Bachelor thesis TU Delft
Supervisors: M. van der Schaaf and C.H. Thill

Integrated Method for Mapping Shipyard Layouts

Obtaining an Insight into the Current State Building Process and Employee Movements

Quintus Dingeldein[1], **Sanne Jongbloed**[2], **Pepijn Lebbink**[3], **David Pap**[4]

[1,2,3,4]Marine Technology, Faculty of Mechanical, Maritime and Material Engineering, Delft University of Technology, South Holland, The Netherlands

January 27, 2023

Abstract

There exists no general method for analysing the efficiency of a shipyard layout through the mapping of building processes and employee movements. Therefore an Integrated Method for mapping shipyard layouts is developed. This is done by implementing multiple ways of analysing and optimising industrial processes, as found in the literature. Usage of the developed Integrated Method starts with the analysis of different Lean wastes. Next, it is important to get a good understanding of the shipyard's building processes through communication with employees and Value Stream mapping. Subsequently, the found processes can be visualised on a map using Rainbow Models. Finally, these Rainbow Models are verified with data from GPS tracking. Using this combination of methods as one Integrated Method helps to get a good picture of how different shipyard processes run, where they take place and which bottlenecks are present. With this information, shipyards can be made more efficient and future-proof.

Keywords: *Shipyard Layout; Shipbuilding; Value Stream; Rainbow Model; Lean*

---

1. Introduction

Most large industrial production processes consist of line assembly or even mass assembly. For shipbuilding, for example, yacht building, this is different. In shipbuilding production per unit is often used. Every ship delivered is unique and is designed together with the customer. This implies that the building process is not the same for all ships and therefore cannot be automated. Due to the customer's specific requirements, a high level of craftsmanship is required for building a ship. Therefore, sometimes it is impossible to work in any other way and production per unit has to be used. If a shipyard wishes to improve its building efficiency, the shipyard's layout must be considered.

In order to find logistical bottlenecks within a shipbuilding process, the current layout of the production process must be examined. There exists no general method for analysing the efficiency of a shipyard layout. This paper presents a general method that can be used for mapping logistical processes in shipyards, using literature on Lean, Process Optimisation, Value Stream Maps, and the Rainbow Principle.

2. Method

As there is no existing general method for analysing shipyard efficiency, a new method will have to be developed. To this end, the literature must be searched for analysis methods for comparable processes, for example, other industries, and assembly line processes. It is important to target your search for specific literature. To do this, it must be determined in advance which data is required to properly map out a shipyard. In the executed inventory phase, it was discovered that a deep understanding of the building process structure is essential. After an extensive literature study, different tools are combined in a general method that can be used to analyse a shipyard's layout. In this section, the proposed Integrated Method is given as a combination of the described tools extracted from existing methods.

2.1. Wastes of Lean

A lot of literature on Lean principles is widely available. The first step of the Integrated Method is familiarising oneself with the Lean wastes on which the focus should be placed. The wastes are defined as all steps in the process which do not add value to the final product [Skhmot, 2017]. The elimination of these wastes should be the key objective during the optimisation of the yard layout. Keeping the wastes in mind during every step of the process will help distinguish main issues from side issues and generate ideas for improvement. Below a summation of the Lean wastes is given and in which way they are affected by the layout of a shipyard [Doctor Liker and Lamb, 2001].

1. **Transport:** Moving materials does not add any value, reduction of transport is therefore a primary goal for shipyards. This is not to be limited solely to transport on the yard itself, but should also take into account transport from and to the premises.

2. **Inventory:** The spatial layout of a yard is highly dependent on the amount of inventory required and where the stock must be kept.

3. **Motion:** Every motion an employee makes which is not part of a necessary step in the production process must be avoided. This can be viewed on different scales. For example, unnecessarily having to reach out to grab a hammer (micro-scale) or walking a long distance to the canteen (macro scale). The method presented in this paper focuses on macro-scale motions.

4. **Waiting:** Time spent waiting is time wasted. It is important to provide enough workstations, so employees do not have to wait unnecessarily for someone else to finish their job. Even more basic examples, such as waiting for toilet usage, should be considered. Also, waiting time can occur on aisles and elevators on busy transport or walking routes.

5. **Overproduction:** Producing more items than necessary is a waste. However, this is not affected by shipyard layout and is therefore of less importance in this paper.

6. **Overprocessing:** Overprocessing can not be reduced by rearranging the shipyard, but can only be eliminated by changing the building strategy.

7. **Defects:** Defects are a waste because they create the need to repair or replace items. This will not have a major role in the remainder of this paper and is also partially covered in the other wastes. For example, the reduction of transport also reduces the chance of defects during transport.

8. **Skills:** In the shipbuilding industry craftsmanship is an important asset. Employees often have a unique set of skills that should be nurtured. The layout of a successful shipyard should utilise these skills. This is also part of the reason why employees need to be involved in a layout optimisation project.

2.2. Conversations with Employees

To successfully understand the logistic processes in a shipyard, it is essential to involve employees who come into daily contact with the layout [Shablykova, 2020]. Therefore, the second step of the Integrated Method will be interviewing employees. They can provide a clear insight into the role of the various sub-processes in the complete shipbuilding process. Besides, they often have a clear vision of current bottlenecks and will share practical ideas for improvements in the layout. It is crucial to involve employees from the beginning, to obtain continued cooperation during further stages, for example, participation in GPS tracking. GPS tracking will be addressed later in this paper (Section 2.5). The input from employees is of great importance for the next steps: creating the Value Stream Maps (Section 2.3) and the Rainbow Models (Section 2.4).

2.3. Value Stream Mapping

To better understand which of the described Lean wastes apply to a particular shipyard, the value-adding processes taking place at this shipyard can be visualised through Value Stream Maps. According to K. Martin and M. Osterling "A Value Stream Map is the sequence of activities an organisation undertakes to deliver on a customer request." [Martin and Osterling, 2014]. The activities an organisation undertakes can take place consecutively or simultaneously. In addition, activities carried out by third parties (outsourced work) also fall under the Value Stream. It is advisable to give these process steps a different colour in the Value Stream to make it evident that the steps are not executed at the shipyard.

Creating a Value Stream Map is the third step of the Integrated Method as it helps to get a good overview of the process steps in the various production departments. Value Stream Mapping also helps to provide insight into which activities directly add value and which do not. In Figure 1 an example of a Value Stream Map of an imaginary shipyard is shown.

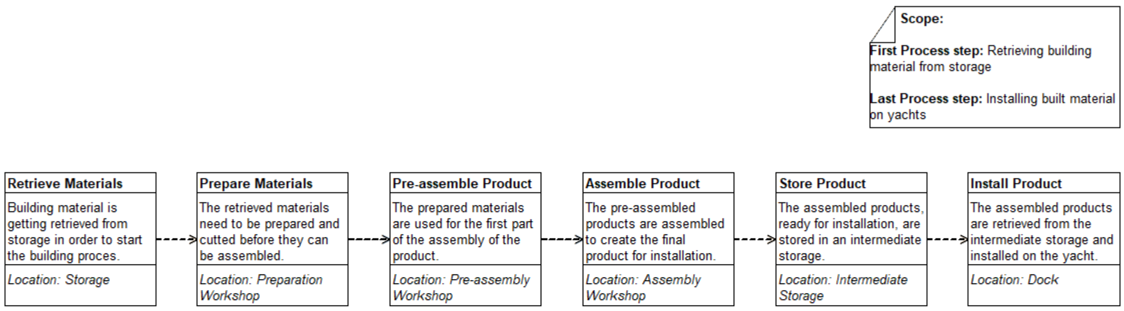

Figure 1. Value Stream Shipyard Process

Important for creating a good Value Stream Map is determining a correct scope. The scope should be defined in the upper right corner of the Value Stream Map as can be seen in Figure 1. In addition, companies often have more than one Value Stream. How many Value Streams a company has can be found by looking at various internal and external "customer" requests. Value Stream Maps are made to map the sequence of activities in the construction process and within the sub-processes taking place at the shipyard. A Value Stream Map should be created for the overall building process as well as for the processes of the production departments that add value to the end product.

Finally, it is important to perform a "Value Stream Walk". This means that during a tour of the shipyard, the Value Stream is observed. The purpose of this is to create a complete understanding of the current state of the work environment. It is important that during this tour, the members of the Value Stream Mapping team are not already consulting with each other and having discussions. Everyone should make notes for themselves that will be discussed later as this contributes to a better group discussion.

In the Value Stream Maps used in the Integrated Method, each of the process steps is named and elaborated in its box. Finally for each of the process steps the location is added. This information is needed for the next step: making the Rainbow Models (Section 2.4).

Usually, Value Stream Mapping is done by people within the organisation, and leadership is included, to make them aware of the logistical issues within the organisation. In addition, employees from different departments within the company are included in the Value Stream Mapping process, including Human Resources and Finance, to achieve a better understanding of the interconnections within the organisation. If the Value Stream Mapping is done by an external team, there may be not enough support to apply solutions to the problems found. To mitigate this risk, it is crucial to involve the company's management.

2.4. Rainbow Model

The Rainbow Model is the next step in the process of the Shipyard Layout Analysis. The model is a graphical representation of the Value Stream Maps, discussed in Section 2.3. The Rainbow Model is based on the Rainbow Principle (personal communication, Ir. J.J.B. Teuben). The Rainbow Principle is a method of analysing a shipyard process using multiple colours. Every step in a process is given a colour, starting with red for the first step of a process. Every following step in the process is then given a different colour. The colours used in sequence are as follows.

Red > **Orange** > **Yellow** > **Green** > **Cyan** > **Blue**

Now it becomes evident that these colours are exactly those found in a rainbow. The principle of assigning distinct colours to different process steps can be used to make a Rainbow Model. This Rainbow Model is used for further analysing the shipyard layout.

The first step in establishing this Rainbow Model is assigning the colours to different process steps, as dictated by the Rainbow Principle. This is illustrated in Figure 2 for a fictional shipyard. The first process step (**red**) of the building process at this shipyard, is the storage of parts and materials. The next step is cutting and preparing the materials (**orange**), and subsequently manufacturing steps **1** (**yellow**) and **2** (**green**) follow. Assembled components are stored (**cyan**) and finally, in the dock area (**blue**) the components are installed.

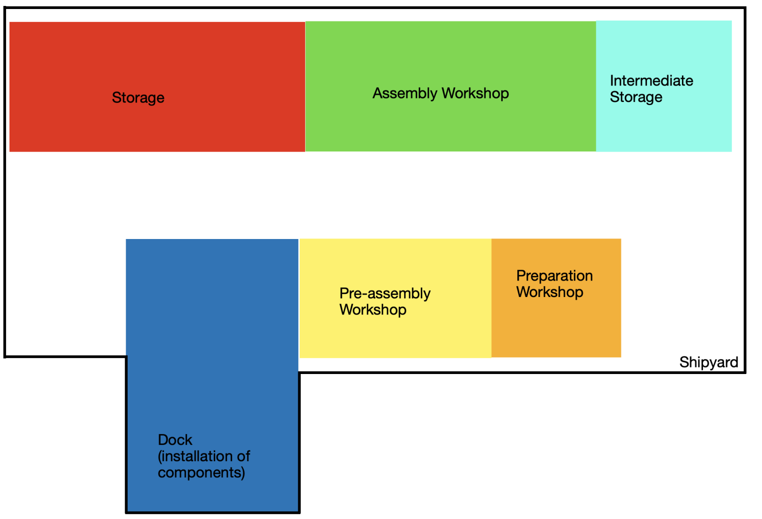

Figure 2. Rainbow Model Shipyard Layout before Optimisation

The next task for creating the Rainbow Model is to analyse transport between the process steps. All transport movement between process steps is visualised with arrows on the map. In the example of the fictional shipyard, this would be as in Figure 3.

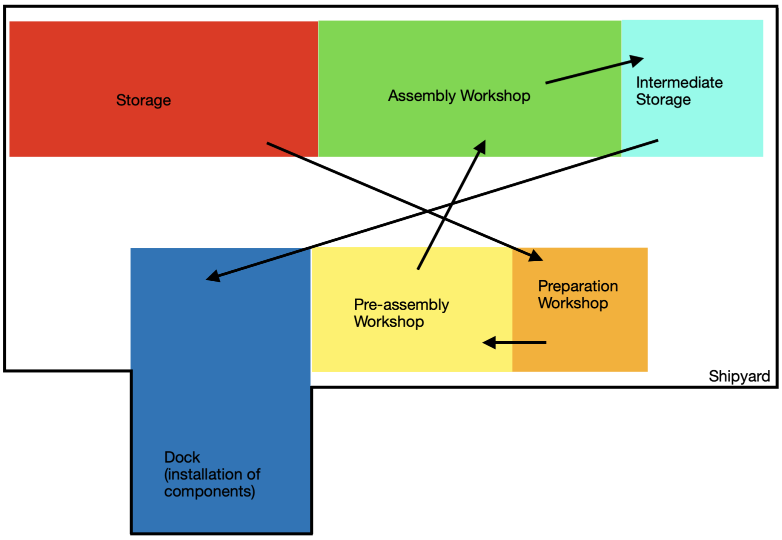

Figure 3. Rainbow Model Shipyard Layout with Transport Arrows before Optimisation

Looking at this Rainbow Model, it is first essential to look at the bigger picture. In theory, process steps that are the furthest away from each other in the Value Stream Map should also be the furthest away from each other in the Rainbow Model. On the contrary, process steps that are next to each other in the Value Stream Map should also be next to each other in the Rainbow Model.

For example the position of the **Orange** and Yellow process steps is not ideal, as they are far away from their predecessors and successors. These process steps are right next to the Building Dock, but they do not have any transport routes leading to the Dock. Analysing the logical placement of process steps is key to establishing a better shipyard layout. Based on this, an indication of placement is concluded in Table 1.

Table 1. Analysis Rainbow Model Figure 3

Analysis	**GOOD** or **BAD** Placement
The **Red** and **Orange** steps are far apart, requiring a long transport route.	**BAD**
The **Orange** and Yellow steps are next to each other, facilitating easy transport. However, they are very close to the dock but have no transport to this step.	**GOOD** and **BAD**
The Yellow and **Green** steps are not immediately next to each other, however as close as they can be given the shape of the shipyard.	**GOOD**
The **Green** and Cyan steps are next to each other, facilitating easy transport	**GOOD**
The Cyan and **Blue** steps are far apart, requiring a long transport route.	**BAD**

Taking these findings into account, an improved shipyard layout can be proposed. Note that it is essential for the different process steps to take up the same amount of space as in the old situation. A proposal could be as the one in Figure 4.

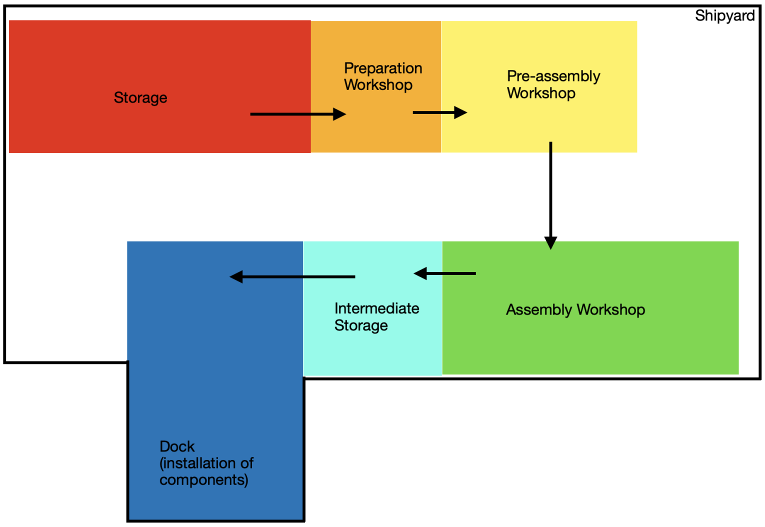

Figure 4. Rainbow Model Shipyard Layout after Optimisation

From this Rainbow Model, it can be concluded that the layout is more efficient. There are shorter transport routes between the **Red** and **Orange** steps and between the **Cyan** and **Blue** steps. The process follows a logical 'flow', with the colours clearly following the pattern of a rainbow. There is no weird pattern or scattering of colours recognisable. This makes the Rainbow Model an excellent tool for quickly visualising shipyard layout (in)efficiency.

Note that this example only describes a single general process. Usually, a shipyard hosts many different sub-processes, such as painting, installing HVAC, or fitting pipes. In order to establish a thorough understanding of the inefficiencies, it is essential to create multiple Rainbow Models: one for the overall building process and one for each of the processes of the production departments.

2.5. GPS Tracking

By tracking the movements of employees, the most frequently used routes and bottlenecks can be identified. There are several possible methods for tracking movements. Three methods have been considered: camera placement, manual counting, and GPS tracking.

Placing cameras is not desirable when taking privacy into account. It is difficult to anonymise camera images. Manual counting by means of a stakeout somewhere in the shipyard is very time-consuming. Additionally, placing cameras and manual counting both give a limited picture because measurements are only taken at a limited number of places at the shipyard. Manual counting can also be done by following various departments for a day to get an idea of the movements. This is also quite time-consuming and only gives data from one employee in one day.

GPS tracking is easy to implement and is not time-consuming. It has a number of other advantages: it displays the entire movement and not just the number of passers-by at a certain location, it can easily be scaled up (several people, several days) and the data found is immediately available digitally and therefore easy to process. However, it has the disadvantage that employees can see this as an invasion of their privacy.

GPS tracking is still considered the best option to implement in the Integrated Method to map the movements. The data provides two results, namely the frequency with which a certain route is walked and a heat map to visualise the walking routes and bottlenecks. A heat map is a quick way of visualising the GPS data. A heat map could be made such as the one in Figure 5. Together, these results support the picture of the logistical efficiency derived from the Rainbow Models (Section 2.4) and help to quantify the movements.

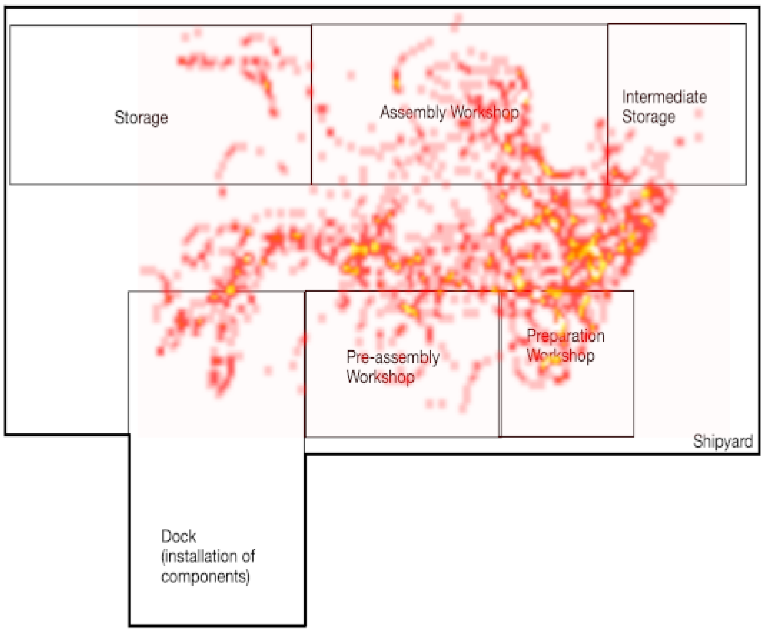

Figure 5. Heat map Shipyard before Optimisation

In the heat map the different recordings can be combined into one map and overview. The heat map is a weighted average of how often a certain point has been passed, which makes it an excellent tool for identifying bottlenecks and busy routes. The bright yellow spots in the image are the places with the most registered data, so those will be the spots and routes to investigate.

3. Result and Discussion

The described tools combined in the Integrated Method, with the goal of invigorating each other, were tested at the shipyard of Koninklijke De Vries Scheepsbouw in Aalsmeer, the Netherlands, part of Feadship. This Integrated Method has proven to be an efficient tool to get a good understanding of a shipyard's layout, processes, and logistic bottlenecks. The Integrated Method has its strengths and flaws, which will be mentioned in this section.

The Integrated Methods knows multiple strengths. First, familiarisation with the Lean wastes at the beginning of the optimisation process helps to identify inefficiencies during all further steps of the Integrated Method. Knowledge of the wastes provides guidance throughout the process and helps with focusing on specific issues.

Second, including employees in the optimisation process, makes sure they feel heard and valued. It is wise to involve employees who work in the production departments, as they come into contact with the layout on a daily basis. This is important to create support for any changes resulting from the study. These conversations establish the foundation for further analysis using Value Stream Maps and Rainbow Models.

Third, GPS tracking is a valuable tool to validate Rainbow Models and eliminate potential misjudgements. These potential misjudgements can be rectified before conclusions are drawn.

A potential flaw can occur when interviewing employees. Questions asked could be too specific or suggestive. To mitigate this risk, open questions should be formulated and it is important to let employees come up with ideas themselves. Furthermore, information received from employees can be subjective. It is important to review their ideas, if this is not done, the input can be compromised and can lead to wrong conclusions.

GPS tracking could be considered a privacy-invading method. However, during conversations with employees of Koninklijke De Vries Scheepsbouw, it appeared that they generally favoured this method. It was found that it is important that employees are informed about GPS tracking and how the data is used. The data is anonymised, which makes it impossible to trace which movements belong to which employee.

During testing of GPS tracking at Koninklijk De Vries Scheepsbouw, it was found that in docks there is often poor coverage, causing the signal to jump. This means that large activities can be tracked well, but it is not possible to measure with great detail which small movements there are. Therefore, it could be difficult to interpret the exact results of GPS tracking. For the conducted project, for which this method was developed, the GPS tracking data was sufficient.

If the Lean wastes are not kept in mind during the research, there is a risk that the scope of the research is not clear enough. That is why it is important to give a clear direction to your research using the Lean wastes.

There is a risk of wanting to display too much information when creating Value Stream Maps, which can cause the Value Stream Map to become unreadable and difficult to interpret. The risk is mainly in collecting information at a too-detailed level. This can complicate subsequent steps and possibly leads to poor conclusions.

The proposed Integrated Method utilises GPS tracking to quantify the movements of employees within a shipyard. While GPS tracking is considered the most suitable option, it is acknowledged that alternative tools may be more appropriate depending on the specific constraints and requirements of the shipyard. The Integrated Method has the flexibility to incorporate other measurement tools as long as they yield comparable results.

It is important to note that the Integrated Method regards the existing production strategy as a given and does not address any potential changes to it. However, it is recognised that modifications to the production strategy may have a significant impact on overall production efficiency. To integrate the production strategy in the analysis, it is recommended to create a future state Value Stream Map in addition to the current state map and to incorporate ideas for improvement during further optimisation studies. A comprehensive guide for creating a future state Value Stream Map can be found in the literature [Martin and Osterling, 2014].

4. Conclusion

The Integrated Method for mapping shipyard layouts proves to be a good asset for layout analysis. The method uses principles from Lean and observations from employees to create a Value Stream Map for the main building process and for each of the processes of the shipyard's production departments. These different Value Stream Maps are then visualised in a series of Rainbow Models. Again, the main process and each of the production departments get their own Rainbow Model. For validation of the Rainbow Models, GPS tracking can be used. GPS tracking is a useful tool because heat maps can be created. Heat maps give insight into the movement of people throughout the shipyard and can be used as a basis for calculating cost reductions. If layout optimisations are being planned, it is important to keep in mind the Wastes of Lean. Layout improvements should never lead to the creation of waste. Instead, the main goal of improvements should be to eliminate these Lean Wastes as much as possible.

The tools included in the Integrated Method work together to validate each other, which is a big strength of the method. Lean principles provide a solid scientific basis and therefore guidance throughout the optimisation process. Rainbow Models provide an intuitive way of visualising efficiency and are easy to create. Including employees in the process makes them feel heard and creates support within the organisation.

Potential flaws can arise. When asking employees questions that are too suggestive this could result in too subjective data. GPS tracking is considered the most suitable option, but other options could be more appropriate, depending on the situation. Also, changing the existing production strategy is not included in this Integrated Method.

As mentioned in Chapter 3, mitigation is possible. During testing of the Integrated Method, it was found that the method provided great insight into the production process and layout of the shipyard. It was a good basis for logistical optimisation and many bottlenecks were identified. Considering these findings and conclusions, the Integrated Method for mapping shipyard layouts is a good logistical analysis tool to use. It can be used in a practical and specific way for almost any type of shipyard.

5. Acknowledgement

We would like to sincerely thank Feadship Koninklijke De Vries Scheepsbouw for opening their Shipyard to conduct our research and implement our Integrated Method. We really appreciate the cooperation and input given during our research. We also like to thank T. van der Schaaf for his unconditional support and motivation to complete the research successfully.

References

[Doctor Liker and Lamb, 2001] Doctor Liker, J. and Lamb, T. (2001). *Lean Shipbuilding*. The Society of Naval Architects And Marine Engineers.

[Martin and Osterling, 2014] Martin, K. and Osterling, M. (2014). *Value Stream Mapping: How to Visualize Work and Align Leadership for Organizational Transformation*. McGraw-Hill Education.

[Shablykova, 2020] Shablykova, V. (2020). *Layout and Material Flow Planning of a Shipyard*. Helsinki Metropolia University of Applied Sciences.

[Skhmot, 2017] Skhmot, N. (2017). The 8 wastes of lean. Last accessed 8 november 2022.