Valeriia Shablykova

Layout and material flow planning of a shipyard

Helsinki Shipyard Oy

Helsinki Metropolia University of Applied Sciences

Master’s Degree

Industrial Management / Logistics Management

Master’s Thesis

29 May 2020

This thesis project is a culmination of intense yet gratifying study process in combination with great support to and from the work at Helsinki shipyard. The Master's Program in Industrial Engineering gave an outstanding opportunity to enhance the professional knowledge of logistics engineering from management point of view. The achievements realized within this study journey would not have been possible without support of the exceptionally professional and encouraging people surrounding me during this stage of my career.

This development project has taken place at a very intense period in my career, personal growth and overall world situation. It is worth mentioning that the pandemic of COVID-19 has complicated the achievement of required results, but has not managed to exhaust the eagerness of my mentors, colleagues and study companions to improve the efficiency of industrial operations, as ultimately it al has impact on the well being of all of us.

My sincere appreciation to the all of the professors of Industrial Management program for sharing their expertise and guiding through the study process with tremendous passion and support, but especially to the principal lecturer Dr. Juha Haimala, as the main instructor on this thesis and the studies of my core interest.

I am grateful for professional support to my mentors at Helsinki Shipyard OY - Vice president of Procurement and Logistics department Mr. Järvinen, Head of Logistics Mr. Suoknuuti, Head of Warehouse Management Mr. Uhre. I thank my colleagues for advise and cooperation, as well as help in keeping my interest in development of logistics processes at the shipyard.

Finally, there are no words to express the gratitude to my family and closest ones for supporting and encouraging me on my professional and personal growth.

All of these people have ensured the quality of the achieved results and assisted me on improvement of my professional skills. My professional achievements, regardless of the scale and appreciation, are merits of people directly or indirectly participating in this study process.

Valeriia Shablykova
Espoo
May 29, 2020

Author Title Number of Pages Date	Valeriia Shablykova Layout and material flow planning of a shipyard 82 pages + 12 appendices (16 pages) 29 May 2020
Degree	Master of Engineering
Degree Programme	Industrial Management / Logistics Management
Instructors	Dr. Juha Haimala, Principal Lecturer Janne Järvinen, Vice President Procurement and Logistics Aatto Suoknuuti, Head of Logistics

The focus of this thesis is on development of layout and material flow plan specifically for shipyard operations. It appears that the available literature on this topic is rather limited and is missing direct shipyard layout planning instructions. The need for this thesis project is caused by the reduction of land and premises of the case shipyard and the need for updated layout plan, which in perspective would also enhance the efficiency of intralogistics and sufficiently facilitate the shipbuilding process of planned projects. Since the changes in core facilities setting are not affecting the core production process, the development project tis focused on optimization of allocation of storage areas.

The study was conducted based applied action and quantitative research and is performed in three rounds of data gathering. First of all, the first set of data was gathered during the current state analysis and examined the weak and strong points of logistics processes, current layout and material flow routing. Most importantly, the current state analysis included gathering of planned production data for further layout planning purposes, as the conceptual framework was built based on the type of available data.

The theoretical part of this thesis studies the existing practices of shipyard layout planning and material flow optimization in combination with similar practices in heavy industry, which are possible to be applied to highly constrained and regulated environment of shipbuilding. The second set of data was gathered during development stage of this thesis and is represented by the set of improvement suggestion from the case company procurement and logistics management representatives in order to complete building of initial layout and material flow routing proposal. The last set of data was gathered at the project validation stage, and is represented by the set of final correction and improvement suggestion for the final proposal.

The layout plan is developed using the systematic layout planning approach in combination with metaheuristic shipyard facility layout planning techniques. The material flow routing optimization is performed in accordance with Intelligent Water Drop algorithm in combination with shipyard material distribution optimization approach. Both optimization procedures are performed using Python programming and results are generalised into comprehensive format to be applied as a part of operating instructions for logistics workforce of the case company. Additionally, a list of further improvement suggestions is generated in order to maximize the positive of proposed layout and material flow changes. The proposed layout and material flow plan minimize aim at minimizing the travel distances and maximizing the set of closeness importance factors for each of the links between the storage areas and shipyard's core facilities.

Keywords	Shipyard layout planning, material flow routing optimization

Figures

Figure 1 Organization chart 2
Figure 2 Research design of the thesis 7
Figure 3 Process map (Supply chain) 12
Figure 4 Process map (material groups) 14
Figure 5 Current layout 16
Figure 6 Vessel blocks and components flow 17
Figure 7 Stock and prefabrications material flow 19
Figure 8 Vessel production schedule 26
Figure 9 Vessel basic parameters 32
Figure 10 Space and activity relationship diagram 39
Figure 11 From-to process intensity matrix (Muther, 2015, 4-17) 42
Figure 12 Original IWD algorithm 44
Figure 13 Conceptual framework visually 46
Figure 14 Storage area coordinates compared to layout 50
Figure 15 Generalized layout suggestion 55
Figure 16 Storage area coordinates graph 57
Figure 17 Vessel blocks routing 59
Figure 18 Interior material flow routing 60
Figure 19 HVAC material flow routing 61
Figure 20 Machinery material flow routing 62
Figure 21 Deck material flow routing 63
Figure 22 Electrical material flow routing 64
Figure 23 Painting material flow routing 65
Figure 24 Proposed location for second receiving dock 74

Tables

Table 1. Research data collection plan 8
Table 2 Interview results (Managers) 20
Table 3. Interview results (CEO) 24
Table 4 Block footprint proportion 27
Table 5. Planned material flow intensity 30
Table 6. Consolidated results CSA 34
Table 7 Closeness rating indicators 38
Table 8 Closeness rating matrix 38
Table 9 Improvement suggestions from management 1/2 48
Table 10 Closeness rating coding (Muther, 2015) 51
Table 11 Storage area weights 53
Table 12 Changes in material assignment 56
Table 13 Proposal draft 66
Table 13 Improvement suggestions from management 2/2 69
Table 13 Final proposal - Layout plan 71
Table 13 Final proposal - material flow plan 72

Contents

1 Introduction 1

1.1 Business context 1
1.2 Business Challenge, Objective and Outcome 3
1.3 Thesis Outline 4

2 Project plan 5

2.1 Research approach 5
2.2 Research Design 6
2.3 Data collection and analysis 8

3 Current Logistics Processes at the shipyard 10

3.1 Overview of the Analysis of the Current Logistics Processes 10
3.2 Description and illustration of current logistics processes 10
3.2.1 Current process flow 11
3.2.2 Current layout and material flow 16
3.3 Interview and observation results 20
3.4 Summary of project limitations and requirements 24
3.4.1 Layout changes 24
3.4.2 Production volumes 25
3.5 Key Findings 33

4 Existing Knowledge on layout planning at shipyards 35

4.1 Shipyard layout planning 35
4.2 Shipyard material flow optimization 41
4.2.1 Material flow analysis in shipbuilding 42
4.2.2 Material flow rooting optimization 43
4.3 Conceptual Framework of This Thesis 45

5 Building Proposal on layout and material flow plan for the Case Company 47

5.1 Overview of the Proposal Building Stage 47
5.2 Data collection for development purposes 48
5.3 Layout planning of the case shipyard 49
5.4 Material flow planning 56
5.5 Proposal Draft 66

6 Validation of the Proposal 68

6.1 Evaluation 68
6.2 Improvement suggestions from management 69
6.3 Developments to the initial layout and material flow plan proposal 70
6.4 Final Proposal 71
6.4.1 Layout plan 71
6.4.2 Material flow plan 72
6.4.3 Further improvement suggestions 73
7 Conclusions 75
7.1 Executive Summary 75
7.2 Thesis Evaluation 78
7.2.1 Validity 78
7.2.2 Reliability 79
7.2.3 Logic 80
7.2.4 Relevance 80
7.3 Closing Words 81
References 82

1 Introduction

In shipbuilding industry production lead times tend to be long and any delays cause tremendous difficulties in all sectors of business - penalties from the customer, mismatch between the production processes, standby times, use of excessive efforts and lost material. Therefore, the fluency of material flow in such industry is crucial.

The case company in this thesis is currently undergoing major changes. The company is losing part of its premises due to an order from the city of Helsinki, a new ERP system is being taken into use and new strategy is applied. Taking into consideration these changes, this moment gives a great opportunity for re-development of the logistics processes for the most benefit of the company.

Logistics management has been studied for decades and has reached such a level of solution development that almost any production system can be optimized to enhance its effectiveness. However, layout and material flow planning specifically of a shipyard requires differentiating approach than for other industries, and the existing knowledge on this topic is in rather limited amount. With the help of this project the shipyard obtains the understanding of sufficiency of remaining layout and facilities for operations of the planned projects, optimized plan of remaining facilities usage and optimized material flow plan. Moreover, completion of this project allows elimination of waste activities and processes, minimization of delays and mismatches in the production process and practical suggestions for future improvement.

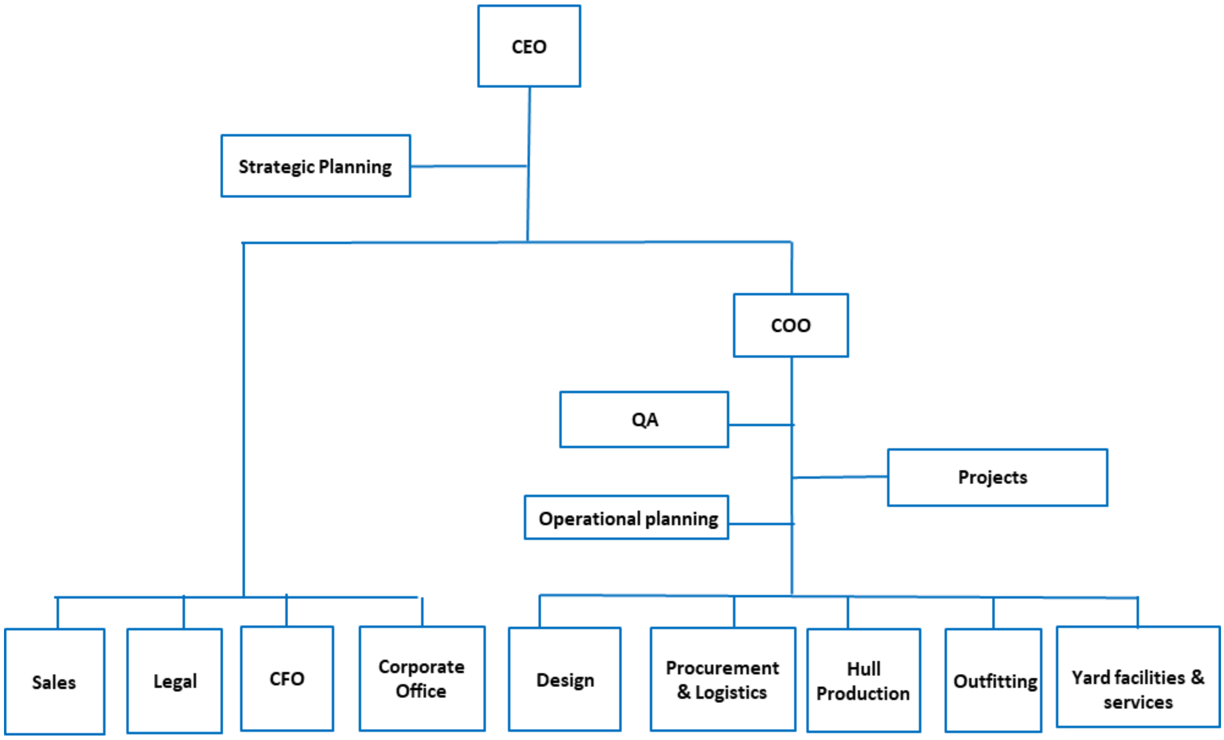
1.1 Business context

The case company reviewed in this thesis is a shipyard focusing on the production of ice-class cruise and supply vessels. Its main customers are private or governmental, who place their orders with a very limited number of shipyards. In this particular field there are rather few competitors of the company, mainly differentiating from each other by quality and reliability.

The case company has always emphasized its quality advantage over the price and has been able to prove this advantage. However, in comparison to competitors, the case company has been suffering from the import sanctions and consequently financial instability due to its belonging to the Russian governmental entity, therefore the orderbook at the moment contains only two major projects. The main competitor is also situated in Finland and has been able to significantly overcome the case company in number of placed orders and therefore turnover due to its stability. In order to prevent the harmful impact to business from continuing, the company has been sold, so the ownership and consequently management has recently changed. Thus, the company finds itself in such a situation where the importance of production efficiency for returning the reputation of reliable producer is exceptionally high.

The production process is the core activity and creates the most value to the case company, while other departments are supporting and facilitating the production. The production volume in terms of workforce amount is varying from 500 workers to 1500 depending on project workload demand, including different departments: block assembly, painting, machinery outfitting, interior outfitting, deck outfitting, electrical outfitting, inspection and commissioning. The production process is supported by sales, design, procurement, maintenance, finance and logistics activities. All material which is used in production is purchased by procurement department, arrives to the shipyard via warehouse and is distributed by intralogistics. As set by the corporate structure of the company, the logistics department is a part of procurement department, making material flow management closely related to purchasing and subcontracting. The corporate structure is illustrated in a figure below for better comprehensiveness.

Figure 1 Organization chart



As it can be seen from the chart, the production activity is managed by two main departments, hull production and outfitting. Project management is assigned separately for each project and is in practice one of the most important entities handling the core activities of the company. Each of departments depicted on the lower level is in turn split to subdivisions by function or responsibility for the different vessel building disciplines.

The production unit is situated in the center of the of Helsinki, on the land owned by the city of Helsinki, and the location appropriateness for industrial facilities has been discussed between the city and the shipyard for ages. Due to a decrease in production capacity use for the reasons mentioned above, the city has been able to reduce the land and premises, leaving only half of the territory available for use.

Using the opportunities provided by the geographical and operational changes happening at once, the management of the company has set the aim at revision, development and planning of the updated layout and material flow if the shipyard in terms of logistics processes.

1.2 Business Challenge, Objective and Outcome

The main challenge with the current logistics processes at the company lies in the lack of thorough planning adaptable to the new layout. The planning of intralogistics processes has been made decades ago based on the premises layout and the material handling system available for industrial use at that time, and then adjusted separately project-wise in moments of urgent need, which is later discussed in current state analysis section. Since the processes were not adjusted to the changing pace of production and technologies available, the operations started to suffer from material loss and misplacement, long travel and handling times. Nowadays the company's territory has been significantly reduced resulting in a pressing need for faultless material flow inside and outside the premises. On the management level, however, the target is set at just-in-time operations aiming at minimization of storage at site.

Positive aspects regarding the timing for this project include implementation of revised system at a time when the new ERM system is being taken into use providing the users with higher transparency of stock levels, internal and external material movement monitoring and supply chain process. Timely corporate strategy reconsideration gives an opportunity for operational processes to be planned and implemented in a way supporting the strategy in the best way.

Given the information mentioned above, the logistics management is targeting at evaluation of the given layout feasibility for manufacturing of the projects existing in the order book. The development stage of the project includes optimization of facility utilization, material flow and operating practices in accordance with JIT approach.

Therefore, the objective of this study is

to develop the layout and material flow plan of a shipyard in terms of logistics processes.

Consequently, the outcome of this study is the layout and material flow plan of the shipyard.

1.3 Thesis Outline

Several research methods are used in this thesis work. First of all, the current logistics processes, the layout and information related thereto is gathered from the company's database and insights of company's management. The gathered data is then analyzed for definition of critical points for improvement. Secondly, the conceptual framework is built on the base of reviewed literature relevant to the subject of this study. The initial proposal of layout and material flow plan is then reviewed by the management of the company, based on whose comments the plan is amended to form the final proposal.

According to the project research and development plan, the next section specifically describes the methods used for research and data analysis. Section 3 includes the current state analysis, followed by relevant literature review in section 4. Based on the findings of the current state analysis and the best practice identified through literature review, the proposal of possible layout, facility usage and material flow arrangement are conducted and evaluated in section 5 and the amended proposal is validated in section 6.

2 Project plan

The purpose of this section is to present the research approaches and material used for conducting this thesis project. It firstly describes which research and analysis methodologies facilitate the development of logistics processes of the case company and then illustrates the process, as well as data collection practices.

2.1 Research approach

There are plenty of research approaches thoroughly described and planned for each particular type of problem solving available for the use of researchers. However, most of these approaches can be characterized by their nature and are therefore divided into two groups: fundamental and applied research. Fundamental research is characterized as scientific and aims at creation of generalized principles and increasing the knowledge of already existing subjects. On the contrary, applied research is rather practical qualitative research and focuses on solving substantial problems. Moreover, studies conducted as applied research are supposed to be addressing issues which are relevant and important to operating managers. (Saunders et al., 2009).

Applied research can be divided into several experiment strategies by the method and object of the research. Such strategies include experiment, survey, case study, grounded theory, ethnography and archival research types. Experiment research focuses on defining the existence between two variables and is used mostly in natural science. Survey is an explanatory deductive research used mainly for conducting statistic results. Case study researches unique single or multiple problems with a focus of creation or proving a theory (Saunders et al., 2009). Action research focuses on solving a particular practical problem within a given context and normally is represented by multiple circles of research stages. Such a research strategy requires the involvement of all participants of the process in which the problem exists, including the researcher and interviewees. (Schein,1999). Grounded theory combines inductive and deductive methods for creation of theory and is mainly used for research of behavioural theories. Ethnography is a deep and time-consuming inductive research involving participant observation and is focused on cultural issues. Research of administrative or historical data is most commonly considered as archival research (Saunders et al., 2009).

As can be seen from the short presentation of the research methods above, the most practical and context-bound of them are case study and action researches. However, case study is more focused on investigation of phenomena, rather than on search for practical solution. Also, the level of researcher involvement is greater in action research.

In the case of this thesis there is a need for the development of a new practical solution with dedication to the managers of the case company and therefore the applied research is as relevant as any. Since the current logistics processes are lacking efficiency and in addition to that shall be applied to a new geographical and strategic layout of the company, the research will be able to support new process development and aim at finding a practical solution, which would facilitate both the management of the case company and process operators. This research requires a vast amount of data and preferably is conducted by the author who has access to internal information of the case company.

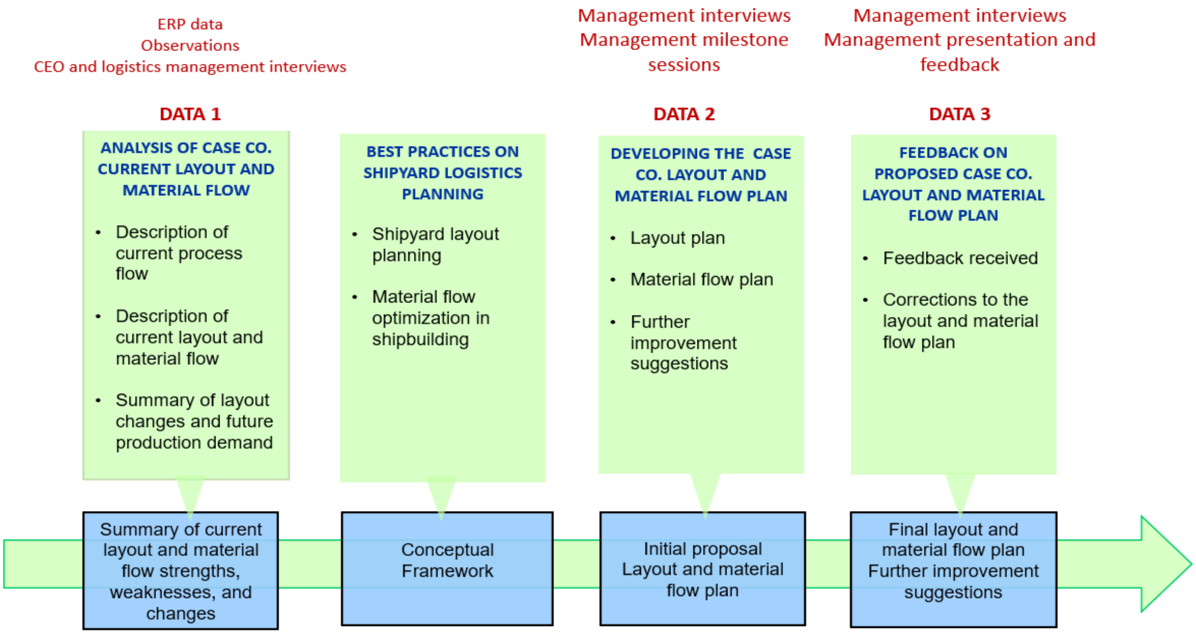
The description of the need for this particular research resembles the characteristics of applied action research. A modified version of traditionally understood action research described above is applied action research that does not require continuous repetition of circles of investigation and action on the problem, but is rather limited by a time frame (Kananen, 2013). Thus, in accordance with the description above, the chosen research method for this project is applied action research.

2.2 Research Design

In the interest of conducting a valuable and structured research, the research design of this thesis was outlined estimating the preferable outcomes of each stage. The research is carried out in four stages, including three different data collection rounds.

In order to ensure practical direction of the research on the topic of layout and material flow planning which is in general widely known in the field of industrial management, the research was narrowed down to the specific problem in the operation of given company. Therefore, in order to find out specific attention areas of the project, as shown in Figure 2, the first stage of the layout and material flow plan development is the current state analysis. The preferred outcome of the first stage is a summarized description of the current layout and material flow of the case company, as well as the inevitable layout changes and the vessel project requirements, the key strengths and weaknesses of current operation.

Figure 2 Research design of the thesis



As the main trigger for the research is the change of the layout and the effect of the change to the arrangement of logistics processes, based on results of current state analysis such topics as the material flow optimization, facility usage and material handling are reviewed in the available literature for ensuring application of the best available practices. The outcome of the theoretical study will be a strong conceptual framework supporting the development of the shipyard layout and material flow in this particular context of case company operations and targets.

The conceptual framework in combination with summarized relevant initial data (data 1 on figure 2) will be utilized in the third stage - development of case company layout and material flow plan. This research is the first step in development of the logistics activities of the case company, which will allow for further improvements in the future. In order for the company management and the researcher to be able to justify the preferable solution, the research will be done in close cooperation with the management, constantly amended and corrected in accordance with management feedback. The outcome of this stage is the initial justified proposal of the layout and material flow plan accompanied by further improvement suggestions.

Consequently, the initial plan will be proposed to management. The feedback received during this presentation will be taken as the last input data and the corresponding corrections will be made to produce the final layout and material flow plan.

2.3 Data collection and analysis

As the applied action research focuses on the development of a solution for a certain problem in a particularly defined processual context by involvement of both process participants and the researcher within a given period of time, the first step is data collection in order to fully describe the process in question. In order to profoundly depict the process and its problematic points, the research shall be based on mainly qualitative but also quantitative data (Kananen 2013).

The data collection and analysis of this thesis project will be based on the research design presented in Figure 2. The data will be collected in three stages. The first set of data will be gathered in the beginning of the research for the purpose of conducting the current state analysis. The second set of data will be received during the development stage in the form of milestone feedback, i.e. additional research requirements and suggestions from the case company management. The final set of data will be collected at a point of final proposal of logistics processes plan to the management. Data collection sources and informants, as well as the projected schedule for data collection stages is presented in the table below.

Table 1. Research data collection plan

	CONTENT	TIMING	OUTCOME
DATA 1 **ANALYSIS OF CURRENT LAYOUT AND MATERIAL FLOW**	• Description of current process flow • Description of current layout and material flow • Summary of layout changes • Summary of future production demands	FEB 2020	**Summary of current layout and material flow strengths, weaknesses, and changes**
DATA 2 **DEVELOPMENT OF LAYOUT AND MATERIAL FLOW PLAN**	• Developing Layout plan • Developing material flow plan • Developing further improvement suggestions	MARCH-APR 2020	**Initial proposal of Layout and material flow plan**

DATA 3 **FEEDBACK ON PRO-POSED LAYOUT AND MATERIAL FLOW PLAN**	• Layout plan • Material flow plan • Further improvement suggestions	MAY 2020	- **Final layout and ma-terial flow plan** - **Further improvement suggestions**

As seen from Table 1, the data collected during the current state analysis is both qualitative and quantitative. Qualitative data will be gathered from interviewing the key actors in logistics processes development. Logistics and procurement managers, who are responsible for management of tightly related departments, as well as warehouse manager will be interviewed aiming at building a process map, identifying the weak points in logistics chain and compiling suggestions for improvement. General short interviews of company's employees, such as the production manager and quality engineer, will be conducted to gather the production demand information and the development framework supporting the company strategy and fit into legislative limitations and regulations. The CEO will provide the initial requirements and strategic limitations to the project. Another part of qualitative data will be received from department-level operation instructions to depict the managerial expectations from current processes. Quantitative data collection will be made with the help of the ERP system of case company aiming to receive a comprehensive representation of strengths and weaknesses of current processes.

The second set of qualitative data will be received during the development process via continuous collaboration with logistics and procurement departments and the milestone presentation to the management of the case company. In such a way the development can be governed and guided by the key employees the company.

Finally, valuable data will be gathered during and after presenting the initial layout and material flow plan proposal. The initial proposal will be presented to the key employees in logistics processes, after which the feedback and correction requests will be implemented to reach consensus on the final plan proposal.

The presentations to the CEO and the management will be recorded in the form of minutes of meeting. Questions presented by the researcher in these presentations will be formed in advance and delivered to presentation participants as a part of the agenda. The continuous face-to-face interviews with the logistics and procurement management will either be recorded or notes will be taken depending on the case circumstances.

3 Current Logistics Processes at the shipyard

This section constitutes one of the largest parts of this thesis in terms of effort consumption and discusses the current flow of logistics processes, both strategic and physical, strong and weak points associated with them and input information for future development, such as planned production volumes and timeframes and limiting factors based on the data collected. As the smoothness of processes and its considerateness of strategic aspects is the key to process optimization, the first step of analysis of current logistics processes is drawing out the map of processes and their position in the supply chain. Next, the physical material movement routes are reflected on the current shipyard layout. Only then the strengths and weaknesses of the process revealed during interviews and observations are summarized in relation to process features discussed at first. Since the project is triggered by changes in current conditions and availability of hitherto utilized facilities, a summary of these changes and limiting factors is also presented in this section. The required future production capacity and the corresponding scheduling is introduced in current state analysis in order to provide a base for layout and material flow planning in the development stage.

3.1 Overview of the Analysis of the Current Logistics Processes

The current state analysis of the process starts with building the process chart on supply chain, company and department levels based on the information received from process flow workshop, interviews of the management and personnel and review of operating instructions. The process flow and material flow maps allow definition of exact problematic points and development focus prioritizing. Next, the requirements for development and inevitable changes are formulated on the basis of existing project and production planning information received during data collection stage interviews.

3.2 Description and illustration of current logistics processes

The current logistics process primarily focuses on facilitation of the production process being the core activity of the company. In tight cooperation with procurement and design departments it ensures fulfilling production needs by timely material receival, storage and internal distribution. Inbound logistics processes, which also constitute a significant part of the logistics work scope, are left out of this thesis for precise concentration purposes. The flow of materials to the production has been experiencing delays, material misplacement and losses. As mentioned before, the difficulties are enlarged by the reduction of the layout territorial layout. In order to define specific points which may indicate the causes of process failures and the available means for development.

3.2.1 Current process flow

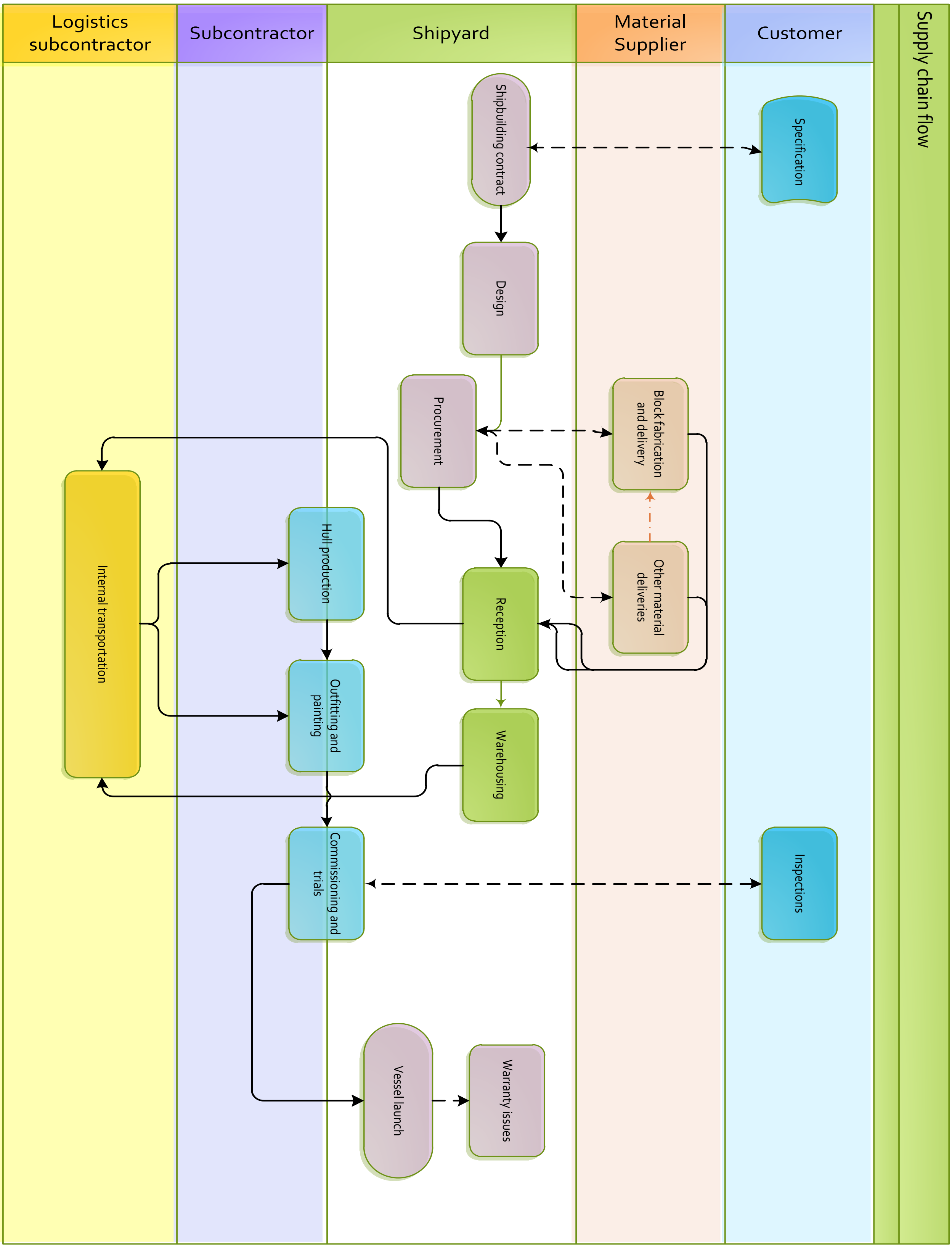
In order to be able to develop the existing process, one needs to understand its structure and position in the supply chain, as it is always linked with simultaneously or in a sequence performing activities. For this purpose, the general production process flow map has been generated with the support and knowledge of department's employees and management. For better understanding, the core activities are consolidated into groups by the actor performing the activity, which are presented on a simplified process map (Figure 3), showing the position of the company and its logistics processes in the supply chain.

The actors of the process are: the customer, from whose demand the process starts; the material supplier, which supplies blocks, component, stock and prefabrication materials to the shipyard; the shipyard itself, which performs the main vessel assembly and outfitting, as well as partial design and part of prefabrication manufacturing; work subcontractor performing installation, painting and outfitting works in joint forces with shipyard; and logistics supplier, which currently is responsible for internal transportation. The process map reflects the core activities performed by the shipyard and cooperative parties, the links and the flow direction between those.

Customer is involved to the production process mainly via inspections and modification negotiations once the specification for shipbuilding contract is compiled and approved by both sides but has a right to participate in design approval and observe production process at any stage.

In Figure 3 the logistics processes performed by the shipyard are marked green, while outsourced internal transportation services are marked yellow and moved to a separate lane for identification. As it can be seen from the process map, the company is following the lean approach in decisions concerning production allocation. Most of production activities, including production of blocks, components, stock materials and most of prefabricated material are outsourced.

Figure 3 Process map (Supply chain)



Only the small part of prefabricated materials is manufactured in shipyard's own pipe manufacturing workshop, but the volume of such items is insignificant in comparison to outsourced share. By revision of shipyard's working instructions, it became clear that the material suppliers are audited for suitability of their production methods and equipment to the manufacturing requirements set by shipyard and all second-tier suppliers are not allowed to be utilized unless approved by the shipyard.

Furthermore, the company uses services of consignment storages of such outfitting material as electrical work consumables, or small outfitting fixtures, which manage stock replenishment on their own according to demand, but the process of reception and internal transportation is the same as of goods owned by the shipyard.

Also, as seen from the figure, the welding, painting and outfitting works are performed largely by subcontracted workforce rather than by own. This is solely stipulated by the labor costs in Finland but reduces the management costs as well. Similarly, the reliability of subcontractors is audited by evaluating the compilation of the subcontractor with general working requirements of Finnish shipyards and the laws of Finland, and second-tier subcontractors are needed to be approved by the shipyard. This description reasonably summarizes the supplier management scope of the shipyard.

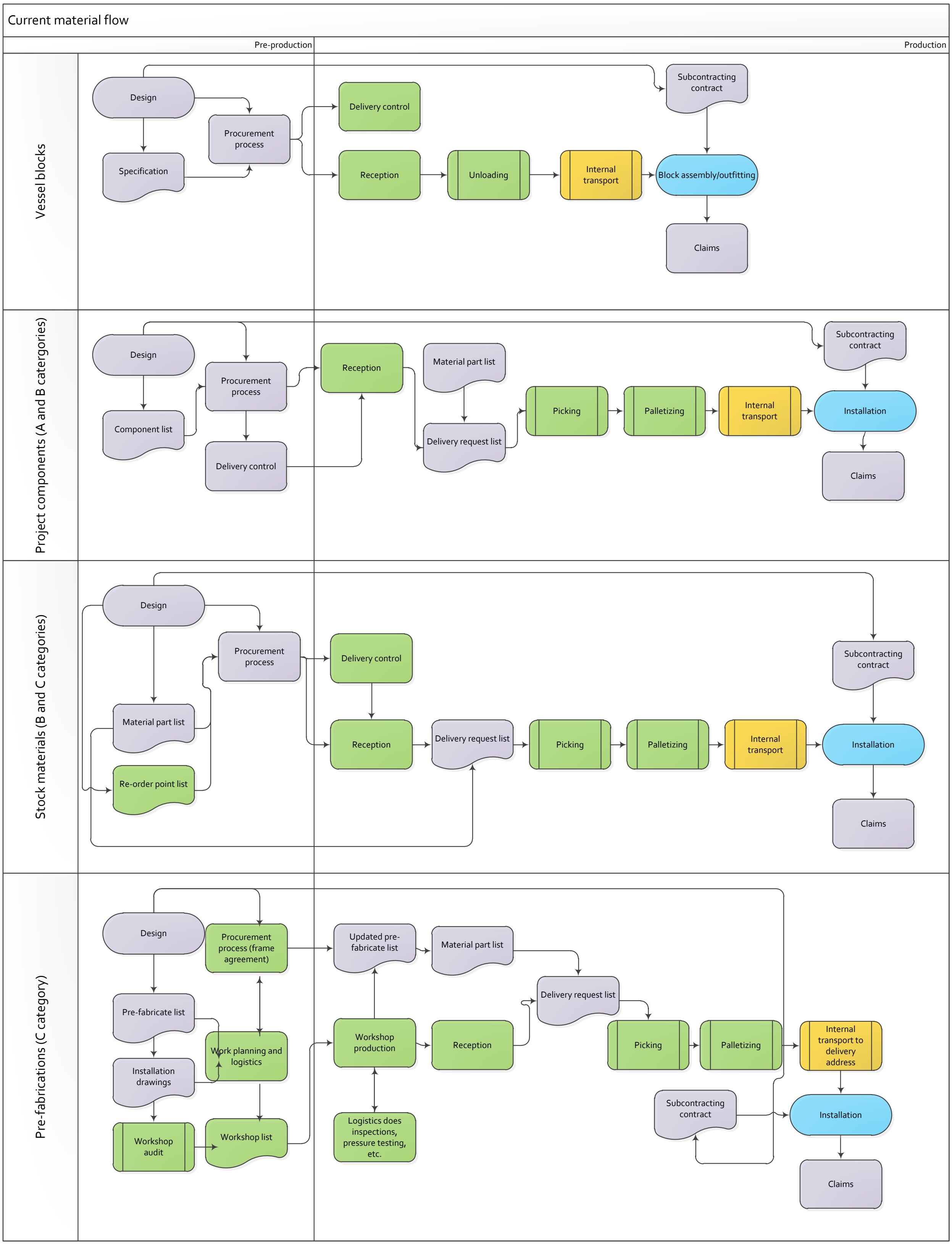
Now that the position, motion and leverage points of the shipyard within the supply chain are clear, the process shall be described separately for each of the product groups supplied by manufacturers, as the handling of these groups of products requires different arrangements, efforts and space. The process split between these groups is represented in Figure to follow. Marking of process ownership by color stays the same as in previous charts.

The categories of goods varying by handling include:

<u>Vessel blocks</u>

This group includes the vessel blocks that are normally subcontracted to an out-side manufacturing site. The steel and outfitting material needed for the blocks is provided by other supplier to the manufacturing site, but such supply is managed, paid and controlled by the shipyard. Unloading of vessel blocks requires special equipment, such as heavy-duty crane and heavy transport, spacious storage area and thorough monitoring of other material and personnel movements at the shipyard. Therefore, the supply of blocks is controlled by both hull department ensuring the quality, logistics department monitoring the sea haulage and preparing unloading facilities for its arrival. Internal transportation of blocks after arrival is carried out by hull assembly department using the heavy transport belonging to the shipyard.

Figure 4 Process map (material groups)



Project components

Component materials, otherwise indicated as A and B category items by the ABC value-based product mix analysis, are the items that represent the most value to the core activity of the company but physically represent small part of the numeric nomenclature of all materials. Specifically, in the practices of the case company, these items are represented by equipment and critical materials. Delivery of such items needs to be as compatible with JIT principle as possible, since the storage of such items is not preferable and their impact on the project schedule is tremendous. Therefore, monitoring of delivery of such materials is done by procurement department and also design department, which attends also possible test-drives of main components at suppliers' premises. and procurement department, while logistics steps in at reception phase. In case the components are delivered earlier than required, they are stored and transported internally to the related production facility by logistics subcontractor.

Stock materials

Stock materials are represented by goods of B and C categories, having small monetary value and requiring less control. Such materials include for example steel profiles, basic valves, connectors, Personal protection equipment, etc. The material ordered by logistics department on the basis of re-order point list, which indicates the minimum quantity of items available in storage, when the order of new batch of same items is needed. Logistics department then takes care of delivery control, reception, storage and palletizing before the logistics department or otherwise logistics subcontractor transports the goods to corresponding production facility according to picking requests filled by production departments.

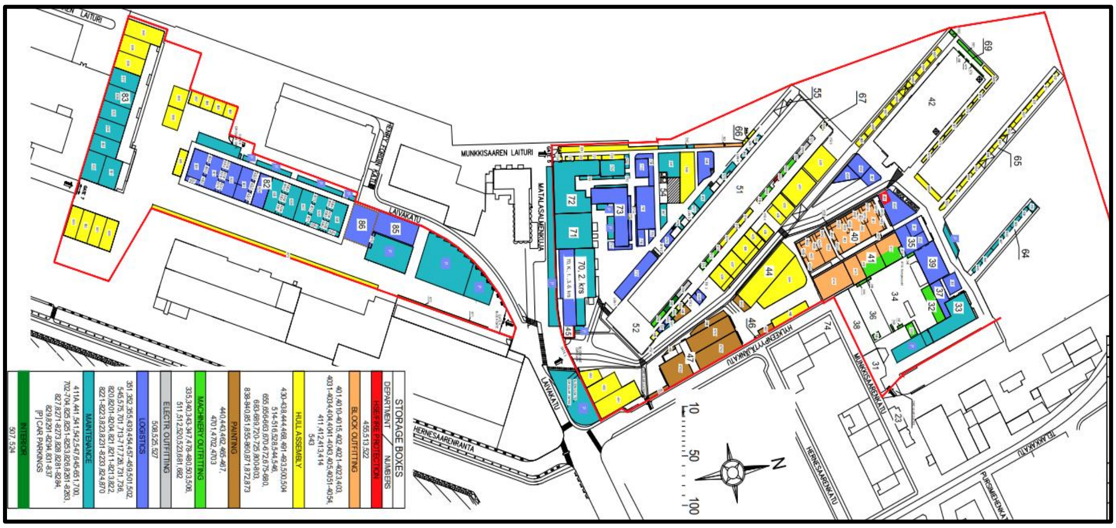
Prefabrication material

Prefabricated material is represented by pipes and hot outfitting prefabrications, such as hatches and stairs. As it can be seen from the figure, procurement of such items is also performed by logistics department in a form of frame agreement usually for a period of project production span. Batches of prefabricates are then ordered as "home calls" in accordance with the production demand. It is essential, that in this kind of arrangement, storage of goods is shifted to the supplier at maximum. In addition to that, logistics department participates in workshop audits to ensure the quality of supplier's manufacturing facilities and its compilation to material standards. Depending on the demand, the prefabricated material is supplied to either block manufacturing site or the shipyard by the supplier. Reception and inspection, followed by storage and palletizing is handled by logistics department in case the material is shipped to the shipyard. In analogy to other material groups, distribution of prefabricates to production areas is performed by logistics subcontractor. A small part of such materials, normally more complex prefabrications existing in project in small amounts, is manufactured at the shipyard's pipe manufacturing workshop using stock materials. Further handling of these items is similar to the one described.

3.2.2 Current layout and material flow

The greatest change that shipyard is currently encountering is the change in layout, more exactly the layout is becoming smaller in territorial terms. In order to understand the challenge, a visual representation of layout is presented below as Figure 5.

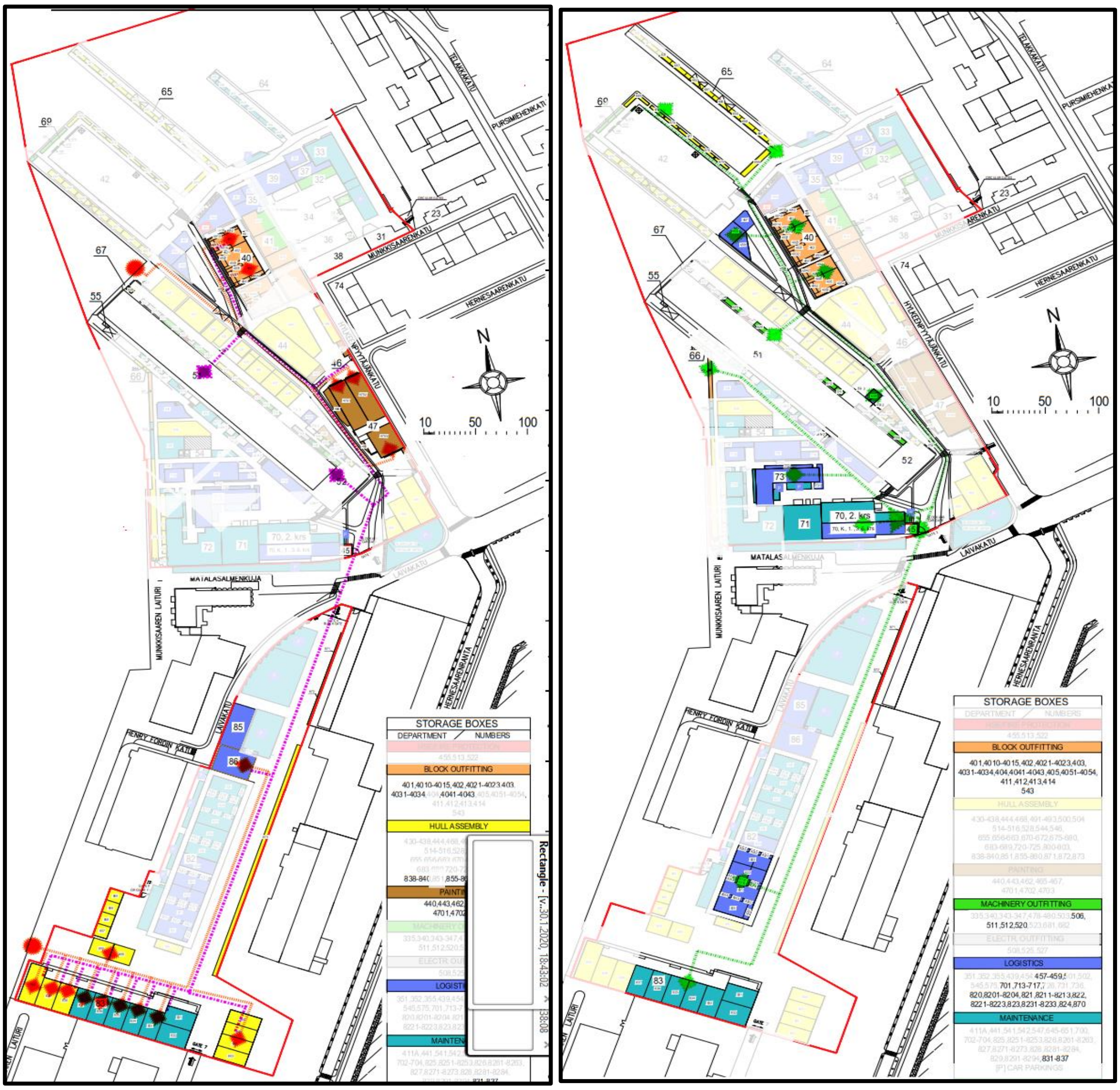
Figure 5 Current layout



Colored areas define storage areas currently being in disposal of the shipyard, including approximately 60 000 m2 of covered and cold storage space placed on the total shipyard area of approximately 170 000 m2. Different colors of those reflect the responsibility for storage areas utilization and maintenance by operational departments. Main responsible departments are block outfitting, hull assembly, logistics and maintenance departments. The full list of storage zones with indication of area purpose and the exact area sizes is provided in Appendices 1 and 2, which are not available for publishing due to confidentiality reasons.

The process of material handling after reception categorized by material groups is then put on the physical layout. Thus, the flow of vessel blocks can be seen on the left-hand side of Figure 6. The red circles indicate unloading points, where the cranes are available and from where the transportation of heavy oversize cargo is not limited. Repeating the general process diagram in Figure 4, after unloading the blocks are either transported to the dry dock for keel laying or hull assembly, in case they are outfitted and painted, or to corresponding hall for outfitting or surface treatment works, marked on layout with red rhombus.

Figure 6 Vessel blocks and components flow

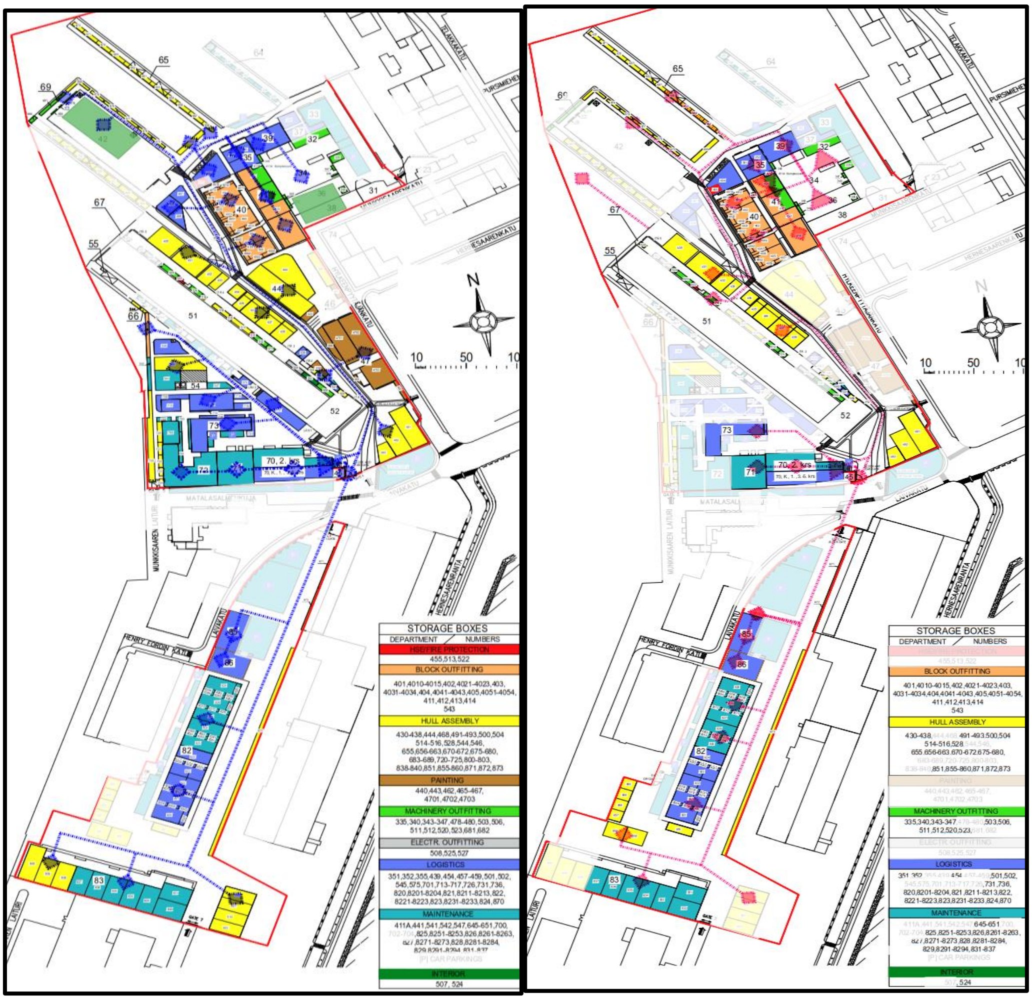


Blocks are rarely stored due to JIT delivery approach, but if such need occurs, they are stored at outside storage areas, which are under control of either block outfitting, hull assembly or in some cases maintenance departments. Regardless of the sequence and number of handling steps at the shipyard, the final point of block material flow is hull assembly in dry dock, marked with pink rhombus. One of the two entrances to the dry dock are chosen in accordance with block assembly number, either to bow or stern part of the ship.

Internal transportation routes for component group of material is shown on the right-hand side of Figure 6. Green circle indicates the entrance of goods to the shipyard. The cargo is then unloaded and inspected at the warehouse entrance floor marked with the second in the flow green rhombus. Next, the equipment is either stored at one of warehouse areas marked with green rhombus, then palletized and transported to the corresponding installation point, or directed straight to corresponding installation point. As also seen from process map on Figure 4, the installation point can be specified as either outfitting hall, dry dock or outfitting quay lifting area, where the ship is transported after hull assembly, preliminary outfitting and painting. Usually at that point the dry dock accommodates hull erection activity of the next vessel. The figures are also available in Appendices 3 and 4.

The left-hand side of Figure 7 illustrates the flow of stock material, which is arriving to the same entrance point as component materials. Then it is transferred to the warehouse for unloading and inspection, after which it is transferred to either the corresponding installation area in case the installation is in nearest 3 days, which include outfitting hall, dry dock and lifting area of outfitting quay, or to the storage place of goods of the same type, either to main warehouse, storage places of dry dock and nearby outfitting quay. Material required by painting department registers as stock material and is transferred to the chemical storehouse or to the painting facility directly. PPE and tools are also considered as stock material and are transported to the corresponding material storage for further use. As mentioned in the previous chapter, consignment storage material replenishment is carried out by the service provider, the reception and transportation flow of such, however is the same as described above. Part of stock materials is directed to pipe manufacturing workshop, where it is used for pipe prefabrication described in the previous chapter.

Figure 7 Stock and prefabrications material flow



The right-hand side of Figure 7 depicts the flow of prefabrication items. As all goods arriving by road transport, prefabricates are received at the main gate of the shipyard, then transported to the warehouse area for unloading and inspection, stored if needed in the corresponding storage area and then transported to the needing installation area. The target storage period of stock and prefabricated items is maximum 3 days due to aim at JIT approach, but due to delays of production stages it is not always possible. In this cases prefabricated items are stored at inside or outside storage areas, depending on available storage space. The figures are also available in Appendices 4 and 5.

Installation of prefabricated items happens at block outfitting stage, preliminary outfitting of assembled blocks and final outfitting at the outfitting quay. Prefabricated materials manufactured by shipyard's own pipe workshop, marked on the figure as pink triangles, undergoes the same procedure of inspection at manufacturing site, storage and internal transport.

3.3 Interview and observation results

The management of procurement and logistics department, as well as the CEO of the company have been interviewed on the subject of effectiveness of current logistics processes and their impact on the core activity of the company - production. The purpose of interviews was to gain the understanding of the management's perception of the efficiency of the current process. The results of interviews are recorded in a form of questionnaire, which consolidate the discussion of operating issues of logistics department and the company overall, to which logistics processes efficiency might have a significant impact. Questionnaire for CEO of the company has different set of issues and in addition to some of the questions asked from management, there are some that address the overall operation. The questions asked and answers to them from each of the managers are presented in the table below.

Table 2 Interview results (Managers)

	Question	**Totally agree**	**Slightly agree**	**Not sure**	**Slightly disagree**	**Completely disagree**
1	HS is in good and tight collaboration with its customers	X, X	X			
			X			
2	HS is in good and tight collaboration with its suppliers	X, X		X		
				X		
3	HS activities are transparent inside the company		X		X, X	
			X			
4	HS activities are transparent to suppliers and customers		X, X	X		
					X	
5	The quality of logistics activities is good	X	X	X		
			X			
6	Claims handing works well		X, X		X	
7	Order-delivery rhythm for internal deliveries is optimal		X	X	X	
8	Internal information flow is effective		X, X		X	
9	Information flow from and to suppliers is effective		X, X		X	
10	Current warehouse spaces are sufficient		X		X, X	

11	Usage of current warehouse spaces is optimized sufficiently enough		X		X, X
12	The equipment and machinery of the warehouse are reliable				X, X, X
13	HS incorporates well the newest technologies		X, X X		
14	The logistics workforce is trained sufficiently enough		X, X, X	X	
15	The logistics workforce is sufficiently productive	X	X, X	X	
16	Forecasting for changes in production volumes is on a good basis		X		X, X X
17	Performance measurements are sufficient and being used			X	X, X
18	HS reacts quickly to problems and solves them		X, X	X X	
19	Working instructions are correct and being followed	X	X		X
	Specific areas for logistics improvement	- information flow from design planning and work planning through production to logistics - Performed purchases and deliveries to the shipyard in accordance with production schedule (JIT) - Performed deliveries to the production - storage at supplier's and "home called" orders - keeping the motivation of personnel - improved storage facilities			

Surprisingly so, the interview results showed that none of the issues discussed are in exceptionally critical condition. More so, neither of the issue rating were unanimously agreed by all informants. Even though the issue regarding information flow inside the company was on average ranked as rather sufficient, as seen from Table 2, row 8, but lacking some enhancement, the fact that answers differ so much proves that the awareness of the process in detail, its inefficiencies and advantage is varying. Therefore, the information transparency, distribution of targeting information and actual process operating efficiency is lacking in this case, and that was indeed reported by some of the managers. It seems that the outer information flow, between the shipyard and its customers and suppliers, is sufficient enough, but the main bottleneck is in internal operational information sharing.

However, the positive aspects revealed during interviews is that the whole management team related to logistics, as well as logistics employees as noticed by observation, are aware of the JIT approach for material deliveries. Also, there is clearly an understanding of the needed measures for maximizing application of the given approach in practice and limitations for it, as mentioned in the questionnaire field for specific logistics improvement needs. In general, consolidated results of specific improvement areas suggestions show the need of material flow and information sharing to be facilitating the JIT approach, including maximum lengthy storage of material deliveries at supplier's premises, tight synchronization of deliveries to scheduled production demand, usage of "home call" orders inside the frame agreement, etc.

The application of JIT approach is in turn suffering from unreliable distribution of production scheduling information to the supporting functions, and poor quality of forecasting and planning as a result. This once again proves the poor traceability of core activity scheduling and corresponding operating efficiency information throughout the company. Another issue, adding to this weakness is almost complete inexistence of key performance indicators (KPI's) for each of the departments' operations. In this way, the operating efficiency is interpreted by observation differently and in verbal transfer of information might be naturally deformed.

For the analysis in terms of material flow and layout planning the issues described above mean that the material flow shall be put on the layout in such a way that it would minimize the impact of delays in information flow and feed the production stages in JIT manner. In order to implement JIT model into material flow, the lacking KPI's need to be set and followed. However, due to the fact that KPI setting and integration is a time and effort consuming process, this development project is left out of the frame of this thesis and KPI inputs for material flow planning are assumptions made on the base of available information of the future production volume planning and tracking of operation flow from previous projects. This information will be discussed in one of the following chapters.

Another issue revealed to be problematic is the usage of current warehousing facilities. It turns out, that for some of the warehouse spaces the needs exceed the warehousing capacity of the area, and some areas, on the contrary, are not utilized up to their capacity.

This is the matter of uneven workload due to delays in previous projects. The vessels had to be placed on vacant berthing places and the outfitting material had to be placed waiting nearby. In addition to that, as the production was delayed, the amount of stand-by material for installation exceeded the estimated amount, and the nearby storage spaces were overcharged with cargo. The temporary layout planning was adjusted accordingly and currently needs thorough planning including risky overcapacity cases on the updated layout. In addition to that, according to observations during problematic situations of previous project, the centermost intermediate storage area marked purple on the layout (no. 457-459) turned out to be the most heavily used and the most overcharged, causing troubles with assigning the stored goods to the correct installation team, losses and misplacement. This, however, reveals another positive aspect concluded from the interview results, such as fast reaction of company's management to problematic situation and ability to temporarily overrule the challenge in surprisingly short period of time. This reflects high rate of collaboration and reactive measures application for the project.

Purely positive findings include that on average the productivity and competence of the logistics workforce was ranked as sufficient. However, it is noticed that the personnel are lacking motivation for improvement, which is a subject outside the framework of this thesis. Surprisingly so, the quality and usage of working instructions was rated well, only the logistics manager saw that there was a need to revise the instructions. In reality observations confirmed that the instructions for each process exist and are fit, but are not necessarily followed. Coming back to the question of effectiveness of such instructions, it is only possible to know when the instructions are being followed, if the performance is measurable and there are set values to be monitored.

The results of the CEO interview are presented in a table below and represent the overall image of the company's operations productivity. The most positive issue revealed is compliance of current operations with the current company's strategy. As obnoxious as it may sound, acknowledgement of this fact increases the probability of project successfulness, if the operations and material flow are improved in the frame of current strategy.

Table 3. Interview results (CEO)

	Question	Totally agree	Slightly agree	Not sure	Slightly disagree	Completely disagree
1	HS is in good and tight collaboration with its customers		x			
2	HS is in good and tight collaboration with its suppliers			x		
3	HS activities are transparent inside the company		x			
4	HS activities are transparent to suppliers and customers				x	
5	The quality of logistics activities is good		x			
6	Information flow from and to suppliers is effective			x		
7	HS incorporates well the newest technologies		x			
8	The logistics workforce is trained sufficiently enough			x		
9	The logistics workforce is sufficiently productive			x		
10	Forecasting for changes in production volumes is on a good basis				x	
11	Performance measurements are sufficient and being used			x		
12	HS reacts quickly to problems and solves them			x		
13	The operations are currently profitable		x			
14	Material expenses are below the budgeted expenses		x			
15	Staff expenses are below the budgeted expenses		x			
16	Operations are in line with current strategy, mission and vision	x				

The CEO interview has revealed the same problematic issues as pointed out by managers. Otherwise, in general, the productivity of company is quite satisfactory and does not need separate investigation at this stage.

3.4 Summary of project limitations and requirements

3.4.1 Layout changes

In terms of layout and material flow planning the project is limited by the territory reduction plan submitted by the city of Helsinki. The core operating facilities stay in possession of the shipyard, such as dry dock, outfitting hall, painting hall, pipe workshop, gas storage, main warehouse and office building. Together with the territory the shipyard is losing such facilities as grand block, multi-purpose and painting halls. Grand block hall is normally used for manufacturing and outfitting of vessels grand blocks and is featured by large size and equipment for handling heavy cargo. Multipurpose hall has been used for accommodation of various large-scale operations, and the painting hall was used for painting of grand blocks in direct proximity of their manufacturing site. Part of these facilities, that are being released by the shipyard, make approximately 17 000 m2, leaving approximately 41 000 m2 of total storage space in possession of the shipyard.

While the territory reduction seems to be rather light 30%, the remaining storage space makes only 3% of total remaining area, which is rather low considering the scale of material volumes. Moreover, it cannot be left out of consideration that some of the storage area is used for storage of shipyard’s equipment, maintenance items, consumables and tools, while the area used for actual project material storage is assumed to be 80% of the available area, resulting in approximately 35 000 m2 available for the project, including intermediate storage and specific production need storage areas. This fact puts extra pressure on planning the remaining area utilization planning and thorough application of JIT principle in material deliveries.

In production downtimes, the facilities dedicated for grand block manufacturing and treatment were utilized for storage of especially large and heavy project components, such as main engines, propulsion systems, etc., that have normally arrived long before the installation point due to delays in production schedules. Storage of such equipment often requires electric heating. In other times, when building cruise vessels of ice class, the facilities accommodated cabin modules, which take up significant storage volume.

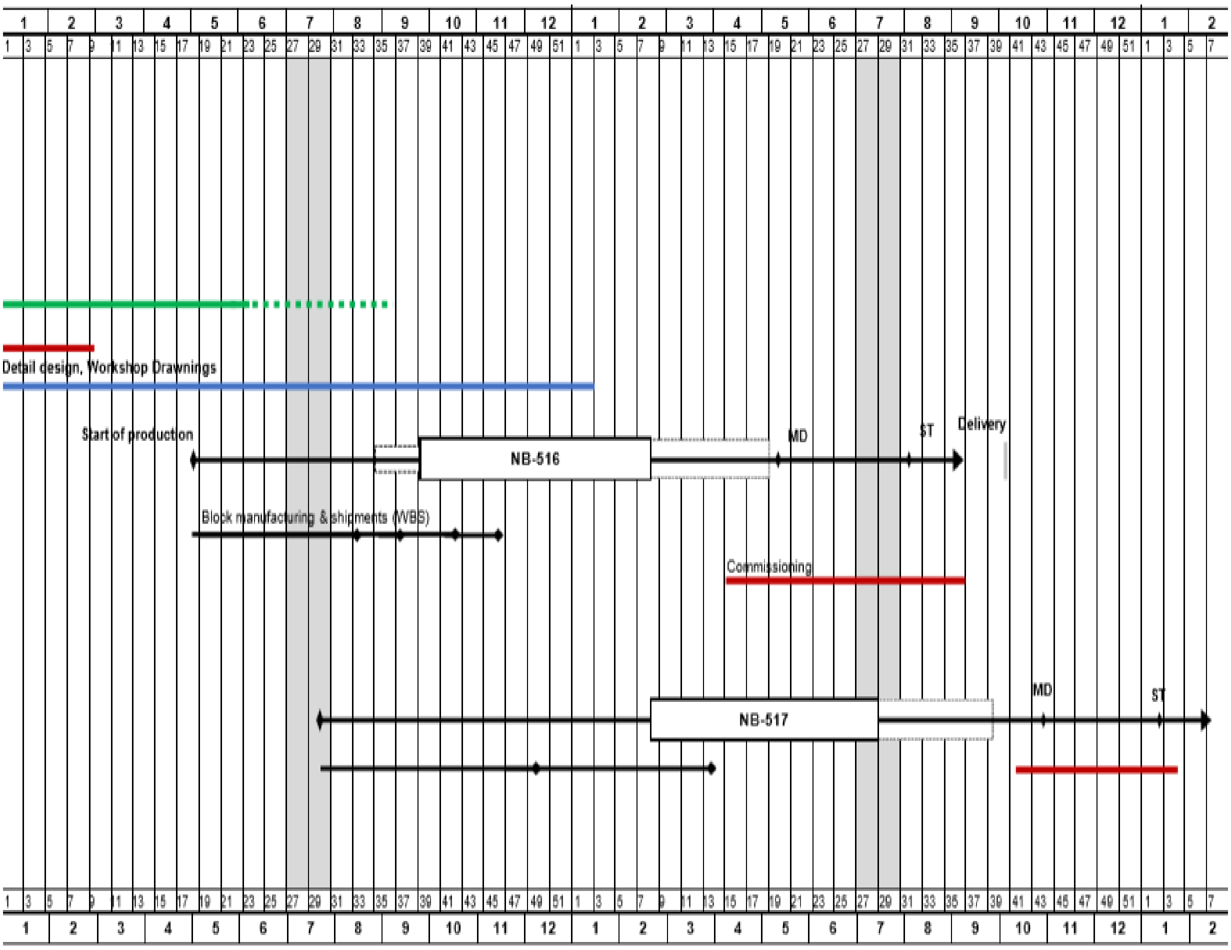
To conclude, the layout part to be lost by the case company does not complicate the operation flow in case the block manufacturing is outsourced, as has been done in latest projects, but challenges the shipyard in terms of lack of storage areas.

3.4.2 Production volumes

Since the company does not use unified KPI’s at the moment, in order to estimate whether the shipyard is able to operate with reduced premises for upcoming projects confirmed to the orderbook, the future project volume and material flow matters are taken into account.

The two identical upcoming projects are planned to be built practically simultaneously with a difference of 12 weeks, as can be seen from the schedule graph below.

Figure 8 Vessel production schedule



The schedule presented is delay-free plan for production of the vessels. As can be seen from the graph, the extended rectangle with the number of the vessel indicated overall production time. Everything marked before this period includes contracting, design and procurement stages, which at the moment are not included into this study. The black lane under it indicates production time of the vessel blocks, which for these projects, as for many other, is subcontracted to supplier in another country. The red lane under the end of production lane indicate commissioning and inspection period, which is naturally shorter for the second vessel of the same construction. The production of prototype vessel project normally takes longer time than indicated by planning calculation due to unexpected failures and corresponding delays. In order to prepare the plan able to facilitate the company in any production situation, the worst-case scenarios must be taken into consideration. Therefore, the actual production time at the shipyard's site per one project is estimated to be 34 weeks, extended by 15 weeks of simultaneous production of both vessel project. After this point the first vessel will undergo sea trials and commissioning period, which does not require consistent material supply and storage of material. Construction of the rollover hull, which is a replica of the previously built vessel, normally results in shorter lead times and smoother operation, therefore the production time for rollover hull is considered to be 45 weeks in total, including the delay buffer. The reason behind it is that shipyards in coordination with their customers usually tend to use the same designs and supplier sets for the rollover hulls, as for the prototype vessel. The assumptions made at this stage of current state analysis are further supported by the data gathered for calculation of storage need.

The block delivery grouping and schedule is available in the project plan. The blocks are planned to be delivered in 4 groups of 5-7 block per barge delivery. The unloading happens at the berth and two of the first blocks will be transported directly to the dry dock for keel laying. Another specific operation problem is that in case one of the blocks will be delivered unpainted, or the paint will be damaged during outfitting and transportation, the block would need to be disassembled and painted once again. The footprint proportion presented below in Table 4 for understanding of the scale of transportation and storage needs, are presented in a table below. The calculation is made based on weight and dimension information, but are presented in percentage format due to confidentiality agreement restrictions, as well as the actual block numbering.

Table 4 Block footprint proportion

	Block number	Footprint, %
Batch 1 (34%)	1	9,0
	2	5,6
	3	3,4
	4	5,4
	5	5,1
	6	5,1
Batch 2 (22%)	7	5,4
	8	3,1
	9	3,1
	10	5,4
	11	5,4
Batch 3 (23%)	12	2,3
	13	3,9
	14	4,2
	15	5,1
	16	5,6
	17	2,1

Batch 4 (17%)	18	4,5
	19	5,1
	20	1,3
	21	2,2
	22	2,3
	23	2,2
Separately straight to drydock (3%)	24	3,5
		100

In order to be able to analyze the volume and scale of material, the weight calculation of the vessel systems and in some cases specifically vessel areas have been used. The physical dimensions of all the materials are only available at detailed design phase and at current stage are missing. However, the footprint dimensions of A-category equipment are available, allowing for more exact planning of the storage and transportation needs.

Since the weight calculation is conducted several times during the project, the initial data available for the future project is an estimation, which might significantly differ from the realized values, which are consolidated in post-production weight calculation. In order to minimize the error and receive a more realistic material flow information, the weight, realized material receival and installation timing of the system materials is compared to the ones of a similar vessel project completed by the shipyard in the past. The footprint of the material required for the production at shipyard's site is calculated based on the above-mentioned weight and proportional relation calculations. The weight calculation is strictly confidential and therefore it is provided in the form of coefficients in this thesis, including all calculations and assumptions made based on this information.

Specific schedule of works at the shipyard and associated material supply demand can be retrieved from the schedule of production demands for the procurement department. The mentioned schedule is available in Appendix 6, but for confidentiality reasons it is not available for publishing. The main points of this schedule and the associated storage need per material group are consolidated in a table below, based on weight calculation and comparison of scale and receival and installation scheduling to the previous project.

The two projects are compared in order to detect the missing information in weight/volume of batched of received material and to estimate the approximate delays in the production/approximate storage time of each system. In any case this estimation is only an assumption of possible difficulties and is used only to forecast the possibility of such for the whole project scope, as the probability of delays happening for material delivery or installation of particular system cannot be exactly projected by application on any algorithm. The storage time estimation is also proportional to the component category scale. For example, the scale of interior group of materials of the planned future vessel project is three times bigger than the one considered as the base for comparison. Concurrently, the scales of machinery and hull material groups are significantly greater for the past project than for the planned one. The storage time estimation is therefore adjusted accordingly. In addition, the difference in area accessibility of the two compared projects is analyzed by means of general block and area arrangement drawings and manhours calculation comparison and reflected in corresponding coefficient in adjustments of the project timeline and therefore storage times. The reason for consideration of such factor is behind the loading and installation difficulty grade, as the areas with lower accessibility require manual material loading and longer production times due to lower number of workers accessing the installation point.

The volume of each material batch to be stored is estimated for each system based on the weight information, specification of main components and calculation of average volume of bulk material and consumables in proportion to main component volume and required fittings, as the installation efforts, and therefore time and supportive material amount is normally proportional to the size of the component.

The weight factor (importance, storage space and control requirements) have to be considered in estimation. E.g. the storage of fittings requires less space, less monitoring and is less financially and operatively harmful in case of prolongation of storage period. Also, replacement time is normally shorter, as supportive bulk material is usually standard and is available from vendor’s stock at a short notice, therefore the impact on project production delay is significantly lower than of the main components.

The start of production at shipyard’s site is taken as a starting point of operations, which is three weeks before keel laying. The procurement period is not taken into consideration. Such buffer is used on order to anticipate the possible delays caused by block production or delivery difficulties. The items not included into the table below are required for block production and outfitting at subcontractors’ premises, therefore these items will not be stored and transported at the shipyard.

The Table 5 represents the storage need reflected in percentage of the total footprint of material storage need of the two vessel projects, considering the period when the both projects require storage and internal distribution of the material arriving from the suppliers. The scheduling of material need is based on the production need scheduling available for the upcoming projects and is adjusted and extended based on weighted average storage time for each material system group of the previous similar project. The timing data of the previous project is available via the case company's ERM system, therefore represents the expected delays of the worst-case scenario. The data is scaled to fit the upcoming project volume on the base of proportions of main component quantities and scale.

Table 5. Planned material flow intensity

	Vessel 1						Vessel 2						
Material group/Week	**Interior**	**HVAC**	**Machinery**	**Tech. Air, Oil, Gas and Lifting**	**Deck equipment**	**El. outfitting and mach. control**	**Interior**	**HVAC**	**Machinery**	**Tech. Air, Oil, Gas and Lifting**	**Deck equipment**	**El. outfitting and mach. control**	**% of the total volume of one shipset**
-3	7,11%	4,31%	0,91%	2,51%	2,46%		0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	18%
-2	7,11%	6,03%	0,91%	2,51%	2,46%	0,90%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	20%
-1	7,11%	4,31%	1,91%	3,62%	3,03%	4,26%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	25%
0	7,80%	6,03%	2,16%	3,78%	3,03%	7,61%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	31%
1	15,57%	6,78%	3,74%	4,28%	3,26%	4,53%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	38%
2	15,15%	6,80%	3,81%	3,34%	3,32%	5,00%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	38%
3	15,15%	6,79%	3,68%	3,34%	3,30%	4,23%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	37%
4	14,44%	6,94%	3,68%	1,27%	3,28%	4,37%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	34%
5	14,44%	7,01%	2,28%	2,90%	3,26%	4,42%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	35%
6	13,73%	8,18%	1,50%	1,78%	3,26%	4,23%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	33%
7	5,24%	8,10%	1,84%	1,30%	3,38%	4,51%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	25%
8	4,53%	7,46%	1,28%	1,30%	3,76%	4,49%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	23%
9	3,82%	8,75%	1,12%	0,84%	3,95%	4,21%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	23%
10	8,09%	8,63%	0,36%	0,84%	4,78%	6,30%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	29%
11	3,48%	8,02%	0,31%	0,51%	4,78%	6,39%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	24%
12	0,41%	8,01%	0,00%	0,19%	5,39%	6,39%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	21%
13	2,71%	7,31%	0,12%	0,02%	6,37%	6,03%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	23%
14	33,89%	6,70%	0,12%	0,34%	4,50%	7,15%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	53%
15	33,43%	6,58%	0,12%	0,31%	4,93%	8,54%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	54%
16	27,18%	2,99%	0,12%	0,22%	2,02%	8,45%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	41%
17	26,72%	1,37%	0,09%	0,22%	2,49%	8,10%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	39%
18	19,91%	1,36%	0,09%	0,12%	2,47%	7,79%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	32%
19	19,45%	1,18%	0,09%	0,12%	5,54%	8,13%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	35%
20	12,73%	1,01%	0,05%		4,39%	7,39%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	26%
21	12,69%	1,00%	0,05%		4,18%	7,39%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	26%
22	6,39%	0,76%	0,02%		3,65%	7,00%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	18%
23	6,35%	0,69%			2,40%	3,40%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	13%
24	0,06%	0,46%			1,15%	3,06%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	5%
25	0,04%	0,46%			1,00%	2,71%	0,05%	0,05%	0,05%	0,05%	0,05%	0,05%	5%
26		0,39%			0,55%	3,49%	0,04%	0,04%	0,04%	0,04%	0,04%	0,04%	5%

27		0,39%			0,62%	1,95%	0,04%	0,04%	0,04%	0,04%	0,04%	0,04%	3%
28		0,39%			0,39%	1,95%	0,04%	0,04%	0,04%	0,04%	0,04%	0,04%	3%
29		0,35%			0,46%	1,42%		6,03%	0,91%	2,51%	2,46%		14%
30		0,35%			0,34%	2,44%		4,31%	0,87%	5,12%	2,46%	0,90%	17%
31		0,38%		0,12%	0,34%	1,03%	7,80%	4,31%	1,68%	2,41%	2,46%	3,99%	25%
32		0,31%		0,07%	0,24%	0,96%	7,73%	5,84%	3,14%	1,51%	3,03%	3,67%	27%
33		0,31%		0,04%	0,20%	0,57%	12,32%	6,41%	2,79%	1,12%	3,20%	3,63%	31%
34	0,01%	0,30%			0,19%	0,54%	8,72%	5,72%	3,16%	0,53%	2,22%	4,18%	26%
35		0,24%			0,06%	0,46%	4,12%	4,55%	2,94%	0,10%	1,95%	4,31%	19%
36		0,24%			0,05%	0,41%	2,60%	3,72%	1,07%	0,08%	1,59%	3,62%	13%
37		0,23%			2,43%	0,37%	3,79%	3,76%		1,67%	1,02%	3,04%	16%
38		0,17%			1,10%	0,29%	2,31%	3,15%	0,56%	1,14%	0,42%	2,73%	12%
39		0,16%			1,08%	0,26%	0,09%	1,08%		0,81%	0,50%	2,65%	7%
40		0,16%			1,27%	0,22%		3,49%		0,49%	0,77%	2,15%	9%
41		0,03%			2,14%	0,21%		2,83%	0,19%	0,02%	0,90%	1,77%	8%
42		0,02%			2,11%	0,13%	0,37%	2,34%	0,12%	0,02%	1,63%	3,90%	11%
43		0,02%			2,01%	0,65%		1,72%	0,00%	0,01%	2,01%	3,23%	10%
44		0,02%			1,79%	0,65%	0,12%	0,74%			2,89%	2,48%	9%
45		0,02%			1,55%	0,65%	33,88%	1,25%	0,12%	0,31%	1,03%	2,43%	41%
46		0,02%			1,35%	0,60%	29,82%	1,12%	0,10%	0,22%	0,74%	3,45%	37%
47		0,02%			1,07%	0,43%	26,00%	1,00%	0,07%	0,11%	0,84%	4,47%	34%
48		0,02%			0,48%	0,43%	19,00%	0,85%	0,05%	0,22%	0,62%	3,99%	26%
49		0,02%			0,48%	0,43%	12,66%	0,62%	0,02%		1,03%	3,47%	19%
50		0,01%				0,26%	6,34%	0,58%			0,78%	3,08%	11%
51		0,01%				0,26%	0,05%	0,58%			3,92%	2,38%	7%
52		0,01%				0,09%	0,04%	0,52%			3,10%	1,64%	5%
53		0,01%					0,04%	0,45%			1,64%	0,73%	3%
54							0,02%	0,39%			0,04%	0,42%	1%
55							0,02%	0,32%			0,04%	0,39%	1%
56								0,26%		0,12%	0,04%	0,39%	1%
57								0,19%		0,06%	0,04%	0,13%	0%
58								0,13%			0,04%	0,13%	0%
59								0,02%			0,04%	0,11%	0%
60							0,01%	0,02%			0,15%	0,11%	0%
61								0,05%			0,15%	0,22%	0%
62								0,04%			0,15%	0,34%	1%
63								0,04%			0,10%	0,28%	0%
64								0,04%			0,09%	0,28%	0%
65								0,04%			0,07%	0,19%	0%
66								0,03%			0,06%	0,10%	0%
67								0,03%			0,05%	0,03%	0%
68								0,15%			1,24%		1%
69								0,14%			0,74%		1%
70								0,12%			1,03%		1%
71								0,10%			1,87%		2%
72								0,08%			1,51%		2%
73								0,05%			1,13%		1%
74								0,00%			0,54%		1%
Max capacity needed	**34%**	**9%**	**4%**	**4%**	**6%**	**9%**	**34%**	**6%**	**3%**	**5%**	**4%**	**4%**	**54%**

Since some of the procurement contracts and therefore deliveries are made for both projects, the buffer of 0,05% of the total shipset storage volume is added for each of the material system groups.

As can be seen in Table 5, the most congestive weeks are 1-6 and 13-16, as well as partially 30-33 and 45-49, the maximum being on week 15 (54%). The risk of overloading some of the storage areas of warehouses falls on the first pick point, in the middle and in the end of the project due to the fact that the delays in production require the equipment and material that has been planned to be installed is placed into storage.

The vessel characteristics are provided on a figure below. As it can be seen from the figure, the dry dock is able to accommodate both of the vessels at the same time. The overall gross tonnage of the two vessels is approximately 21 400 t, which includes steel material, blocks, equipment, outfitting material and other.

The specifics of the vessel type imply a large number of cabin modules, in total 302 pcs for the two vessels. Significant decision in this case is the place of final assembly of cabin modules, either at supplier's and this option requires complex transportation procedure, or at shipyard's workshop area, which is logistically more efficient, but in this case occupies the space for possible storage.

Figure 9 Vessel basic parameters

LENGTH	OVERALL	abt.	113.2	m
LENGTH	PP	abt.	111.7	m
BREADTH	MLD		20.2	m
DRAUGHT	SCANTLING		5.7	m
DRAUGHT	DESIGN		5.45	m
SPEED	TRIAL		14	kn
SPEED	DESIGN		12	kn
LSA			280	pers
PAX CABINS			75	pcs
CREW CABINS			76	pcs
DEADWEIGHT			1,200	t
GROSS TONNAGE		abt.	10,700	

Another aspect is the number of cabins and the period of their storage at shipyard's premises in both options, as cabin storage demands large space parameters. In accordance with a previously made assumption, this thesis will concentrate on the worst-case scenario, according to which, the storage space need for cabin assemblies is on the highest anticipated level. A distinct specific feature of the vessel is that it has more electrical equipment compared with vessels built earlier, and the supply and assembly of which shall be planned and batched as well managed in a warm warehouse. This feature is taken into account in the calculation of the storage space need as an increased coefficient.

3.5 Key Findings

The investigation of current process flow has shown that the logistics process is very dependent on the production scheduling, forecasting and information sharing between production, design, procurement and logistics departments. Process mapping has not revealed any significant negative aspects but has on the other hand shown the missing process steps, such as delivery control and incoming inspection procedure. Even though these activities are actually performed as necessary ones for completion of the vessel projects, but they are not clearly assigned nor instructed. Otherwise the process is clearly structured, the maximum outsourcing approach can be seen from the map. The company also employs clear categorization of material handling and transportation.

The main positive results concluded from interview results include tight cooperation with the customer and suppliers, awareness and understanding of application of JIT approach, efficiency of logistics workforce and operational focus being in line with the strategy of the company. However, the results of the analysis of the interviews indicate that there is a problem related to sharing of internal scheduling and production planning information and how changes in scheduling are communicated to other functions such as procurement or production sub-divisions, which are forced to redo their work or experience stand-by periods in dependence with production schedule and specification changes. Another logistics-related problem is the usage of warehousing facilities, resulting in over- and under capacity of separately viewed storages. Adding to the mentioned challenges, non-existence and non-usage of unified KPI’s complicate the assessment of operation profitability and responsiveness of the process to the deviations from the planned production schedule throughout the operation and supply chain flow. Logistics operating KPI’s for this project are therefore assumed based on the general observation and company’s goals.

The layout change stipulated by forces outside the management area of the shipyard entail such challenges as inefficient usage of the remaining storage and production facilities and inefficiently planned flow of various material groups. Due to loss of large amount of material storage and handling areas, there is a possibility of storage overload and threat to the timely project completion within the updated layout, as well as large material losses and mishandling.

The overall analysis of current logistics processes, which are also summarized in Table 6, revealed the challenge of application of JIT approach to the logistics processes within the frame of existing scheduling, facility usage and material flow plan, regardless of the awareness of such target. The results of process analysis are also supported by the quantitative data of the future production volume and schedule gathered and analyzed.

Table 6. Consolidated results CSA

Strengths	Weaknesses
Awareness of the JIT goal approach	Sharing and communicating scheduling and production planning information
Efficiency of logistics functions	Adaptation of storage capacity to needs (process flexibility)
Aligning of floor level activities with corporate strategy	Lack of real-time monitoring of supply chain
Core facilities are able to accommodate the projects	Current layout based on significantly larger area
Planned production volume for two consecutive projects	

The focus of this study is therefore planning the updated layout, more specifically focusing on storage areas allocation, and material flow, that are able to accommodate the production volume of two simultaneously built vessel project targeting at reaching the efficiency of JIT approach.

In order to employ best existing practices for improvement of logistic processes on the shipyard in the given conditions, the literature review shall include practices in planning of shipyard layout, material flow and facility usage optimization with direction of JIT approach application. The existing knowledge on these topics is reviewed and discussed in the following section.

4 Existing Knowledge on layout planning at shipyards

This section reviews existing knowledge on the shipyard layout planning, more specifically optimized facility usage and material flow planning. The literature review is narrowed down to particular fields and approaches based on the type and amount of information made available for the purposes of this thesis.

First of all, the overall layout planning for shipyards is taken into consideration, as shipbuilding processes and particularly shipbuilding layout is differing from the ones of other industrial sectors. The difference is expressed in terms of natural resources, such as berth, accessibility and remoteness of the area from habitation areas, and the scale of operations, products and materials, but otherwise follows the heavy industry layout planning techniques. Secondly, intersecting with the main topic, the available information on heavy industry facility usage optimization is reviewed in order to determine the best suitable practices for application to the given problem. And last, but not least, the heavy industry material flow optimization practices are revised for finding the best possible combination of material handling points and movements. The undertone goal in all of these sections is JIT approach and best possible suitability of practices to it.

4.1 Shipyard layout planning

The coverage of best practices particularly on shipyard layout planning is rather limited. One of the founding works on shipyard layout optimization was presented by Y. Song (2009), who presented a simulation-based layout design framework specifically for shipyards. Song points out that the shipyard layout and its constraints are not similar to any factory layout. One of the major differences besides the scale of product and associated materials and facilities is engineer-to-order type of production, which stipulates the impossibility to produce exact prototype models for long-term layouts, and even on the project-based timeline. Considering these specifics, the shipyard layout design framework takes into account main and sub-operational processes based on the system engineering approach (Song, 2009, 206). The systems engineering approach is focused on design, management, optimization and integration of complex systems of work processes throughout their life cycles (Blanchard, 2004, 46).

According to Song (2009), the shipyard layout planning must begin with analysis of the core processes, starting from berth and loading procedures to more detailed processing workshops, such as machinery outfitting or painting. In this approach the core scheduling point is at grand block assembly, on which the rest of the process is scheduled. The scaling also takes its beginning from block sizes. In such a way, the critical process steps and material dimensions are defined. This step is followed by the identification of the activity flow, or otherwise understood as production sequence and associated material flow. The lifecycle data is considered at the stage of optimizing the workshop layout, which is left out of the scope of this thesis due to constraints on layout changes allowed. The rest of the framework is focusing on detailed indoor shipyard production layout planning, practically following general systematic layout planning practice.

A number of academic works have been conducted as additional featuring of basic layout design practices. The objectives or type of research projects might include layout planning of not yet existent future shipyard, re-arrangement of existing one, or only focused on production or storage spaces. Regardless of that, the shipyard layout planning research works tend to take their beginning in heavy industry systematic layout planning practices supported with Song's simulation-based shipyard planning framework. In general shipyard operation flow and therefore layout arrangement can be viewed as any heavy industry. The scale of material is large and the movement of materials requires usage of non-manual handling and large-scale production, storage and handling areas.

The systematic layout planning which mostly applies to heavy industry operations requires consideration of two main components - product mix and its volume. Once these components are defined, the layout planning process is assumed to consider all features steering the following development. In this particular case viewing the shipyard operations, the perspective is reverse, as the dimensions and movement of the single product do not affect the internal storage and logistics, but instead the inbound material flow resembles the product movement in the most of industrial layout planning cases. Therefore, hereinafter the term "product mix" is replaced with the more applicable term "material".

The next step is to define the routing by which the given material in the given volumes ought to be moved and handled within the layout, both timely and physically (Muther, 2015, 1-3). In these terms particularly the shipyard industry is characterized by the inadequate information availability (Matulja, 2009, 587), which complicates data gathering and definition of preferencing the data for development basis.

Based on the previously described information, any layout planning undergoes the following steps:

1. Current location and layout setting. The physical conditions of the location chosen or given generally puts a significant amount of restrains on layout planning. This is the point of planning where the shipyard industry brings in its special features. Shipyard operational activities are tightly linked with berth and water utilities availability and location. Moreover, the layout of existing shipyard is rather fixed due to large investment-consuming already established structures, facilities and the corresponding infrastructure (Matulja, 2009, 589). Therefore, this step-in shipyard layout planning is relatively light-weighted and mainly requires consideration of restrictions rather than possibilities.

2. Relationships charting. Once the initial routing of the material in its quantities is set, the relationships between the existing facilities, production processes and material storage and movement routing has to be set. Since the information availability as well as its differentiation and completeness are rather limiting the following the deterministic algorithm, the shipyard layout planning falls under the multi-objective dynamic layout group and can only be performed by heuristic or metaheuristic approaches (Chen GY, 2007). However, since heuristic approach is understood as problem-specific algorithm, the metaheuristic is characterized as problem-independent and searches ways to develop heuristic optimization algorithm, the metaheuristic approach is more applicable in the case of shipyard layout planning. Metaheuristic approaches are used when the linear deterministic approach fails to solve a problem due to high amount of uncertainties and restrictions (Deroussi, 2016, 43). Osman and Laporte (1996) have well defined a metaheuristic as follows:

   "A metaheuristic is formally defined as an iterative generation process which guides a subordinate heuristic by combining intelligently different concepts for exploring and exploiting the search space, learning strategies are used to structure information in order to find efficiently near-optimal solutions."

   One of the metaheuristics approaches applicable for these purposes is the closeness rating and corresponding weight factors, which are largely used in order to define the combinations of the relationships between areas and material locations that have the most effect on production process and therefore productivity of the whole factory. The rating of the importance of the bond between the activities and corresponding areas is indicated by the letters with the corresponding meaning, presented in Table 7 (Muther, 2015, 5-3).

Table 7 Closeness rating indicators

Value	Relationship
A	Closeness absolutely necessary
E	Closeness especially important
I	Closeness important
O	Ordinary closeness
U	Closeness unimportant
X	Closeness not desirable

The closeness rating is defined by filling out the above listed indicators into matrix shown in Table 7, where the numbers indicate the facilities and each of the intersecting cells is filled with the closeness rating defined by the existing layout constraints, existing optimal material flow rooting requirements and logically built assumptions.

Table 8 Closeness rating matrix

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															

The weight factor of bonds that are assumed to be existing between facilities in the previous step is defined by the following formula with using the evaluation data:

$$w_x = \frac{\sum_{k=1}^{n} \rho_{jk}}{n}, \qquad (1)$$

where:

w_x - weight factor for x-th closeness

ρ_{jk} - closeness rating for x-th closeness from k-th factor

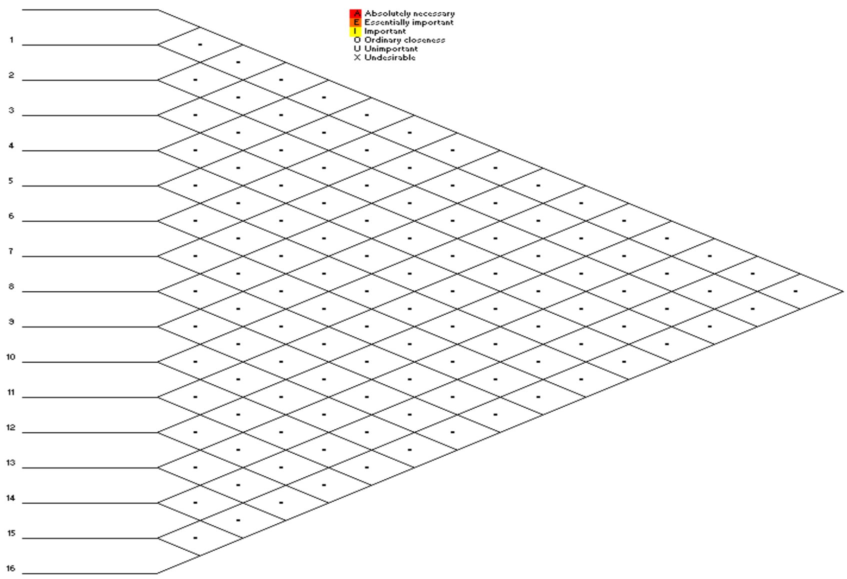
n - number of factors

While the formulas and matrix building underlie in the frames of heuristic approach (Matulja, 2009, 591), the planning process becomes metaheuristic with the choice of the weight factor. The weight factor can either be economical, operational, such as cruciality of fast internal delivery to the core facility, or indicating the flow intensity (Chen GY, 2007).

Maximizing the weighted closeness rating value, as much as constraints allow, is an objective for development in the framework of layout planning, as implementation of maximized closeness rating ultimately aims at minimizing the total movement distances and therefore time and effort consumed. This objective follows the JIT principle, which is as such one of the most important in shipyard operations. (Samarghandi, 2013, 2703).

The closeness rating calculation results in space and activity relationship diagram, which by systematic layout planning I looks as shown in the following figure.

Figure 10 Space and activity relationship diagram



The diagram shows the importance of bonds with the corresponding weight factors in the required order of spaces, grouped by activity nature or effect level on production process (Muther, 2015, 5-18). The diagram becomes a base for actual layout planning added with space adjustments and specific practical constraints consideration.

3. The next step of systematic layout planning is establishment of space requirements and availability. With the data gathered on the material volumes in combination with restrains and availability information, the available and required space is compared, after which the adjustments are made in terms of material special requirement decrease or area physical dimensions increase, considering time and area conditions effects, in order to balance the space required and available and avoid future difficulties with misplacement already at this stage (Muther 2015, 7-24).

   This step also normally implies consideration of facility shaping based on material features, as well as economic factors. However, as discussed before, the shipyard industry is characterized by fixed facility location and therefore shaping, as well as facility internal layout model, which is in most cases job workshop layout. The economical, planning of utilities, safety issues and personnel affecting factors are out of the frame of this thesis, and therefore the further development of this step is not considerable in the given case.

4. Based on closeness rating and considerations regarding space and material flow intensively a number of alternative area allocation combinations. The set of combinations is then evaluated and adjusted on case basis to construct a final feasible layout plan (Matulja, 2009, 591). The shipbuilding industry is characterized with domino effect of delays affecting the production and rather unexpected changes in requirements. Material flow analysis and planning is reviewed more closely in the following section.

5. The final step of any planning process, and especially layout planning is validation. Song proposes simulation-based digital validation (2009, 210), using a software, which are nowadays available in multiple versions, with varying focuses and availability for public use. The simulation which brings out the critical issues and most effective points in metaheuristic understanding, and allows to address and adjust them at a relatively early stage before implementation. The majority of studies, however, emphasize the effort and cost consumption of such method, mainly meaning impossibility of its usage in the frame of shipyard layout planning, and therefore rely on general decision-making procedure, when the proposals are manually reviewed, discussed and adjusted.

4.2 Shipyard material flow optimization

Partially reviewed in the previous section, material flow holds a surprisingly significant part of efficiency of the whole production and therefore deserves separate consideration in layout planning. Muther (2015) defines material flow as the heart of majority of layouts. Ideally, the initial layout needs to be built on the base of already optimized flow. However, there are cases, such as in shipbuilding, where layout and therefore material flow is restrained by location of already established core facilities. An effective flow of materials supposes progressive movement of them throughout the production process with minimized number of cases of mishandling, detouring and reverse flow actions (Muther, 2015, 4-1).

Since the layout planning of the case company is mostly focused on allocation the storage areas between the different material groups, the motion in between these areas has to be well routed and schedules in order to make it ultimately possible to apply the JIT approach to internal supplies of material.

The material flow at almost any shipyard starts at receiving dock, where the material is inspected and registered to the bookkeeping. Receiving procedure can either be performed using the old packing list method of logging, the main disadvantage of which is high level of inaccuracy due to human error and long processing times. The alternative methods include such technologies as RFID, barcodes and mobile devices, which approximate the receiving process to its ultimate goal of accurate logging and keeping the information of material at the same time minimizing the human error level and handling times (Dwivedi, 2003).

The specifics of material flow at the shipyard include large number of work-in-progress (WIP) storage spaces to be used as intermediate storage point allowing the ease and short delivery time to the material installation points. The delivery of material to such storage spaces is made based on the storage allocation planning and available space, while delivery from the WIP storage space to the installation shall be made in accordance with production requests regarding the timing and quantity of the material (Cakravastia, 1999).

4.2.1 Material flow analysis in shipbuilding

Prior the actual rooting of material flow, one must analyze the existing material flow in order to define the appropriate optimization technique. Besides the general operation process mapping, the analysis of the process for flow optimization shall also include the analysis of intensity of material flow. This ensures the base for arrangement of operations in a proper relationship with one another. The intensity of material flow is normally analyzed to detect the most complicated links of it. Therefore, the corresponding measure unit is chosen depending on the availability of the data and the priority of result format for the company. When the routing is required for the movement of vast variety of goods and their parameters, which is clearly the case in shipbuilding operations, the process map is suggested to be converted to a so called from-to process chart, indicating the values or coefficients for movement intensity of material categories. The matrix example is illustrated below.

Figure 11 From-to process intensity matrix (Muther, 2015, 4-17)

TO / FROM	*Shear* 1	*Notch* 2	*Draw* 3	*Pierce* 4	*Bend* 5	*Trim* 6
Shear 1	–	ABC 3	–	EF 2	–	–
Notch 2	–	–	BD 2	AC 2	–	–
Draw 3	–	–	–	–	BCDF 4	C 1
Pierce 4	–	–	CEF 3	–	A 1	–
Bend 5	–	–	–	–	–	BDE 3
Trim 6	–	–	–	–	–	–

The listed activities indicate the points of material flow where the material changes its form or quantity. Each of them can be a start or end point of the flow link. Correspondingly, the material category is marked by a single letter to an intersecting point of the two points as register of the movement, both general and reverse. The letters can also be replaced by the material size and quantity for more straightforward calculation. With the help of this matrix, the transportation links between the points can be ranked by complexity, excessive load or bottleneck probability (Muther, 2015, 4-20).

As can be noticed, the matrix resembles the closeness rating matrix for detection of relationships between the facilities. Combining the two matrixes ensures consideration of the most important factors affecting the efficiency of production process.

4.2.2 Material flow rooting optimization

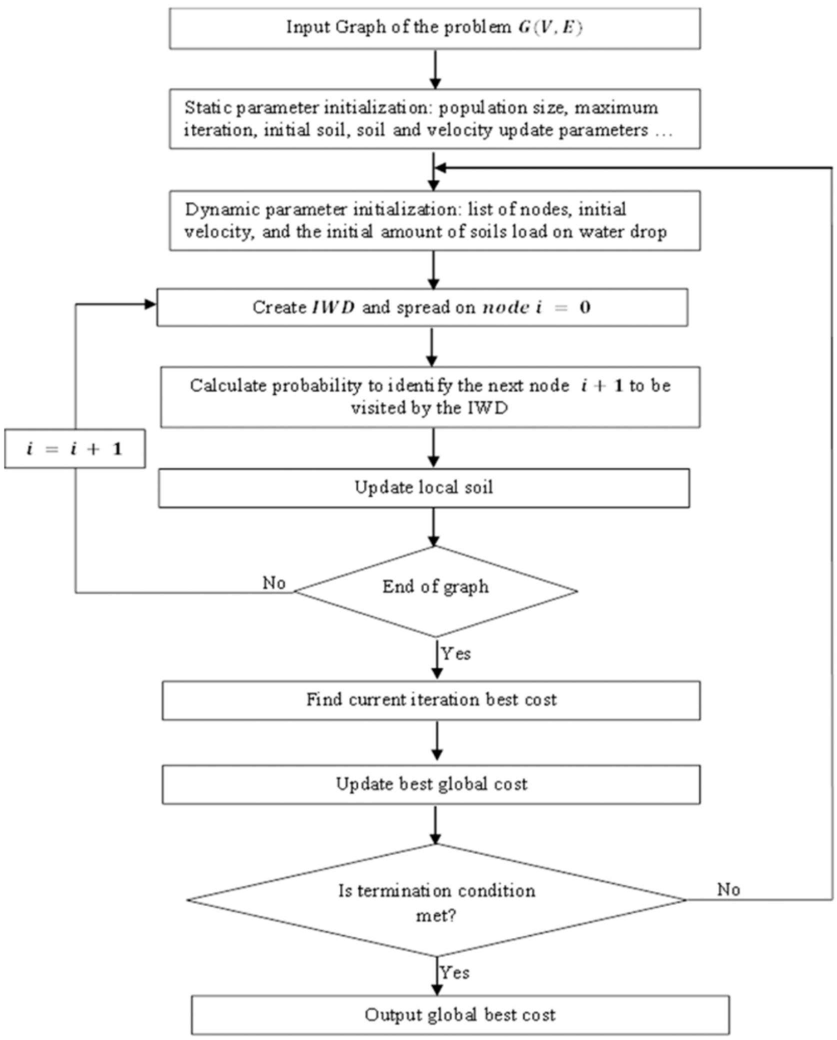
The optimal rooting problem has been used for flow optimization for the purpose of travel time and costs optimization for ages, and the problem of material flow routing at a shipyard is overall not studied separately due to its almost total alignment with one of the general types of material distribution routing. Even though there are a few studies available specifically for shipyard intralogistics, but the models are based on conventional principles. Therefore, the literature review of the routing problem has been approached from the perspective of industrially used practices, mainly performed by automobile vehicles.

Graphically, the material flow of the shipyard, excluding the block transportation, is represented by one stating hub, since the rest of the material undergoes the same procedure of receival and inspection at the main unloading dock. Further, the material is transported to the available storage dedicated for corresponding material type or the workshop points. The difficulty is that the workshops are interlinked with each other with material routes as well, therefore the generally applied for distribution problem hub-and-spoke structure is not applicable in this case. Since the usage of workshops as starting point cannot be clearly defined, as well as the exact volumes per each transportation tour, the problem appears to be nondeterministic polynomial, and therefore requires a focus on the heuristic optimization solutions for tour-like vehicle travel distance optimization scheduling problem.

Chen et al. (2019) proposes a modification of classic genetic algorithm to be applied at steel batch distribution to the workshops at the shipyard. Genetic algorithm, first introduced by Holland (1987), is a reflection of biological mechanisms to practical distribution problems. The belongingness of such solution to heuristic practical solution is defined by the natural ability of chromosome to mutate. Therefore, when applied to industrial example, the calculation result includes the allowance for initial data deformation. (Chen et al., 2019, 6) It provides multiple approximate solutions to the distribution problem, allowing to choose from the computed solutions.

A slightly different approach, but generally solving the same NP-hard problem by a practice mirrored from nature and intersecting in terms of mathematical representation of algorithm, is the intelligent water drop (IWD) algorithm. The water drop algorithm is a graph-based metaheuristic algorithm, which mirrors the behavior of water drops in the river forming streams, but the IDW provides a higher quality of solution due to random use of initial data (Shah-Hosseini, 2009). The algorithm is used for solving multi-objective problems for optimization of routing, distribution in economic, power generation, transportation and layout optimization perspectives. The original algorithm procedure is, however, illustrated in Figure 12.

Figure 12 Original IWD algorithm



As can be seen from the figure above, the algorithm is rather simple when generalized into a process. Static parameters mentioned in the second step of the algorithm for shipyard operation mean the material variety, initial layout availability and material handling and transportation velocity parameters. Dynamic parameters include the list of loading/unloading or assembly stations, and the intensity of the flow in size per time unit. As explained before, the algorithm starts the process at the starting depot and choses the optimum path for visiting the next ones based on their need and availability. This process performs numerous iterations to reach the best global solution for the path set (Ezugwu et al., 2018). Figure 12 displays the value of optimization to be in cost. However, the cost in distribution is caused by movement frequency and complexity, and therefore in the cases where financial factors are not taken into account directly, the cost focus can be replaced by effort focus.

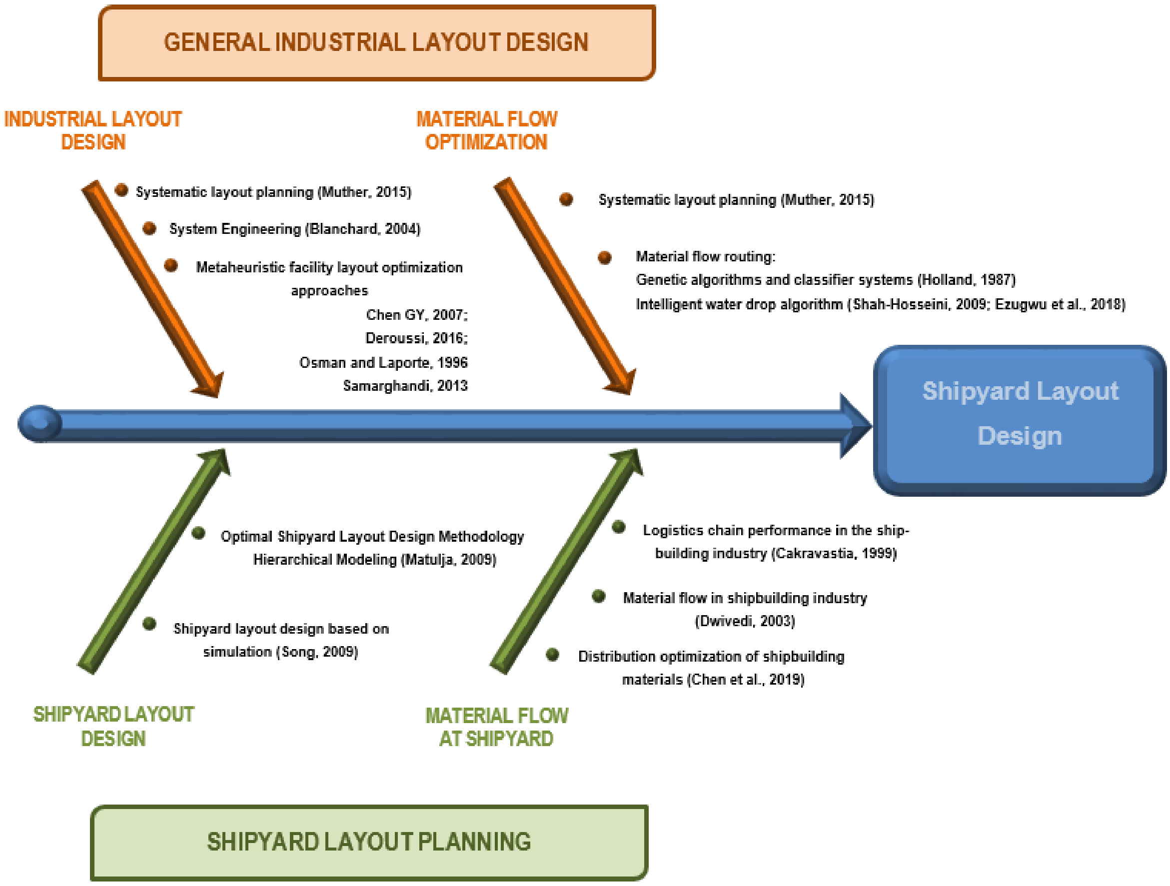
The solving approach of the algorithm is modelled as a graph $G = (V, E)$, where V and E denote sets of nodes and edges. In application to shipyard operations, these are the loading/unloading points and the links between these points. The algorithm assumes that there is a starting point of each path, which in shipyard case is the main storage depot. The algorithm includes a number of formulas for calculation of the best solution, which require in-depth attention for understanding, and therefore, for simplification purposes are presented as a list in Appendix 8.

4.3 Conceptual Framework of This Thesis

The literature review was carried out in respect of the data made available for the analysis in Section 3. Based on this, the layout planning practices for shipbuilding sector have been studied and resulted in routing of the practiced to basic industrial planning methods adjusted and modified for highly constrained specifics of shipyard operations. Thus, the shipyard layout planning includes the general steps of current layout and process analysis, establishment of activity relations and material flow optimization. Practices in material flow optimization and routing are reviewed separately and more deeply due to the high effect of material flow efficiency on the overall production process performance.

In accordance with the review described above, the conceptual framework, including the main references, is visually represented as shown in Figure 13.

Figure 13 Conceptual framework visually



The conceptual framework is built from the two main blocks, each of them based on the main concepts found in available literature - layout design and material flow. The literature has been reviewed from two perspectives: concepts in general and especially applied to shipbuilding industry, and then fit together for to form a set of concepts applicable for the case company at the development stage of this particular thesis projects. The main sources that best describe the ideas and concepts discussed by multiple authors, are shown in Figure 13.

Based on the data gathered during the current state analysis stage and employing the combinations of best practices investigated in this section, the development process of layout and material flow plan for the case company is presented in the next Section 5.

5 Building Proposal on layout and material flow plan for the Case Company

In this section the results of current state analysis presented in Section 3 are used in accordance with the merged practices presented and discussed in Section 4 Conceptual framework in order to develop the logistics processes of the case company and develop a proposal for layout and material flow plan, including practical recommendations for further improvement. The development process is supported with the next set of data received during the milestone presentations and management interviews when required.

5.1 Overview of the Proposal Building Stage

The proposal building stage describes the ways of application of best practices to the set of initial data and special features of this particular company case and proposes the optimal approach combination of described approaches. The layout and material flow planed are practically drawn up using the chosen optimal approaches.

As described in the summary of Section 3, the current state analysis resulted in understanding of the operational fractions needing special attention and development. This include adjutancy of the actions and scheduling of production supporting functions to the core production schedule, the storage allocation process flexibility, lack of supply chain monitoring and most importantly for this project, the basis of the current layout on significantly larger area than is available currently. The core facilities of the shipyard, as well as their location and storage capacity, stay the same and the JIT production supply approach is well known by the operators. This shipyard is getting ready to accommodate production process of two consecutive projects allowing to estimate the storage needs and material flow intensity in order to draw up a layout able to accommodate these needs with optimal efficiency.

Following the logic of the problem setting based on results of current logistics processes analysis and application of best practices found in the corresponding literature, the development stage of this project includes at first practical setting of the updated physical layout and it’s constraints. This gives a graphical base to develop. Nest, the activity relationship diagram of the corresponding action points of the material distribution, storage and installation is set in order to be able to hierarchically sequence the importance and therefore the attention level to the bonds between operations. Once the activities in relations to each other, taking into account the flow intensity in between these activities, the routing of material flow is made on the basis of metaheuristic algorithm applied to shipyard material flow distribution problem. A combination of this practices results in a number of optimal combinations employing metaheuristic problem solving approaches and systematic layout planning. The decision making on the proposal best applicable to the operations of the case company to be validated is made by procurement and the logistics management of the company. Therefore, the final proposal is built based on development stage results integrated with and adjusted based on the suggestions from the management as main informants.

5.2 Data collection for development purposes

Results of interviews of the case company management has shown that the development of shipyard layout and material flow plan has to be focused on accommodation of the storage demands within the remaining territory according to the JIT principle for supply of production process. Additionally, some of the principles for proposal building has been assumed in accordance with the suggestions of the management presented in the following table.

Table 9 Improvement suggestions from management 1/2

	Key focus area	Suggestions from management	Description of the suggestion
1	JIT approach of storage area prioritizing	Main priority of the storage relationships to be set on timely delivery of the material from storage area to the corresponding production facility.	The main aim of storage areas allocation and material supply routing is timely facilitation of core production process. Thus, the main focus of layout and material routing planning has to be set on transport and delivery time minimization and importance factors maximization.
2	Sharing and distribution of planning information	Utilization of ERM system for storage allocation purposes	The Enterprise Resource Management system of the case company has so far not incorporated the planning module for transparency of production demand and scheduling information. Therefore, the layout and material routing plan need to be built in such a form that the practical application of these plans is possible to be made available to core users of the ERM system for updating and review.

As it can be seen from the table above, the suggestion from the case company management mostly include strategic aiming of the development process. However, the major share of data collection is represented by quantitative surveys of site and statistical measures. This, for instance, includes measuring of distances and closeness importance withing the current set storage areas. The input of the data for project development can be recognized in each of the stages of planning process described in the following sections of this thesis.

5.3 Layout planning of the case shipyard

This part describes the application of best practices in shipyard layout planning to the case company operations taking into account real-case restrictions and demand. As proposed by Song (2009) and Muther (2015), any layout planning must start by analysis of the current core process. During the current state analysis stage the data was approached from the process analysis perspective, and gave a clear structural and graphical representation of the position of the company in the supply chain, arrangement of the logistics processes in the frame of local shipyard operations and arrangement and changes to be established of the current layout.

Matulja (2009) points out that shipyards generally possess information in adequate availability, meaning that the scales of data gathering are humongous and the type of data is very restricted. Therefore, the data used for the analysis shall be set based on the availability of the data closest to the demanded by general practices of layout planning. Further during the current state analysis stage, the analysis of the most descriptive available data of planned or demanded logistics process based on the weight calculation and scheduling of vessel projects for planed future production resulted in clearly structured representation of the internal material flow intensity.

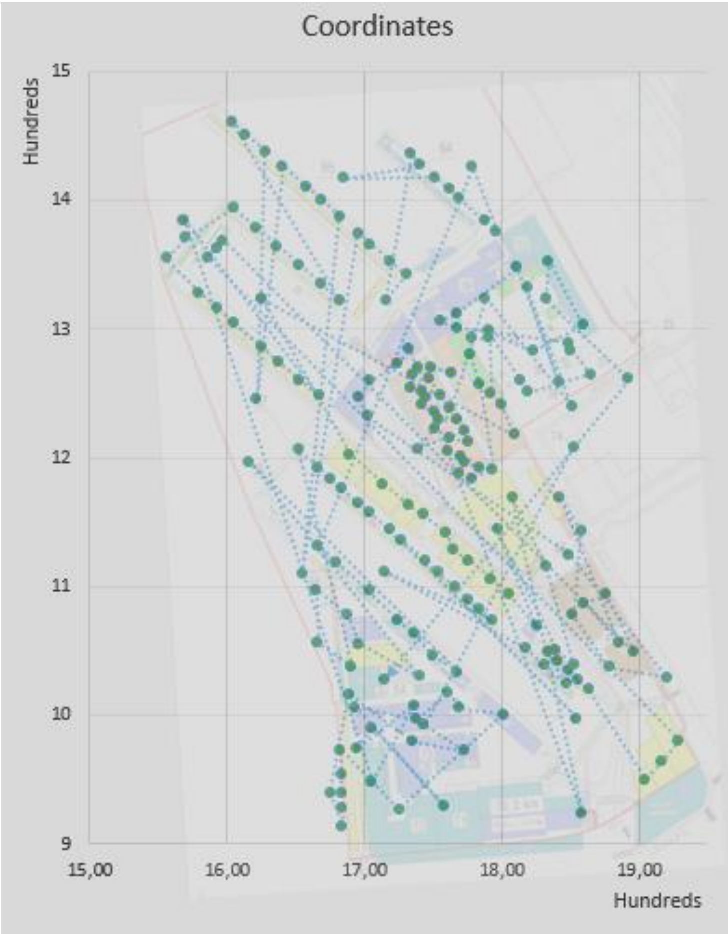
Employing the assumptions made above, the layout planning process follows the steps described in the Section 4.1, adjusting the development to the available information given in Section 3.

1. Current location and layout setting

As mentioned before, shipyard location and layout setting are normally quite restrained by the physical location requirements of operations. This peculiarity also applies in this project. First of all, the location changes are set as reduction of 30% of the area. The core activities that require certain facilities, the allocation and scaling of which cannot be changed under any circumstances, constitute the largest share of all facilities utilized at the shipyard. Therefore, it is more reasonable to point out the facilities and areas, location of which changes. These mostly include the material storage areas of bulk and oversize material. Thus, the development project of this thesis focuses on the storage allocation and accommodation capacity of those.

The setting of storage areas in the frames of current layout of the remaining area is defined in a form of graph fulfilling the input requirements for layout and material flow planning.

Figure 14 Storage area coordinates compared to layout



The graph describes the position of storage areas in two-dimensional extension. The links between the points describe the positional relations of the storage area, as can be seen when compared to layout drawing, but cannot be utilized for optimization calculations as distances, since the constraints of the layout planning in this case include impossibility of changing the location of majority of the points and the infrastructure, which regulates the movement and accessibility of each point. Therefore, the distance relation matrix is generated to record the closeness of storage areas in terms applicable for transportation and distribution problems. Due to the scale of the matrix and confidentiality of the company information, this matrix is provided as Appendix 9. The format of the matrix corresponds with relationship chart described as the following step of layout planning process.

2. Relationship , space requirements and availability charting

In spite of the fact that the location of the facilities is set, in order to improve the performance of the inter-facility activities, the relationships between these facilities has to be set and prioritized. Therefore, following the metaheuristic approach of relationship charting laid out by Muther (2015) and Matulja (2009), the activity relationship is analysed using closeness rating matrix. The closeness relationship is coded as shown in the following table.

Table 10 Closeness rating coding (Muther, 2015)

Value	Relationship
A	Closeness absolutely necessary
E	Closeness especially important
I	Closeness important
O	Ordinary closeness
U	Closeness unimportant
X	Closeness not desirable

In this particular case the rating is defined by the importance of positional closeness in between the areas, the importance of JIT delivery for each of the facilities and the effect to overall production process. There is a difference in focus on relationships between activities, such as pipe production or painting between each other, and the movement of material between the storage areas. The difference is in the demand for JIT delivery and the quantities. Material flow between storage areas is the main subject of this project and therefore the relationships between facilities and between storage places in relation to facilities are viewed. The constructed relationship matrix is provided as Appendix 10.

In order to include practical and strategic issues into consideration, the usage and flow intensity are recognized as weight factors.

The intensity of the material flow is defined by the area weights provided in Appendix 11, and the projected material flow intensity weekly defined for each product group presented in Table 5. Based on these two sets of input data, the weight factor of each area is calculated using the formula suggested by Matulja (2009):

$$w_x = \frac{\sum_{k=1}^{n} \rho_{jk}}{n}, \qquad (1)$$

Where in this particular case:

w_x - weight factor for x-th closeness

ρ_{jk} - closeness rating for x-th closeness from k-th factor

n - number of factors

The factors for calculation of weight of each area are:

1. Flow intensity to and from the storage area
2. Usage of the area for its initial purpose
3. Demand for the area occupation by intensity of the flow versus availability
4. Closeness to core facilities

The calculation results in the set of data as shown in Table 11 below. The highest weight factors presented in the table represent the areas which experience the highest demand for the given production plan, highest material follow-through rate and the highest demand for fast-reaction time. Additionally, the flow intensity is supported with calculation of participation of each area in most common material flow sequences of each material group considering the volumes of material undergoing these sequences.

Table 11 Storage area weights

Area No	% of storage area	Purpose	AVG weight
1	6,51%	Hull assembly (38%)	**14**
2	6,29%		**8**
3	2,70%		**4**
4	3,09%		**12**
5	3,09%		**6**
6	2,86%		**12**
7	2,32%		**6**
8	1,34%		**7**
9	1,57%		**6**
10	1,17%		**7**
11	0,99%		**7**
12	0,94%		**5**
13	0,54%		**7**
14	0,42%		**7**
15	0,42%		**2**
16	0,62%		**5**
17	0,41%		**7**
18	0,33%		**9**
19	0,53%		**7**
20	0,31%		**7**
21	0,25%		**6**
22	0,41%		**8**
23	0,41%		**7**
24	0,41%		**6**
25	0,11%	Logistics (9%)	**6**
26	3,14%		**3**
27	1,98%		**6**
28	2,12%		**6**
29	0,58%		**3**
30	0,89%		**2**
31	0,12%		**10**

Area No	% of storage area	Purpose	AVG weight
32	14,47 %	Main (15%)	**4**
33	3,87%	Prefabrication material (11%)	**4**
34	2,99%		**4**
35	1,20%		**4**
36	1,11%		**2**
37	0,90%		**2**
38	0,82%		**4**
39	0,45%		**2**
40	0,36%	Block outfitting material (8%)	**6**
41	2,26%		**6**
42	1,52%		**6**
43	0,74%		**8**
44	0,60%		**8**
45	0,65%		**8**
46	0,78%		**8**
47	0,91%		**8**
48	0,53%	Intermediate (8%)	**9**
49	3,37%		**9**
50	1,32%		**9**
51	1,02%		**9**
52	0,96%		**5**
53	0,78%		**4**
54	0,75%		**3**
55	0,54%		**6**
56	0,42%	Painting material (4%)	**6**
57	1,14%		**6**
58	1,10%		**6**
59	0,60%		**6**
60	0,58%		**6**
61	0,42%		**6**
62	0,35%		**6**

Area No	% of storage area	Purpose	AVG weight
63	0,15%	Machinery outfitting (3,5%)	**3**
64	0,14%		**4**
65	0,68%		**4**
66	1,00%		**3**
67	0,50%		**4**
68	0,40%		**4**
69	0,40%		**4**
70	0,20%		**4**
71	0,17%		**3**
72	0,09%		**3**
73	0,05%		**3**
74	0,02%		**4**
75	0,29%	Electrical out-fitting material (1%)	**3**
76	0,41%		**3**
77	0,29%		**3**
78	0,17%		**3**
79	0,12%	Interior material (0,5%)	**6**
80	0,40%		**6**
81	0,13%		**6**
Total		**Max Weight**	
	100%		**14**

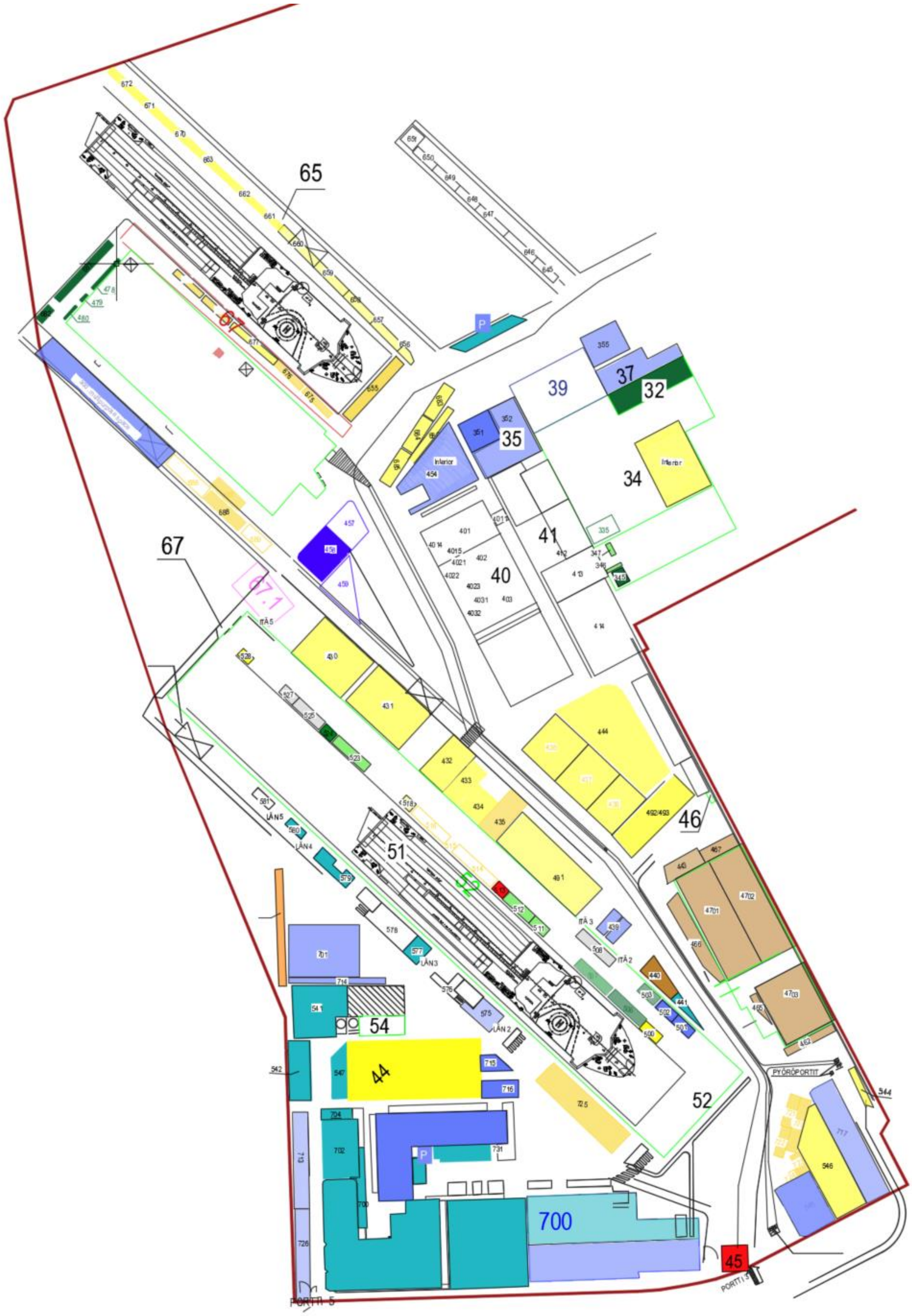
The weight factor calculation results also revealed that the areas purposed for interior material storage are not sufficient for accommodation of goods for a period of three weeks at the point of overlap of production project schedules. However, the overall available storage area of 19 000 square meters is required to accommodate 15 000 square meters of material expected as maximum material in singular time unit, which in this case is considered to be 1 week. Therefore, a special attention has to be paid to planning of storage space compatible with interior material storage requirements, but no additional weight has been added to weight factor calculation of the storage areas in question.

The full image of positional, strategic and flow intensity relationships between areas and core facilities, as well as established space requirements and availability, is received as a result of combining the distance relationship matrix provided in Appendix 9 and the weighted closeness relationship matrix provided in Appendix 10. The final result of this is presented in Appendix 12.

3. Layout proposal building

Since the chosen method for layout planning is metaheuristic approach, the result of the data processing cannot be ideal, nor exact. For calculation simplification purposes, the results of the areas location, relationship and constraints setting are converted into input data set in python programming language script and run using the corresponding software, which utilizes the logic described above and is able to consider a large number of entities and constraints. In principle the ultimate layout suggestion is built by optimizing the combination of weighted closeness factors and combination of distances between the nodes of the matrix. In theory, the ideal layout is represented as storage areas concentrated closest to weighted center point of material flow intersection between the core facilities. Constraints, such as fixed locations and infrastructure, regulate the proposed allocation. For decision making simplification purposes, the suggested layout has been generalized into one graphical proposal with listing of changes. Each of the changes is then discussed with the key informants and management to find the best applicable final solution. The layout proposal is presented in Figure below.

Figure 15 Generalized layout suggestion



The suggested layout proposes a set of the following alternative changes:

1. One of the material groups characterized with most problematic material flow is represented by vessel blocks due to the scale and monitoring demand of movements of this material. Thus, the centermost and prospectively allowing for transportation with minimum amount of obstacles area shall be utilized for storage of blocks and hull assembly material.
2. Location of covered storage area 61, currently used for storage of maintenance goods and machinery is located at a rather advantageous point of the layout, therefore to be used for (a) block storage or (b) interior storage.
3. Additional areas: by reallocation storage areas purposed for hull assembly, the layout allows for utilization of area 454 and partly 34 for storage of the interior material or any other material group that experience excessive storage demand in the future. The weight factor of these areas is rather high and entails placement of these to the centermost point of installation nodes.
4. Aim at utilization of south-west part for maintenance and long-term storage rather than for storage of project components for reduction of distances travelled in between the nodes, since the loading and installation points are consolidated on the right-hand side of the dry-dock.
5. Changes in goods material assignment:

Table 12 Changes in material assignment

Issue	Area number (purpose)	To be replaced with
1	701 (general logistics)	545 (hull assembly) and 546 (general logistics)
2	713 (general logistics)	725 (hull assembly)

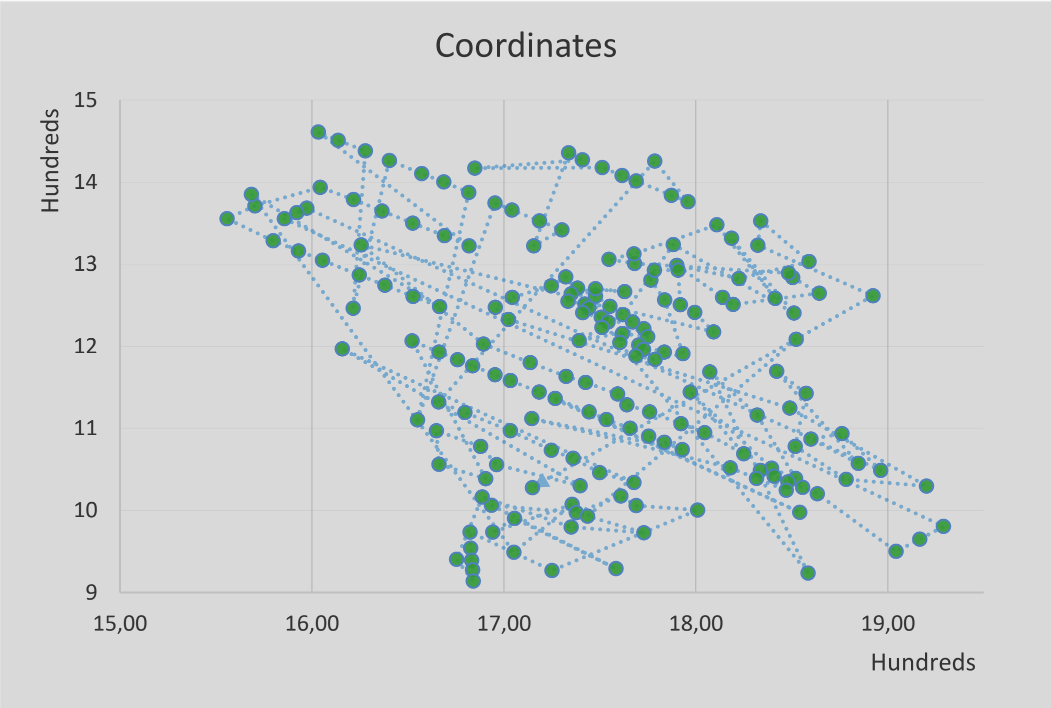
6. Proposal for more efficient space utilization requiring additional investments:
   a) establishment of loading and installation points on the left-hand side of the dry dock. This option, however, entails separate layout planning procedure.

5.4 Material flow planning

In order to ensure better performance of intralogistics in terms of supply with materials for production process, the flows of differing by conditional demand and volumes have to be optimized. While a part of material flow input data is already employed in relationship evaluation stage of the layout planning, a more thorough optimization of material flows is done using the intelligent water drop algorithm for already established proposal for updated allocation of storage areas. Moreover, utilization of this algorithm is made available in comparable format as the ones used for layout planning.

The initial setting for material flow optimization is the definition of nodes and edges, in this case storage areas and facilities to be considered are the nodes and the transportation links between these areas being considered as edges. For this purpose, the initial coordinates graph and the distance relationship matrix are used.

Figure 16 Storage area coordinates graph



This way, the input data for intelligent water drop algorithm is defined as the graph $G = N, E)$, where $N = \{1,2, \dots, n\}$ is the set of nodes and the $E = \{(x, y)x \neq y; x, y \in N\}$ is the set of edges between two nodes in the sequence. Node 1 represents the beginning and ending point of each sequence. The distance between the nodes two nodes is represented as $d_{x,y}$. The transport units are represented by the set of the sequences over all materials groups as an assumption that each sequence is performed as a single case. Therefore, $K = \{1,2, \dots, m\}$, with maximum capacity being set as Q. The demand for material to be delivered to the node x is defined as q_x, which is defined in the material flow intensity data set. In original form of algorithm demand is regarded as $Soil$ that the water droplet carries, gains and loses throughout its path. This time period in which the node needs to be provided with demanded quantity of material is also set by the material flow intensity data set and is defined as required period $[a_x, b_x]$.

While most of routing optimization problems using intelligent water drop algorithm take into account minimizing the cost factor for defining one of the ultimate goals of solution, this thesis project considers the set of reverse evaluation of relationship weight of each edge to be minimized in each sequence. Therefore, the cost function is in this case defined as $fw = W_k d_{xy}$.

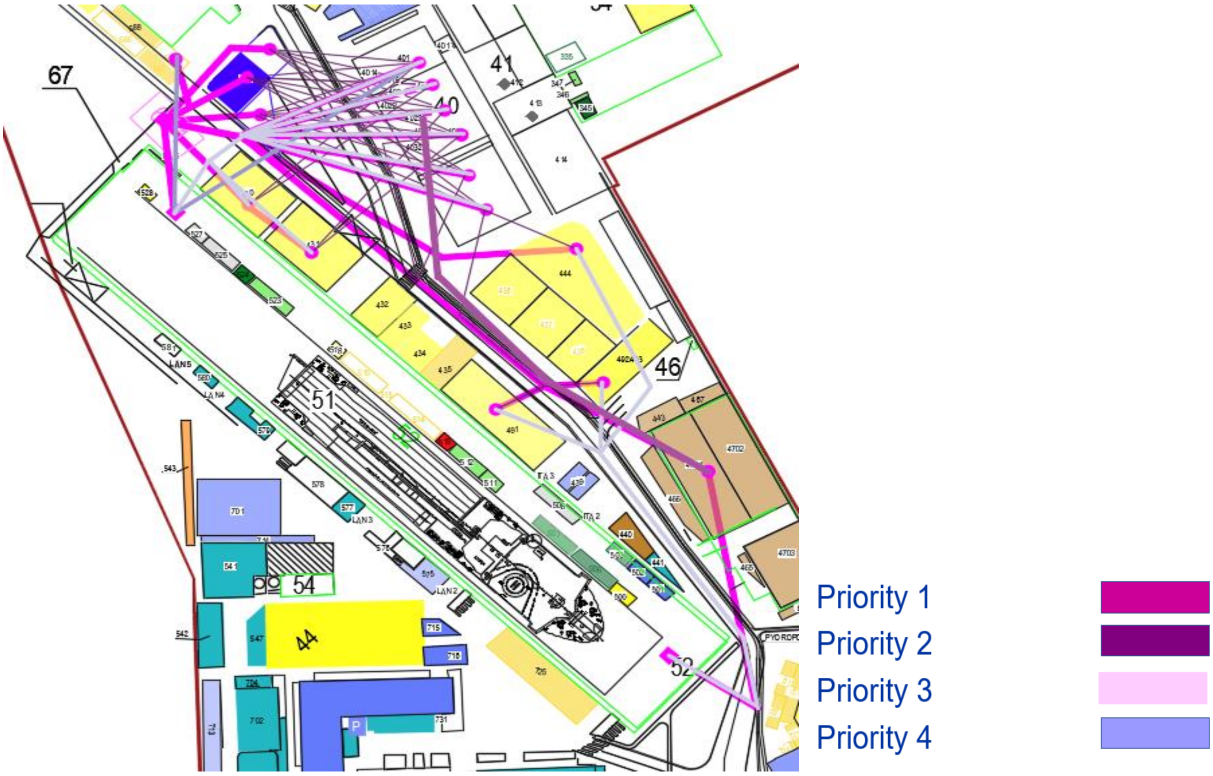
The intelligent water drop algorithm defines the shortest distance for a quantity of material to be delivered to the node in priority within a period of time to complete the final a sequence of movements in order to deliver the overall quantity of material over the nodes requiring it. The priority of nodes is decided by repeated updating the information from lists of nodes to be visited and nodes available, the quantity, and time update parameters. The minimum solutions of objective function for each sequence, being optimizing the weight, time and distance of the route are being found and updated until in total demands of the final nodes are satisfied, and the optimal solution is chosen by comparison of minimum updated solution for each of the edges.

Using the input data described above has been transcribed to python programming language format and run using the corresponding software. Finally, the resulting solutions are modified to fit practical constraints and monitoring practices of the case company, applied on optimum layout proposal. The material flow proposals are provided below per each material group.

1. Vessel blocks flow

The proposed routing of vessel blocks is presented in Figure 17.

Figure 17 Vessel blocks routing

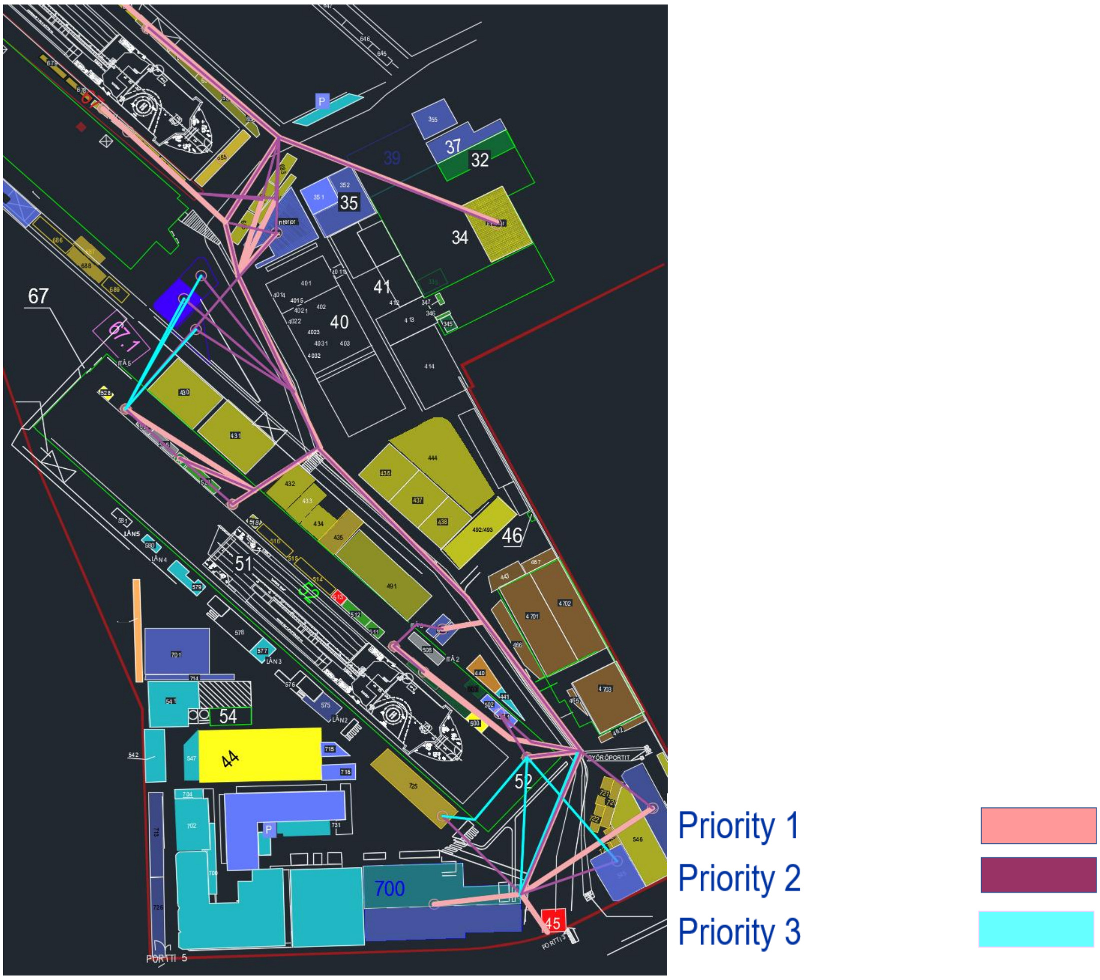


As described in preceding sections of this thesis, vessel blocks are considered to be critical material group due to the scaling and transportation requirements. Therefore, the travel distances for this material group are minimized with highest weight factor. As can be seen from the figure above, the vessel block are prioritized to be moved directly to the block outfitting hall in case the particular vessel block is delivered not outfitted, to the painting hall in case it is delivered upainted and to the hull assembly point, which is the loading point of corresponding location of the dry dock. In case the capacity of any of the installation points does not allow for direct installation, the second priority is set on intermediate storage closest to the corresponding installation point. In the worst case scenario, when the vessel block delivery batches are not followed, and the number of delivered block exceed the expected, the material is delivered to the available stand-by storage areas that allow for access by large-scale tranport. In Figure 17 the routing to these stand-by storage areas are represented by Priority 3 and 4.

2. Interior material flow

The proposed routing of interior material group is presented in Figure 18.

Figure 18 Interior material flow routing

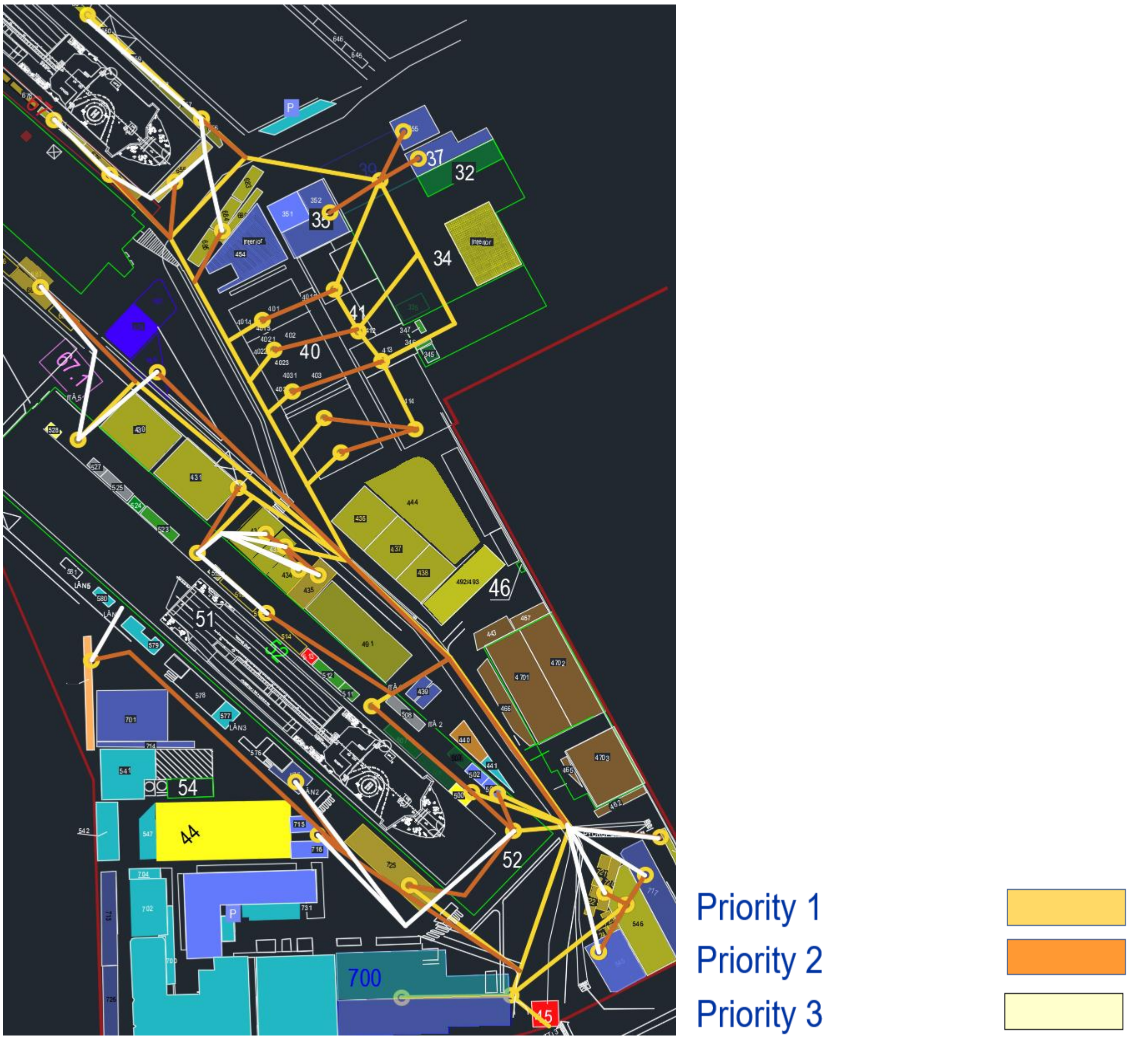


Interior material group is defined as critical by analysis of the material flow intensity. Thus, it requires consideration of additional storage space for meeting the excessive demands at certain 3-week period of production. Taking this feature into account, the first priority is set on deliverying the interior material to installation or loading points of outfitting quay, which is characterized by the highest grade of material demand. However, the loading and installation points througput is limited by the maximum hanlding volume. Therefore, the remaining material is delivered to the storage areas closest to outfitting quay, which includes the storage area inside of piping workshop marked as building 34 and the area made available by space usage optimization in direct closeness to outfitting quay. Similar to other material groups, second and third priority is set on storage areas of remote location from the installation points.

3. HVAC material flow

The proposed routing of HVAC (heating, ventilation, and air conditioning) material group is presented in Figure 19.

Figure 19 HVAC material flow routing



HVAC material group is mostly represented by prefabricated steel material, including a large share of piping. Storage of piping material is only possible in few piping warehouses at the shipyard. Nevertheless, the first priority for supply direction, similar to other material groups is set on installation and loading points. The second priority is set on storage areas that fill the requirement for storage of prefabricated material. And lastly, in case the storage areas of second priority are occupied, the material is directed to intermediate or multi-purpose storage areas.

4. Machinery material flow

The proposed routing of machinery material group is presented in Figure 20.

Figure 20 Machinery material flow routing

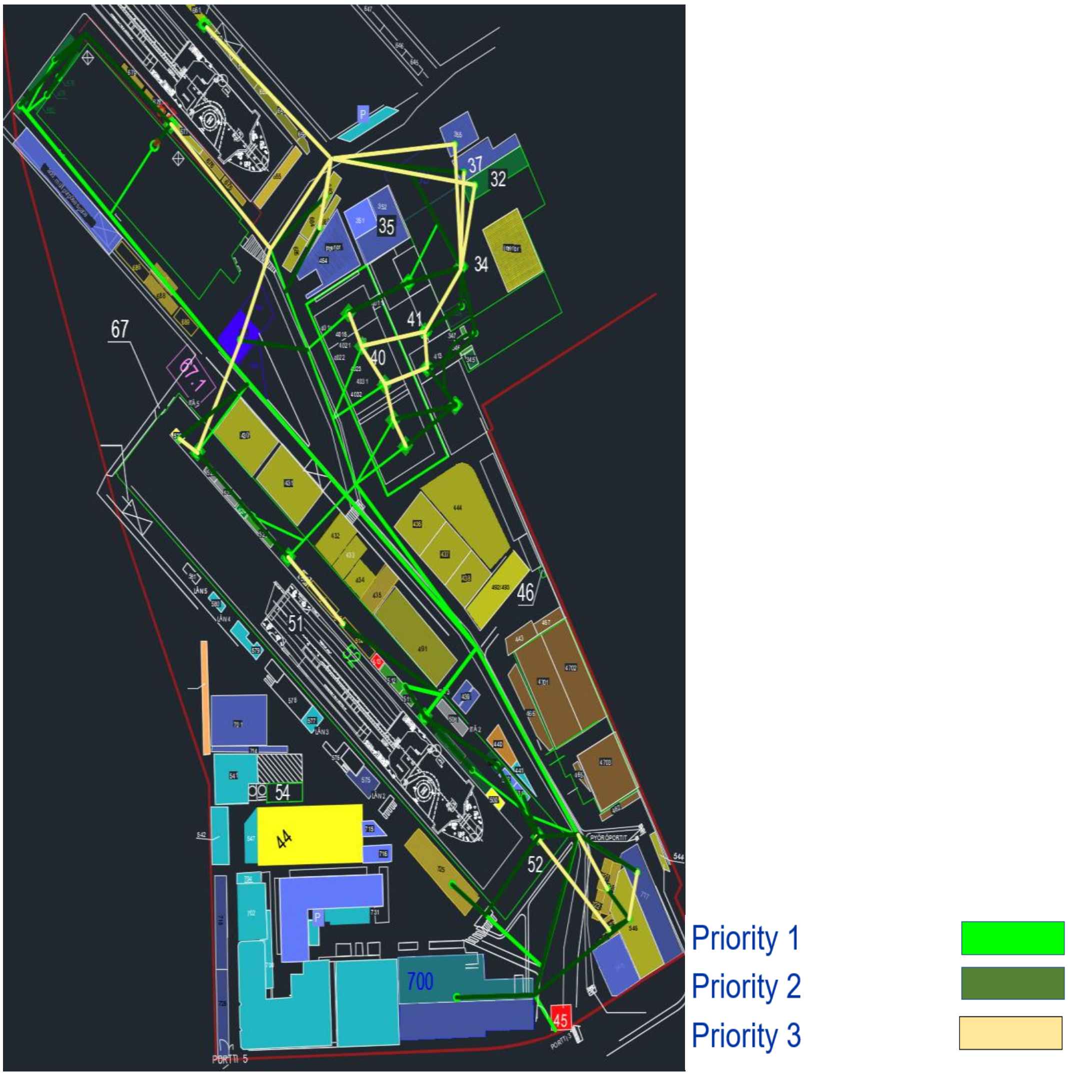
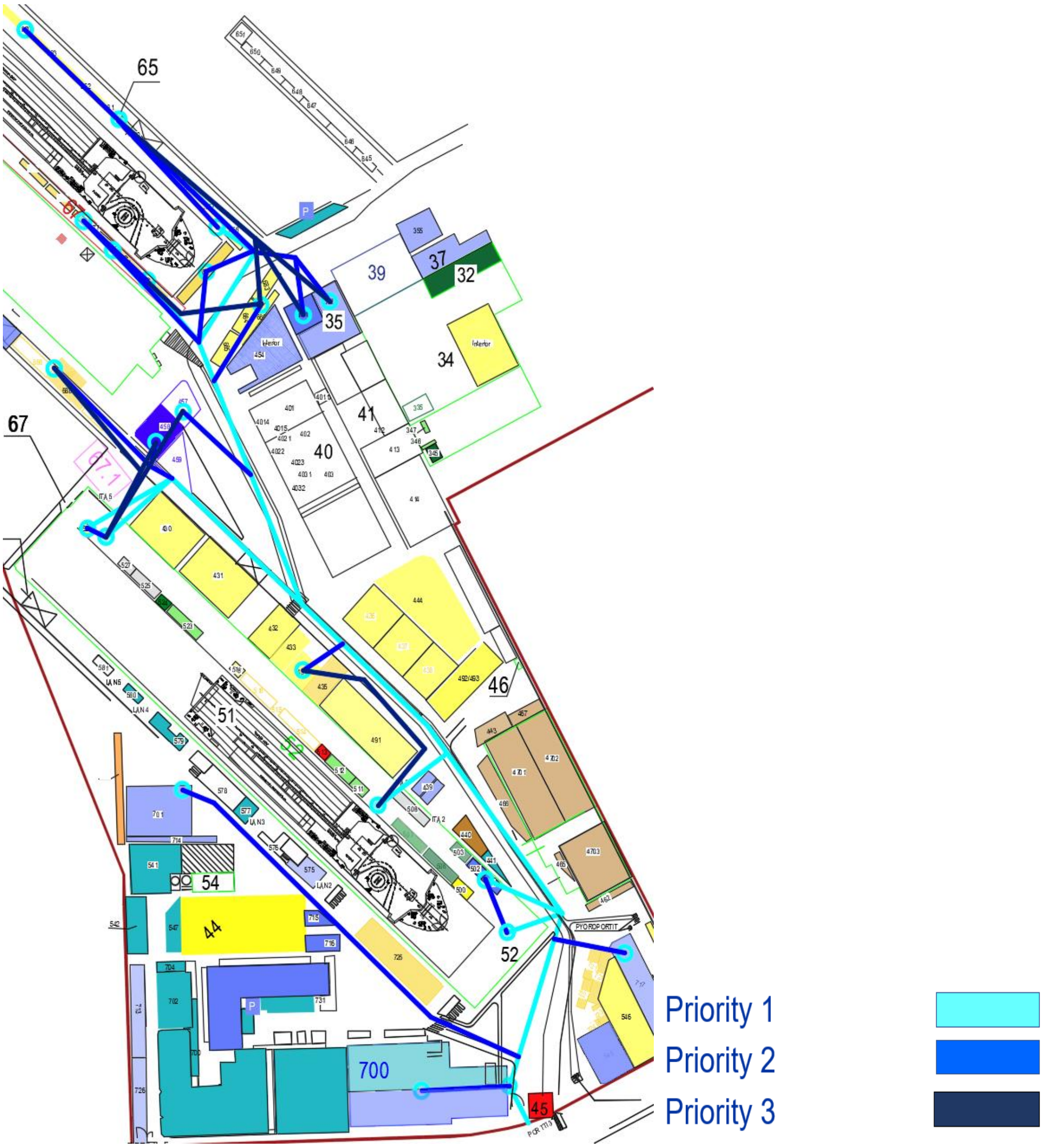


Figure 20 presents the prioritized routing of the machinery material group. Taking into account that machinery used in shipbuilding is characterized by large scales and high requirement on weather proof storage, it is recommendable to transport the machinery material directly to the installation point, represented mainly by loading points of block outfitting hall, outfitting quay and the dry dock. In case the scheduling of machinery installation process experiences delays, this material is directed to the covered storage areas closest to the installation points. In worst case scenario, when the closest covered storage areas are occupied, the material is supplied to available storage areas dedicated for storage of this material group.

5. Deck material flow

The proposed routing of deck material group is presented in Figure 21.

Figure 21 Deck material flow routing

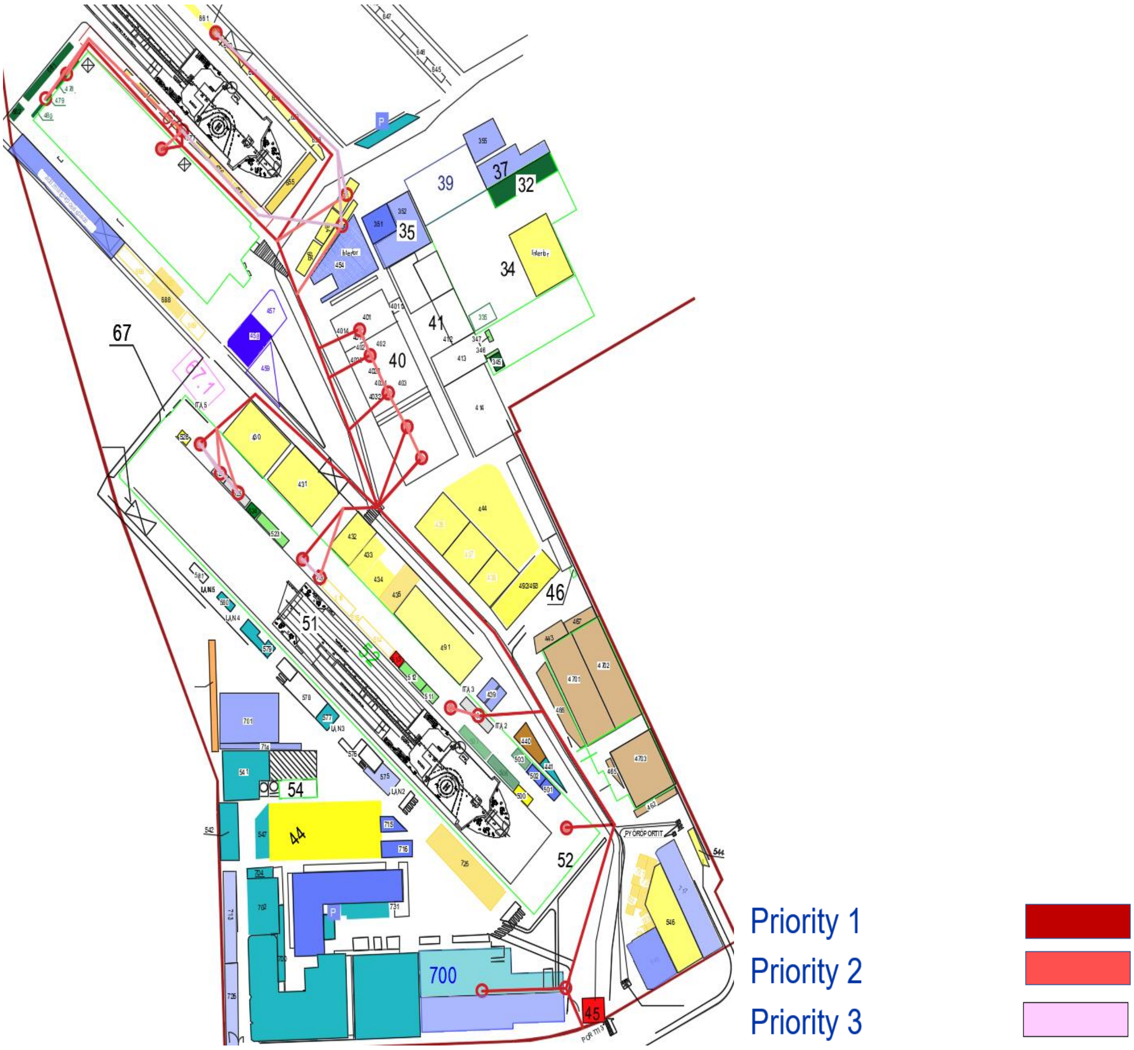


As seen from the figure above, the first priority of deck material supply is set at the loading points of the outfitting quay and dry dock. Second priority is set on the storage areas nearest to installation points, while the least prioritized supply directions are set on the remote storage areas, transportation to which happens only in cases when the storage areas of first and second priority are occupied.

6. Electrical material flow

The proposed routing of electrical material group is presented in Figure 22.

Figure 22 Electrical material flow routing

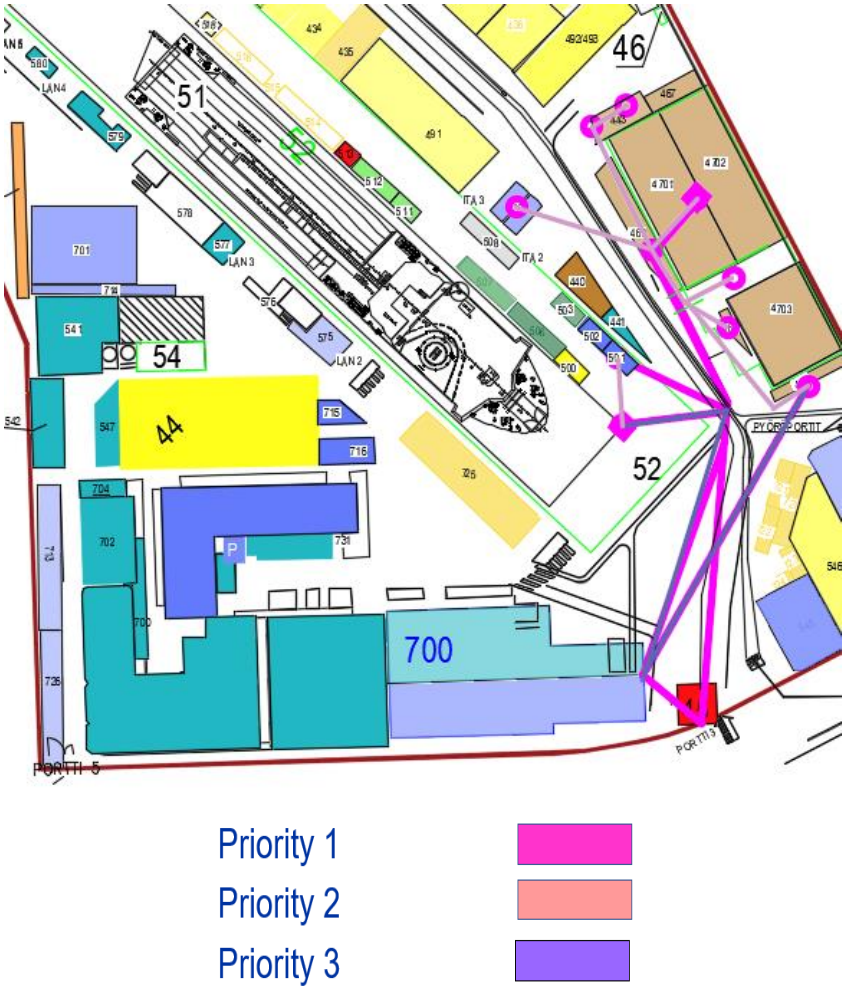


Electrical material storage special weather-proof conditions, mainly meaning that the storage area is covered. Therefore, the setting ofspaces for storage of such material are limited and do not allow for significant location changes. The flow of electrical material group, as indicated in Figure 22 is prioritized to direct delivery to main installation points, which first of all include the loading points and covered storage near the outftitting quay, dry dock and outfitting hall, which are represented by the largest share of material flow intensity. Second priority is set on relatively remote storage areas and the least prioritized directions are uncovered storage areas.

7. Painting material flow

The proposed routing of painting material group is presented in Figure 23.

Figure 23 Painting material flow routing

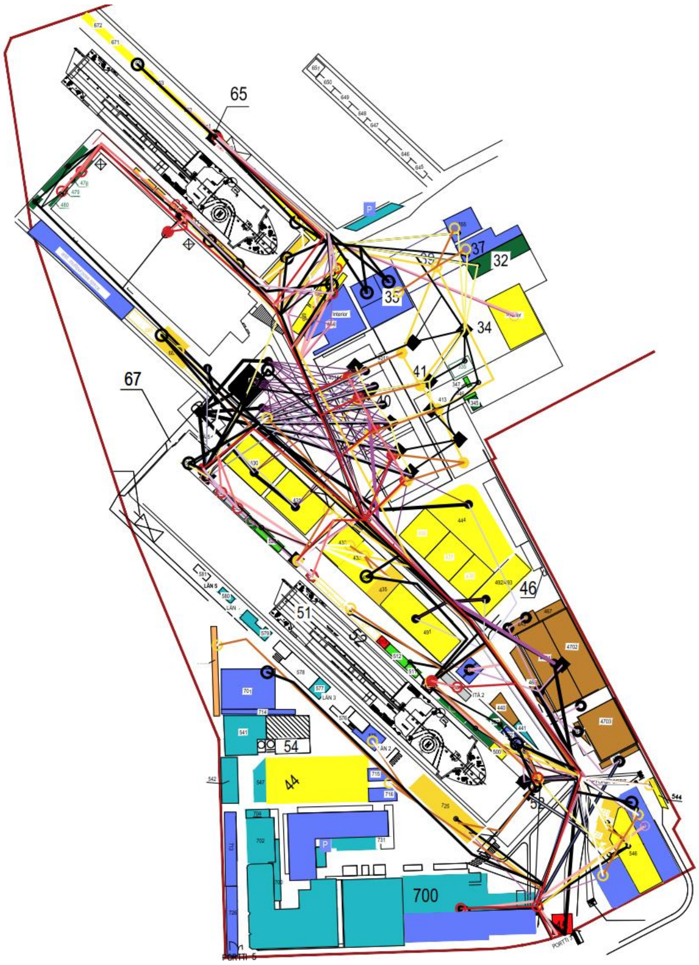


As can be seen from the figure above, the flow on painting material concentrates on south-east part of the layout. Such routing ensures minimal distance from the main gate, receiving dock and the painting workshop. The first priority for transportation of this material group is set on delivery to straight to the painting work shop. By statistical data analyzed during current state analysis, minor share of painting material is delivered directly to the dry dock. In such case, the first priority is set on delivery directly to the loading point of the dry dock. The second priority is set on material supply to storage areas closes to either painting workshop or the loading point of the dry dock. Finally, the least prioritized storage areas are most remote from the usage locations or the ones characterized by complicated physical access.

5.5 Proposal Draft

The following table presents the initial proposal on the shipyard layout plan in the format provided to the case company.

Table 13 Proposal draft

<table>
<tr><th>Proposal visually</th><th>Changes listing</th></tr>
<tr><td rowspan="5">

The visual representation of the proposal is provided as a set of AutoCAD and PDF- format files, detailed per material group, as well as generalized.</td><td>The centermost and prospectively allowing for transportation with minimum amount of obstacles area shall be utilized for storage of blocks</td></tr>
<tr><td>Location of covered storage area 44 to be used for project-related block or interior material</td></tr>
<tr><td>Additional areas: 454 and partly 34 for project-related storage (advantageous location)</td></tr>
<tr><td>Aim at utilization of south-west part for maintenance and long-term storage</td></tr>
<tr><td>Changes in goods material assignment:
- 701 (general logistics purpose) to be replaced with 545 (general log. purpose) and 546 (hull assembly purpose)
- 713 (general log. purpose) to be replaced with 725 (hull assembly purpose)</td></tr>
<tr><td colspan="2">Further improvement suggestions:</td></tr>
<tr><td colspan="2">1. Interior material group is expected to cause overflow of material to the available storage areas dedicated for this material group. Even though the proposed layout considers such complication, as well as proposes additional areas for storage of interior material, the management should consider outsourcing of part of interior material storage and assembly services in order to minimize the period and the volume of the material stored at shipyard.</td></tr>
</table>

2. JIT approach for timely supply to the installation process is incorporated in the planning as a part of weighted area closeness calculation in terms of prioritizing and minimization of the travel distance to the merging points with production, but practical application of this principle at the shipyard requires through planning of production and procurement processes as a set. In addition to this, uniform key performance indicators, currently missing from the operation evaluation instructions, have to be set. The advised key performance indicators in regards to this thesis project are:
3. Average storage holding time (to be measured regularly), the aim being straight delivery to the installation point, or 3 days in average for inspection and distribution purposes. The measure shall be monitored separately for each priority group of the areas, as provided in material flow proposal per material group. This indicates the material holding time for long-term and intermediate storage. The later indicates the material holding right before the installation onto the vessel or vessel blocks, and therefore defines the efficiency of production progress in these installation points.
4. Setting the home-call delivery practice in the company procurement policy for implementation at major part of goods deliveries. Home-call delivery practice in this case means maximum storage time of the goods at the supplier's premises. Performance indicator is the number of home-call delivery practice contracted in comparison to the overall material contract number.
5. Usage indicator measured in average filling percentage per each area. When monitored regularly, such indicator provides valuable information on the storage area usage feasibility and can be used as deciding factor for area purpose assignment, as well as for location optimization.
6. General transportation time to each of the nodes of the shipyard has to be measured for indication of bottleneck points and used for further improvement of material supply routing.
7. The availability of the information of the usage of areas initially dedicated for logistics and maintenance purposes is rather poor. However, the percentage of these areas in comparison to the whole territory of the shipyard is rather high. There is a separate research needed to define the usage percentage of each of such storage areas in order to be able arrange additional storage space for vessel project material, and possibly organize additional production facilities, such as piping or assembly workshops.
8. The major part of current storage value holding monitoring is currently done manually, and is not in easy access for the rest of the departments of the shipyard. Consideration of usage of technology, such as RFID tagging, or similar, has to be done in order to get the information of the material availability and delivery timing accessible for representatives of procurement and production departments.
9. Proposal for more efficient space utilization requiring additional investments: establishment of loading and installation points on the left-hand side of the dry dock. This option, however, entails separate layout planning procedure.

The proposal described in the table above is built according to the received data during the current state analysis stage and development stage interviews, incorporating the best practices found and analyzed from the existing literature on the best practices of layout and material flow planning specially for shipbuilding industry. The proposal is presented to the management of case company in order to realize the additional practical constraints of application of such layout and material flow plan to the operations of this particular shipyard and correct the final proposal accordingly. Validation process of this proposal is presented in the next section.

6 Validation of the Proposal

This section describes the validation process of the conducted layout and material flow rooting plan. The proposal draft developed in the previous Section five is presented to the procurement and logistics management of the case company in order to receive the feedback on possibility of practical implementation of these plans and correct built the final proposal taking into account the received requests.

The draft proposal is built according to the best practices found in the literature on layout and material flow planning for shipyards described in conceptual framework, bringing together approach of systematic layout planning for heavy industry, metaheuristic approach of facility layout planning problems with large amount of data entities and constraints. The principles are applied to the geographical, strategic and production planning data gathered during the current state analysis, complemented with analysis and development of the data sets received by quantitative surveys, such as distance and priority setting of storage areas, and management interviews during the development stage of this thesis. When proposed to the management, the proposal was evaluated as complying with the main objective of this project, improving the usage of the facilities and territory of the shipyard and more efficient facilitation of the core production process. One of the main questions regarding the ability of the shipyard to accommodate the worst-case scenario storage demand for two overlapping in terms of production period projects as long as the vessel block production is outsourced. Therefore, the validation stage is rather light and majorly includes the discussion of suggestions for further improvement.

6.1 Evaluation

The objective set for this project is to develop a shipyard layout and material flow plan in terms of logistics processes for the new territory. The objective underline includes planning of the shipyard layout and material flow routing in such a way that the shipyard would be able to facilitate the production process within the reduced territory of the vessel projects available in the order book. It has been defined that in current setting of procurement decisions, mainly including outsourcing the vessel block fabrication and division of material to be installed to vessel blocks before delivery to the shipyard, the proposed layout of storage areas is able to accommodate the storage needs for the given production plan and have a reserve of approximately 20%. However, in case the vessel block fabrication supplier experiences the need for changes in delivery schedule of the goods or the scope of outfitting and surface treatment of vessel blocks will be shifted to responsibility of the shipyard, the layout accommodation capacity reaches its critical point.

Application of JIT approach, which has been revealed as one of the most important during the interview stage of current state analysis, has been taken into account in layout and material flow routing plan. Therefore, the proposal satisfies this requirement sufficiently. The critical groups of material are defined in order to focus the monitoring of procurement and logistics processes in relation to these items more efficiently.

The routing plan considers specifics of the shipyard operations and is provided in a usable generalized form. Running or route planning program is not feasible for each of the transportation case due to high workload of the logistics workforce, and therefore the plan is provided in a form of priority listing for each of the material groups.

To conclude, the proposed layout and material flow plan satisfies the set objectives and proposes solutions for recognized problematic points in logistics processes at the shipyard. However, some of additional development are suggested by the case company management for higher improvement grade and effect.

6.2 Improvement suggestions from management

The management of the case company is in general satisfied with the proposed layout and material flow routing plan, and considers application of most of suggestions to the actual operation. However, there are some opinions suggested to be implemented into the final proposal. These suggestions are presented in the table below.

Table 14 Improvement suggestions from management 2/2

	Key focus area	Suggestions from management	Description of the suggestion
1	Definition of critical material groups	Vessel block material group to be set as the most critical for evaluation of weight factors	By the opinion of the Vice President of procurement and logistics department, the vessel block material group is the most critical due to the scaling of singular batch allocation and movement, and most importantly due to historically proved challenges in the delivery timing of vessel blocks. The vessel blocks fabrication is normally outsourced, and in case the delivery of these is delayed or complicated by the undelivered scope of outfitting or painting

			services, it causes a high special demand for storage of vessel blocks at the shipyard.
2	Assignment of purpose of the storage areas	Revise the purposes of storage areas according to actual usage	The logistics and warehouse managers have revised the assignment of usage purposes of some reviewed storage areas to actual usage of those, which is slightly differing from the information delivered by storage area responsibility plan established earlier. Revision of this information affects the area importance calculation and routing priority setting.
3	Allocation of core facilities	Consider allocation of the main material receiving facilities and the number of them for future development purposes	The current setting of shipyard layout considers only one gate for incoming facilities and loading points of dry-dock. However, there is a need for consideration of additional receiving gate and loading points of dry dock. The Vice president of procurement and logistics department suggest consideration of such cases for the future development projects. This request has been filed at late stage of development process, and therefore can be considered only in suggestions for future development.

6.3 Developments to the initial layout and material flow plan proposal

The final proposal is modified in accordance with the development suggestions from the management of the case company. These ideas are mostly regarding the suggestions for further improvements.

However, the suggestion upon establishment of the second gate for incoming materials as well as the establishment of additional loading points at the dry dock has been ran using the same set of data used for material flow routing with modified input upon core facilities and infrastructure constraints. The loading points are considered the same as current, but mirrored to the left-hand side of the dry dock.

The layout plan in this case requires a separate planning process and therefore is not included into this thesis, but the approximate location of the receiving dock in this case is recognized using the intelligent water drop algorithm as a centermost point of material flows intersection. The proposal for location of the receiving dock is presented in the final proposal section of this thesis.

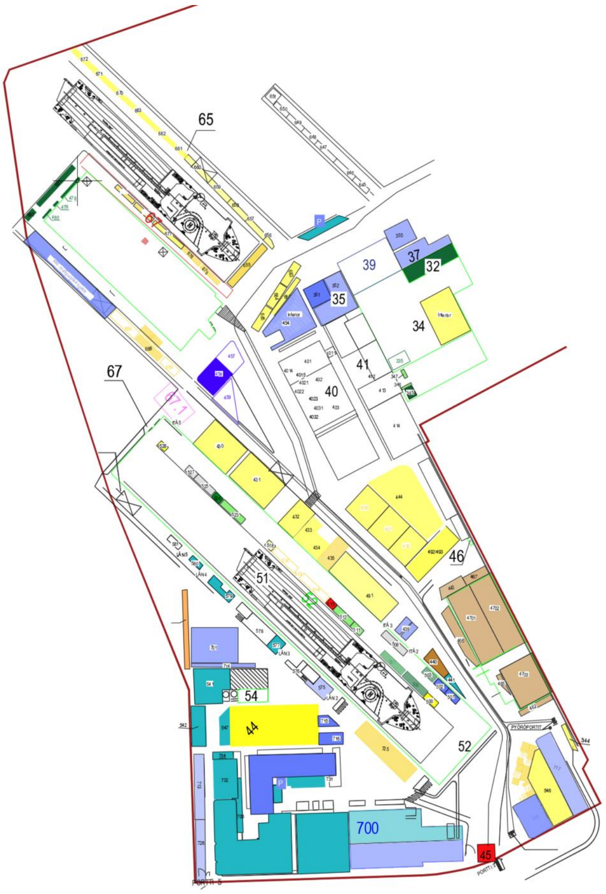
6.4 Final Proposal

The final proposal is built by modification of the first proposal draft according to management suggestion and is presented in three parts: layout plan with listing of changes, material flow plan and further improvement suggestion list.

6.4.1 Layout plan

The following table presents the final proposal on the shipyard layout plan in the format provided to the case company.

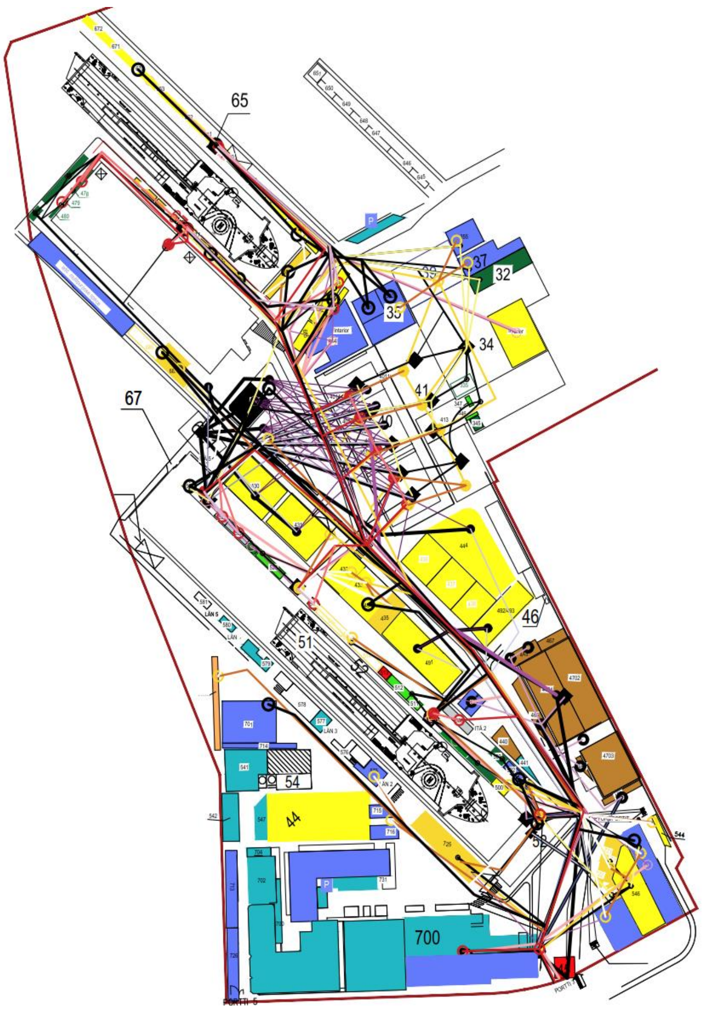
Table 15 Final proposal - Layout plan

<table>
<tr><th>Proposal visually</th><th>Changes listing</th></tr>
<tr><td rowspan="5">The visual representation of the proposal is provided as a set of AutoCAD and PDF- format files.
</td><td>The centermost and prospectively allowing for transportation with minimum amount of obstacles area shall be utilized for storage of blocks</td></tr>
<tr><td>Location of covered storage area 44 to be used for project-related block or interior material</td></tr>
<tr><td>Additional areas: 454 and partly 34 for project-related storage (advantageous location)</td></tr>
<tr><td>Aim at utilization of south-west part for maintenance and long-term storage</td></tr>
<tr><td>Changes in goods material assignment:
- 701 (general logistics purpose) to be replaced with 545 (general log. purpose) and 546 (hull assembly purpose)
- 713 (general log. purpose) to be replaced with 725 (hull assembly purpose)</td></tr>
</table>

6.4.2 Material flow plan

The following table presents the final proposal on the shipyard layout plan in the format provided to the case company.

Table 16 Final proposal - material flow plan

Proposal visually	**Priority setting per material group**
The visual representation of the proposal is provided as a set of AutoCAD and PDF- format files, detailed per each material group.  	1. Vessel blocks Priority 1 Priority 2 Priority 3 Priority 4
	2. Interior material Priority 1 Priority 2 Priority 3
	3. HVAC material Priority 1 Priority 2 Priority 3
	4. Machinery Priority 1 Priority 2 Priority 3
	5. Deck material Priority 1 Priority 2 Priority 3
	6. Electrical material Priority 1 Priority 2 Priority 3
	7. Painting material Priority 1 Priority 2 Priority 3

6.4.3 Further improvement suggestions

1. Interior material group is expected to cause overflow of material to the available storage areas dedicated for this material group. Even though the proposed layout considers such complication, as well as proposes additional areas for storage of interior material, the management should consider outsourcing of part of interior material storage and assembly services in order to minimize the period and the volume of the material stored at shipyard.
2. JIT approach for timely supply to the installation process is incorporated in the planning as a part of weighted area closeness calculation in terms of prioritizing and minimization of the travel distance to the merging points with production, but practical application of this principle at the shipyard requires through planning of production and procurement processes as a set. In addition to this, uniform key performance indicators, currently missing from the operation evaluation instructions, have to be set. The advised key performance indicators in regards to this thesis project are:
    a) Average storage holding time (to be measured regularly), the aim being straight delivery to the installation point, or 3 days in average for inspection and distribution purposes. The measure shall be monitored separately for each priority group of the areas, as provided in material flow proposal per material group. This indicates the material holding time for long-term and intermediate storage. The later indicates the material holding right before the installation onto the vessel or vessel blocks, and therefore defines the efficiency of production progress in these installation points.
    b) Setting the home-call delivery practice in the company procurement policy for implementation at major part of goods deliveries. Home-call delivery practice in this case means maximum storage time of the goods at the supplier's premises. Performance indicator is the number of home-call delivery practice contracted in comparison to the overall material contract number.
    c) Usage indicator measured in average filling percentage per each area. When monitored regularly, such indicator provides valuable information on the storage area usage feasibility and can be used as deciding factor for area purpose assignment, as well as for location optimization.
    d) Average transportation time to each of the nodes of the shipyard has to be measured for indication of bottleneck points and used for further improvement of material supply routing.
3. The availability of the information of the usage of areas initially dedicated for logistics and maintenance purposes is rather poor. However, the percentage of these areas in comparison to the whole territory of the shipyard is rather high. There is a separate research needed to define the usage percentage of each of such storage areas in order to be able arrange additional storage space for vessel project material, and possibly organize additional production facilities, such as piping or assembly workshops.
4. The major part of current storage value holding monitoring is currently done manually, and is not in easy access for the rest of the departments of the shipyard. Consideration of usage of technology, such as RFID tagging, or similar, has to be done in order to get the information of the material availability and delivery timing accessible for representatives of procurement and production departments.

5. Proposal for more efficient space utilization requiring additional investments:
6. establishment of loading and installation points on the left-hand side of the dry dock for better utilization of available storage areas
7. establishment of second gate for incoming materials. The layout and material flow plan proposal considers the Gate 3 as the main and only receiving point of all material groups except for vessel blocks. Due to spatial limitations of infrastructure for transportation of the materials from Gate 5 to the dry dock, the transport mode selection is limited to truck mode. However, as per the suggestion regarded in the previous point (a), in case the loading points are arranged at the left-hand side of the dry dock, the receiving dock for material coming in through the gate 5 by route optimization algorithm shall be placed at centermost point of the dry-dock, main storage and most of storage areas in this part of the shipyard. Therefore, the suggestion is to place the receiving dock at the point marked on the layout proposal map as area 44. The position is also presented in the following figure.

Figure 24 Proposed location for second receiving dock

However, in case any of the arrangements regarded as (a) and (b) in this listing under point 9 are to be realized, the layout and routing plan has to be revised as a separate planning project, as the weight and distance dependence of the storage area and routing arrangement changes drastically.

7 Conclusions

This section contains the results of this thesis project, explaining the achievement of initial objectives and the ones set during development process.

7.1 Executive Summary

The initially set objective of this thesis is *to develop the layout and material flow plan of a shipyard in terms of logistics processes.* Additionally, during development stage of this project the management has set the objective on development of starting setting for further improvements of logistics processes in terms of core facilities and storage areas allocation, as well as ideas for key performance indicator setting.

The need for this thesis project is caused by reduction of its premises and is losing a large share of storage space dedicated for accommodation of material required for production of the vessels contained in the existing order book. The current state analysis revealed that the setting of core facilities does not change significantly, and therefore the focus of the layout and material flow planning is set on optimal allocation of storage area dedicated for purposes of planned production for two vessel projects.

During the current state analysis, the overall logistics processes of the shipyard, as well as their position in the supply chain have been analyzed and revealed a relatively adequate strategic efficiency. However, deeper analysis in combination with overview of operating instruction and performed interviews of the procurement and logistics management representatives has shown that the awareness of logistics practices and key performance indicators throughout the workforce of differentiating department is rather low and requires arrangement of higher grade of transparency and workforce education.

In order to define the scope for which the best existing practices of shipyard layout and material flow routing planning need to be defined, the current state analysis included gathering of the available quantitative data. Shipyard operations are generally characterized by a large volume of scattered data, availability of which is questionable. In this particular case the information made available for the development project has appeared to be the metric volume and scheduling of vessel block supplies and separately a weight calculation of the planned vessels. In order to defined the scheduling and storage demand of the planned production, the weight calculation of the planned projects has been compared to the production process of the two similar previously built vessel. In such way, the material supply and installation scheduling, storage holding times, as well as metric volumes of the material per material group is established in proportion to the historically available data. Analysis and comparison of this data also revealed that the most critical material groups, being vessel blocks and interior material.

Based on the information type made available for this project, the best existing practices on layout planning and material flow routing have been reviewed. It turns out, the available literature specifically for shipyard operations is rather limited. Thus, the conceptual framework for layout planning is formed as a combination of systematic layout planning and metaheuristic facility layout and optimization principles with shipyard layout hierarchical modelling and shipyard layout design based on simulation. For material flow routing the conceptual framework combines practices of route optimization by use of intelligent water drop algorithm and material distribution practices in shipyards.

Integration of the best existing practices found in the available literature and the data gathered during the current state analysis results in development of the set of calculated data on the spatial allocation of existing facilities and storage areas, travel distance relations and the weighted closeness relationship between production facilities and storage areas. The weighted closeness relationship matrix takes into account the material flow intensity to and from each of the storage areas in terms of volume and schedule; usage of storage area for the initially dedicated purpose; demand for the storage by project requirements in relation to flow intensity and storage area availability; the importance of closeness of each area to core production facilities.

The optimization objective in both layout and material flow plan is to minimize the travel distance between the storage areas and core production facilities, while maximizing the set of weight factors. The generated data sets are characterized by a large number of entities and constraints, which limits the possibility of optimization of this data using manual calculation or exploitation of primitive optimization tools. Therefore, the data sets are transformed into format of python programming language and run using the corresponding publicly available program.

The layout planning procedure using the relationship charting, modified to include constraints, and application of these results in accordance with systematic layout planning resulted in a number of layout suggestions. The algorithm constructed for this problem aims at placing the most prioritized storage area to the centermost point of intersection of major material flow routes in between the core production facilities. When the constraints regarding the fixed location of core facilities and required infrastructure are applied, the few suggestions are generalized into one layout plan proposal, including the list of changes for better comprehension. The proposed layout solves the problem of allocation of storage areas for most critical material groups, being vessel blocks and interior material by placement of these closest to their supposed installation points. By optimization of the space usage, a share of territory is made available for placement of additional storage spaces for the needed material groups. Additionally, the layout proposes utilization of the space closest to installation or loading points for the project material rather than for maintenance or shipyard's own material storage.

By utilizing the proposed layout data sets the material flow routing is done by intelligent water drop algorithm. Application of this algorithm to the shipyard material flow movement as described in the Section 5, produces an optimal sequence of the areas to be visited and provided with the certain amount of material over a certain time period. Generalizing these results culminates in material flow route suggestion per each material group, which indicates the choice prioritizing for the transporter. In other words, the transporter has a set of areas where the material is best to be delivered to for facilitation of production process, as long as the storage area is vacant. In case the areas are occupied, the decision moves to the second priority set of areas. In this way, the material distribution routing is optimized, yet modified to comprehensive format for usage of the logistics workforce in the given circumstances.

In order to maximize the efficiency of the application of the developed layout and material flow routing plan, the case company shall consider the definition of the key performance indicators, ways of measurement, monitoring and delivery of such to the workforce throughout the company. Therefore, a list of further improvement suggestion is generated, including main key performance indicators and application of up-to-date technology for transparency of storage-related planning data. After validation meeting with the management, the layout proposal is completed with a brief suggestion on further improvement of space usage, which requires additional planning and investments.

Overall, the final layout and material flow routing proposal is evaluated as a valuable and applicable solution. It will be further enhanced with additional improvement projects, including key performance indicator setting and planning of possible additional facilities before application.

The shipyard operation is undoubtedly depending on the smoothness of the supply process and experiences considerable economic losses in cases the project production process is delayed. Application of the proposed layout is likely to enhance the efficiency of intralogistics and shorten the supply time of the material to the corresponding production facility, supposedly increasing the savings and customer satisfaction in a long run.

7.2 Thesis Evaluation

Summarizing the assessment of the performed study, this thesis project has met its initial objective. The layout and specific material flow plan have been generated fulfilling the needs of the shipyard in the conception of set requirements and changes. However, there are multiple problems revealed during the current state analysis that appear to be affecting the efficiency of logistics processes and have not been addressed within this thesis. Such problems include direct application of JIT principle to logistics processes, key performance indicator setting. The question of legitimacy of this solution in comparison to the other existing challenges is controversial. Nevertheless, the project results do have a significant abstract effect on the performance of the shipyard's production process. Maximum improvement of the shipyard logistics operation requires a large number of additional relative development project, necessitating involvement of a group of professionals, data measurement and time resources.

This particular development project was complicated by restricted availability of initial input data and lack of possibility for direct communication. Providing constructive criticism, the use of greater number of interviews especially on the thesis objective matter rather than evaluation of logistics processes in general, would have brought more validity, reliability and logic to the thesis. Additionally, in case quantitative research on site would be started at early stage of the thesis project and results of it would be approved and discussed with the case company management on more detailed level, the results would have been more exact and providing more practical suggestions.

In order to perform objective evaluation of this thesis project, such evaluation criteria as validity, reliability, logic and relevance have been chosen. Evaluation by each of the chosen criteria is presented in following sub-sections.

7.2.1 Validity

Validity evaluation criteria measures how well the research and analysis methods are applicable to the objective of this particular thesis work. (Elvik, 1999). In this particular case, as mentioned before, there are multiple problems detected in logistics processes of the case company. It is however true, that the company management has set the objective on building an updated layout. So, even though by different opinions the objective of this thesis might not address the main problems of the shipyard logistics operations, it is rather relevant in the given circumstances of inevitable changes in available premises.

The research methods chosen for performance of this thesis project include applied action research and quantitative research on site. In this particular environment, where the smoothness of processes is vital to the core activity, and requires attendance of the researcher to the process evaluation on site, there is no more appropriate methods of conducting research for layout planning. Whether these methods were kept in the correct proportion is defined by the availability of the resources and data. In this particular case it is considered to be more quantitative than action research, which is in my opinion more applicable to the required result, as the solution method is rather mathematical.

7.2.2 Reliability

Research is evaluated as reliable when it provides a rational and stable result (Carmines and Zeller, 1979). Moreover, reliability can be viewed as the truthfulness of the used methods and data used for the research. Regarding this matter, this particular thesis has relied on reliable sources, which provide the academically proven information on methods and data gathering techniques especially framed for heavy industry and shipbuilding industry. The used practices are aligned with the objective of this thesis and the available data gathering and analysis methods.

Since the layout design and material flow optimization problem in terms of shipbuilding is regarded as an NP-hard problem, the applied metaheuristic development methods do not provide an exact optimum solution. Therefore, even though the reliability of the gathered data is on a high level, since it is the set of statistical data received from class-approved vessel weight and scheduling calculations, the results are rather generalized and cannot be regarded as solely possible solution.

By different opinion, the reliability of research can be measured in comparison to the similar academic works (Dudovskiy, 2018). When compared to limited number of similar academic works on shipyard layout planning and material flow optimization, the methods used and the results received are evaluated to be comparable and complementing each other. This thesis project focuses more on the specifics of shipyard operations and proposes solution drawn from the best available practices in general.

7.2.3 Logic

The logic of the thesis is evaluated as sufficient, when the solution and description of it logically answer the research question and relates to the theory in question. (University of Jyväskylä, 2014) While logic criteria definition is close to reliability criteria, the difference is in consistency of structure of the thesis. Thus, the thesis work is considered to answer the logic requirement, when the research and development stages logically explain to the reader the idea of the research problem, describe the applicable data gathering methods, explain the available practices and guide to drawing up the corresponding solution in understandable and reasoned manner. In this case, the thesis explains the drives for the need for layout planning, presents the types of data available for analysis and describes the limitations of this process. Further, based on the data made available, the theory research is conducted accordingly. As the availability of theoretical knowledge is not sufficient for formulation of valid solution, the theoretical research is expanded to wider perspective. Consequently, the available data is analyzed and formatted according to the available practices and narrowed down to a generalized optimum result, which eventually meets the set objective.

Nonetheless, the current state analysis focuses on detailed process efficiency evaluation, and the interview content is rather broad. Even though the mentioned current state analysis practices assisted in appraisal of process weaknesses for future development, the results of those are not connected directly to the development process of this thesis. Therefore, the structural logic of this thesis is evaluated as average.

7.2.4 Relevance

The relevance of any academic work is understood as the theoretical and practical usefulness of it to the industry, educational institutes and professional field in general. Since the theory on shipyard operations optimization is rather limited, this thesis provides a valuable input to the theoretical scope especially for shipbuilding industry. Being focused on rather narrow set of problems, it still provides the clear instruction on layout planning and material flow routing procedures in the restricted data availability and comparatively constrained circumstances. Thus, the relevance of this project to the shipbuilding industry is evaluated as relatively high.

7.3 Closing Words

Summarizing the performed research and development process, this thesis provides an overview of the practices applicable to shipyard operations in the environment of restricted data and constrained development opportunities. While the results are rather general, they do solve the set problem and impact on the core production process. By employment of generously made available human and database resources of the case company, the author of the thesis has been given an opportunity to apply the academic and practical knowledge on industrial and logistics management, improving the professional skills and expectedly bringing more value to the intelligent property of the shipyard.

References

Blanchard B.S. “System engineering Management”, *Third edition.* 2004

Cakravastia, A., Diawati, L. (1999), “Development of system dynamic model to diagnose the logistic chain performance of shipbuilding industry in Indonesia”

Chen G,.m Jiang Y, Sheng X, Jingquan W., Hui J., “Workstation-oriented distribution optimization of shipbuilding materials” 2019

Chen GY-H, “Multi-objective evaluation of dynamic facility layout using ant colony algorithm” 2007

Deroussi L., “Metaheuristics for Logistics” *Volume 4.* 2016

Dudovskiy J., “The Ultimate Guide to Writing a Dissertation in Business Studies: A Step-by-Step Assistance”, 2018

Dwivedi, S.N., Crisp, J. “Current trends in material management in the shipbuilding industry*”, International Journal of Computer Application*, 2003

Elvik R., “Assessing the Validity of Evaluation Research by Means of Meta-Analysis”, Rune Elvik, 1999

Ezugwu A.E., Akutsah F., Olusanya M.O., Adewumi A.O., “Enhanced intelligent water drops algorithm for multi-depot vehicle routing problem” 2018

Holland J.H., “Genetic algorithms and classifier systems: Foundations and future directions” 1987

Kananen J. “Design Research as Thesis Research”. 2013

Matulja, T., “Hierarchical Modeling as Basis for an Optimal Shipyard Layout Design Methodology” 2009

Muther R., Hales L. “Systematic layout planning” *Fifth edition 2015*

Osman I.H., Laporte G., ”Metaheuristics: a bibliography” *Annals of Operations Research* 1996

Samarghandi H., Taabayan P., Behroozi M.,” Metaheuristics for fuzzy dynamic facility layout problem with unequal area constraints and closeness ratings” *The International Journal of Advanced Manufacturing Technology*. 2013

Saunders M., Lewis P., Thornhill A. “Research Methods for Business Students” *Fifth edition.* 2009

Schein E., “Process Consultation Revisited: Building and helping relationship”. 1999

Shah-Hosseini H., “The intelligent water drops algorithm: a nature-inspired swarmbased optimization algorithm," *International Journal of Bio-Inspired Computing*, 2009

Song Y.J, Lee D.G., Woo, J.H., Shin J.G., “A concept and framework for a shipyard layout design based on simulation”. *Journal of Ship Production*, 2009

Song Y.J, Lee D.G., Woo, J.H., Shin J.G., “A simulation-based capacity analysis of a block-assembly process in ship production. *Journal of the Society of Naval Architects of Korea*,

Song Y.J, Lee D.G., Woo, J.H., Shin J.G., “System development and applications of a shipyard layout design”. *Journal of Ship Production and Design*

Tao N., Cui X, Jiang Z., Chen Y., “Research and Application of Location Assignment and Routing Strategies in Block Storage Yard of Shipbuilding” 2012

UNIVERSITY OF JYVÄSKYLÄ, *Master’s thesis evaluation criteria,* 2014