wish to focus on doing as much work as possible early on. Admittedly, the poor pre-conditions of section outfitting has made the subcontractors unwilling to commit too many resources but, in the end, it is crucial to fix the pre-conditions and do more work with possibly lesser intensity. The number of workers on site simply needs to be increased to be able to match the future pace. If the same continues, there will be tens of thousands of hours of work slipping further due to possibly shorter square times. As mentioned, Little's law defines the situation in the section outfitting. Increasing WIP requires investments to more squares, which is not ideal. The throughput cannot be obviously lessened. Therefore, the only remaining option is to shorten the cycle time through completing the tasks quicker, which leads to increased number of workers needed.

Unfinished work was compensated for during the storage phase, which makes sense from the point of view of the subcontractors. However, the production planning assumes that no work is to be done during the storage, which will create problems when the storage times are significantly shortened or even cut out entirely for some blocks in the future. That is why it is important to understand the needed square time for the blocks during JMS. At the moment, the issues are hidden under the possibly long storage phases. In any case, the shipyard needs to find ways to stabilize the production and secure the pre-conditions, so that the subcontractors do not need to create so large work buffers for themselves.

Crude understanding of variation within yard outfitting

The first step towards controlling variation is recognizing it. By no means have all the sources of variation been recognized. Rather, the tip of the iceberg has been discovered. The most baffling discovery was the amount of Mura found in the required number of workers to complete the planned work in the section outfitting. This varied between 1.3 and 9.6 workers. Ideally, an even workload should be strived after due to making the resourcing much easier. Understandably, there are other factors affecting the available square time in section outfitting, e.g. the hull schedule, but this level of Mura is unacceptable.

It is important to understand that the installation times are only calculated averages of work. In reality, the actual working hours will differ from the planned hours. Due to the nature of manual labor, the standard deviation was very large. Reducing natural variation is very difficult. Therefore, some buffers are needed to maintain the schedule. Ideally, extra capacity would be the best choice due to not needing to change the schedules or invest into more squares. As a reminder, buffers are not equal to waste.

Buffers should be well-calculated and be based on statistics. It is better to pay a little more in advance than pay much more, later.

Measuring indicators in the future

From the point of view of an area, it is possible to make do with only three KPIs: completion percentage for a component group within a drawing, actual delayed hours and delayed hours to be earned. These focus on providing a realistic picture of the progression, which is most definitively needed. Although not a KPI due to a technicality, installation times are the key ingredient in all of the suggested KPIs. Therefore, the installation time collection should be completed as soon as possible, since it is mostly a one-time project except the maintenance afterwards.

Generally, more information from the subcontractors and the TK suppliers should be required. It is essential to have the expended working hours for Meyer's own areas recorded, and the TK suppliers should mark the installed materials to the bill of materials. In addition, Meyer's employers are needed to verify the data quality. This ensures accurate reporting of KPIs and good raw data for calculating the installation times.

9.2 Limitations of the study

The study has a broad scope in order to understand the holistic picture of the yard outfitting. The information may be utilized for almost all area types with the exception of stairs and shafts. To put this into perspective, a ship project contains approximately 30 different area types. Therefore, this thesis has covered 25 out of 30 area types, which is roughly 83% of the ship. Firstly, the reason for limited sample size is discussed. Secondly, the partial ability to plan JMS-time for blocks is explained.

Smaller sample size received than planned for installation times

The performed measurements consisted of 9 different areas and 13 blocks, yet the sample size for block outfitting varied between 3 and 6 depending on the component. The plan was to obtain around 10 samples per component but the amount of unfinished work was unexpectedly high. In hindsight, the targets should have been selected out in the field according to the amount of work taking place rather than in advance, but there would have still been the need to request permission for the measurements. No one could have accurately predicted, whether any work would be taking place due to the problems with the pre-requirements and the changing schedules. Obviously, the smaller sample size makes the results less accurate, i.e. the suggested installation times and their variation range according to 2σ, which is why conducting more measurements is so strongly recommended.

Partial ability to plan the needed JMS-time for blocks

There are two missing aspects for being able to plan JMS time wholly. Firstly, the blocks often contain shafts or trunks, which have not been studied. Therefore, it is possible to give workload estimations for each deck of the block but not for the shafts. Secondly, some of the areas might contain other work on top of the HVAC work studied, e.g. installation of windows (public), outer doors, fire doors, balconies and railings. However, these components are not presented in Cadmatic. That is why each block needs to be manually inspected, whether there are any of these, further increasing the workload. An accurate estimation of the needed JMS time requires understanding of each deck’s and possible shaft’s workload. Only then can the most demanding entity be identified and time given based on that.

9.3 Recommendations for future improvement and study

The three most concerning issues have been listed in this chapter: CSA on area outfitting along with a study of installation times there, ensuring the working pre-requirements and enabling more accurate reporting method through more specific activities. Some of the other future recommendations have already been presented earlier: detail design improvements, updating building method to include correct working order and the measurement plan for the yard outfitting installation times.

Current state analysis on area outfitting and measuring installation times

The study of outfitting production started from the section outfitting CSA and this thesis has expanded the understanding to block outfitting. Logically, the next step is to study the area outfitting, which is by far the largest of the three phases. The area outfitting starts by finishing off the remaining background work, i.e. mostly HVAC and plate works. After that, it is mostly visual work, which includes interior- and electrical work. The background work needs to be completed before certain visual works can be started. Additionally, there are more interfaces than in the yard outfitting, which makes the area outfitting a complex process to control. By doing this study, a holistic picture of the outfitting production can be attained and the area outfitting process optimized, hopefully shortening the cycle time of the entire area.

Besides the recommended installation time measurements for yard outfitting, it would be crucial to study both background outfitting and visual outfitting in area phase. Even though, areas have a fixed deadline delivery date, planning needs to understand the effort needed to complete the activities, so that the given timelines for the activities are viable and guide production.

Ensuring working pre-requirements

As earlier mentioned, there are four pre-requirements so that work may take place: section/block, material, drawings and workers. Out of these, outfitting can affect the material and the drawing availability. The last one will likely follow as long as the other pre-requirements are fixed. The first one is up to the hull production.

Material can be divided to pre-fabricated material and standard material and each has separate processes. The pre-fabricated materials always have pre-fabricated drawings. These drawings are sent to workshops, who manufacture the components. Then, they are sent to the ship yard. At the moment, there are no specific checks for each step. There should be added visibility in this process through milestones, so that everyone involved will know when they are expected to do their part. On the contrary, standard material comes from the central warehouse, which is an outsourced function. In order to make sure that the central warehouse has enough of all standard material, there should be a standard material forecast based on the detail design. Additionally, there is already a promise of 99% delivery success rate. The material forecast's purpose is to help the central warehouse in ordering the right amount of material without the need to have enormous stock available. However, the assumption must be that all standard material is available when needed. The optimization of warehouse operations cannot come at the expense of the production.

According to the regulations, installation drawings need to be ready 2 weeks before the production. However, this is the end result of the detail design process. Instead, it should be studied, why detail design is not always on time and why contents of the drawings vary greatly. The detail design process starts by receiving basic design's output material. The purpose of the detail design is to correctly route all the material, while the basic design has already decided the material to be utilized, e.g. type and diameter of the pipe. The first milestone would be to check whether the given basic design material from Meyer is of sufficient quality. After ensuring the quality, 3D modelling may begin by the detail designer. From the 3D model, installation drawings are created to 2D format. It would be good to have an additional milestone for completion of 3D model so that the progress of detail design could be tracked better. Currently, there is very limited visibility for detail design process and the discovery of detail design being late is made just before the production. This is a pre-requirement that cannot be allowed to be late or otherwise lacking, if the aim is to complete more work earlier.

Enabling more accurate reporting method through more specific activities

This was already touched upon in chapter 8.1. The current activities especially in the yard outfitting are based on the stage, e.g. EMV, but nowhere is it specified exactly what work is to be done there. Instead of reporting the stage, it would be better to report the installation of component groups. At the very least, sub-activities should be created under the current activities, e.g. EMV spiral ducts installation. These sub-activities should have workload estimations based on the installation times. Together, all of the sub-activities define the total workload for the original activity. The square time for sections can, then, be given based on the total workload. As mentioned, JMS is more complex but the same principle applies to it, as well.

The current situation for reporting is absurd. Activities are reported to Safran without telling what has actually been done. The installation times are a powerful tool to help planning and reporting but they will not be of much help unless the work scope is defined. All of the recommended KPIs will be for naught if it is not possible to do more accurate reporting.

10.0 Conclusion

The conduction of the current state analysis has given new insights on yard outfitting, which enables proper analysis of the current gap plan, regarding the sufficiency of the ongoing development projects in order to double the production pace. The analysis included interviews with all stakeholders ranging from blue-collar workers to area managers, and measurements were performed to provide numerical evidence. Especially, the following aspects gained new insights: reporting, building method, reasons for unfinished work, sources of three kinds of waste and variation within production.

To support the CSA and confirm the validity of the stakeholders’ claims, measurements were needed. The utilized measurements were limited to measuring the performance of the process, thus, key performance indicators and performance indicators were used. The focus of measurements were on the installation times (section and block outfitting), expended hours, yard outfitting completion percentages and utilized worker capacity. The testing of these provided a good estimate for each indicators characteristics, which were essential for making the future measurement process proposal.

The significance of the installation times was recognized already in advance, and that is why it was so heavily focused on. They are the key ingredient in production planning but they also help the procurement to estimate the value of the subcontracted work. Unfortunately, it was not possible to reach a level of accuracy such as in car industry due to variation. In any case, more sampling was obtained for the section outfitting installation times, while block outfitting received its very first installation times to help plan the length of JMS time. The measured components were mostly HVAC material, which makes up for the largest share of the yard outfitting work.

Based on the CSA and the tested measurements, a future measurement process proposal was made, which focuses on measuring the critical aspects such as progress reporting and delay. Additionally, the future measurement of installation times was proposed in order to increase the sample size behind the installation times and potentially come closer to the real average time. The indicators and their implementation are designed to only consider what matters without wasting unnecessary resources. A recommended responsible person has been named for each indicator.

This thesis has built upon the work accomplished in the section pilot project. More information about the section outfitting was collected, while totally new insights were gained from the block outfitting. This should solidify the need for even more development projects and verify the direction of existing ones. Hopefully in the near future, a similar study can be accomplished for the area outfitting, so that the entire outfitting process may be optimized from the holistic view.

11.0 Summary in Swedish – Svensk sammanfattning

Avhandling om sektions- och blockutrustning för att stöda produktionsplanering

Syftet med denna avhandling är att stöda produktionsplaneringen inom sektions- och blockutrustningen på Meyer Turkus skeppsvarv och att kunna bidra till en mera balanserad arbetsbelastning inom produktionen. Sektionsutrustningen sker efter att stålproduktionen har sammanställt sektionen, som är en relativt liten del av skeppets skrov. En sektion motsvarar en del av ett däck. Ett block är en större del av skeppets skrov, som vanglien innehåller fyra sektioner monterade ihop som ett höghus. Sektions- och blockutrustningen innebär installation av alla slags VVS-komponenter (värme, ventilation och sanitet) på skeppsvarvet före blocken lyfts till torrdockan. Avhandlingen omfattar inte områdesutrustningen, som sker i torrdockan och utrustningskajen efter blockutrustningen. Avhandlingen kan vara av intresse för dem som vill läsa mera om utmaningar inom utrustningsproduktionen, bekanta sig med möjligheterna till processmätningar och förstå förutsättningarna för produktionsplanering.

Orsaken valet av tema är bristande information om blockutrustningens nuvarande tillstånd och precisionen av estimerade arbetstimmar både i sektions- och blockutrustningen. De existerande nyckeltalen rapporteras inte ordentligt i skeppsvarvets informationssystem. Detta är delvis p.g.a. ett strategiskt beslut att använda kontrakt, som täcker grovt 80 % av utrustningsarbetet. Därför samlas det för lite information om produktionen, som bidrar till bristfällig synlighet för Meyer Turku.

Avhandlingen omfattar fyra forskningsuppgifter: kartläggning av nuläget genom intervjuer och processmätningar, mätningar av installationstiderna för de vanligaste komponenterna, undersökning av olika indikatorer samt rekommendation för framtida användning av nyckeltal. Avhandlingen bygger på mina tidigare undersökningar om blockutrustning ur produktionens synvinkel utförda sommaren 2017 och 2018 som en del av en större kartläggning av nuläget vid sektionsutrustningen.

Den empiriska delen stöds av teorier för att kunna förklara resultaten. Först behandlas nulägesanalysen, som innehåller både intervjuer och numeriska data. Sedan introduceras Lean-konceptet, var tyngdpunkt ligger i betydelsen av flöde, förlust (Mura, Muri & Muda) och nyckeltal. Ytterligare fokuseras på variation inom produktionen och dess effekt. Sist introduceras grunderna för produktionsplanering, som hjälper att framhäva betydelsen av installationstiderna.

Mätningsmetoderna baserar sig på sådana metoder som använts inom tidigare arbetsstudier, men denna avhandling innehåller ett nytt koncept för att underlätta insamlingen av rådata. Konceptet skapades för att kunna beräkna installationstiderna för olika komponenter inom en komponentgrupp utan att behöva kategorisera arbetstimmarna för varje enskild komponent t.ex. kurvor och raka delar. Konceptet bygger på att mäta referenstider för olika komponenter inom en komponentgrupp och sedan anta att installationsförhållandena för komponenterna alltid är samma. Denna metod räcker för att kunna fastställa arbetstimmarna för hela komponentgruppen.

Installationstiderna som undersöktes i avhandlingen är väsentliga för produktionsplaneringen och beräkningen av produktionsbelastningen. De har redan använts vid uppgörandet av investeringskalkyler inom produktionen. Av speciellt intresse är skillnaden mellan installationstiderna för sektions- och blockutrustning, som varierar beroende på komponentgruppen. Till exempel tog installeringen av kabelbanor lika länge inom sektions- och blockutrustningen även om det är lättare att installera komponenter inom sektionsutrustningen eftersom installationen sker nedåt. Andra komponenter (tunnluftkanaler, rörkanaler, blücher-rörledningar) tog ungefär 1,2 – 2,8 gånger mera tid att installera uppåt. Installationstiderna fungerar som grund för de rekommenderade framtida nyckeltalen.

Utgångslägetanalysen tillsammans med processmätningarna tydliggör utmaningarna i produktionen. Till exempel otillräckliga förutsättningar, lågt kapacitetsutnyttjande och källor för variation är tydliga utmaningar. De otillräckliga förutsättningarna innebär t. ex. försening av ritningar och avsaknad installationsmaterial. Variation föranleds av obalanserad planering av schema (Mura) och manuellt arbete (Muda). Flödet analyseras med hjälp av Littles lag, som betyder att lågt kapacitetsutnyttjande leder till längre cykeltid och det leder till ett behov av mera produktionsplatser. Faserna i blockutrustningen, EMS (*fi: ennen maalausta suurlohkovarustelu*, blockutrustning före målningen) och JMS (*fi: jälkeen maalauksen suurlohkovarustelu*, blockutrustning efter målningen), analyseras separat. Det största fyndet är mängden av arbete, som sker efter JMS under mellanlagringsperioden. Enligt produktionsschemat planeras inget arbete dit över huvud taget. Dessutom, analyseras och jämförs den nuvarande byggnadsmetoden med ritningarna och själva produktionsfasen. Det fanns ganska mycket avvikelser i båda, speciellt i fråga om installationen av materialet för ventilationssystemen. Avhandlingen innehåller bl.a. ett förslag till en bättre byggnadsmetod med tillhörande arbetsordning för komponentgrupper inom samma fas.

På basis av utgångsläget och mätningarna rekommenderas det tre nyckeltal: andelen utförda installationsbilder och två olika nyckeltal för förseningar. Inom produktionen är det viktigt att vara medveten om förseningar i budgeten (beräknad i arbetstimmar) och vilken effekt den uppskjutna arbetsmängden har på den allmänna arbetsbelastningen. Dessutom rekommenderas det att fortsätta mäta installationstiderna tills urvalet är större än 30 stycken per komponentgrupp. På det sättet är det möjligt att komma närmare det riktiga medeltalet för installationstiderna och förekomsten av variation kan identifieras noggrannare.

Meyer Turkus målsättning är att fördubbla produktionstakten inom fem år. Med information från denna avhandling är det delvis möjligt att analysera ifall de existerande utvecklingsprojekten är tillräckliga för att nå den önskade produktionstakten. Samma undersökning behöver utföras för områdesutrustning för att kunna forma en helhetsbild över hela utrustningsprocessen. Ur vetenskapligt perspektiv har denna avhandling utökat kunskapen om praktiska tillfällen till de existerande mätningsmetoderna. Innehållet skulle kunna utnyttjas för liknande undersökningar i maskinverkstäder eller liknande platser, som innehåller mycket manuellt arbete och variation.

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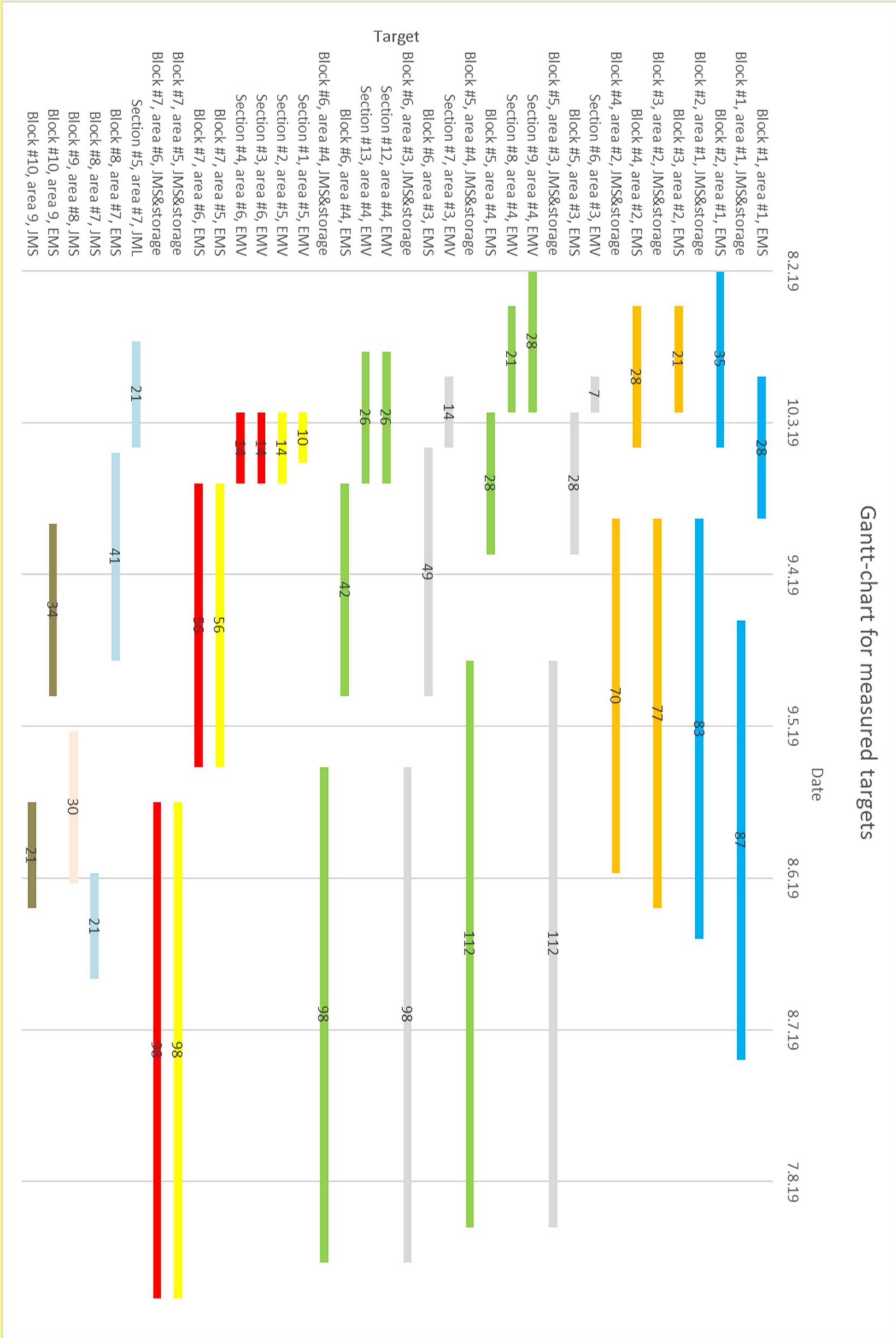
Table of figures

Appendix

Appendix A – Final Gantt-chart for measured targets



Appendix B – Reference times

Reference times are only shown in Meyer Turku –version of thesis.

Reference times for components			
Component group	Component	Unit	Reference time
Thin sheet ducts	std. straight part 1500 mm	h/piece	x
	std.parts	h/piece	x
	silencers	h/piece	x
	pre-fabricated plates	h/kg	x
	duct insulation	h/piece	x
Spiral ducts	spiral duct R	h/m	x
	spiral duct RI	h/m	x
	spiral duct part (R&RI)	h/piece	x
	spiro silencers	h/piece	x
Blücher-piping	blücher pipe	h/m	x
	blücher part	h/piece	x

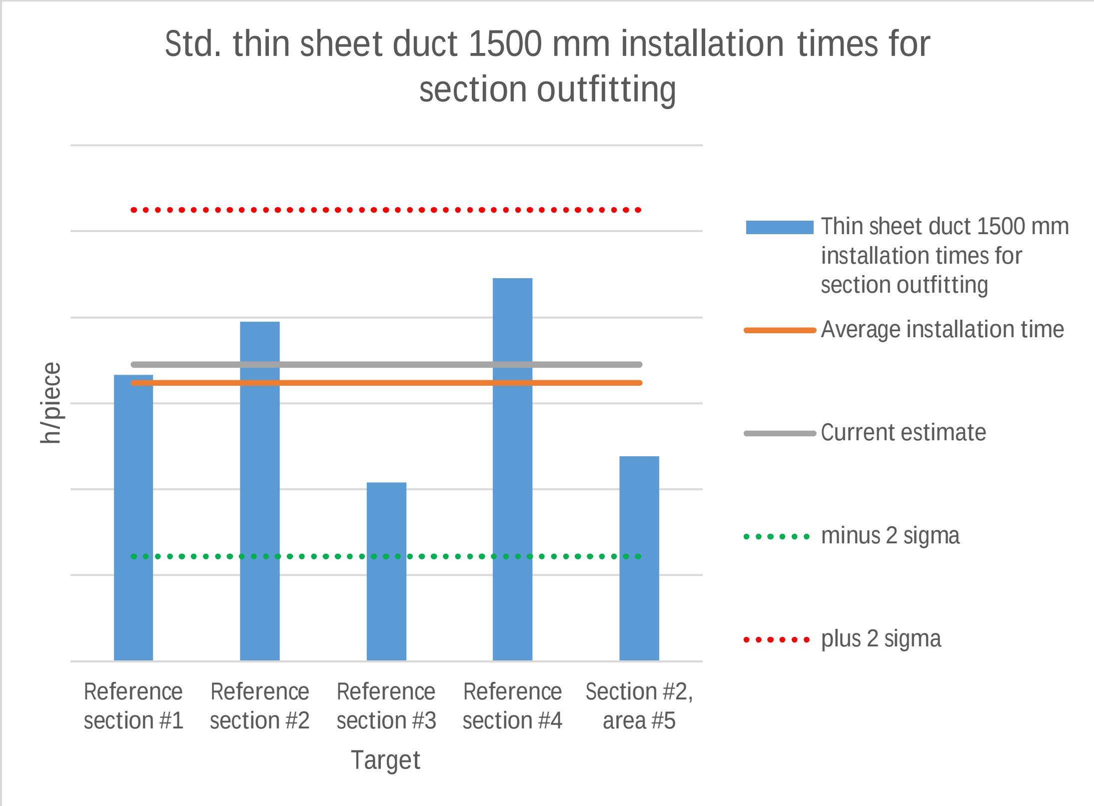
Appendix C – Installation times for section outfitting

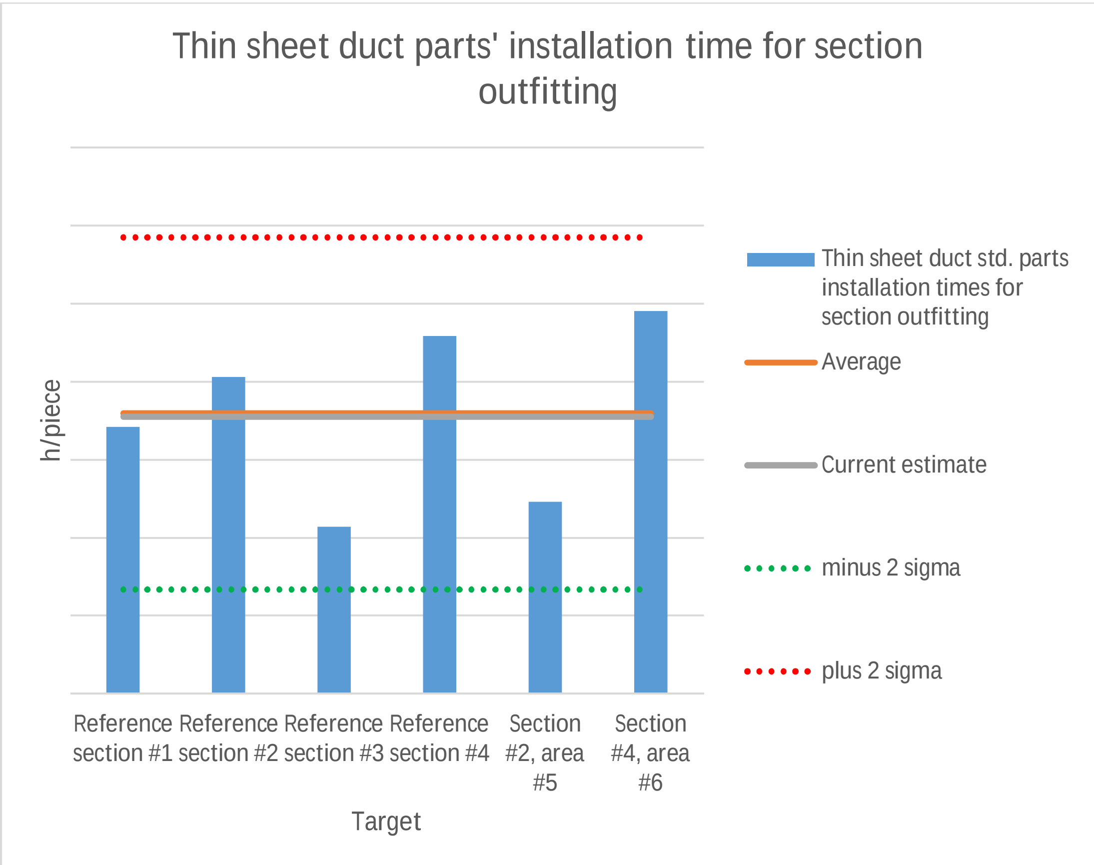
Example of calculating installation times

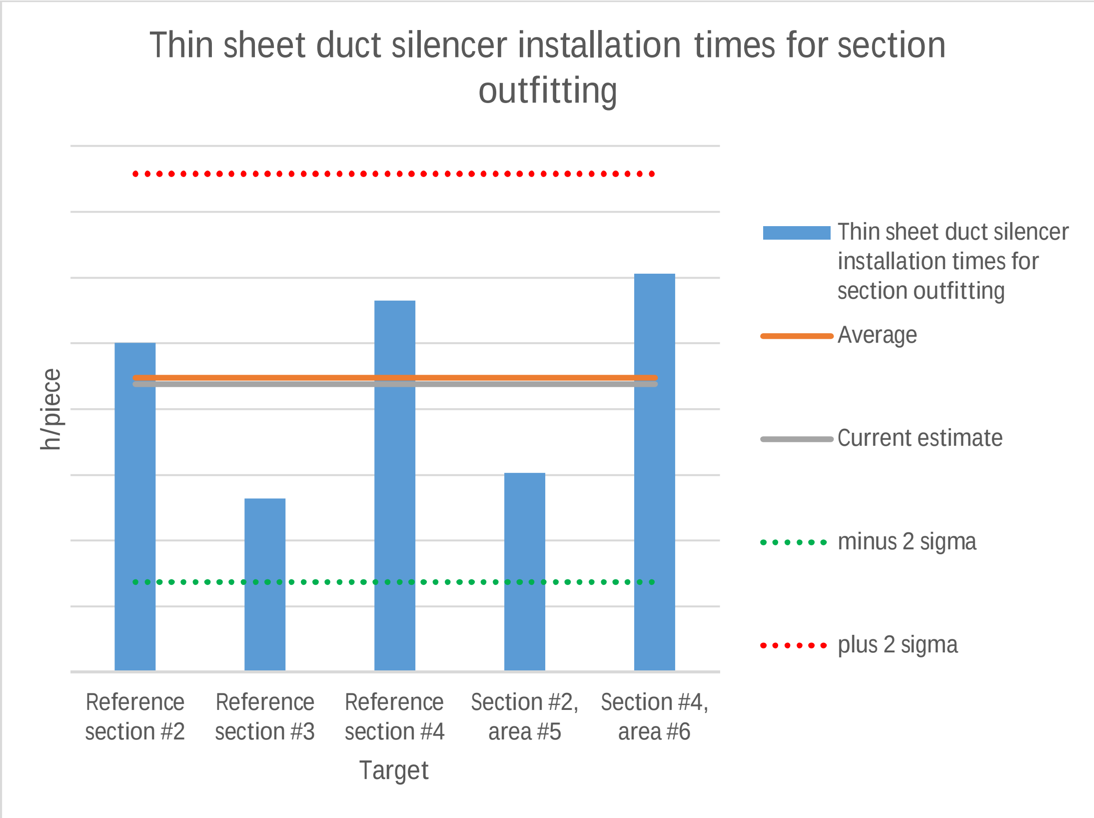
See “Installation times Toni Saranki’s master’s thesis” –Excel for all calculations. Installation times and working hours are shown only in Meyer Turku –version of thesis.

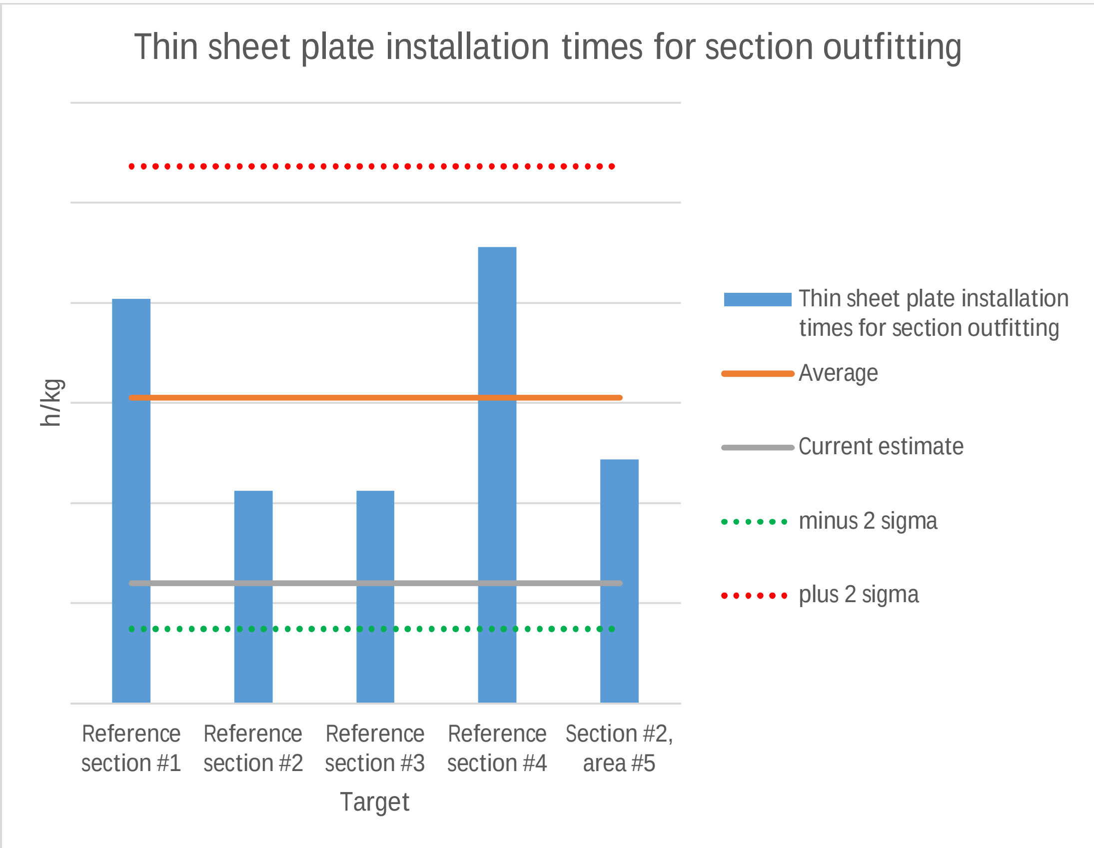
Spiral ducts, section #1 area #5		Cadmatic				Not installed		Installed		Reference time		
Straight	R	127785	mm	127,785	m	9	m	118,785	m	x	h/m	
	RI	143116	mm	143,116	m	9,5	m	133,616	m	x	h/m	
Parts	branch spiro R & RI	29	pieces			1	pieces	28	pieces	x	h/piece	
	bends R & RI	113	pieces			8	pieces	105	pieces	x	h/piece	
	offset R & RI	8	pieces			0	pieces	8	pieces	x	h/piece	
	reducer R & RI	9	pieces			2	pieces	7	pieces	x	h/piece	
	Total	159	pieces			11	pieces	148	pieces	x	h/piece	
Theoretical installation time, T_theory			x	h		Final installation time for straight R, T_final, R					x	h/m
Real installation time, T_real			x	h		Final installation time for straight RI, T_final, RI					x	h/m
Ratio, R			x			Final installation time for part R&RI, T_final, part					x	h/m

Thin sheet ducts' installation times for section outfitting

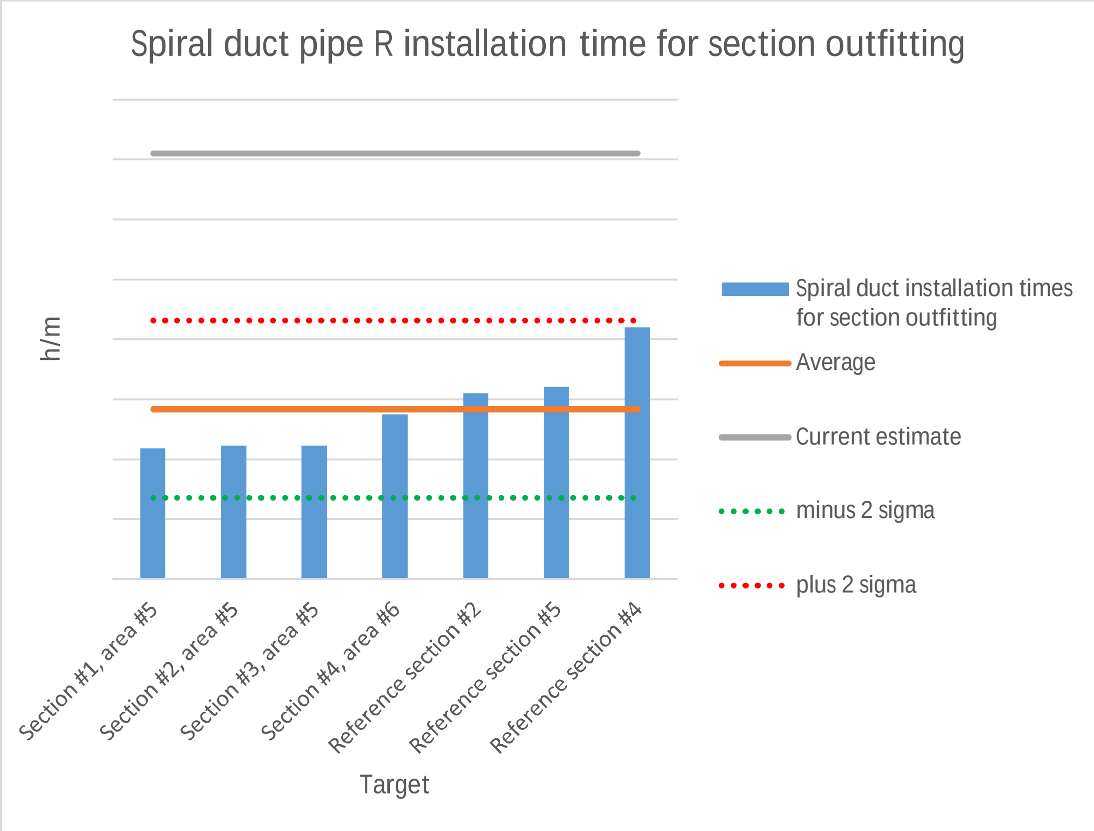


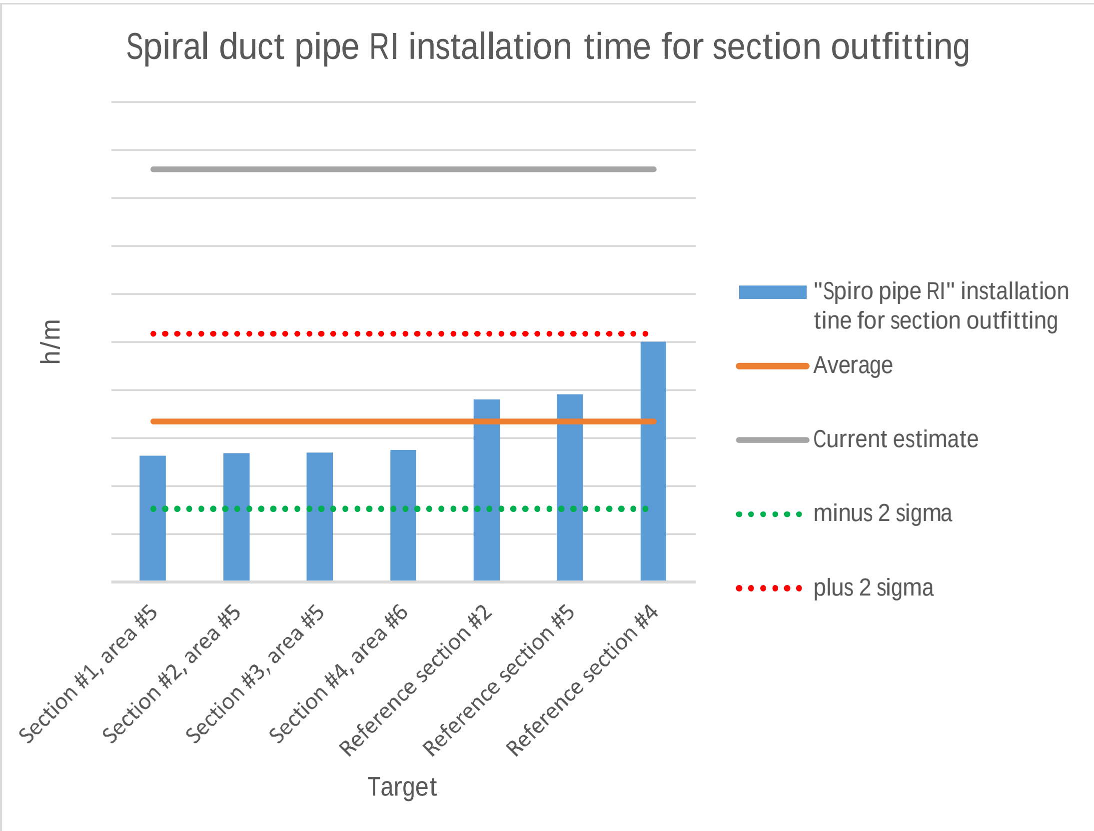


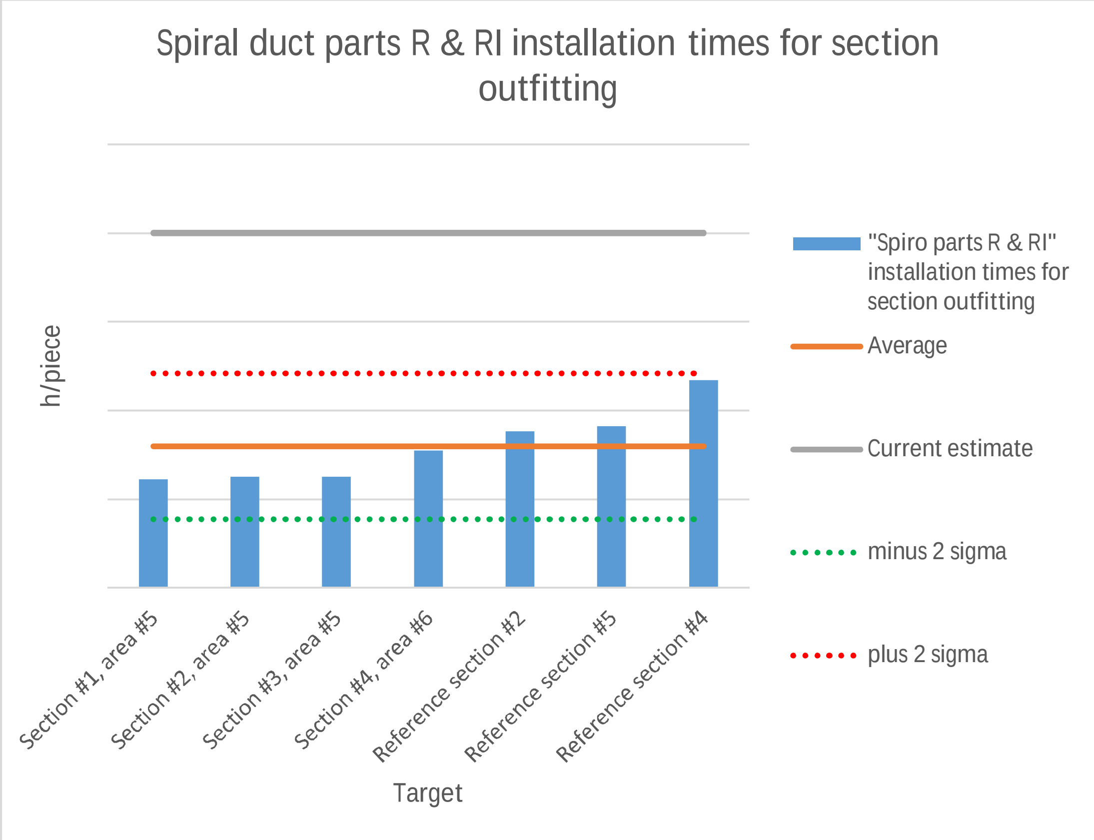

Thin sheet duct silencer installation times for section outfitting
h/piece
Reference section #2
Reference section #3
Reference section #4
Section #2, area #5
Section #4, area #6
Target
Thin sheet duct silencer installation times for section outfitting
Average
Current estimate
minus 2 sigma
plus 2 sigma

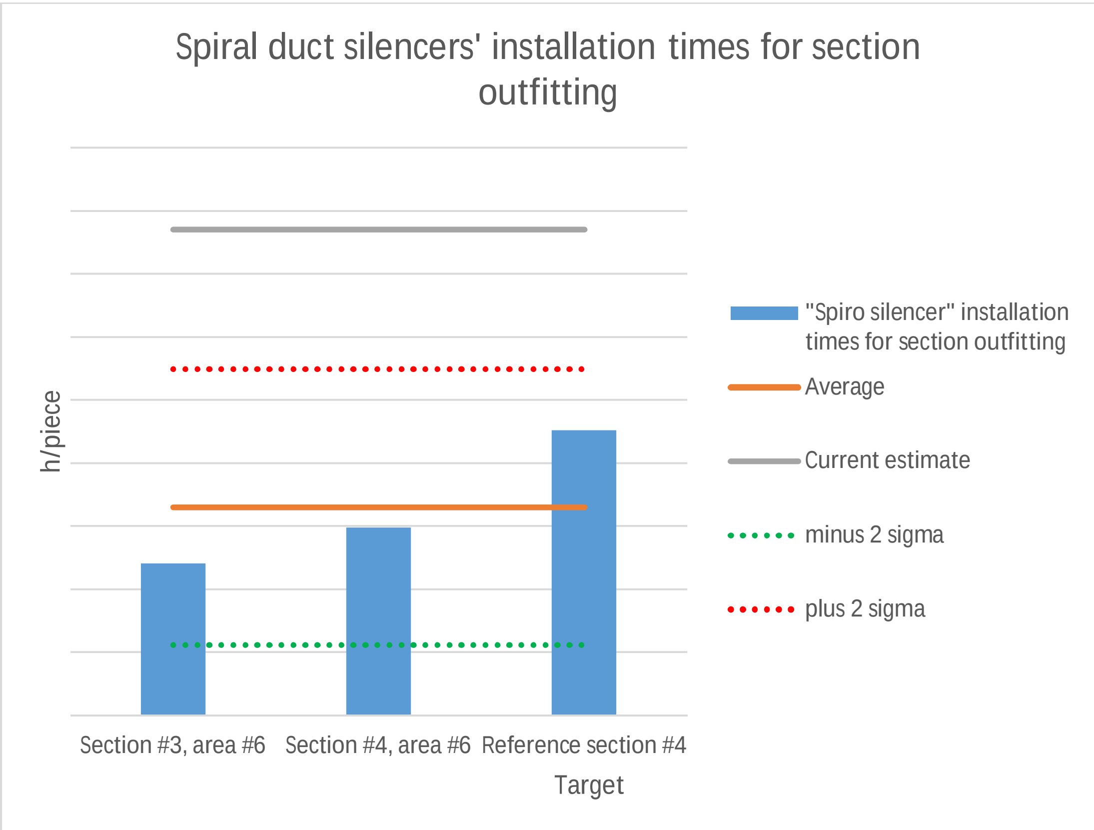

Thin sheet plate installation times for section outfitting
h/kg
Reference section #1
Reference section #2
Reference section #3
Reference section #4
Section #2, area #5
Target
Thin sheet plate installation times for section outfitting
Average
Current estimate
minus 2 sigma
plus 2 sigma

Spiral ducts' installation times for section outfitting

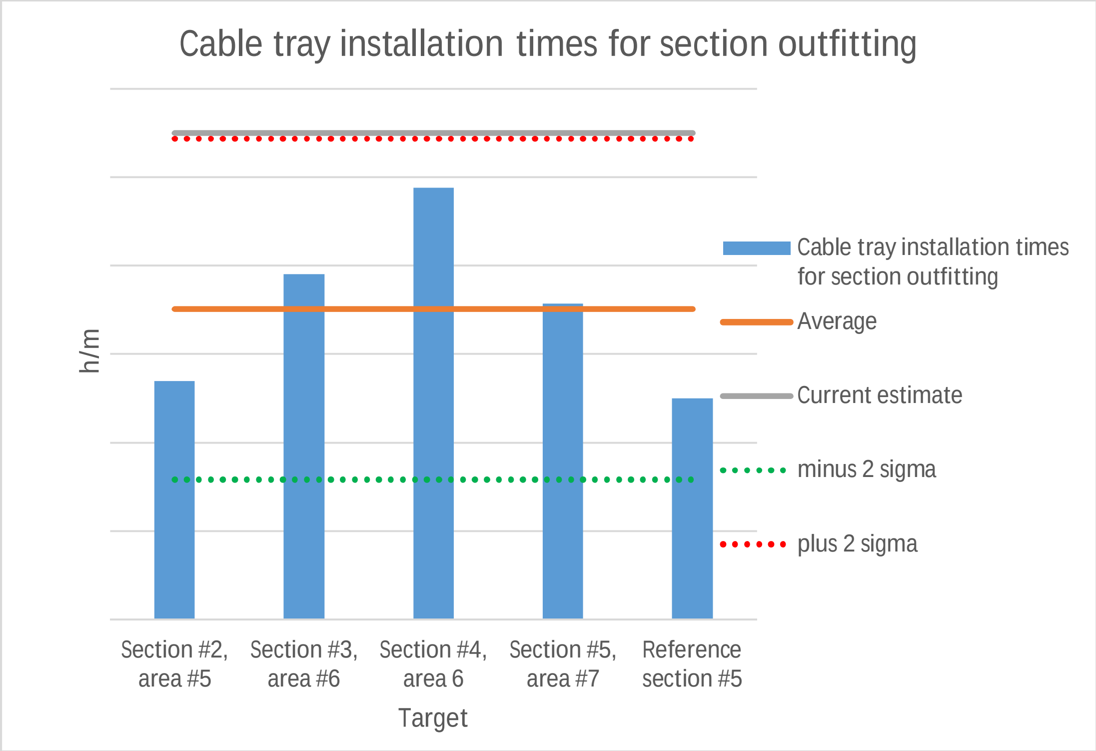




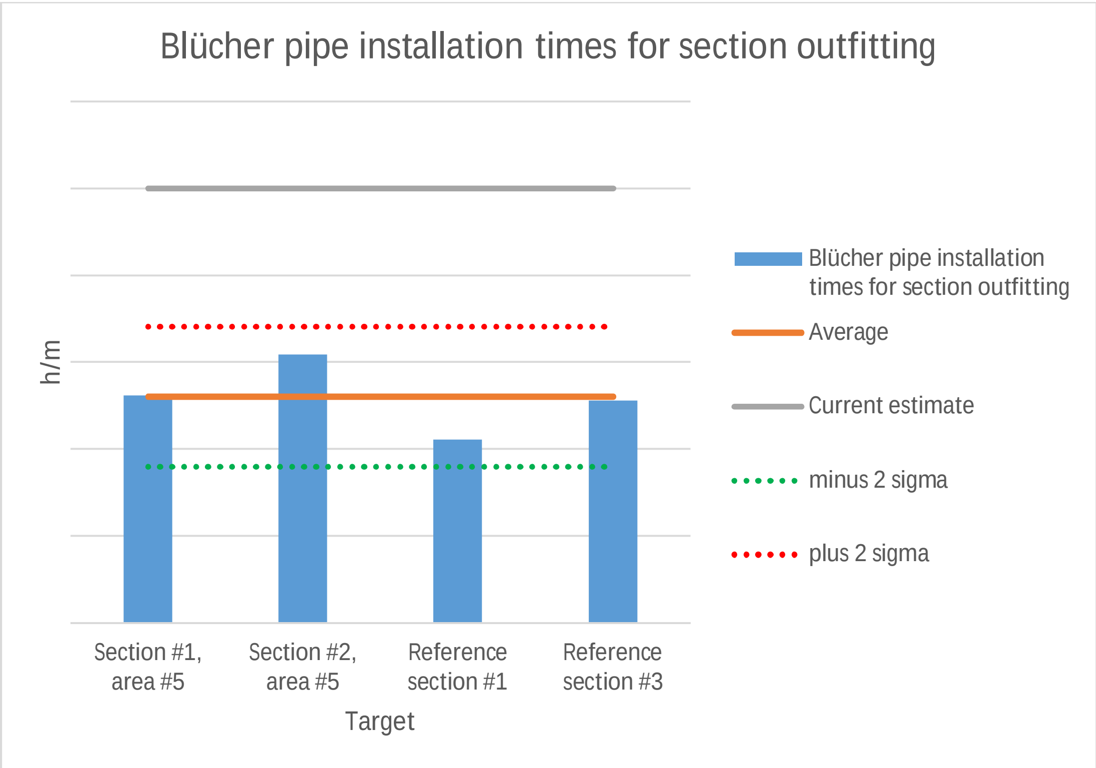

Spiral duct parts R & RI installation times for section outfitting
h/piece
Section #1, area #5
Section #2, area #5
Section #3, area #5
Section #4, area #6
Reference section #2
Reference section #5
Reference section #4
Target
"Spiro parts R & RI" installation times for section outfitting
Average
Current estimate
minus 2 sigma
plus 2 sigma

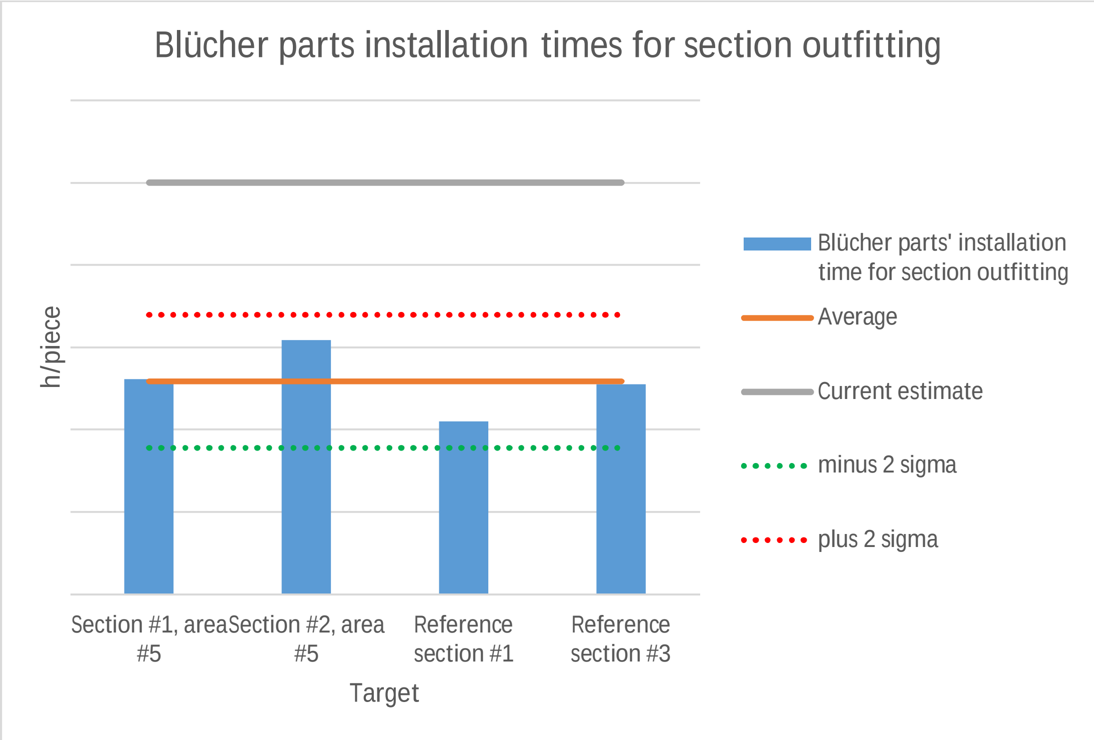

Spiral duct silencers' installation times for section outfitting
h/piece
Section #3, area #6
Section #4, area #6
Reference section #4
Target
"Spiro silencer" installation times for section outfitting
Average
Current estimate
minus 2 sigma
plus 2 sigma

Cable trays' installation times for section outfitting



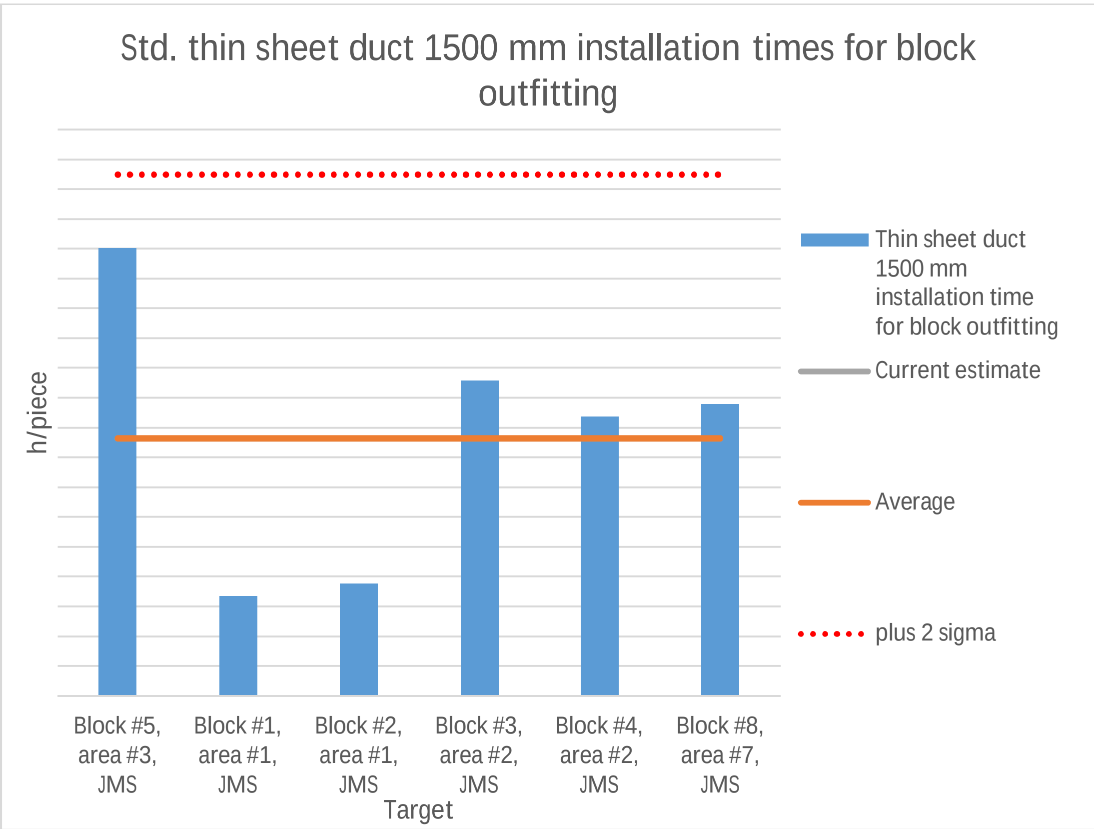
Blücher-piping's installation times for section outfitting

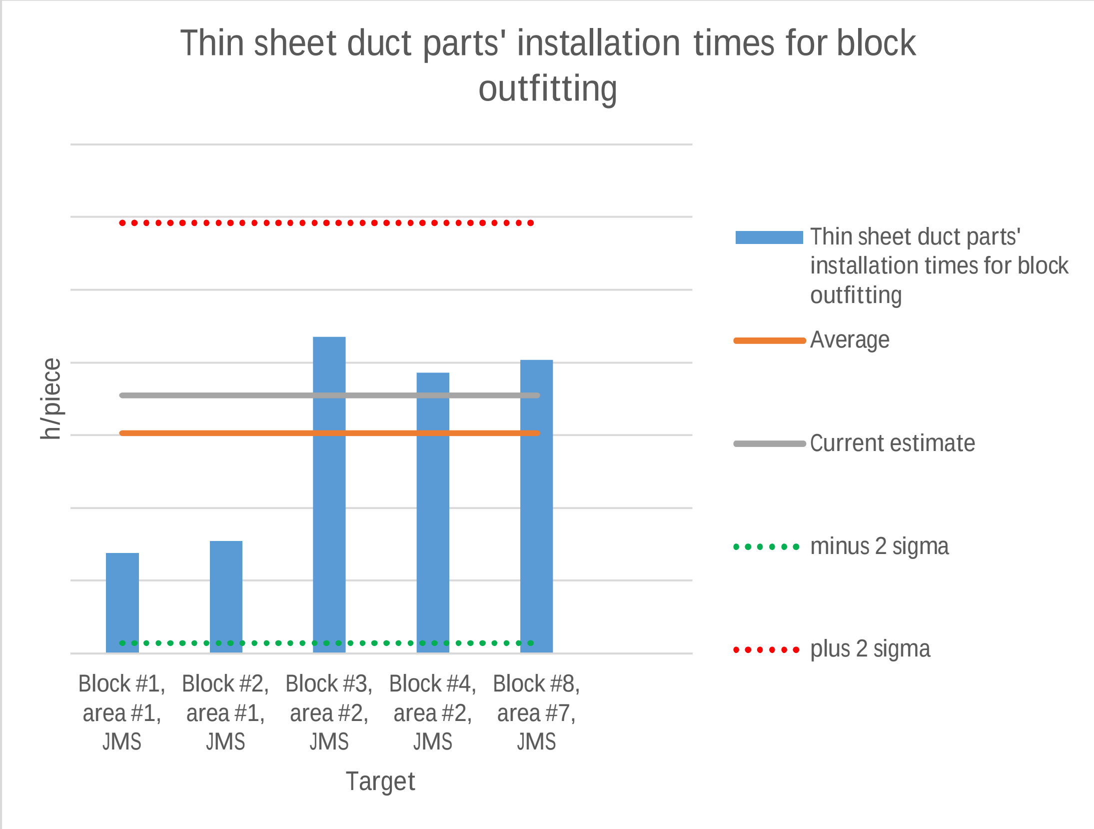


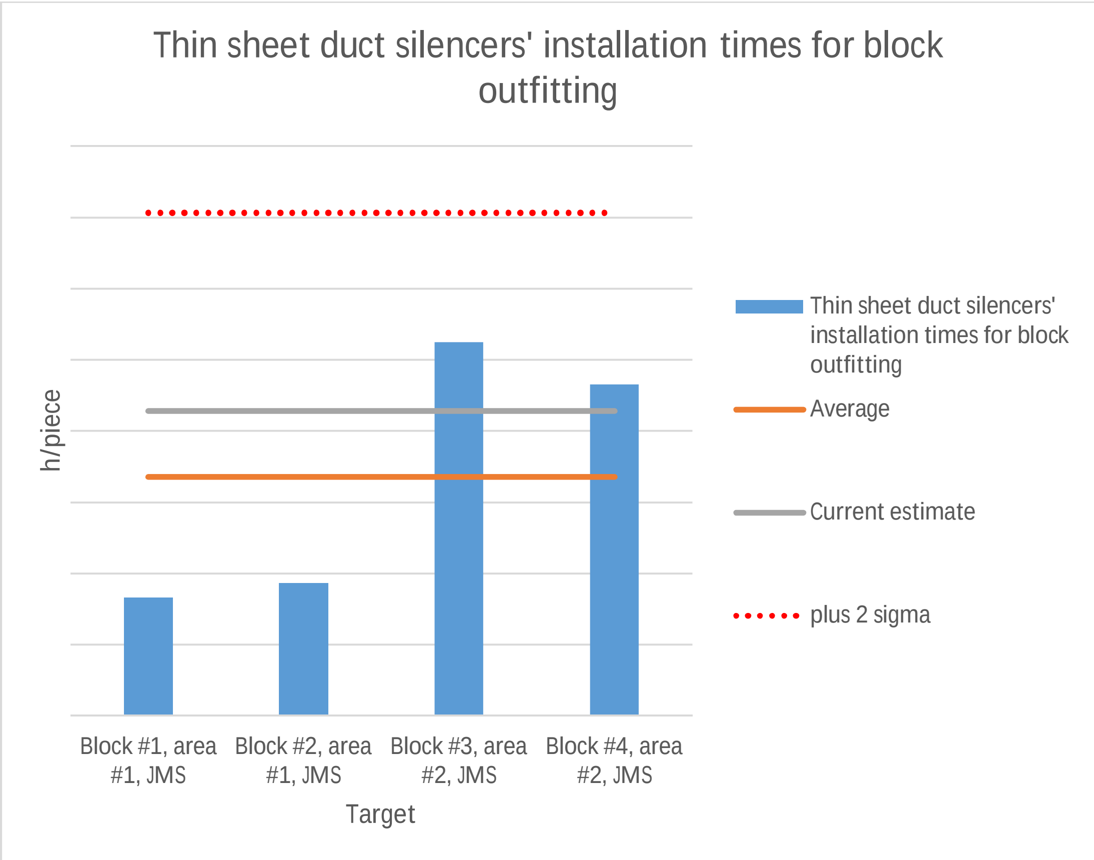


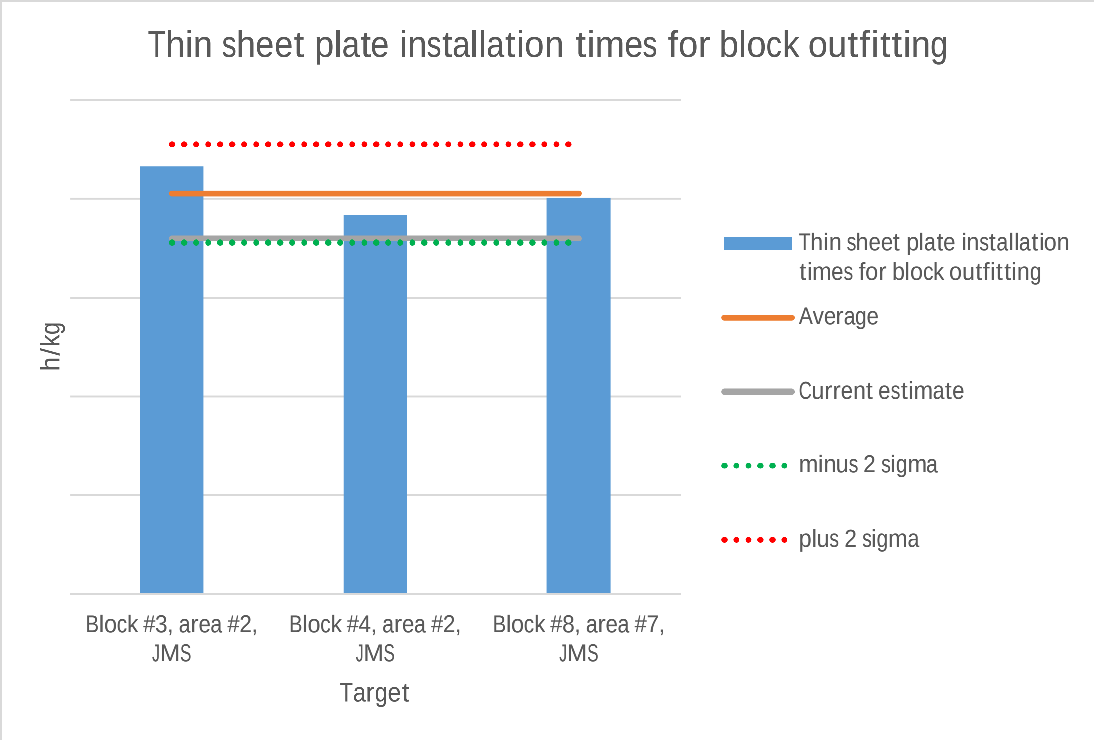
Appendix D – Installation times for block outfitting

Thin sheet ducts' installation times for block outfitting

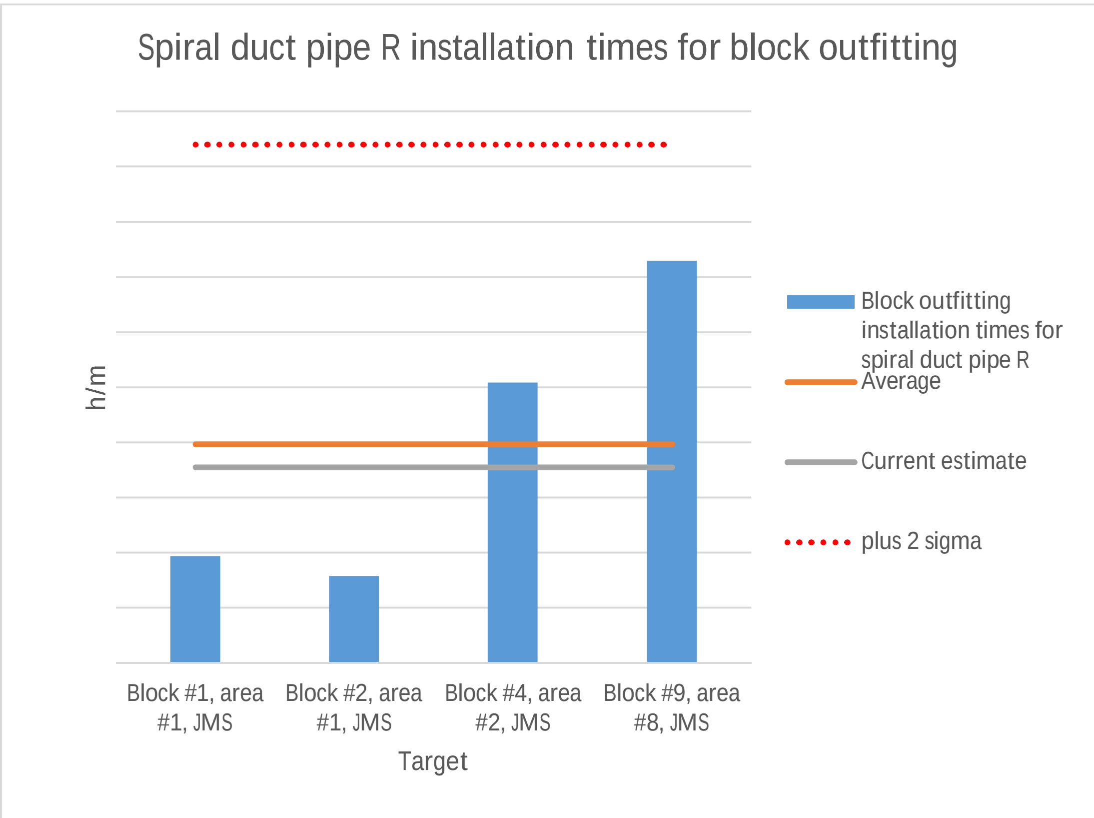


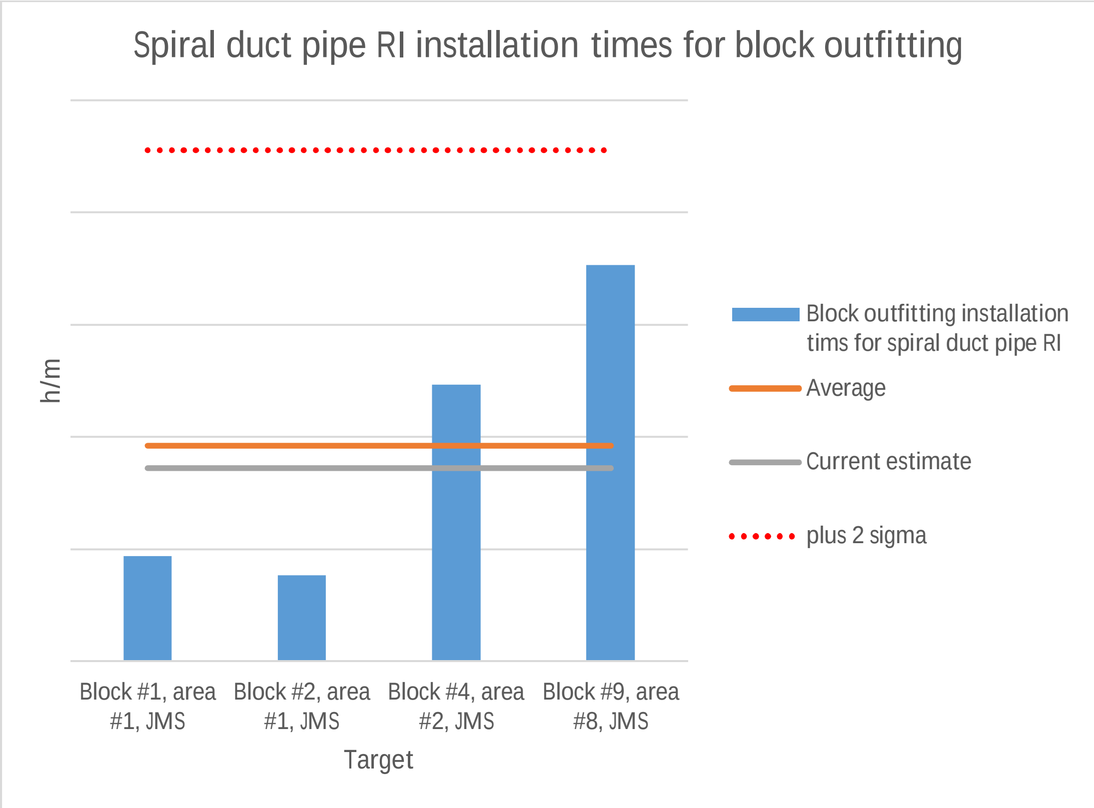

Thin sheet duct parts' installation times for block outfitting
h/piece
Block #1, area #1, JMS
Block #2, area #1, JMS
Block #3, area #2, JMS
Block #4, area #2, JMS
Block #8, area #7, JMS
Target
Thin sheet duct parts' installation times for block outfitting
Average
Current estimate
minus 2 sigma
plus 2 sigma

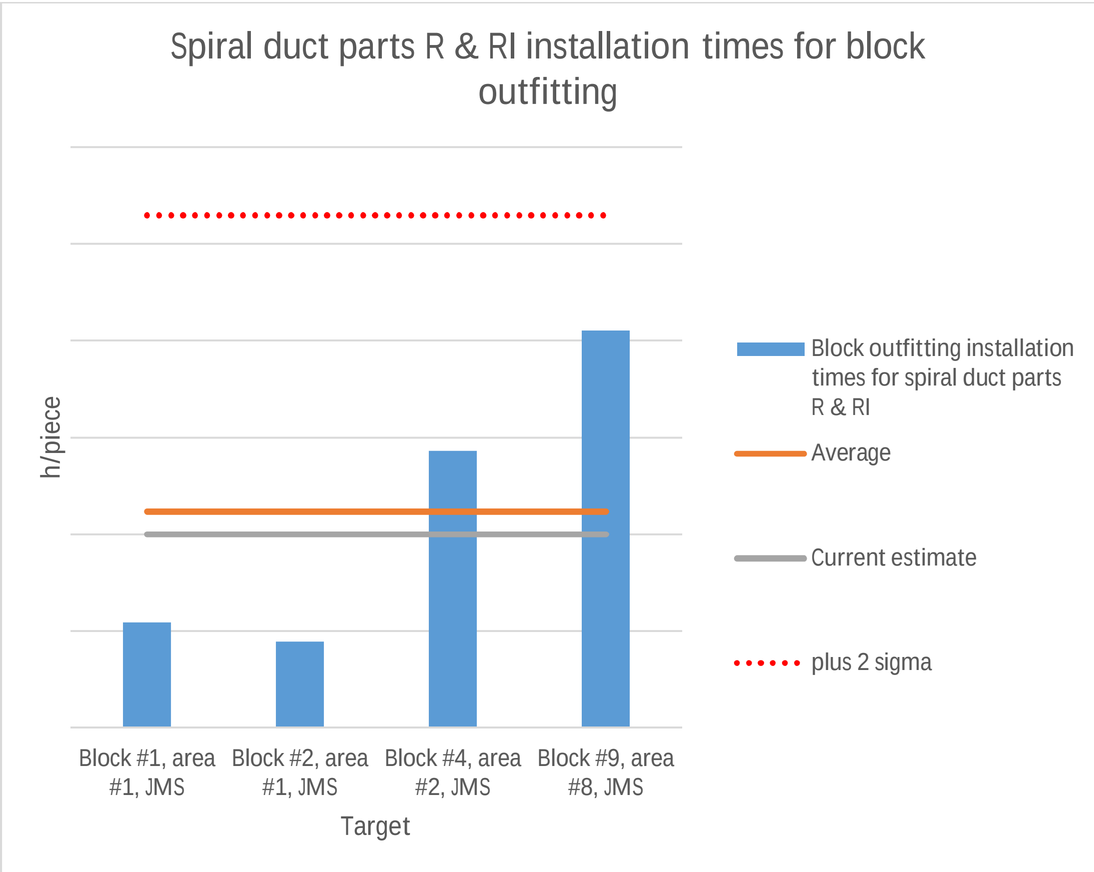

Thin sheet duct silencers' installation times for block outfitting
h/piece
Block #1, area #1, JMS
Block #2, area #1, JMS
Block #3, area #2, JMS
Block #4, area #2, JMS
Target
Thin sheet duct silencers' installation times for block outfitting
Average
Current estimate
plus 2 sigma

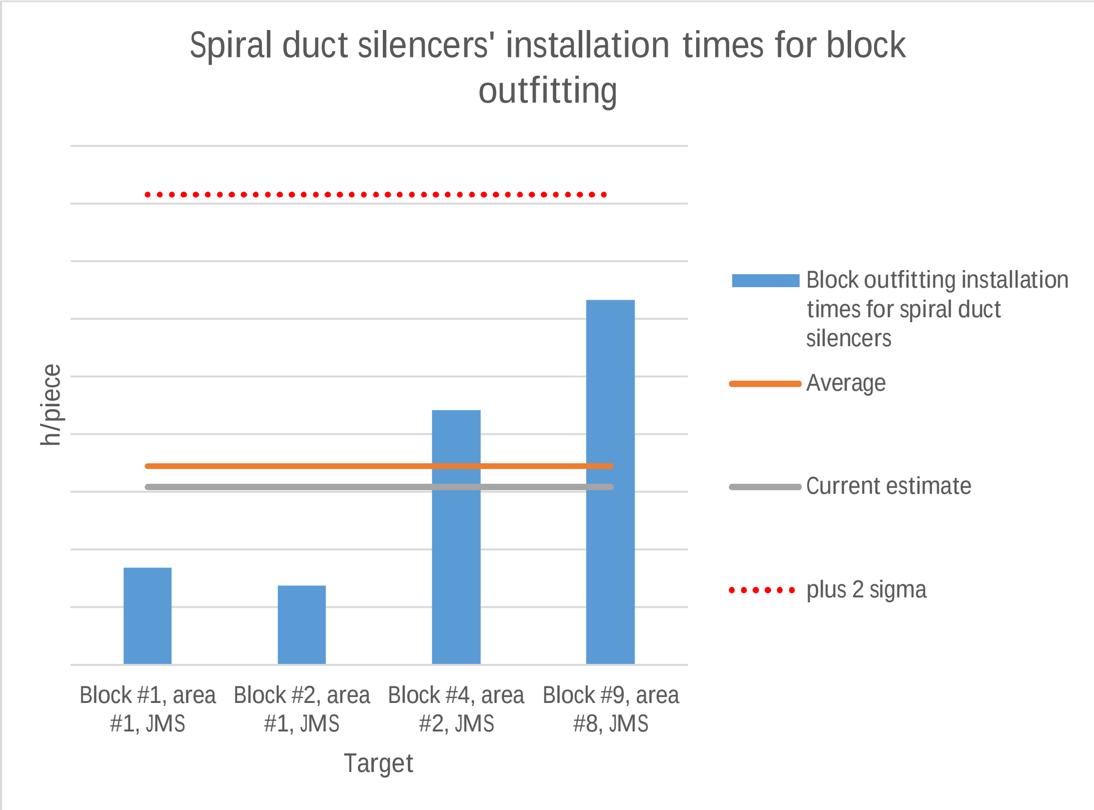


Spiral ducts' installation times for block outfitting

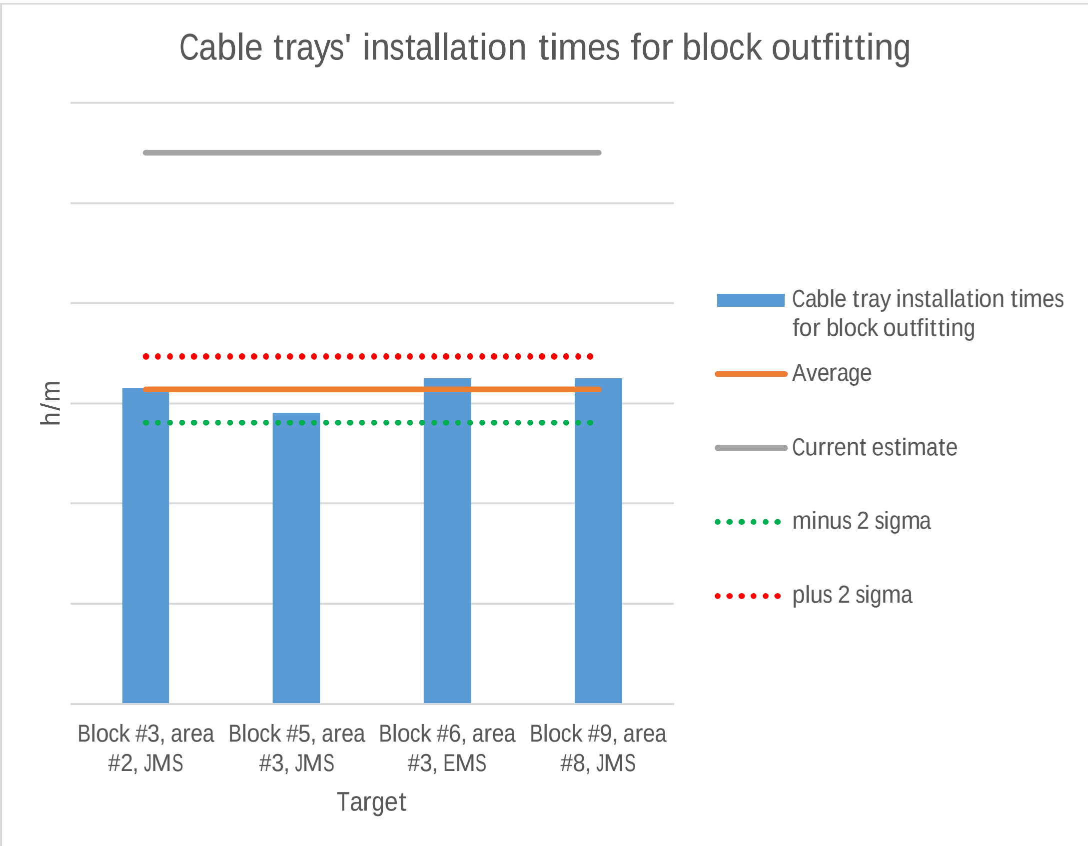



Spiral duct pipe RI installation times for block outfitting
h/m
Block #1, area #1, JMS
Block #2, area #1, JMS
Block #4, area #2, JMS
Block #9, area #8, JMS
Target
Block outfitting installation tims for spiral duct pipe RI
Average
Current estimate
plus 2 sigma

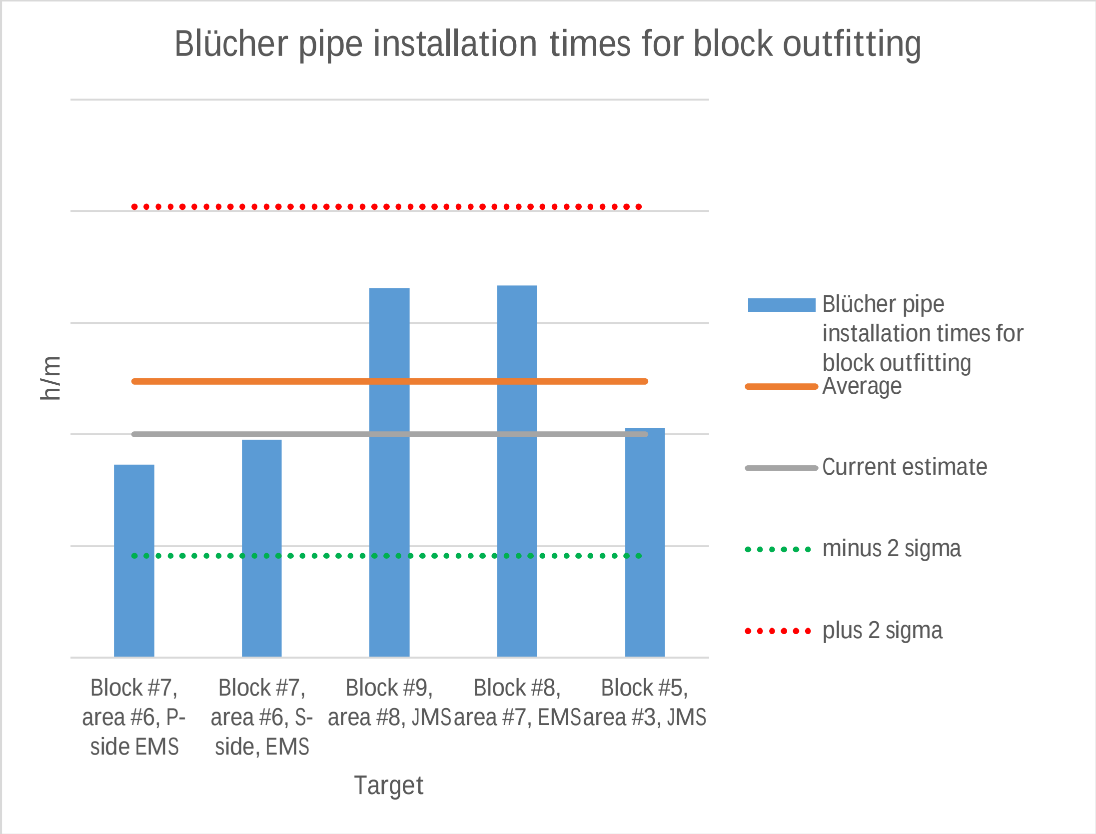

Spiral duct parts R & RI installation times for block outfitting
h/piece
Block #1, area #1, JMS
Block #2, area #1, JMS
Block #4, area #2, JMS
Block #9, area #8, JMS
Target
Block outfitting installation times for spiral duct parts R & RI
Average
Current estimate
plus 2 sigma

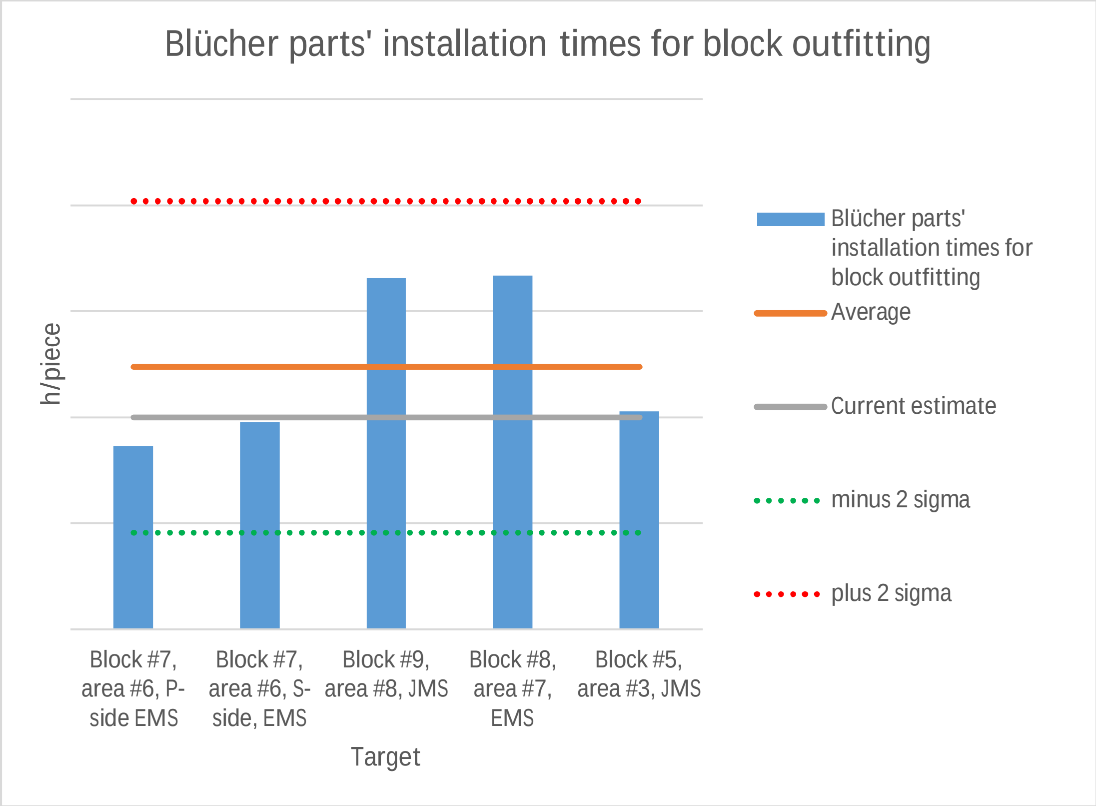


Cable trays' installation times for block outfitting



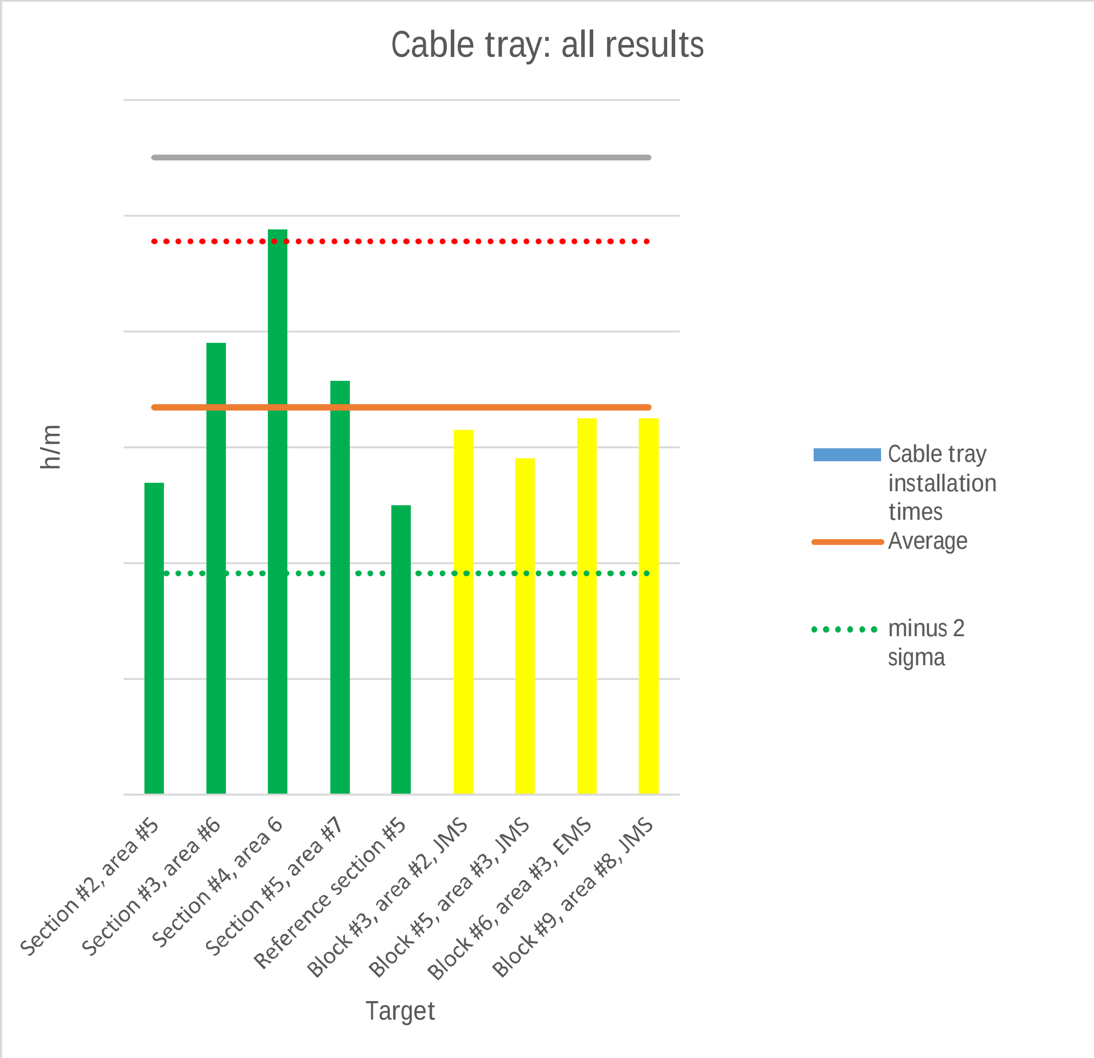
Blücher-piping's installation times for block outfitting





Appendix E – Recommended installation values

Combination of cable trays' installation times



Recommended installation times for section and block outfitting

Recommended installation times for section and block outfitting				
Component group	Component	Unit	Section	Block
Thin sheet ducts	std. straight part 1500 mm	h/piece	x	x
	std.parts	h/piece	x	x
	silencers	h/piece	x	x
	pre-fabricated plates	h/kg	x	x
	duct insulation	h/piece	x	x
Spiral ducts	spiral duct R	h/m	x	x
	spiral duct RI	h/m	x	x
	spiral duct part (R&RI)	h/piece	x	x
	spiro silencers	h/piece	x	x
Blücher-piping	blücher pipe	h/m	x	x
	blücher part	h/piece	x	x
Plastic piping	pipe straight	h/m	x	x
Cable trays	LZCT, NCT, HZCT, WFC	h/m	x	
	SMCT	h/m	x	
Penetrations	thin sheet penetration	h/piece	x	
	spiral duct penetration	h/piece	x	
	piping penetration	h/piece	x	
	cable tray penetration	h/piece	x	
	scuppers	h/piece	x	

Appendix F – Spent working hours

Section outfitting spent working hours

Sections belonging to blocks #1, #2, #3 and #4 could not be measured from start to finish due their early production start. A few thing should be noted. Firstly, thin sheet duct hours include their insulation. Secondly, cable trays include the time for SMCT-cable tray and finally, insulation covers both installation of insulation pins and material. Reason for barely any outfitting work taking place except insulation pins, is that detail design was not finished by that time.

Section outfitting spent working hours and their general allocation										
Target	Phase	Total (h)	Pene-trations	Thin sheet ducts	Spiral ducts	Cable trays	Blücher-piping	Pre-fabricated pipes	Insulation	Support rail brackets
Section #1, area #5	EMV	x			x	x	x		x	
Section #2, area #5	EMV	x	x	x	x	x	x	x		
Section #3, area #6	EMV	x		x	x	x		x		
Section #4, area #6	EMV	x		x	x	x		x	x	
Section #6, area #3	EMV	x							x	
Section #7, area #3	EMV	x							x	
Section #8, area #4	EMV	x	x					x	x	
Section #9, area #4	EMV	x	x			x		x	x	
Section #5, area #7	JML	x	x			x			x	x
Section #11, area #9	EMV	0								
Section #10, area #9	EMV	0								

EMS outfitting spent working hours

No work took place in areas #1 and #2. Note that cutting of opening is included under penetrations due to not being able to separate the time accurately. Column “Other” includes jobs that were either extra jobs with the exception of cutting opening for penetrations or did not belong to any of the former categories e.g. installation of a sliding door.

EMS outfitting spent working hours and their general allocation										
Target	Total (h)	Pene-trations	Thin sheet ducts	Spiral ducts	Cable trays	Blücher-piping	Pre-fabricated pipes	Insulation	Support rail brackets	Other
Block #3, area #2	0									
Block #4, area #2	0									
Block #1, area #1	0									
Block #2, area #1	0									
Block #7, area #5	0									
Block #7, area #6	x	x				x				
Block #5, area #3	x	x					x			
Block #6, area #3	x	x			x		x			
Block #5, area #4	x				x	x	x	x	x	
Block#6, area #4	x	x			x		x	x		x
Block #8, area #7	x	x				x	x			x
Block #10, area #9	x	x					x			

JMS outfitting spent working hours and their general allocation											
Target	Total (h)	Pene-trations	Thin sheet ducts	Thick sheet duct	Spiral ducts	Cable trays	Blücher-piping	Pre-fabricated pipes	Insulation	Plastic pipes	Other
Block #3, area #2	x					x					
Block #4, area #2	x		x								
Block #1, area #1	x	x	x		x		x	x			
Block #2, area #1	x		x	x	x				x		
Block #7, area #5	0										
Block #7, area #6	0										
Block #5, area #3	x								x		
Block #6, area #3	x								x		
Block #8, area #7	x	x	x					x			
Block #10, area #9	x							x			

Storage outfitting spent working hours

Storage outfitting spent working hours and their general allocation											
Target	Total (h)	Pene-trations	Thin sheet ducts	Thick sheet duct	Spiral ducts	Cable trays	Blücher-piping	Pre-fabricated pipes	Insulation	Plastic pipes	Other
Block #3, area #2	x		x			x		x	x		x
Block #4, area #2	x		x		x						
Block #1, area #1	x		x		x					x	
Block #2, area #1	x		x	x	x		x		x	x	x
Block #7, area #5	x								x		
Block #7, area #6	x								x		
Block #5, area #3	x	x	x			x	x	x			x
Block #6, area #3	x	x					x	x	x		
Block #8, area #7	NO										
Block #10, area #9	NO										

Appendix G – Calculations for completion percentages

Completion percentages and theoretical delayed hours

Completion percentage after yard outfitting		
Target	Completion percentage	Unfinished work (h)
Block #1, area #1	85 %	x
Block #2, area #1	89 %	x
Block #3, area #2	76 %	x
Block #4, area #2	100 %	0
Block #7, area #5	84 %	x
Block #7, area #6	91 %	x
Block #5, area #3	35 %	x
Block #6, area #6	32 %	x
Block #8, area #7	46 %	x
Block #10, area #9	11 %	x

Completion percentage calculation: Block #1, area #1

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #1	EMV	Cable trays		98	98	x	x	x
Area #1		Blücher	pipe	16		x	x	
			part	21		x	x	
		Pre-fabricated pipe		54	64	x	x	x
		Penetration small		3	8	x	x	x
		Penetration large		1	4	x	x	x
		Support rail brackets					x	x
		Insulation					x	x
							x	x
	EMS	NO WORK DONE						
	JMS &	Blücher-piping	pipe	59	75	x	x	x
	Storage		part	97	118	x	x	x
		Pre-fabricated pipe		30	30	x	x	x
		Thin sheet ducts	Std. 1500 mm	94	97	x	x	x
			Std. part	145	177	x	x	x
			Silencer	32	44	x	x	x
			Plate	0	262	x	x	x
			Duct insulation	99	119	x	x	x
		Spiral ducts	pipe R	40	43	x	x	x
			pipe RI	80	102	x	x	x
			parts	150	176	x	x	x
			silencers	19	20	x	x	x
		Penetration small		11	11	x	x	x
		Penetration large		4	4	x	x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work:				x	h	

Completion percentage calculation: Block #2, area #1

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #2	EMV	Cable trays		97	100	x	x	x
Area #1		Blücher	pipe	70		x	x	x
			part	75		x	x	x
		Pre-fabricated pipe		89	89	x	x	x
		Penetration small		10	10	x	x	x
		Penetration large		3	3	x	x	x
		Support rail brackets					x	x
		Insulation					x	x
							x	x
	EMS	NO WORK DONE						
	JMS &	Blücher-piping	pipe	15	115	x	x	x
	Storage		part	20	172	x	x	x
		Thin sheet ducts	Std. 1500 mm	37	40	x	x	x
			Std. part	45	49	x	x	x
			Silencer	13	13	x	x	x
			Plate	0	108	x	x	x
			Duct insulation	22	32	x	x	x
		Spiral ducts	pipe R	76	78	x	x	x
			pipe RI	51	53	x	x	x
			parts	74	91	x	x	x
			silencers	3	4	x	x	x
		Penetration small		12	12	x	x	x
		Penetration large		3	3	x	x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #3, area #2

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #3	EMV	Pre-fabricated pipe		80	82	x	x	x
Area #2		Penetration small		36	36	x	x	x
		Penetration large		17	17	x	x	x
		Insulation					x	x
							x	x
	EMS	NO WORK DONE						
	JMS &	Cable trays		99	103	x	x	x
	Storage	Blücher-piping	pipe	0	39	x	x	x
			part	0	63	x	x	x
		Pre-fabricated pipe		11	11	x	x	x
		Thin sheet ducts	Std. 1500 mm	89	99	x	x	x
			Std. part	35	44	x	x	x
			Silencer	34	34	x	x	x
			Plate	1200	1246	x	x	x
			Duct insulation	250	263	x	x	x
		Spiral ducts	pipe R	0	107	x	x	x
			pipe RI	0	91	x	x	x
			parts	0	171	x	x	x
			silencers	0	12	x	x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #4, area #2

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #4	EMV	Pre-fabricated pipe		51	51	x	x	x
Area #2		Plastic piping		126	126	x	x	x
		Thick sheet duct		734	734	x	x	x
		Cable tray		124	124	x	x	x
		Penetration small		2	2	x	x	x
		Penetration large		1	1	x	x	x
		Insulation					x	x
							x	x
	EMS	NO WORK DONE						
	JMS &	Thin sheet ducts	Std. 1500 mm	106	106	x	x	x
	Storage		Std. part	25	25	x	x	x
			Silencer	35	35	x	x	x
			Plate	675	675	x	x	x
			Duct insulation	143	143	x	x	x
		Spiral ducts	pipe R	66	66	x	x	x
			pipe RI	31	31	x	x	x
			parts	58	58	x	x	x
			silencers	4	4	x	x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x		

Completion percentage calculation: Block #7, area #5

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #7	EMV	Pre-fabricated pipe		29	43	x	x	x
Area #5		Blücher	pipe	122	236	x	x	x
			part	209	412	x	x	x
		Cable tray		105	114	x	x	x
		Thin sheet ducts	Std. 1500 mm	3	3	x	x	x
			Std. part	22	22	x	x	x
			Silencer	11	11	x	x	x
			Plate	24	24	x	x	x
			Duct insulation	14	14	x	x	x
		Spiral duct	pipe R	294	306	x	x	x
			pipe RI	349	361	x	x	x
			parts	368	383	x	x	x
							x	x
	EMS	NO WORK DONE						
	JMS &	Insulation					x	x
	Storage							
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #7, area #6

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #7	EMV	Cable tray		70	82	x	x	x
Area #6		Thin sheet ducts	Std. 1500 mm			x	x	x
			Std. part	28	36	x	x	x
			Silencer	8	8	x	x	x
			Plate	30	51	x	x	x
			Duct insulation	18	26	x	x	x
		Spiral duct	pipe R	314	344	x	x	x
			pipe RI	382	397	x	x	x
			parts	308	350	x	x	x
			silencers	15	15	x	x	x
							x	x
		Blücher	pipe	139	155	x	x	x
			part	345	386	x	x	x
		Penetrations small		9	9	x	x	x
	EMS						x	x
	JMS &	Insulation					x	x
	Storage	Plastic pipes		0	364	x	x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	
	Completion percentage with plastic pipes included after storage					x		

Completion percentage calculation: Block #5, area #3

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #5	EMV	Insulation					x	x
Area #3								
	EMS	Penetrations small		25	25	x	x	x
	JMS &	Blücher-piping	pipe	39	39	x	x	x
	Storage		part	19	19	x	x	x
		Pre-fabricated pipe		36	49	x	x	x
		Thin sheet ducts	Std. 1500 mm	18	87	x	x	x
			Std. part	0	62	x	x	x
			Silencer	0	24	x	x	x
			Plate	0	192	x	x	x
			Duct insulation	0	111	x	x	x
		Cable trays		113	128	x	x	x
		Spiral ducts	pipe R	0	115	x	x	x
			pipe RI	0	130	x	x	x
			parts	0	284	x	x	x
			silencers	0	13	x	x	x
		Support rail brackets					x	x
		Bottom plates for draught and fire stop					x	x
		Penetration large		11	11	x	x	x
		Insulation					x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #6, area #3

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #6	EMV	Insulation					x	x
Area #3								
	EMS	Penetrations small		37	37	x	x	x
		Cable trays		103	128	x	x	x
							x	x
	JMS & storage	Blücher-piping	pipe	15	17	x	x	x
			part	15	18	x	x	x
		Pre-fabricated pipe		43	66	x	x	x
		Thin sheet ducts	Std. 1500 mm	0	28	x	x	x
			Std. part	0	26	x	x	x
			Silencer	0	9	x	x	x
			Plate	0	109	x	x	x
			Duct insulation	0	49	x	x	x
		Spiral ducts	pipe R	0	178	x	x	x
			pipe RI	0	195	x	x	x
			parts	0	424	x	x	x
			silencers	0	16	x	x	x
		Support rail brackets					x	x
		Penetration large		11	14	x	x	x
		Insulation					x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #8, area #7

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #8	JML	Cable trays		178	178	x	x	x
Area #7		Insulation					x	x
		Support rail brackets					x	x
		Penetration large		8	8	x	x	x
							x	x
	EMS	Thick sheet ducts		767	767	x	x	x
		Blücher	pipe	119	119	x	x	x
			part	136	136	x	x	x
		Pre-fabricated pipe		44	88	x	x	x
							x	x
	JMS	Thin sheet ducts	Std. 1500 mm	20	138	x	x	x
			Std. part	13	92	x	x	x
			Silencer	0	0	x	x	x
			Plate	366,3	751	x	x	x
			Duct insulation	40	261	x	x	x
		Spiral ducts	pipe R	0	119	x	x	x
			pipe RI	0	163	x	x	x
			parts	0	275	x	x	x
			silencers	0	0	x	x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after JMS				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Completion percentage calculation: Block #10, area #9

Target	Phase	Component group	Component	Installed	Total	Installation time	Theoretical installed time	Theoretical total time
Block #10	EMV	NO WORK DONE						
Area #9								
	EMS	Penetrations small		4	31	x	x	x
		Copper pipe		0	32	x	x	x
		Pre-fabricated piping		40	250	x	x	x
							x	x
	JMS & storage	Blücher-piping	pipe	0	3	x	x	x
			part	0	7	x	x	x
		Spiral ducts	pipe R	0	12	x	x	x
			pipe RI	0	37	x	x	x
			parts	0	317	x	x	x
			silencers	0	1	x	x	x
		Support rail brackets					x	x
		Penetration large		0	12	x	x	x
		Insulation					x	x
							x	x
		Yard outfitting theoretical total hours				x	h	
		Yard outfitting percentage after section outfitting				x		
		Yard outfitting percentage after EMS				x		
		Yard outfitting percentage after storage				x		
		Not installed				x		
		Amount of unfinished work				x	h	

Appendix H – Capacity measurements

Section outfitting capacity –measurements

Target	Working hours	Square time	Number of days work done	Square utilization rate	Average number of workers (square time)	Average number of workers (days work done)
Section #1	x	x	x	75 %	1,4	1,9
Section #2	x	x	x	100 %	2,9	2,9
Section #3	x	x	x	67 %	1,0	1,6
Section #4	x	x	x	100 %	1,6	1,6

Block outfitting capacity –measurements

Target	Working hours	JMS & storage length (network days)	Number of days work done	Working days vs network days ratio	Average number of workers (phase length)	Average number of workers (days work done)
Block #1, area #1	x	x	x	0,80	1,2	1,4
Block #2, area #1	x	x	x	0,52	0,9	1,8
Block #3, area #2	x	x	x	0,65	1,3	2,0
Block #4, area #2	x	x	x	0,63	1,4	2,2
Block #5, area #3	x	x	x	0,24	0,4	1,6
Block #6, area #3	x	x	x	0,26	0,3	1,2
Block #8, area #7	x	x	x	0,61	1,2	2,0
Block #10, area #9	x	x	x	0,17	0,2	1,0
Block #7, area #5	x	x	x	0,04	0,0	1,0
Block #7, area #6	x	x	x	0,04	0,0	1,0
Block #9, area #8	x	x	x	0,86	2,1	2,4

Capacity measurements of an entire block per deck

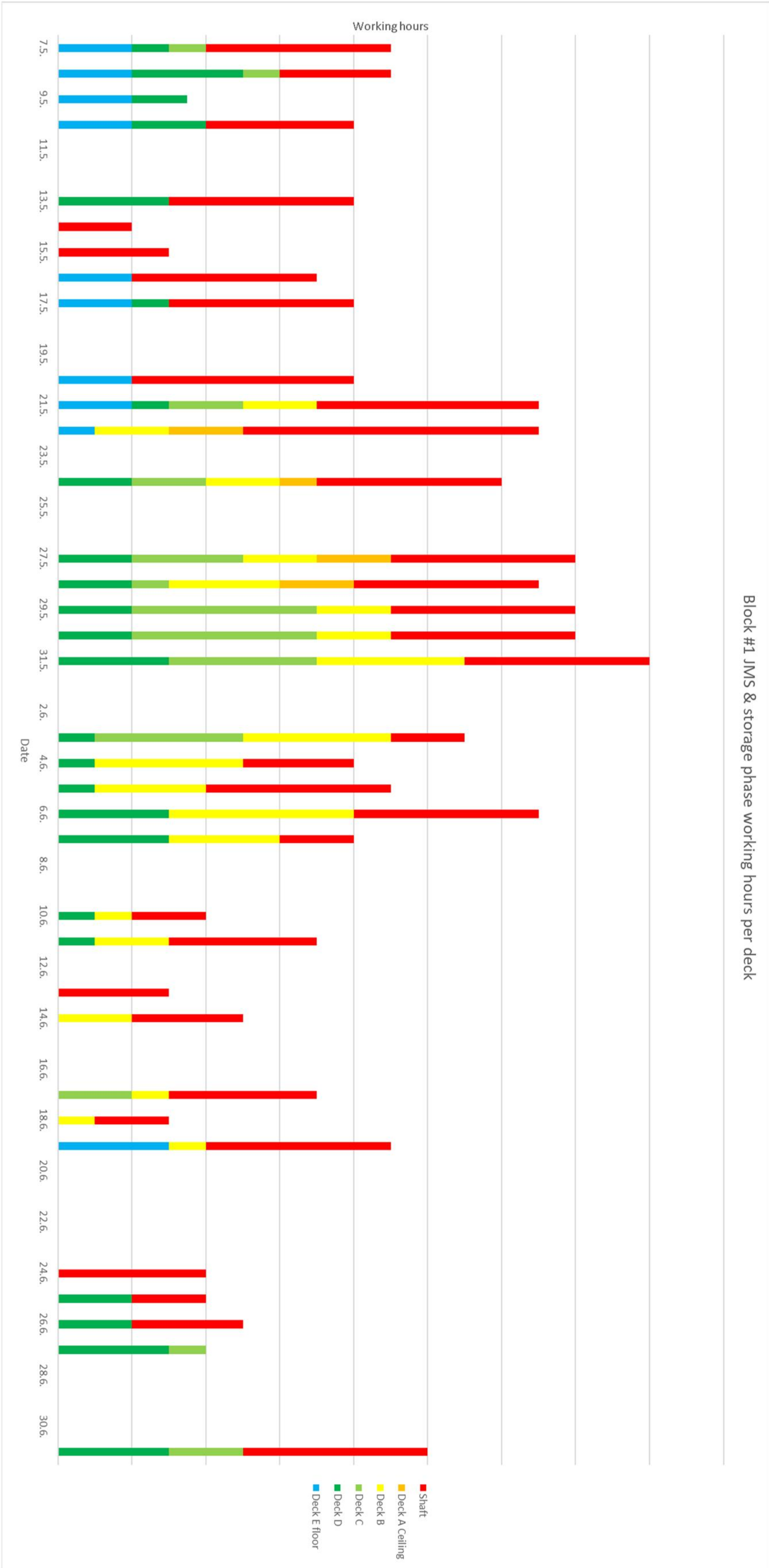
Total working hours for each deck

Working hours per deck and shaft	
Deck E floor	x
Deck D	x
Deck C	x
Deck B	x
Deck A Ceiling	x
Shaft	x
Total	x

Capacity measurements and raw data for decks: B, C and D

Deck	Number of days work done	Number of network days	Utilization rate	Average number of workers (network days)	Average number of workers (days work done)
4.	x	x	0,48	1,2	2,4
5.	x	x	0,33	0,8	2,5
6.	x	x	0,60	1,2	1,9

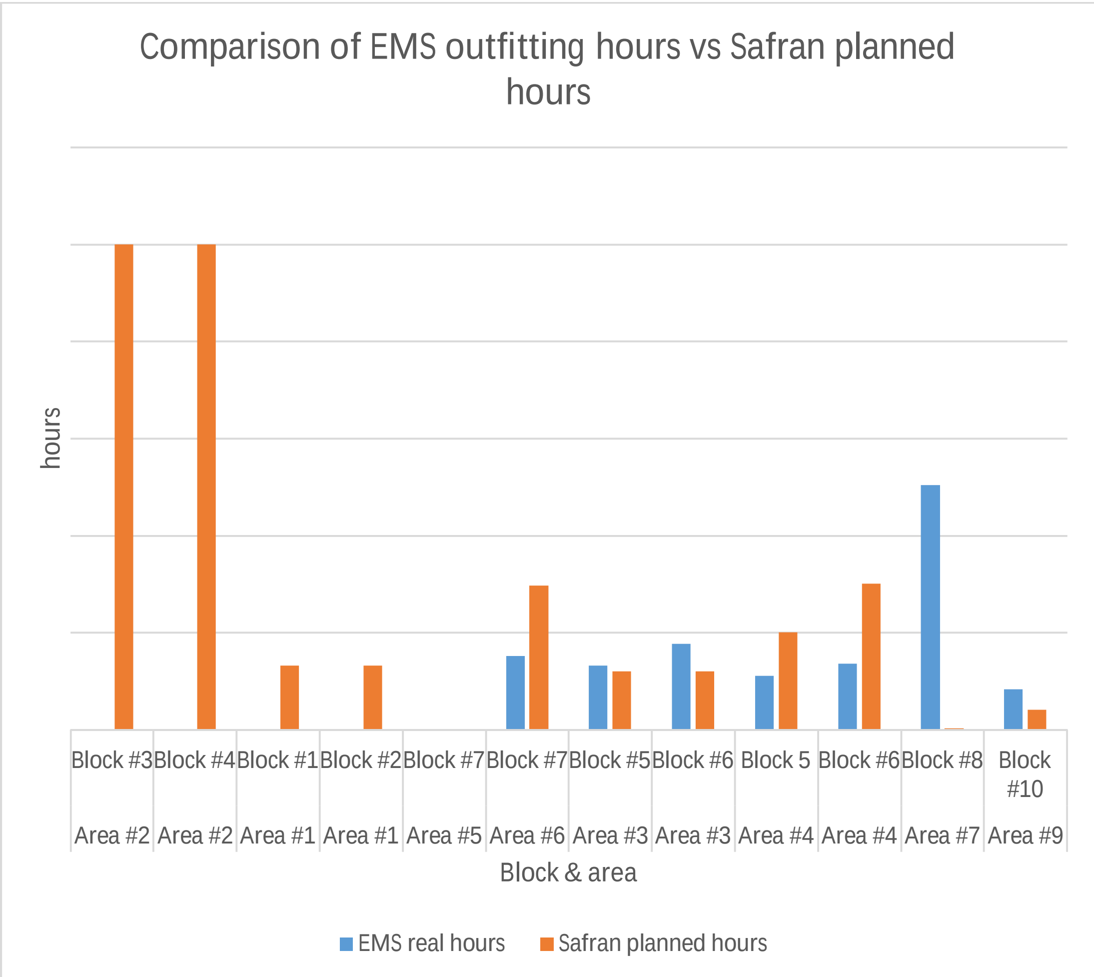
Chart of Block #1's daily working hours per deck



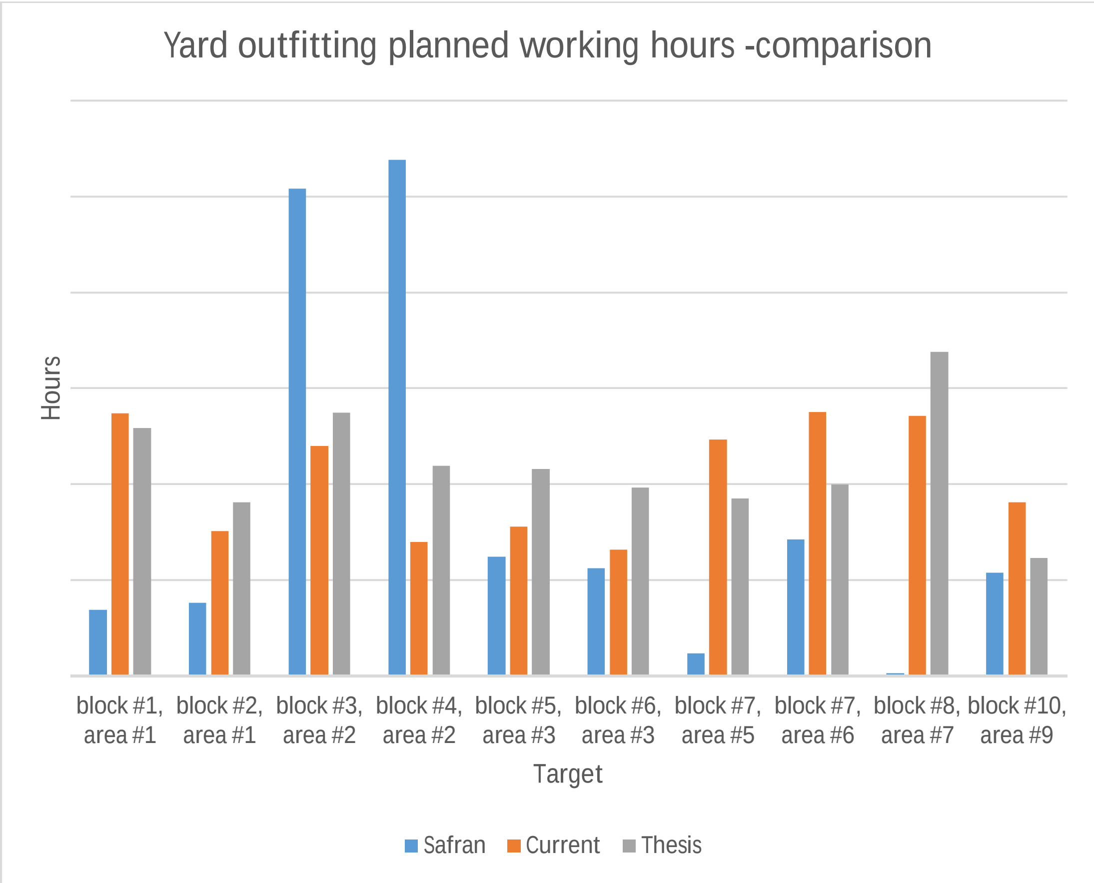
Data for calculating required capacity due to uneven production schedule

Section	Duration	Duration -2	Estimated workload	Required capacity
Section #1	x	x	x	4,5
Section #2	x	x	x	8,8
Section #3	x	x	x	7,4
Section #4	x	x	x	9,6
Section #5	x	x	x	7,3
Section #6	x	x	x	2,8
Section #7	x	x	x	3,8
Section #8	x	x	x	4,9
Section #9	x	x	x	4,3
Section #10	x	x	x	1,3

Appendix I – EMS working hours and planned Safran hours – comparison



Appendix J – Yard outfitting planned workload –comparison



Calculations for yard outfitting planned workload –comparison including deviation from current estimation

Coded target	Safran	Current	Thesis	hesis - Saf	D (Thesis - Current)	Safran's deviation from Thesis	planning's deviation from
block #1, area #1	x	x	x	x	x	-74 %	6 %
block #2, area #1	x	x	x	x	x	-58 %	-17 %
block #3, area #2	x	x	x	x	x	85 %	-13 %
block #4, area #2	x	x	x	x	x	146 %	-36 %
block #5, area #3	x	x	x	x	x	-42 %	-28 %
block #6, area #3	x	x	x	x	x	-43 %	-33 %
block #7, area #5	x	x	x	x	x	-87 %	33 %
block #7, area #6	x	x	x	x	x	-29 %	38 %
block #8, area #7	x	x	x	x	x	-99 %	-20 %
block #10, area #9	x	x	x	x	x	-13 %	47 %

Data for calculating deviation between planned estimate and actual hours

Target	Actual working hours	Theoretical working hours	D(theoretical - actual)	Deviation %
block #1, area #1	x	x	314	-47 %
block #2, area #1	x	x	-8	2 %
block #3, area #2	x	x	-51	7 %
block #4, area #2	x	x	-4	1 %
block #5, area #3	x	x	-59	16 %
block #6, area #3	x	x	-90	31 %
block #7, area #5	x	x	39	-7 %
block #7, area #6	x	x	-41	8 %
block #8, area #7	x	x	-694	90 %