Master's thesis

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Towards Effective Production Logistics at Ship Recycling Yards

Master's thesis in Mechanical Engineering
Supervisor: Marco Semini
June 2023

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Preface

This report concludes my Master's degree in Mechanical Engineering at the Department of Mechanical and Industrial Engineering (MTP) at the Norwegian University of Science and Technology (NTNU) in Trondheim.

I want to extend my deepest gratitude to my advisor, Marco Semini, for his invaluable guidance, insightful feedback, and unwavering commitment throughout the process of writing this thesis.

Further appreciation goes to Ingvild Jenssen, the CEO of NGO Shipbreaking Platform, for her receptiveness to the subject of this study and for connecting me with Johannes from AF Offshore Decom. I owe considerable thanks to Johannes, who generously provided a wealth of information about AF Offshore Decom and participated in an end-of-semester workshop with Elias, where the results were presented and deliberated.

Elias deserves special recognition for his hospitality during my visit to the base in Vats, his efforts in facilitating an insightful tour, and his availability for answering queries and organizing interviews with other staff members on-site.

A general note of thanks is extended to AF Offshore Decom for permitting the execution of this case study. I am grateful to all who contributed their information and engaged in discussions on the subject matter.

Fredrik Haugen Petersen

Trondheim, June 2023

Fredrik Haugen Petersen

Summary

This master's thesis explores the complex realm of ship recycling through the lens of production logistics, concentrating on AF Environmental Base Vats, one of the industry's foremost yards. It investigates the challenges and opportunities within this context and assesses the potential applicability of production logistics principles to enhance operational procedures.

The study begins by giving an overview of the ship recycling industry, highlighting the current scenario, associated issues, and the necessity for optimisation. It then narrows down to the specific context of the AF Environmental Base Vats, offering a comprehensive understanding of its operations and challenges.

A thorough investigation of the ship recycling processes details activities ranging from front running and actual dismantling to the segregation, storage, and recycling or reuse of materials. Emphasising the need for effective resource utilisation, waste minimisation, and safety, the study also outlines key challenges, such as yard size constraints and project variation.

The research includes an extensive literature review of various production logistics principles, theories, and methods. It assesses their potential applicability in ship recycling, drawing parallels with similar industries. A detailed analysis identified three methodologies, namely takt time combined with bottleneck analysis, visual management, and layout optimization, as particularly promising for ship recycling.

This study offers novel insights into how these principles can be adapted and utilised at AF Environmental Base Vats, potentially leading to enhanced material flow, better resource utilisation, and improved productivity. It comprehensively analyses how these methodologies can contribute to a more efficient, sustainable, and safe ship recycling industry.

This master's thesis significantly contributes by addressing an underexplored area of research and enhancing the understanding of ship recycling from a production logistics perspective. Its findings hold broad implications, extending beyond the specific yard studied, and serve as a valuable reference for further improvements in the global ship recycling industry.

Sammendrag

Denne masteroppgaven utforsker det komplekse området med skipsgjenvinning sett fra et produksjonslogistikk-perspektiv, med fokus på AF Environmental Base Vats, en av bransjens fremste verft. Oppgaven undersøker utfordringer og muligheter i denne sammenhengen og vurderer potensiell anvendbarhet av prinsipper fra produksjonslogistikk for å forbedre operative prosedyrer.

Studien starter med en oversikt over skipsgjenvinningsbransjen, der den fremhever nåværende scenario, relaterte problemer og nødvendigheten av optimalisering. Den fokuserer deretter på den spesifikke konteksten til AF Environmental Base Vats og gir en omfattende forståelse av virksomheten og utfordringene der.

Gjennom en grundig undersøkelse av skipsgjenvinningsprosesser beskriver oppgaven en rekke aktiviteter, fra forberedende arbeid og faktisk demontering til sortering, lagring og resirkulering eller gjenbruk av materialer. Med fokus på behovet for effektiv ressursbruk, redusering av sløsing, og sikkerhet, gir studien også en oversikt over sentrale utfordringer, som begrensninger på verftsstørrelse og prosjektvariasjon.

Forskningen inkluderer en omfattende gjennomgang av ulike prinsipper, teorier og metoder innen produksjonslogistikk. Den vurderer deres potensielle anvendbarhet innen skipsgjenvinning ved å trekke paralleller til lignende industrier. En grundig analyse førte til identifiseringen av tre metoder; takttid kombinert med flaskehalsanalyse, visuell styring og optimalisering av layout, som særlig lovende innen skipsgjenvinning.

Denne studien gir nye innsikter i hvordan disse prinsippene kan tilpasses og brukes ved AF Environmental Base Vats, som potensielt kan føre til en bedre materialflyt, bedre ressursutnyttelse og økt produktivitet. Den gir en grundig analyse av hvordan disse metodene kan bidra til en mer effektiv, bærekraftig og sikker skipsgjenvinningsindustri.

Denne masteroppgaven gir et betydelig bidrag ved å adressere et lite utforsket forskningsområde og øke forståelsen for skipsgjenvinning sett fra et produksjonslogistikkperspektiv. Funnene har implikasjoner som strekker seg utover det spesifikke verftet som ble studert og fungerer som en verdifull referanse for videre forbedringer i den globale skipsgjenvinningsindustrien.

Abbreviations

ATO	Assemble-to-Order
CONWIP	Constant Work In Process
EOL	End-of-Life
ETO	Engineer-to-Order
EU	European Union
EUSRR	European Union Ship Recycling Regulation
FPSO	Floating Production, Storage and Offloading
HKC	Hong Kong Convention
HSE	Health, Safety and Environment
IHM	Inventory of Hazardous Materials
ILO	International Labour Office
IMO	International Maritime Organization
JIT	Just-in-Time
LDT	Light Displacement Tonnage
MTO	Make-to-Order
MTS	Make-to-Stock
NEVS	Non-Economic Value Stream
NGO	Non-Governmental Organization
NORM	Naturally Occurring Radioactive Materials
OECD	Organization for Economic Cooperation and Development
PCB	Polychlorinated Biphenyls
SJA	Safe Job Analyses
SMED	Single-Minute Exchange of Die
SPMT	Self-Propelled Modular Transporter
SRFP	Ship Recycling Facility Plan
SRP	Ship Recycling Plan
TPS	Toyota Production System
TQM	Total Quality Management
WEEE	Waste Electrical and Electronic Equipment
WSR	Waste Shipment Regulation

Table of Contents

List of Figures

List of Tables

1 Introduction

The first chapter serves as an introductory section to the master's thesis, providing an overview of the research topic and emphasising its importance in driving industry change. It commences with a discussion of the background and motivation behind the study, shedding light on the challenges and complexities associated with ship recycling. Following this, the research questions are presented alongside the objectives, which serve as a guiding framework for the thesis, aiming to address these questions.

Furthermore, an outline of the subsequent chapters is provided, delineating the structure and content of the thesis. This chapter ensures that readers understand the research's purpose and significance, along with insights into the current state of ship recycling.

1.1 Background and Motivation

Ship recycling involves the dismantling of end-of-life ships and sorting their components based on what can be discarded and what can be reused. The decision to recycle a ship is influenced by various factors, including the introduction of new innovative technologies and changes in trade patterns (Mikelis 2019). Vessels recycled today are often old and contain hazardous waste that must be handled safely for the operators and the environment. Therefore, ship recycling yards must have methods and guidelines for handling hazardous waste. Unfortunately, this is not always the case, as there are varying standards among shipyards, both within a country and especially across borders and continents.

Several regulations have been introduced or attempted to be submitted by organisations such as the International Maritime Organization (IMO) and the European Union (EU), as this is a dangerous job, and operators are exposed to toxic substances. However, bypassing these regulations and recycling a ship at yards that do not meet high enough standards is still possible. A ship owner can sell their ship to a cash buyer who changes the ship's flag and sells it further to less reputable shipyards without the ship owner being held accountable. Over half of the ships sold to South Asia in 2022 changed their flag to countries such as Cameroon, Comoros, Palau, St. Kitts and Nevis, and Tanzania, often just weeks before the ships arrived on the beaches (Mulinaris 2023). The IMO has attempted to create an international regulatory framework in the form of the Hong Kong Convention, which has been criticised and has not entered into force as it lacks ratification. The EU did not want to wait for a flawed regulation to come into force, so they created their own based on it but with higher standards. This is called the European Union Ship Recycling Regulation, and it must be followed to become an approved shipyard on the European List of Ship Recycling Facilities. Compliance with the EUSRR should be an absolute minimum for everyone involved in the industry. For ship recycling to become a sustainable value chain, it relies on countries and companies adopting national and international rules and conventions to protect the environment and operators (Sánchez Ocampo and Pereira 2019).

The worst method of ship recycling is beaching, which mainly occurs in Bangladesh, India, and Pakistan. The ships are dragged onto beaches, dismantled, and their components are sold in local markets. Due to the open layout of this process, it is challenging to control hazardous waste and gases such as asbestos. Operators are exposed to these hazards, and the surrounding environment is affected by this lack of control. In Norway, continuous tests are conducted in the surroundings of ship recycling yards, and the results are publicly available, but this is not the case in areas where beaching is practised. In 2022, 80 per cent of the global end-of-life gross tonnage ended up in these three countries. In Chattogram, Bangladesh, there were reports of at least ten fatalities and 33 injuries due to shipbreaking activities in 2022 (NGO Shipbreaking Platform 2022). In 2004, the International Labour Organization (ILO) called this one of the most dangerous activities in the world. The current practices of beaching are unacceptable in any way and must be changed (International Labour Office 2004).

Better methods are used in developed countries, and there is more transparency between ship recycling yards. To be able to recycle EU-flagged ships, a yard has to be on the EUSRR list, which means the yard has to meet a certain standard to be able to accept ships. Of course, it costs more to run the yards as there is a much higher focus on the employees and the surrounding environment. In the top ship recycling yards in Europe, HSE (Health, Safety and Environment) is very much at the centre. This requires extra time and costs more than if there had not been the same focus. This is just one factor that makes it challenging to outcompete the developing countries on price. We see an increasing focus on being environmentally friendly in the industry and that NGOs are increasingly singling out shipowners who choose shipyards practising beaching. This paper focuses on high-standard shipyards and will try to contribute to their development to become even more efficient and competitive. Competing on price against yards with much lower standards will always be challenging. However, if regulations continue to evolve and there is more pressure to choose those with high standards, those that have invested early in an environmentally friendly yard will be highly sought after.

Production logistics is a critical domain within the broader field of supply chain management, with a focus on efficient planning, execution, and management of physical and informational flows in production processes. It involves optimising production processes and operational performance to achieve desired outcomes. Production logistics principles and theories have traditionally been associated with manufacturing, particularly mass production. However, these concepts are increasingly being applied to other forms of production, such as Engineer-to-Order (ETO) and project-based production. Research has shown the impact of production logistics in industries such as shipbuilding and construction, where concepts like lean shipbuilding and lean construction have gained prominence. This thesis aims to explore the potential applicability of production logistics in the context of ship recycling.

The motivation for the thesis has always been to contribute to making Norwegian ship recycling more efficient. Regulations in this industry are becoming increasingly strict, but 80 per cent of vessels still end up on beaches in Asia (Mulinaris 2023). The aim is that this study can contribute to a better and more sustainable ship recycling industry.

1.2 Research Questions and Objective

The main research objective of this master's thesis is to advance the researcher's understanding of ship recycling yards, pinpoint areas for enhancement, and explore the potential contributions of production logistics in facilitating these improvements. The following research questions have been formulated to guide the inquiry and knowledge development process.

RQ1: How is ship recycling carried out from a production logistics perspective?

The first research question investigates the ship recycling process from a production logistics perspective. This inquiry centres on the logistical aspects associated with ship recycling, encompassing the methods of dismantling, processing and managing ships as they approach the end of their lifecycle, with particular attention to the production-related facets of the process. From a production logistics standpoint, ship recycling encompasses a multifaceted series of meticulously planned and executed activities to ensure efficient and effective dismantling and disposal of ships while minimising environmental impacts and ensuring worker safety. These activities may include decontamination, cutting and separating various ship components, handling and disposing of hazardous materials, and recycling or repurposing salvageable materials. Gaining a thorough understanding of the production logistics perspective of ship recycling is paramount for identifying opportunities to enhance efficiency, sustainability, and safety in the ship recycling process. It can provide insights into the challenges and prospects associated with ship recycling operations and inform decision-makers about potential areas for innovation and improvement within the industry. Furthermore, research findings on this topic can contribute to developing guidelines, standards, and best practices for sustainable ship recycling, which can benefit the maritime industry as a whole.

A two-day site visit will be conducted at the AF Environmental Base Vats to address this research question. During the visit, interviews will be conducted with employees responsible for various tasks related to ship recycling, and a guided tour of the yard will be shown with explanations provided on the production processes. Following the site visit, ongoing communication will be maintained with employees of AF Offshore Decom through digital meetings to verify the information and discuss potential opportunities.

RQ2: Which principles, theories and methods from production logistics can potentially be applicable at ship recycling yards?

The second research question aims to identify and analyse the applicability of production logistics principles, theories and methods within the unique operational context of ship recycling yards. This research question investigates the potential transferability of established production logistics concepts to the specific processes involved in dismantling and disposing of ships in ship recycling yards. The research may involve conducting a comprehensive review of existing literature on production logistics, specifically examining relevant concepts, principles, and theories. This analysis will focus on how these concepts could be adapted or applied to the distinct operational environment of ship recycling yards. Some relevant concepts that may be explored include process optimisation, production planning and scheduling, inventory management, transportation and logistics, material handling, and waste management.

The ultimate objective of this research question is to identify potential opportunities for enhancing the operational efficiency, sustainability, and safety of ship recycling yards by applying established production logistics concepts, principles, and theories. This investigation will contribute to understanding how production logistics approaches can be effectively utilised in the unique context of ship recycling and may inform the development of strategies and practices to optimise ship recycling operations.

RQ3: How can the most suitable principles, theories and methods identified from production logistics be utilised at AF Environmental Base Vats?

The third research question aims to investigate the practical application of the principles, theories and methods from the field of production logistics, which were identified in response to RQ2, within the specific context of ship recycling yards. RQ3 centres on the application and operationalisation of the identified production logistics principles in ship recycling yards. The anticipated findings from RQ3 are expected to yield practical guidance on the effective application of production logistics principles in the unique operational environment of ship recycling yards. Furthermore, the findings shed light on how these principles can improve the operational efficiency, sustainability, and safety of ship recycling.

RQ3 will be an amalgamation of RQ1 and RQ2, focusing on the application of production logistics at AF Offshore Decom. The most promising principles, theories and methods identified in response to RQ2 will be elaborated upon in detail, specifically discussing how they could be applied at AF Environmental Base Vats.

1.3 Research Scope

The research scope of this study is limited to the applicability of production logistics concepts in the ship recycling industry, specifically focusing on the AF Environmental Base Vats. The scope is restricted to this recycling yard but aims to provide insights and recommendations applicable to the broader industry. The study excludes processes occurring before a ship arrives at the yard or after dismantling and sorting.

The research does not examine Industry 4.0 or the various new technologies, as another researcher from NTNU is concurrently investigating that aspect. At the same time, this study focuses solely on the applicability of traditional production logistics concepts in their original form. The study aims to offer insights and suggestions to optimise the material and information flow within ship recycling yards.

The production logistics concepts included in this study primarily encompass the following identified and relevant concepts: kanban, CONWIP, takt time, visual management, SMED, just-in-time, total quality management, layout optimisation, bottleneck analysis, and kitting.

1.4 Research Outline

This thesis is structured as follows:

Chapter 1 provides the background of the study and outlines its objectives. It establishes the context and purpose of the research.

Chapter 2 explains the research methodology and the methods employed. The main methods used include a literature review and case study analysis.

Chapter 3 presents the theoretical framework in a two-part format. The first part focuses exclusively on ship recycling, providing necessary background knowledge. The second part discusses the production logistics theory, exploring various concepts within this field.

Chapter 4 presents the findings from the case study. It begins by introducing the company, followed by insights into its processes and logistics. Finally, it provides an overview of the company's current utilization of production logistics.

Chapter 5 presents the results of the study. It examines the applicability of production logistics concepts in ship recycling, explains the selection process for specific concepts, and proposes how the case company can implement these concepts.

Chapter 6 is the discussion chapter where the results are critically analyzed, and their implications are examined. It also reflects on the insights and knowledge gained from the study. Lastly, based on the study findings, it offers suggestions for the ship recycling industry.

Chapter 7 concludes the thesis by summarizing the answers to each research question, highlighting the study's contributions, discussing its limitations, and providing suggestions for further research.

Figure 1 depicts the relationship between the research questions and the chapters in the master's thesis. Chapter 3 establishes the theoretical framework for ship recycling, forming the basis for the subsequent case study conducted in Chapter 4. The case study addresses RQ1. Building upon the insights gained from RQ1 and the literature review on production logistics in Chapter 3, RQ2 is investigated. The answers to RQ1 and RQ2 are then utilised to address RQ3, further explored in the results presented in Chapter 5 and subsequent chapters of the thesis.

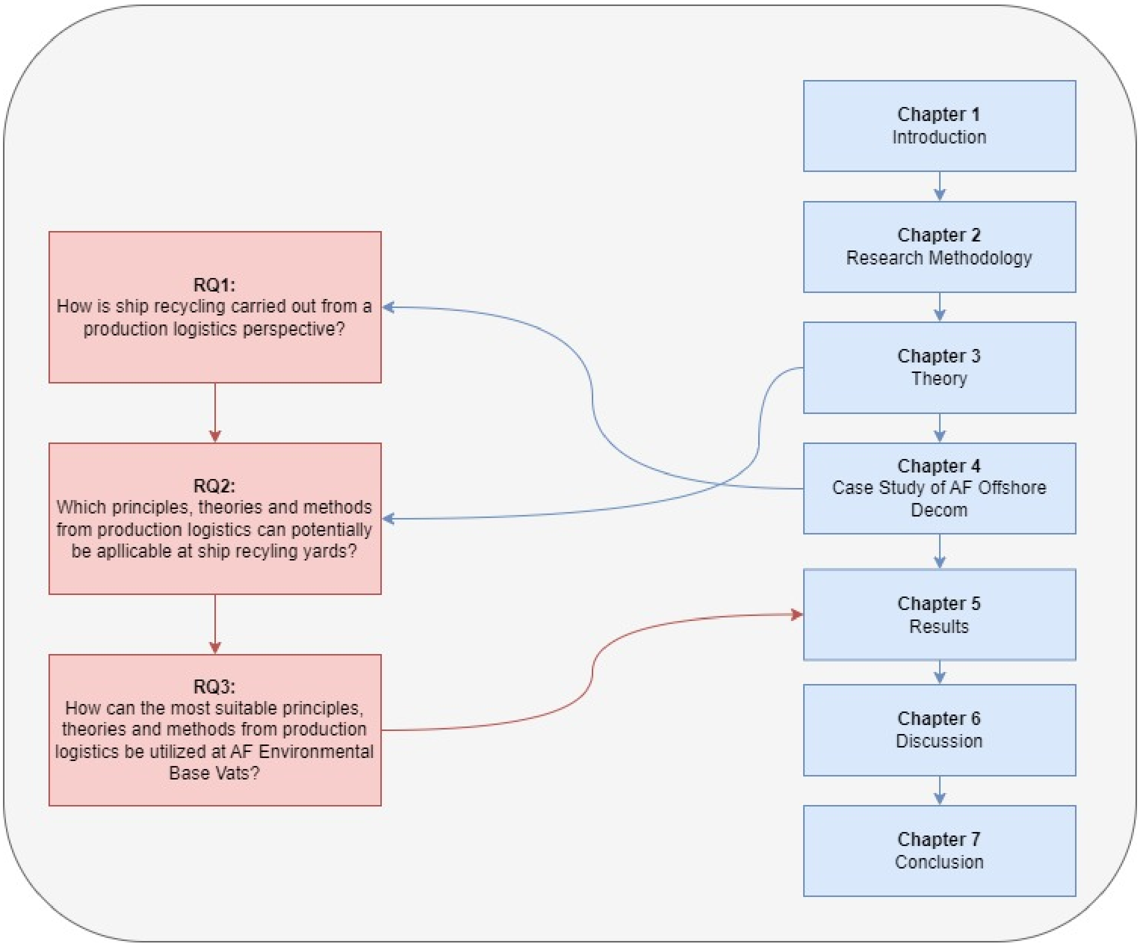

Figure 1: Relationship between Research Questions and the Thesis Structure

2 Research Methodology

This chapter presents the methodology employed for data collection and execution of the master's thesis. It begins with an overview of the methodology employed, followed by separate sections dedicated to the literature and case studies.

The research methodology employed in this thesis included a case study conducted at the AF Environmental Base Vats, a ship recycling yard operated by AF Offshore Decom. A comprehensive literature review was also conducted to gather existing research on production logistics in ship recycling and similar industries. Following the framework proposed by Kothari (2004), the research methodology involved a qualitative approach that aimed to explore and gain a deeper understanding of the possibility of applying production logistics to ship recycling. The primary methods utilised in this research were literature study and case study, which will be elucidated in subsequent sections to provide a detailed account of their application in the research project. Most of the contextual knowledge the researcher has obtained about ship recycling is derived from the project assignment from the fall of 2022. A literature review was conducted during this period, focusing on ship recycling.

In order to maximise the quality of the technical master's thesis and minimise any potential language barriers, translation tools such as Grammarly and ChatGPT were utilised to enhance the researcher's writing. However, it is crucial to emphasise that strict oversight and review were consistently applied to the translated content to ensure its accuracy and clarity. This approach aligns with the recommended guidelines for utilising supportive tools in academic writing.

2.1 Literature Study

A thorough literature study explored existing research on principles, theories, and methods concerning production logistics in ship recycling. The focus of the literature study was primarily guided by research question 2, which was reflected in the selection of relevant keywords used for searching and reviewing the literature. As articulated by Yin (2013), literature is a means to an end, not the end itself. Therefore, the literature review was conducted to leverage existing research to inform and support the research objectives of the current study.

This literature review aimed to verify the hypothesis that the research in this area is limited. Moreover, it allowed for a more specific focus on the research scope. The review analyzed research articles and master theses that specifically addressed the topics of ship recycling, production logistics in ship recycling, and production logistics in shipbuilding, construction and other engineer-to-order production.

2.1.1 Data Collection

The literature review was conducted following a systematic five-step process. The initial step involved identifying relevant keywords for the search. The second step included setting selection and rejection criteria for the papers. The third step consisted of reviewing the abstract and conclusion of the selected papers. In the fourth step, a full-text review of the selected papers was carried out. Finally, in the fifth step, the references and cited-by feature of the selected papers were reviewed.

Primary Keywords	**Secondary Keywords**
Ship recycling	Production logistics
Ship breaking	Lean
Ship decommissioning	Kanban
ETO	Challenges
Shipbuilding	Layout optimization
Ship demolition	CONWIP
Construction	Takt time
	SMED
	TQM
	Kitting
	Bottleneck analysis
	Just-in-Time

Table 1: Primary and Secondary Keywords

Initially, the keywords used for the literature review were broad to provide a general overview of the existing research and gain an understanding of the researched topics. This approach was influenced by previous work on the project assignment. Subsequently, more specific keywords were used to conduct a thorough investigation and link the literature to the research questions. Scopus was the primary database used, and articles from Google Scholar and Science Direct were also utilised. The literature search in Scopus followed a systematic approach, while a snowballing method was employed for the other databases. Additionally, master's theses completed by previous students at NTNU were examined. The search process involved the use of primary and secondary keywords. Table 1 displays the essential keywords employed in the initial search. The search terms were modified as the research progressed to include new perspectives and angles. The search term ”ship recycling” was occasionally eliminated to obtain research materials relevant to the research objectives. This step was crucial to explore its application in other industries and locate relevant research articles. Typically, multiple criteria are established for selecting relevant articles. However, in this research area, where there is limited existing literature, determining suitable articles was more subjective. For instance, recently published articles with minimal citations may be less reliable. Therefore, a comprehensive evaluation was performed to determine the appropriateness of articles for the study. Ultimately, satisfaction was achieved with the chosen articles.

2.2 Case Study

The present thesis has also employed the case study approach. Despite possessing a thorough understanding of the ship recycling process, firsthand observation and immersion in the everyday activities of a shipyard hold incomparable value.

2.2.1 Case Selection

Case selection is the primordial task of case study research, for in choosing cases, one also sets out an agenda for studying those cases (Seawright and Gerring 2007/2008). The case selection process was extensive, requiring a decision between examining many cases at a more superficial level to gain a general understanding or focusing on a single case to explore it in greater depth. While exploring multiple cases offers a broad understanding of the industry, it may lead to less open responses and limited opportunity for in-depth analysis of each case. Initially, the plan was to visit as many shipyards as possible in Norway, which were listed under the EUSRR. However, after conducting thorough research, it became evident that more cases would be more beneficial than a single, simplistic one. They are about something larger than the case itself, even if the resulting generalization is issued in a tentative fashion (Gerring 2004). Nonetheless, reaching out to shipyards and scheduling visits presented a challenge, as it required a significant amount of time and effort from them.

To address this challenge, a meeting was arranged with Ingvild Jensen, head of the NGO Shipbreaking Platform, an organization dedicated to enhancing the safety of the shipbreaking industry and its impact on the environment and individuals involved. Through her extensive network, Ingvild connected the researcher with individuals who might be interested in the task at hand. During the meeting, it was discovered that there were varying standards within the industry in Norway and that visiting a leader with high standards would be more valuable than visiting several smaller ones. As such, the researcher was strongly recommended to visit AF

Offshore Decom's shipyard in Vats, where an FPSO (Floating Production, Storage and Offloading) ship weighing 25,000 tonnes was being recycled. Ingvild provided a list of three shipyards, including AF Offshore Decom, a shipyard in Denmark, and one in Belgium. These yards were selected based on their high standards and available ships for recycling. Following the recommendation, a meeting was arranged with AF Offshore Decom, allowing both parties to learn about each other and discuss their intentions for collaboration.

2.2.2 Data Collection

The sources utilised in this study can be categorized into two main groups: primary and secondary sources. The theoretical framework presented in this research draws from the researcher's project thesis. The primary sources utilised in this study include direct observations made during the yard visit, semi-structured interviews with key personnel at AF Offshore Decom and the yard, and information shared by AF Offshore Decom. The researcher posits that firsthand observation is essential to acquiring knowledge. This assertion is supported by research conducted by Falk and Dierking (2010). During the yard visit, the researcher gained insights into the yard's processes, layout, and logistics. The researcher was under the guidance of a designated individual who provided information and answered queries. When questions arose for which the individual did not have answers, the researcher was referred to other personnel at the yard who were interviewed. Additionally, specific questions were emailed to key personnel within AF Offshore Decom, who provided supplementary information. These questions pertained to the yard's logistical challenges and opportunities for improvement, among other topics. As the researcher gathered more information about the yard's operations, new questions emerged. Two project directors and a project manager from AF Offshore Decom attended the meetings. The researcher's contact person during the yard visit was the engineer manager, who was responsible for conducting the yard tour. At the end of the study, a workshop was conducted between AF Offshore Decom and the researcher, during which the researcher presented their findings and proposals for AF Environmental Base Vats. Additionally, the researcher had the opportunity to obtain verification of the gathered information. Participants in the workshop included one of the project directors and the engineering manager.

3 Theory

This chapter presents the theoretical background of the master's thesis in two parts. The first part focuses exclusively on ship recycling to provide necessary contextual knowledge about the industry. Much of the information presented in this section is derived from the literature study conducted as part of a previous project assignment in the autumn of 2022. The second part delves into the field of production logistics, encompassing the definition of key concepts and their application and research in related industries. The information presented in this section is drawn from the literature study conducted specifically for this master's thesis.

3.1 Ship Recycling

The term "ship recycling" refers to the process of dismantling a ship in a designated area or yard, intending to collect components, waste, and materials for reuse, handling, or recycling. Ship recycling is considered "green" because almost all parts of the ship can be reused or recycled, including materials, machinery, electrical components, and household equipment. However, recycled ships may contain hazardous waste such as polychlorinated biphenyls (PCBs), asbestos, and heavy metals, which pose significant environmental and health risks. As such, it is essential to handle such waste responsibly to minimize negative environmental impacts.

Ship recycling yards are authorized by relevant authorities to conduct ship recycling activities and must comply with national and international regulations. Different types of yards exist, including shipyards that engage in shipbuilding and recycling and designated ship recycling yards that specialize in ship recycling activities.

3.1.1 The History

The historical background of ship recycling reveals the evolution of different methods and techniques. In earlier periods, ships were dismantled, and their materials were repurposed for various construction projects. However, the advent of metal-hulled ships made traditional methods less feasible. During the industrial revolution, ship scrapping gained importance, with retired British ships providing a significant source of steel. In the 1930s, beaching ships emerged as a cost-effective alternative, dismantling ships on shorelines using hydraulic shears, wrecking balls, and torches. Developing countries, such as India, Taiwan, Pakistan, and Bangladesh, experienced significant growth in shipbreaking (due to their lower standards, the term "shipbreaking" has been chosen) from the 1980s onwards. Increasing awareness of the hazardous working conditions and environmental pollution associated with shipbreaking led to adoption of cleaner and safer practices in the industry. This was driven by the development of environmental regulations in the 1980s and 90s, aiming to minimize the environmental impact and ensure worker safety during ship recycling processes.

3.1.2 Methods

The ship recycling process involves cutting the ship into smaller manageable pieces for further handling and recycling. The process generally involves pre-cutting, cutting, and post-cutting stages, with different methods used depending on the ship's size, type, and condition. The four primary techniques used in ship recycling today are alongside, beaching, dry-dock, and landing.

The alongside method involves dismantling the ship from top to bottom by cranes while it is brought alongside a wharf or quay in a sheltered harbour or river. The beaching method involves laying the ship on a tidal mudflat during high tide and cutting it into smaller pieces during low tide. This method is commonly practised in South Asia, where 88% of ships are scrapped using this technique (UNCTAD 2022). However, the practice is strongly criticized (NGO Shipbreaking Platform n.d.) for the environmental harm it causes, as pollutants are freely discharged into the environment and washed out into the sea by the tide.

The dry-dock method involves placing the ship in an enclosed, flooded dock and dismantling it when the water is pumped out. This technique ensures that the ship is taken apart in a fully contained area, minimizing the risk of environmental pollution. Cranes can lift bigger chunks of the ship away for further handling. Finally, the landing method involves driving the ship onto the shore or pulling it up onto a concrete slipway that extends into the sea. The cutting process starts at the front of the ship and moves towards the back, ensuring that the cutting area is always above the drainage systems. Cranes pull the ship further onto the shore and remove the cut sections (NGO Shipbreaking Platform n.d.).

3.1.3 Processes and Material Handling

The sequence of processes in ship recycling remains broadly consistent, irrespective of the specific techniques employed. These processes can be categorized into three phases: pre-cutting, cutting, and post-cutting.

In the pre-cutting phase, the ship is prepared for dismantling by removing loose items, liquids, hazardous materials, insulation, flooring, tiling, cables, and electrical equipment. Research conducted by Jain et al. (2017) revealed that approximately 7% of the light displacement tonnage (LDT) from a representative case ship was eliminated during this initial phase before the cutting stage.

The cutting phase of ship recycling consists of two main stages: primary cutting and secondary cutting. The ship's hull is divided into ferrous and non-ferrous blocks during the primary cutting stage. While there may be minor variations in the techniques used, the overall processes remain similar. One example of variation is the handling of blocks and equipment. Some shipyards that practice beaching utilise gravity, where the cut segments are allowed to fall to the ground or into the water naturally. In contrast, other methods and the more advanced South Asian yards employ cranes for this operation. Additionally, the cutting of machinery occurs during this phase. Machinery that is still functional and can be reused is cut out and preserved, while machinery no longer viable is sent to secondary cutting as scrap. The larger blocks from the primary cutting are further divided into smaller pieces in the secondary cutting stage. This phase commonly uses gas-cutting torches.

In the final post-cutting phase, the first step involves collecting and sorting the pieces into those suitable for reuse or recycling and those deemed unsuitable. Subsequently, the reusable and recyclable pieces undergo segregation and transportation. The unusable pieces are further separated to assess if any valuable components can be recovered, considering that the separated part's value should exceed the separation process's cost. Lastly, worthless pieces are transported to landfill sites or downstream disposal locations. As the scope of this thesis is limited to ship recycling yards, further downstream processes will not be discussed. The research by Jain et al. (2017) estimated that 3.4% of the case ship held no value and was destined for disposal, while approximately 96.6% could be reused or recycled. Although these percentages pertain to a specific case ship, they provide insight into the proportion of a ship that can be repurposed and the importance of ship recycling processes. All processes mentioned above within the three phases are depicted in Figure 2.

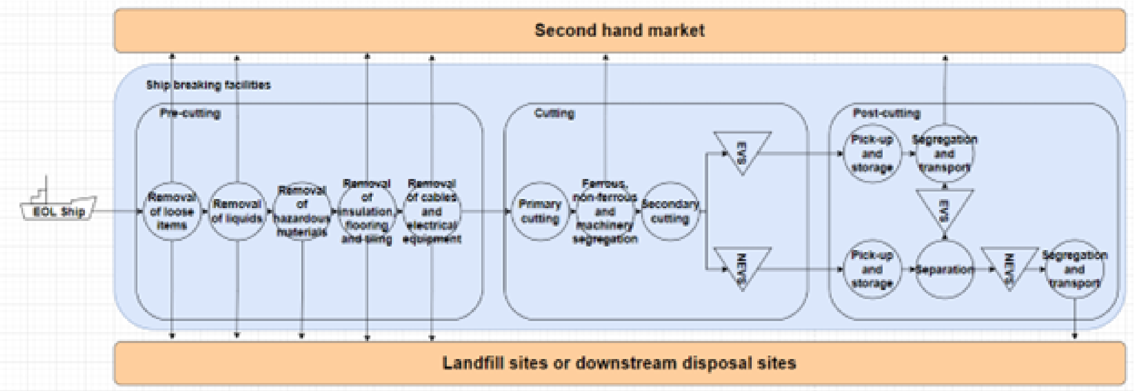

Figure 2: Processes in a Ship Recycling Yard (From Researcher's Project Thesis)

In Figure 2, the acronyms EOL, EVS, and NEVS are employed. EOL refers to end-of-life ships, EVS represents the economic value stream, and NEVS signifies the non-economic value stream.

3.1.4 Relevant Rules and Regulations

In the 1990s, increasing concerns about poor working conditions and environmental damage in shipbreaking yards prompted heightened attention from environmental activists and the need for regulatory measures. One significant regulatory framework is the Basel Convention, adopted in 1989 to control transboundary movements of hazardous wastes, including ship recycling. The convention focuses on reducing and managing waste at its source, ensuring environmentally sound waste management, minimizing the transboundary movement of wastes, and controlling waste trade through a prior informed consent mechanism.

The Basel Convention's Ban Amendment was adopted in 1994 to strengthen the protection of developing countries. The amendment aimed to prohibit the export of hazardous waste from OECD (the Organization for Economic Cooperation and Development) countries to non-OECD countries. However, its implementation faced challenges and discussions regarding its interpretation. As a result, country-led initiatives were established to facilitate the implementation of the Ban Amendment and provide guidance for environmentally sound management practices.

Another important regulatory development is the Hong Kong Convention, officially known as the "Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009." Adopted after extensive work by the International Maritime Organization (IMO), the convention sets standards for ship recycling, and the objective was to place responsibility for enforcement on the flag state and recycling state. It requires ships to have an Inventory of Hazardous Materials (IHM), approved ship-recycling yard plans (SRFP), and ship-specific recycling plans (SRP). However, the Hong Kong Convention has drawn both support and criticism from different stakeholders in the shipbreaking industry (NGO Shipbreaking Platform 2019) and has not entered into force due to the lack of ratification by participating countries.

Within the European Union (EU), waste shipment regulations were implemented to address the trading of waste materials, including hazardous waste. The EU implemented the Basel Convention into European law in 1993 and subsequently added the Ban Amendment to the European Waste Shipment Regulation in 2006. This regulation prohibited EU member states from exporting hazardous wastes to non-OECD countries. The objective was to protect the environment, reduce health risks, and establish clarity in waste shipments.

Furthermore, the European Union developed its own ship recycling regulations, known as the European Union Ship Recycling Regulations (EU SRR). These regulations were established to address the unsound and unsafe practices in ship dismantling. EU SRR requires that EU-flagged ships above 500 gross tonnages must be recycled in safe and environmentally sound ship recycling yards listed on the European List. The regulations encompass various requirements for hazardous material handling, waste management, and the use of built structures in shipbreaking operations.

Overall, these international and regional regulations aim to mitigate the negative impacts of ship recycling on human health and the environment, encourage responsible waste management, and promote safe and sustainable practices in the ship recycling industry.

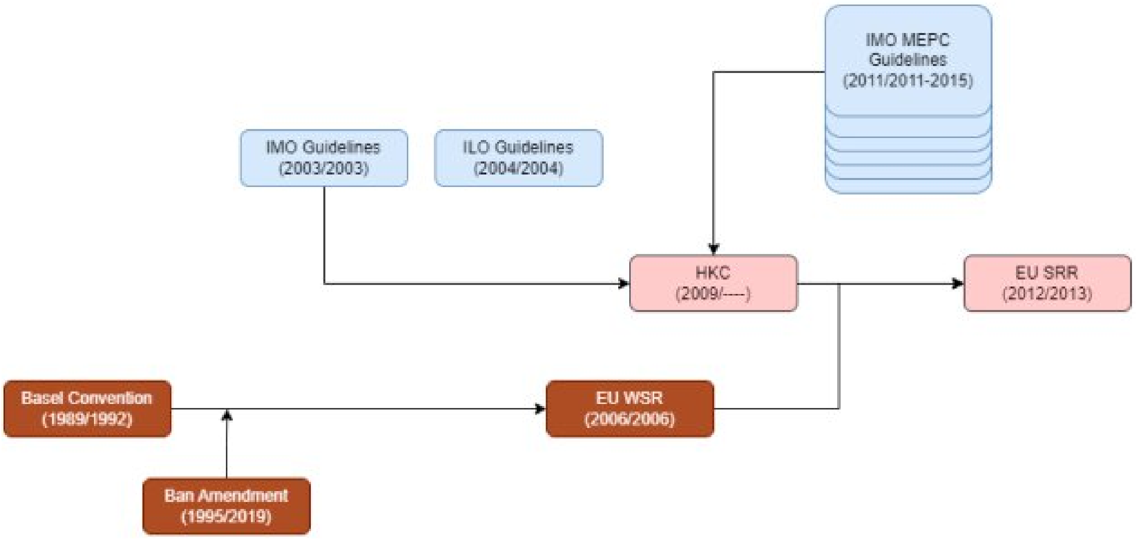

Figure 3: The Interplay between Waste Handling and Ship Recycling Regulations (From Researcher's Project Thesis)

Figure 3 was created in the researcher's project assignment and illustrated the interrelation of key ship recycling regulations. The arrows depict the regulatory dependencies over a timeline from left to right. Although numerous regulations exist, this model's primary objective is to present a concise overview of the most renowned ones. The brown boxes represent waste handling regulations, the blue boxes represent ship recycling guidelines, and the pink boxes represent regulations tailored explicitly for the ship recycling industry. The numbers in parentheses indicate the publication and enforcement years. The box containing ILO (International Labour Organization) Guidelines is not directly connected to any other boxes as they are independent guidelines for the industry.

3.1.5 Market Share

In recent decades, the ship recycling industry has been dominated by the big five shipbreaking countries: Bangladesh, India, Pakistan, Turkey, and China. According to UNCTAD (2022), in 2020, Bangladesh had the largest market share of the gross tonnage with 40.3%, followed by India with 30.4%, Pakistan with 17.4%, Turkey with 9.2%, China with 1.1%, and Europe and rest of the world with 1.6%. This data highlights the significance of the beaching method in shipbreaking, with 88.1% of recycling taking place on beaches in Bangladesh, India, and Pakistan. It is important to note that this was the first year with COVID-19, and the impact of the pandemic may have affected these countries differently. Nonetheless, this distribution of market shares reflects the last decade's trend.

In 2022, 443 ships were sent for recycling, with 292 dismantled in South Asian countries, namely Bangladesh, India, and Pakistan. Among these countries, Bangladesh held the largest market share, accounting for approximately 36.8 % of the gross tonnage, followed by India with around 30 % and Pakistan with around 16.3 %. Turkey accounted for approximately 9.6 % of the market share, the rest of the world contributed approximately 6.8 %, and the European Union accounted for approximately 0.9 % (NGO Shipbreaking Platform 2022). Notably, most ship recycling activities, representing over 80 % of the total, occurred in these South Asian countries.

3.2 Production Logistics

In product manufacturing, numerous processes are undertaken before a final product emerges and is dispatched to the customer. A fundamental rule is that a product's selling price and total revenue must surpass the cost of its production and delivery. This principle is essential for business survival and continuity. Numerous factors contribute to a product's value, resulting in a profit upon sale. One significant element in generating this profit is efficient production logistics control.

Production of products often forms part of a larger value chain with multiple players, material flow, and information exchange. While maintaining effective production logistics within a single business or process is vital, optimising logistics when considering the entire value chain is equally important. Effective production logistics is about devising intelligent solutions to enhance control, efficiency, and productivity in production.

Production Logistics
Type of Control or Delivery Form
Control Principle
Planning Processes in Different Areas and Levels
Information Management
Supply Chain
Delivery Chain
Layout and Material Flow
Inventory Management
Use of Forecasts
Digital Systems for Control and Processes

Table 2: List of Topics in Production Logistics (Strandhagen et al. 2021)

In the Norwegian textbook, "Produksjonslogistikk 4.0", production logistics is defined as a set of components, which are displayed in Table 2 (Strandhagen et al. 2021). These concepts and their respective constituents have evolved with the advent of techniques and technologies. From the inception of the "Spinning Jenny" during the first industrial revolution to the mass production of automobiles in the second, the integration of computers during the third, and now, where technology pervades every facet of industrial activities, commonly referred to as the fourth industrial revolution. Discussions are underway about the onset of the fifth industrial revolution, a term formally introduced by the European Commission in 2021. This revolution differentiates itself from the fourth by its human-centric focus (Xu et al. 2020), incorporating existing technologies, thereby representing a more sustainable industry from a human perspective.

The primary forms of production control are typically divided into four categories: Make-to-stock (MTS), Assemble-to-order (ATO), Make-to-order (MTO), and Engineer-to-order (ETO). These categories are distinguished by the point at which the customer enters the process. In the case of MTS, the customer has a minor influence on the production of the order, with a typical example being grocery items that are continuously produced and restocked for customer convenience. ATO and MTO follow, with ETO sitting at the other end of the scale, involving significant customer input in product creation. An example of ETO is shipbuilding, where each ship can be vastly different from the last, and everything is customised to meet customer needs.

The field of production logistics has developed methods and theories to facilitate efficient logistics, with literature suggesting their primary application in businesses engaging in repetitive and mass production. Here, minor modifications can have a significant overall impact due to the repetitive nature of tasks. Therefore, it is understandable that more literature is available on the application of production logistics in mass production compared to shipbuilding and other product types that fall under ETO. The methods used in production logistics originated from various sources, but a large proportion arose during the development of lean manufacturing.

3.2.1 Lean Manufacturing

The concept of lean manufacturing originated from Toyota's development of its car production system, known as the Toyota Production System (TPS). This system emerged as Toyota strived to differentiate itself in its competition with Henry Ford. While Ford had the financial stability to produce cars en masse, storing them in inventory until sold, Toyota's production was only a tenth of that of American automobile manufacturers, and their financial status was less robust (J. Liker and Lamb 2000). This economic discrepancy necessitated Toyota's innovative approach and led to the creation of TPS, based on the principle of waste reduction.

Initially referred to as TPS, the term 'lean' was coined when American researchers studied Toyota's production system and especially after the release of the book "The Machine that Changed the World" (Womack et al. 1990) in the 1990s. Lean manufacturing's objective was to reduce costs and improve quality by eliminating waste or non-value-adding activities. This approach minimises the need for storage and advocates for a just-in-time production system (Iranmanesh et al. 2019).

The techniques and methods of lean were developed before the advent of digitalisation. Thus the foundational methods are centred on managing the shop floor without digital tools. More recently, digital solutions are being incorporated, building upon the basic principles of lean methods and theories.

Lean can be an ambiguous term given the breadth of elements it encompasses. However, it can be more readily understood as a philosophy equipped with an extensive toolbox of methods designed to enhance production efficiency and minimise waste. The book "Produksjonslogistikk 4.0" (Strandhagen et al. 2021) lists several vital elements of Lean, indicating that it is comprised of fundamental principles for managing, leading, and governing businesses. Lean provides a range of business improvement models and has many methods for analysing, enhancing, and developing businesses and systems. It also offers numerous techniques and practical tools for developing, operating, and managing production.

At the heart of lean as a philosophy is focusing on the customer and the value generated for them. All processes are evaluated for value creation, and efforts are made to eliminate non-value-adding processes, which are considered waste. The objective of Lean is to establish a seamless flow within the value stream, minimising interruptions and promoting the continuous production of individual products. Wherever possible, lean philosophy promotes pull production, manufacturing upon customer order rather than maintaining a stockpile in the finished goods inventory. The philosophy also encourages continual self-improvement and striving for perfection. From this philosophical standpoint, lean is applicable across many different industries, and even businesses not engaged in production can draw inspiration from lean principles.

To gain a more comprehensive understanding of the components of Lean, one may examine one of its most renowned frameworks, known as the "House of Lean" or the "Toyota Production System House" (Figure 4). This model integrates diverse concepts, including elements derived from both Japanese and English languages, reflecting the evolution of TPS and Lean principles.

The house's structure consists of a foundation embodying the Lean philosophy, as previously described, represented here as the "Toyota Way Philosophy". The house is then supported by two pillars: Just-In-Time (JIT) and Jidoka. JIT encapsulates methods for waste reduction and customer-centric approaches, while Jidoka encompasses techniques to ensure quality and prevent errors. The house's core comprises human collaboration and a focus on continual improvement. The roof of the house signifies Lean's overarching goal.

Subsequent sections of the theoretical discussion will elaborate on some of these concepts, but only those relevant to the scope of this study. A comprehensive exploration of all elements within Lean would be exhaustive; thus, the focus will be on the methods that present potential applications in ship recycling.

Figure 4: House of Lean (Jeffrey Liker 2003)

Kanban

Kanban falls under the ”Pull System” category in the left pillar of the ”House of Lean”, as it is a production methodology controlled by the interchange of introduction cards within the production chain. In a pull system, work is pulled by the subsequent operation, while in a push-production system, the preceding operation pushes more work forward. The term ”Kanban” originates from Japanese, where ”kan” denotes ”visual” and ”ban” signifies ”card” or ”board” (Lage Junior and Godinho Filho 2010). This terminology aptly captures the essence of Kanban, which is typically characterised by a visual board composed of numerous information cards.

A Kanban card typically contains an identification for a specific product, a quantity that indicates how many of the product the card holds, an operational instruction outlining what needs to be done with the product, and the destination where the product will be delivered. For instance, if a card represents ten units of a product, it follows these ten items to the finished goods warehouse. Once these units are used, the card is sent back to instigate the production of an additional ten units of the product. Subsequently, the card is placed on a Kanban board, symbolising that the product is under production, facilitating an accessible overview for the planner. In simple terms, the need for production arises when the board is sparse with cards (indicating low ongoing production), and production can slow when the board is filled with cards (indicating high ongoing production).

Although Kanban has been employed in many sectors, it may not be suitable for all types of production. It is an effective method when there is a steady demand for products. However, in the face of highly fluctuating demand, this method could lead to situations where the supply cannot meet the demand until stocks run out or when there are excessively stocked warehouses.

The research will further examine the use of Kanban in ship recycling or similar industries, such as shipbuilding or construction. Within the sphere of shipbuilding, the process has been segmented into smaller tasks, and each represented on a Kanban board (Kjersem et al. 2015). This provides a comprehensive overview of the project, facilitating resource management in a complex production environment. If implemented effectively, Kanban can be a valuable tool for managing inventory levels and material flow.

However, most literature used in this study examines the implementation of Kanban in conjunction with other Lean concepts, with very few focusing on the impact of Kanban in isolation. A study conducted by Kjersem, Kristina, Halse, Lise Lillebrygfjeld, Kiekebos, Peter, and Emblemsvåg, Jan (2015), concluded that the pull production concept, including Takt Time, Kanban, and ConWIP, can lead to a more continuous flow for hull units production at VARD's shipbuilding yard in Norway. Nevertheless, there are limitations on how these methods can be used in Engineer-to-Order (ETO) production environments (Kjersem et al. 2015).

CONWIP

Constant Work-In-Process (CONWIP) is also a concept that falls under the "Pull System" category in the left pillar of the "House of Lean", sharing some similarities with the Kanban system in its aim to manage and minimise the volume of work in progress (WIP). Like Kanban, CONWIP employs a card system to dictate when production should occur. In the Kanban system, each card corresponds to a specific product. As mentioned earlier, when a Kanban card is issued for production, for example, ten units of the corresponding product are manufactured, reducing the inventory of finished goods. However, in the CONWIP system, the cards are not tied to any specific product. Instead, when a CONWIP card is dispatched to production, for example, ten units of the first product in the backlog are manufactured as goods have been removed from the finished goods inventory, creating space for more products. This system maintains a consistent volume of products in progress since the initiation of new product production coincides with the completion of existing products.

The CONWIP system offers a straightforward management method, providing excellent control over inventory and promoting a steady workflow. Nonetheless, it may diminish control over individual products and can lead to bottlenecks due to poor management. This system aligns closely with pull production principles. However, in ship recycling, one could argue for both pull and push production, especially with steel continuously shipped to smelters and hazardous waste and radioactive materials that require payment to receivers for handling.

Wang Yue, Ma Rui, and Lin Yan investigated implementing a CONWIP-based planning process in shipbuilding that combined push-pull production (Wang et al. 2018). The proposed solution aimed to address issues in traditional shipbuilding and improve areas where the Kanban system falls short. The study concluded that it is beneficial to utilise CONWIP when operating below peak capacity to prevent loss of control over WIP. It suggested that implementing CONWIP-based technology could enhance production efficiency due to its flexible and balanced properties. While ship recycling can be viewed as reverse shipbuilding, the distinct strategies and work processes make it challenging to foresee whether CONWIP would bring more advantages than disadvantages.

Takt Time

Takt time is a concept used in Lean manufacturing, construction, and production planning to balance production with customer demand. Like Kanban and ConWIP, Takt Time can be located in the left pillar of the ”House of Lean”. It involves dividing the available time by the customer’s requirements, excluding breaks, maintenance, and similar factors. This concept is more commonly used in repetitive production than ETO production and industries like ship recycling. The advantage of takt time is that it can optimise production processes, ensure efficient resource utilisation, and meet customer demands. This reduces lead times, minimises waste, and increases overall efficiency. Takt time can also identify bottlenecks and areas in need of improvement. Once a takt time is set, it is not necessarily permanent, as customer demand may vary or multiple factors may influence available production time. Adjustments should be made periodically to ensure the most efficient operation and to meet customer requirements.

An article by Emdanat et al. (2021) that developed a framework for integrating takt time in construction management found that takt time is a crucial concept from Lean construction management that helps streamline project planning and execution. Determining the optimal work rhythm and sequence of tasks reduces variations and minimises delays, leading to increased productivity. The article also explores the integration of takt time with the Last Planner System and labour tracking. Takt time can further enhance collaboration, optimise resource allocation, and contribute to continuous improvement, resulting in more efficient and successful construction projects. Although the article does not focus on ship recycling, it provides valuable insights into the benefits of implementing takt time in a similar industry, such as construction. This knowledge can potentially be applied to ship recycling to improve efficiency, predictability, and resource utilisation.

Applying takt time in large-scale projects such as shipbuilding, where the demand for a ship might arise every six months, and the ships being built can have significant differences, might initially seem challenging. However, research conducted by J. Liker and Lamb (2000) discovered that the most competitive shipyards in Japan successfully incorporate takt time into their ship production process. They divide the project into smaller tasks, with the ship’s delivery schedule setting the takt time for all preceding processes. This ensures each task is completed just in time for the next one to begin, fostering a smooth flow in production and promoting optimal resource utilisation.

Visual Management

Visual management, found within the ”House of Lean” foundation, is a system utilising visual cues to communicate information as succinctly and efficiently as possible. Rather than relying on words, texts, or complex concepts, it engages drawings, symbols, and images to facilitate understanding (Strandhagen et al. 2021). This approach simplifies the presentation of a company’s status to all stakeholders (Singh and Kumar 2021), highlighting areas necessitating improvement and fostering enhanced coordination.

Operators may become immersed in their respective tasks in industries undertaking large-scale projects, such as ship recycling. Consequently, visual management gives all participants a panoramic view of the project’s progress. Although most companies employ mechanisms to monitor progress, the distinctive attribute of Visual Management is the concept that the work situation should be comprehensible through rapid visual inspection, thereby obviating the need for extensive reports or various software tools.

One study examined the impact of Visual Management on the construction industry, determining, among other findings, that this approach facilitated seamless communication, i.e., a one-piece flow of information between respective stakeholders without interruption or obstacles (Singh and Kumar 2021). This open communication improved the organisation’s transparency, as there were no obstacles to information sharing.

In their literature synthesis on visual management in production management, Tezel, Koskela, and Tzortzopoulos discovered that although visual management is often associated with Lean production, it should be considered as a standalone strategy because it is a close-range visual (sensory) communication strategy (Tezel et al. 2016). They contend that an understanding of lean principles is unnecessary to leverage visual management’s benefits. The authors state, ”Visual management can be employed wherever there is a communication need and interaction between human and process elements.” Recognising the value of this approach implies that any industry could implement or improve upon it.

SMED

Single-Minute Exchange of Die (SMED) is a method encompassed under the ”Quick Changeover” concept within the left pillar of the ”House of Lean”. This approach was initially introduced by the Japanese engineer Shigeo Shingo (Roser 2014b). As the name implies, the objective of SMED is to optimise the changeover time of machines, a process that often consumes considerable time. SMED has been formulated over numerous years of empirical testing and theoretical application. It represents a research-driven approach designed to curtail setup times, applicable across any manufacturing setup and machinery involved (Dillon and Shingo 1985).

If changeover poses a significant challenge and is identified as a critical area for improvement within a company, adopting SMED could potentially present a constructive solution. A state-of-the-art literature review by Silva and Filho (2019) in 2019 revealed that despite emphasising enhanced productivity, the tools also demonstrated increased flexibility. Further, applying the SMED technique facilitated a reduction in setup time by incorporating Shingo's stages.

The number of stages typically varies per different sources, often suggested to range between 4 to 8, but the core concept remains consistent. For this theory, it is presented as a six-stage process (Roser 2014a):

1. Measure the changeover duration precisely, considering potential variations in the execution by different operators.
2. Identify internal and external elements, with internal elements referring to steps taken when the machine is stopped, while external steps are performed while the machine is still running.
3. Transition as many steps as possible to external operations to reduce downtime.
4. Minimise the duration of internal elements by simplifying or shortening steps taken when the machine is stopped.
5. Shorten external elements to reduce the overall changeover time, despite not affecting the production halt.
6. Standardise and maintain new procedures to ensure continued use of the newly established changeover standard rather than merely focusing on a quick changeover.

There is limited literature on the application of SMED in industries such as ship recycling, shipbuilding, and construction. According to a study on SMED in construction by Tezel (2016), despite SMED being a significant component of Lean, it has received little attention in construction, potentially due to a misconception that it is exclusively a manufacturing concept. While ship recycling may not initially appear as an ideal industry for SMED implementation, given that it does not involve the production of products that require machine changeovers, it is conceivable that each machine used by operators could incur changeover time in the form of stops for part replacement and maintenance. Anticipatory preparation of materials and performing maintenance outside the machine's operating hours could be improvements that align with some of the SMED steps.

Just-In-Time

The Just-in-Time (JIT) principle is situated in the left pillar of the "House of Lean". It encapsulates the philosophy of the methods previously explained, which also belong to the left pillar. JIT and Lean management concepts are often used interchangeably, given their shared focus on customer satisfaction and waste reduction. It is understandable, therefore, that JIT is considered one of the pillars of Lean. As suggested by its name, JIT discourages the maintenance of extensive intermediate or finished goods inventories. Instead, parts and processes should be completed just in time to meet customer demand. In a typical manufacturing firm, it is crucial to have necessary raw materials and components readily available in order to practice JIT (Strandhagen et al. 2021).

A study conducted by Fullerton and McWatters (2001) suggested that JIT is a vital manufacturing strategy for building and sustaining a competitive advantage. Two other studies found that by minimising delivery time and redundant steps, JIT production was a critical factor in achieving agile manufacturing (Lucherini and Rapaccini 2017)(Mazanai 2012).

Total Quality Management

Total Quality Management (TQM) represents a philosophy or vision developed over time, emphasising the imperative of continual improvements throughout an entire organisation. According to TQM, ensuring product quality is not confined to a specific department but is shared among all stakeholders within the business.

Quality is construed in three progressive stages within the quality hierarchy, with TQM occupying the apex (Dahlgaard et al. 2008). Initially, quality pertains to satisfying customer requirements. The subsequent level, total quality, seeks to attain high-quality outcomes with the lowest possible cost. At the pinnacle of this hierarchy, Total Quality Management aims to realise total quality with the active participation of all involved parties. TQM is globally implemented through diverse concepts, and numerous strategies, methods, and tools have been developed to facilitate its application (Hys 2014).

A study conducted by Faeq et al. (2021) yielded results suggesting a strong positive influence of TQM on the performance of construction firms, endorsing the assertion that TQM leads to enhanced performance levels. The empirical findings revealed that TQM principles contribute to improved performance metrics.

3.2.2 Layout Optimization

In this context, layout optimization refers to the systematic arrangement of space, machinery, equipment, and buildings to maximise efficiency and streamline production. The objective of layout optimization is to minimise waste and maximise space utilisation. For instance, substantial time savings can be achieved if the layout is optimised to reduce unnecessary movements. In addition, layout optimization can lead to decreased material waste and safety improvement.

Identifying a company's layout is a crucial prerequisite before proposing any improvements. Typically, layouts can be divided into two main categories: stationary product layouts, where the product maintains a fixed position, and process layouts, where the product moves through different stages (Strandhagen et al. 2021).

Stationary product layouts are commonly adopted when the product is of a substantial size, making it impractical to relocate frequently. On the other hand, if the product undergoes movement, various strategies are used to manage this process.

A linear layout, often employed in mass production, is a strategy where the product progresses along an assembly line through different process stages.

Another approach is the cellular layout, which involves more manual product movement. This layout typically clusters various machines close together in one area.

The functional layout is another approach for grouping machines performing related tasks. For instance, a manufacturing setup may include a welding department, a painting department, and an assembly department.

It is common to encounter combinations of these layouts within a single production environment. Each layout offers distinct advantages, and the choice often depends on the specific demands of the production process.

Determining the optimal layout is challenging due to the myriad of factors that must be considered. For instance, changes in the market may require modifications to the layout, or the integration of new equipment may necessitate their incorporation into the existing layout. Several methods can be employed to devise a new layout, ranging from using architectural drawings for detailed planning and employing mathematical simulations for optimal space utilisation to implementing lean methodologies for waste elimination. The ideal layout depends on the focal point; a layout emphasising material flow will differ from one where flexibility or human factors, such as operator comfort and ergonomics, take precedence.

In manufacturing, production, service, and similar industries, productivity challenges are typically addressed through detailed simulation approaches to optimise work processes (Gunbeyaz 2019). However, such an approach is not commonly adopted in ship recycling, where there is a significant gap in the literature. Sefer Anil Gunbeyaz addresses this gap in his doctoral thesis by focusing on the ship recycling industry. While similar studies have been conducted on shipbuilding with a focus on shipyard design and operation improvement potential, this is the first study to focus on ship recycling. This lack of focus may be attributed to the extensive data and detailed investigation of different recycling processes required. Another reason could be the relatively recent evolution of ship recycling into its current form. This thesis has developed a simulation framework for this industry to design and optimise ship recycling yards.

3.2.3 Bottleneck Analysis

Bottleneck analysis is concerned with identifying a process or task that impedes a company's productivity, meaning that no matter how efficiently the other processes operate, this particular process dictates the company's overall productivity. A bottleneck is a resource with the smallest capacity relative to its demand. Poor logistics management or failure to identify potential bottlenecks can result in wasted time and effort on non-bottleneck tasks, yielding minimal impact compared to prioritising the actual bottlenecks. Once bottlenecks are defined, it is essential to ensure they are consistently active. A bottleneck might occasionally shift, hence the term 'dynamic' or 'shifting' bottleneck (Roser et al. 2021), necessitating continuous bottleneck analysis to accurately identify current bottlenecks.

Bottleneck analysis consists of four main processes: detection, diagnosis, prediction, and prescription (West et al. 2022). Potential bottlenecks are identified, followed by determining and prioritising their causes. Subsequently, potential future bottlenecks are forecasted, and recommendations are provided for further operations based on the bottleneck analysis.

During a study conducted by Okubo and Mitsuyuki (2022), it was observed that production managers, based on the results of bottleneck analysis, could identify which delay would have the most significant impact on the day's plan. By informing operators about the bottleneck before they commence work, delays in the schedule can be prevented.

3.2.4 Kitting

Kitting, also called Lean kitting, is a method employed to diminish the waste of time and enhance the efficiency of a production station. This concept involves the preparation of a kit, encompassing all the requisite components and parts necessary for manufacturing a given product. Consequently, the operator tasked with the assembly has immediate access to all needed materials, eliminating downtime associated with waiting for parts and enhancing productivity. Kitting is not constrained to any specific mode of production or industry and can be utilised to some extent in any business. This approach could eliminate what might otherwise become bottlenecks, and it could be interpreted as thorough preparatory work facilitating maximal productivity during execution.

Despite its long-standing utilisation in manufacturing, there is scant research on the influence of kitting (Hanson and Medbo 2012). A study investigated the potential of kitting to enhance on-site work performance within construction projects (Tetik et al. 2021). The findings indicated that kitting improved product flow in certain phases that involved numerous small parts. Conversely, they found that kitting decreased productivity in some phases and concluded that it was not as practical for larger parts. Another key finding was the necessity of effective planning and ongoing updating to maximise the benefits of kitting. Other limitations of kitting primarily involve the necessity for a dedicated kitting area to assemble the various kits, which is inherently a non-value-adding process from the customer's perspective (Varghese 2020). Therefore, a decision must be made regarding whether the benefits gained from the improved material flow provided by kitting outweigh the resources expended in its creation. Varghese (2020) also points out that kitting is not particularly popular within the shipbuilding industry. However, outfitting yards could benefit from kitting as materials could be located where they will be used instead of scattered across numerous storage areas. Furthermore, incomplete kits can potentially cause delays and increase material flow (Hanson and Medbo 2012), (Corakci 2008).

4 Case Study of AF Offshore Decom

This chapter presents the case study conducted at the AF Offshore Decom facility known as AF Environmental Base Vats in Vats, near Haugesund, Norway. It begins with an introduction to the company, followed by an exploration of the processes and challenges related to logistics. Finally, it provides insights into the production logistics practices employed at the facility. The information presented in this chapter is derived from a variety of sources, including a site visit to the Vats facility, presentations provided by AF Offshore Decom, semi-structured interviews conducted at the base, follow-up queries exchanged after the visit, information from the official AF Offshore Decom website, and knowledge gained through both project and thesis work.

AF Offshore Decom is a Norwegian company specializing in the recycling of oil and gas installations, and in recent times, it has expanded its operations to include ship recycling. The company's shipyard, located in Vats, Norway, is one of the country's largest and most prominent recycling facilities. Although the recycling processes required for various projects are mainly similar, each assignment is treated as an individual project, as the specific methods and approaches may differ. As a result, the logistics operations at the shipyard are intricate, requiring careful planning and coordination.

This master's thesis aims to contribute to a more efficient shipyard by examining the application of principles, theories, and methods from production logistics in its operations. To gain insight into ship recycling practises and identify potential areas for applying these principles, a case study was conducted, which involved a two-day visit to the shipyard.

The results of this case study have provided a precise understanding of ship recycling, both for this particular shipyard and in general practice. Furthermore, it has elucidated the principles that can be feasibly applied in ship recycling and the areas with the most significant potential for improvement. Overall, this study has offered invaluable insights that have been instrumental in proposing the integration of production logistics within the ship recycling industry.

4.1 Case Company - AF Offshore Decom

4.1.1 AF Offshore Decom

AF Offshore Decom, a Norwegian company established in 2005, has a rich history with a primary focus on recycling oil and gas installations. Over the years, the company expanded its operations to include ship recycling, thus becoming a prominent player in the industry. As a subsidiary of AF Gruppen, which was founded in 1985 and encompasses over 100 companies, AF Offshore Decom benefits from a wide range of expertise. Initially, AF Gruppen concentrated on complex civil engineering projects before extending its experience to the construction and property sector and eventually venturing into demolition and recycling assignments.

The continuous development of knowledge and skills led AF Gruppen to venture into the offshore demolition business, consequently establishing Miljøbase Vats in 2005, one of the most advanced facilities in Europe for the recycling and demolition of offshore installations. In 2013, offshore operations were established as a separate business area within AF Gruppen. Over time, the company also diversified into the energy sector, becoming a significant centre of expertise in energy efficiency and renewable energy production.

AF Offshore Decom's evolution mirrors the broader trends and transformations within the ship recycling industry. With a rising focus on sustainable practices and environmental responsibility, the company aligned its operations with these values, investing in innovative solutions to reduce waste and minimize the environmental impact of ship recycling. Recognizing the challenges posed by the diverse nature of recycling projects, the company continually refines its practices by incorporating new technologies and methodologies.

The shipyard in Vats, Norway, developed into one of the country's largest and most advanced recycling facilities, adhering to international regulations such as the European Union Ship Recycling Regulation (EUSRR). Furthermore, AF Offshore Decom is verified as a shipyard on the European List of Ship Recycling Facilities, affirming its compliance with international, national, and local environmental and safety requirements. The recycling yard, AF Environmental Base Vats, represents the forefront of the industry, consistently prioritizing safety and emission control. Even if international regulations were to become more stringent, it is anticipated that the yard would meet these requirements without requiring new investments.

The case study presented in this thesis examines AF Offshore Decom's efforts to integrate production logistics principles into its operations. It explores the challenges faced by the company in managing the complexities of ship recycling logistics and the implementation of lean production practices to improve overall performance. By investigating the company's history, background, and current practices, this case study offers valuable insights into the potential benefits and challenges of adopting production logistics principles within the ship recycling industry. The comprehensive suite of services offered by AF Offshore Decom includes planning, engineering, project management, dismantling, and recycling.

4.1.2 AF Environmental Base Vats

AF Environmental Base Vats, owned by AF Offshore Decom, is a recycling yard specialising in demolition and recycling. Previously, the yard was used for building platforms before being repurposed. The yard primarily recycles offshore installations but currently has a 235-meter, 25,000-tonne Floating Production, Storage and Offloading (FPSO) ship for demolition and recycling. Although the machinery in the yard is mainly standardised, the set-up of equipment and other aspects can vary between projects. The general process involves weakening, demolishing, and dismantling structures at the lowest possible height. The company aims to own as little equipment as possible and instead hires as needed for each project. In terms of personnel, the company has its burners and cutters but hires other workers for processes such as front running. Planning is crucial to ensure efficiency and safety before ships and installations arrive at the yard.

The production area of the yard is around 70 acres and slopes inward towards the mountain. All water is collected in a 9,000 cubic meter underground hall before being purified in a tank. This system is almost 20 years old but remains state-of-the-art. The surface comprises three layers of asphalt, a 3-4 mm plastic membrane, and a 40 cm layer of sand. This base can be removed easily without impacting the area, and the high focus on providing a competitive advantage that is important for customers and reputation.

4.2 Processes and Logistics Challenges

Ship recycling at AF Offshore Decom involves complex processes requiring careful planning, execution, and management. These processes can be broadly categorized into three primary phases:

1. Pre-cutting: The initial phase involves preparing the ship for dismantling, which includes removing all loose items, cleaning, draining liquids, and eliminating hazardous waste. These tasks must be performed safely and by personnel with the appropriate certifications to handle such materials. This phase ensures that the subsequent stage is safer for operators to execute and helps mitigate environmental impacts.

2. Cutting: This primary phase involves disassembling the ship, tearing it apart, and dividing it into smaller pieces. Components are separated based on their material composition and the potential opportunities for reuse or recycling. The process entails cutting the ship's structure, removing machinery and engines, and segregating metals and other materials.

3. Post-cutting: The final phase focuses on handling, sorting, and transporting the resulting materials to their destinations. Metals, materials, and other items that can be reused or recycled are sorted and loaded onto transport vehicles before being sent to facilities such as smelting plants. Other materials, such as hazardous waste, are safely transported in secure containers to designated disposal sites, such as landfills.

Operating a ship recycling yard involves numerous logistical challenges. Here are some of the challenges identified through the case study:

1. Project Variability: Ships slated for recycling vary based on operational history, construction dates, and vessel types. Consequently, each ship recycling project is unique, with different execution requirements. This necessitates thorough planning and results in a complex and dynamic logistical environment.

2. Material Handling and Storage: AF often has a relatively full yard with various dismantling projects. Efficient material handling is crucial for maintaining productivity and preventing delays. Challenges include optimizing storage space usage, maintaining an organized inventory, and ensuring the steady transportation of materials.

3. Coordination and Communication: Effective coordination and communication are vital within the company and with subcontractors working at the shipyard. If this aspect falters, safety and efficiency can be compromised. Challenges related to coordination and communication include managing information flow, coordinating plans, and making prompt decisions.

4. Environmental and Safety Regulations: Adherence to environmental and safety regulations is essential for maintaining a sustainable and responsible ship recycling

operation. Navigating these regulations and ensuring compliance with industry standards can pose logistical challenges and be resource-intensive.

5. Resource Allocation: To maintain productivity and minimize costs, efficient allocation of labour, equipment, and space is crucial. Balancing resource allocation among projects that sometimes require the same resources while adhering to different deadlines presents a significant logistical challenge.

4.2.1 Processes

1. Pre-cutting

The initial phase of the ship recycling process is commonly referred to as "front running" within the industry. Thorough planning and preparation are conducted long before the ship arrives at the shipyard to address risk assessments and logistical considerations appropriately. AF Offshore Decom's offices in Oslo often carry out this planning process, though it was not the primary focus during the visit to Vats.

For instance, in the case of the FPSO ship, the shipyard had approximately two years to prepare and initiate front running, as they had to wait for a heavy-lift vessel from China. As depicted in Figure 5, the FPSO ship, measuring 235 meters in length and weighing roughly 25,000 tons, required the removal of approximately 4,000 tons before it could be lifted. This process, referred to as "float over, float in," involved the heavy-lift vessel being partially submerged below the water's surface, allowing the FPSO ship to be positioned on the lifting vessel's platform before being raised and transferred to land. The FPSO ship was then moved using 748 Self-Propelled Modular Transporter (SPMT) axles. During the front running and cutting processes, oil booms were deployed to prevent spills, and the deck structure was sealed to prevent rainwater from leaking into the fjord. Rainwater collected on board was channelled to an onshore treatment facility through a hose.

Figure 5: A Floating Production, Storage, and Offloading (FPSO) Vessel at Vats (Internal Source with Permission from AF Offshore Decom)

Front running comprises several operations that must be completed before cutting can safely commence. AF Offshore Decom hires personnel at the Vats shipyard to perform many of these front-running tasks. First and foremost, the ship is cleared of marine growth, such as mussels. Loose items on the ship are sorted in the washing area, and cables and equipment that can be resold are labelled. Items that can be removed without extensive cutting, such as furniture, are transported off the ship. Next, all fluids, including fuel oil, lubricating oil, hydraulic oil, bilge water, ballast water, and wastewater, are drained and stored in closed containers.

In the case of the FPSO ship, which operated in the North Sea oil and gas sector, its large oil storage tanks were pressure washed using lifts to access all areas. Squares were cut into the ship's side, as illustrated in Figure 6, to facilitate the entry of lifts into the tanks. Subsequently, the removal process involves extracting hazardous materials, including asbestos, toxic chemicals, heavy metals, materials containing naturally occurring radioactive materials (NORM), and other cleaning and maintenance chemicals. Special certifications are required to handle asbestos, a service provided by a locally certified company that also handles marine growth cleaning.

Figure 6: Opening to Entry Lifts for Washing (Internal Source with Permission from AF Offshore Decom)

Furthermore, insulation flooring and tiling are removed, as they often contain asbestos and other harmful materials. All cables and electronic equipment are removed, and potentially valuable items like navigation systems are resold. During the front-running phase, AF also creates an Inventory of Hazardous Materials (IHM) to provide a better overview of the ship's components and ensure compliance with international regulations.

The final aspect of front running involves securing the ship for cutting and ensuring safety. This includes stabilizing the ship and setting up equipment and safety measures for the cutting process. Once the ship is emptied, thoroughly cleaned, and prepared, it is deemed safe for AF workers to proceed with the second phase, which entails cutting and disassembling the ship.

2. Cutting

The primary focus of ship recycling is often perceived to be the cutting and dismantling of the ship. However, after examining this case study, it has become clear that the other phases are equally time-consuming and must be considered holistically. Although the safety of operators differs significantly between this shipyard and those in South Asia, it is perhaps during phases one and three that the most significant disparities in yard standards can be observed. This section will focus solely on the cutting process, even though operations occur concurrently; the accurate material flow will be further elaborated in phase three for each material classification.

AF Offshore Decom adheres to a policy of owning minimal equipment and leasing additional resources as needed. The company purchases consumables and often relies on agreements established by "AF Gruppen" for equipment. The base owns a simple crane, a 200-ton excavator, and a recently purchased 40-ton excavator for clearing steel behind the 200-ton machine. Other equipment includes stationary shear, wheel loaders, forklifts, and trucks. Most other machinery is leased on an as-needed basis. Logistics must be carefully planned to ensure sufficient machinery is available while minimizing idle time for leased equipment.

At the time of the shipyard visit, the front running and cleaning of the FPSO ship were not entirely complete, but the front section had been cleared, as that is where the dismantling would begin. Primarily, the front was chosen for dismantling to create space for future projects. It generally seems more efficient to begin at one end rather than starting with the entire upper deck and working downward. Regardless of incoming projects, it is essential to maintain as much workspace on the platform as possible. A general approach was outlined, while there is no standard procedure for dismantling ships due to varying designs. While the ship's hull can be dismantled relatively easily, the ship's edges present a more resilient structure. The proposed strategy entails elevating an operator within a crane, who employs a torch to create an opening in the hull slightly below the edge. Subsequently, an excavator with shears is lifted to this opening to tear apart the ship's hull. Once the hull is removed, excavators with shears will cut from the top downward. The workers always strive to operate at the lowest possible height. If there is a need to demolish larger sections of the ship using explosives, AF Decom specialists are called in. Gravel piles are laid out to cushion the fall and prevent damage to the underlying surface. Suppose the method of beginning at the top of the front section and working downward proves effective as anticipated. In that case, it is assumed that they will continue in this manner along the entire ship until it is completely disassembled.

After the shears cut the ship into larger pieces, the sections are moved further into the shipyard's working area. Here, smaller machines cut the pieces into smaller segments, and operators with torches are employed when necessary. Some materials are stored in intermediate storage around the ship before further processing. Conventional excavators are also used to tear materials apart. The shipyard features a unique stationary shear that can cut steel up to 20-30 cm thick and 6 meters wide. Several factors determine the size of the pieces, including the dimensions accepted by the melting plant. Generally, the aim is to maintain a maximum size of 4 x 4 meters, with a weight of less than 300 kg. Once this process is complete, the pieces are transported to the main quay for further transportation.

Previous attempts to use a guillotine in a crane proved problematic due to shock loads when the guillotine cut. Alternative methods, such as diamond cutters and wire saws, were also tried, but shears and torches were found to be the most effective in assisting with dismantling by machinery with shear.

3. Post-Cutting

Following the removal of waste from the ship and its disassembly into pieces during the first two phases, segregation and recycling commence. Much of this is carried out in parallel with phases one and two but is presented here as a single process occurring after the ship has been cut up.

Usable Equipment

Equipment and components that are suitable for reuse are sold to parties known to be interested or through platforms for the industry. Such items often comprise a low percentage of the ship's weight, and if their condition is not optimal, treating them as scrap may be more economically viable. Potential buyers expect the equipment to be in good condition, and if, for instance, a motor is involved, greater care must be taken during the ship's disassembly to avoid damage. This increases the time required, possibly rendering the total cost of the motor too high for the buyer's willingness to pay.

After this, waste and materials are sorted. Metal is categorized as process steel, structural steel and other metals. The process steal is weighed using radar to measure NORM values, and the structural steel and other metals are sent directly for cutting.

Structural Steel

Structural steel and other materials are cut and stored at the main quay for further transport. The transport vessel is a bulk carrier, used regardless of the cargo. AF Environmental Base Vats retrieves the vessel when needed, and two vessels may be utilised during high production periods. The company employs push production of scrap steel, shipping approximately 40,000-50,000 tons of steel yearly. As shown in

Figure 7, thick mats are placed between the ship and the quay as a safety measure to prevent debris from entering the sea or damaging the vessel. An excavator with a triple claw, containing a contamination monitor, is used, as depicted in Figure 8, to double-check that no steel with NORM values is shipped.

Figure 7: Loading the Steel onto the Transport Vessel (Internal Source with Permission from AF Offshore Decom)

Figure 8: Excavator with Triple Claw (Internal Source with Permission from AF Offshore Decom)

Process Steel

Process steel is scanned through a radiation portal, by manual scanning or by the triple claw. Following this, the steel is weighed, separating non-NORM and NORM materials. Non-NORM process steel is stored for washing in the wash bay, where an excavator holds the pieces as they are sprayed with high-pressure water jets. The cleaned steel is inspected and either re-sprayed or, if approved, sent through the control portal for further NORM value checks. Afterwards, it enters the structural steel cycle and is cut and stored at the main quay. Process steel containing NORM values is stored separately in the wash bay and cleaned using the same methods with high-pressure water jets to remove NORM. Once cleared, it enters the non-NORM process steel cycle and undergoes subsequent processes.

Waste

Waste is segregated and classified into non-metals, Waste Electrical and Electronic Equipment (WEEE), and hazardous waste. Each type is weighed separately before being stored for further transport. Non-metals and hazardous waste are sent to recovery or landfill sites, while WEEE is sent for reuse or recovery. Most waste is transported by truck from the shipyard and stored near the wash bay, closer to the shipyard entrance. Waste from the wash bay is segregated and classified into four categories: low NORM value, high NORM value, hazardous waste, and ordinary waste. Ordinary and hazardous waste from the wash bay are sent to landfill sites. In contrast, NORM waste is sent to NORM waste reception facilities, which typically charge a fee for radioactive waste disposal.

Water

One of the major competitive advantages of AF Environmental Base Vats is their water system. The entire platform is slightly inclined toward the mountain, with a pipe system directing all water into a 9,000-cubic-meter mountain hall. Rainwater and wash bay water are collected in this hall. In a region with high annual rainfall, such a system is crucial to prevent runoff into the sea during heavy precipitation. The water is then channelled to a tank that separates particles from the water and purifies it. The water is monitored and subjected to multiple rounds of separation until it is entirely clean and can be discharged into the Vats fjord. Although nearly 20 years old, this facility remains state-of-the-art. The production area's substrate, covering approximately 68,000 square meters, consists of three layers of asphalt, a plastic membrane, and a roughly 40-centimetre layer of sand, adhering to the same principles as a bathroom floor. Sediments separated from the water in the tanks are incorporated into the waste cycle for segregation and classification following the wash bay process.

4.2.2 Logistics Challenges

A major logistical challenge is the inherent variability of projects in ship recycling. Although there are similarities, and the working methods and principles remain consistent, each project necessitates thorough planning to determine the optimal approach. AF Offshore Decom has handled numerous offshore installations, but the FPSO ship is the first large ship they have dismantled. As they take on more ships, there will always be significant differences arising from factors such as their previous functions and ship types. For instance, there will be notable disparities between a ship like the FPSO ship and a cruise ship, which would have many cabins, making the front-running process more time-consuming but potentially benefiting from more modular construction, facilitating disassembly.

Another factor contributing to the differences between ships is their construction materials. Older ships tend to contain higher amounts of asbestos and other hazardous waste, while more recent vessels have moved away from these dangerous materials. One could envision ship recycling in 30 years will be cleaner, as the ships being recycled will have been built with fewer hazardous materials. Project variation is inevitable in this industry, but AF Offshore Decom manages this effectively by owning certain machinery used across projects and leasing equipment for specific needs. This approach also extends to their workforce, ensuring their employees have steady work while leasing additional labour during the initial phase when a ship arrives at the yard.

Effective material management and efficient storage space utilisation become crucial with multiple simultaneous projects at various stages. A crowded base demands impeccable logistics to maintain productivity and safety. In some cases, limited safe access options might hinder operators on one project. Much of the material flow is planned during morning meetings, but many decisions are made on the fly using radio communication. Operators often carry out the transportation of materials, overseeing the process to ensure efficient material flow.

Storage capacity at the quay can become a limiting factor, necessitating a larger, more distant storage area. This arrangement requires more time to transport materials and reduces the visibility of ongoing operations. All materials entering and exiting the yard are measured using a NORM radar scale, as illustrated in Figure 9, located near the washing hall. This streamlined approach facilitates efficient material flow while ensuring proper oversight.

Figure 9: Weight and NORM Radar (Internal Source with Permission from AF Offshore Decom)

Coordination and communication within the yard are vital for making efficient decisions and ensuring operator safety. Safe Job Analyses (SJAs) and Toolbox Talks are used for planning, with all personnel involved in the work participating in these meetings. External communication with subcontractors is essential for ensuring all necessary materials and resources are available on-site. Employing temporary workers can be challenging due to differing perspectives and training on handling tasks. All personnel must complete a mandatory health, safety, and environment (HSE) course before being allowed to work in the yard. They strive to be as thorough as possible to minimise misunderstandings. When temporary workers are from other countries, efforts are always made to ensure the presence of a responsible party who can facilitate communication in the event of language barriers. If language issues become a significant barrier and pose a minor risk to safety, those workers are not permitted to work at the shipyard, and others must be hired.

Ongoing communication occurs via radio, with different channels assigned based on the task. Work at the stationary shear has its channel for efficient communication without disturbing others. This also applies to the crane, while the rest use a main channel for the remainder of the work. Oral communication is also used for more significant decisions, depending on the scope, whether the responsible manager and operator engage in a discussion or address it through larger meetings. One could imagine even more modern communication possibilities. However, the human aspect of being able to speak with someone via radio is crucial for safety and avoiding misunderstandings, making it a suitable solution for this type of industry.

Complying with international and national regulations can also pose logistical challenges. While international regulations tend to be more lenient, Norwegian national regulations impose stricter requirements, which AF Offshore Decom further supplements with their standards. AF Offshore Decom's established routines and a strong emphasis on safety greatly facilitate the management of these logistical challenges, ensuring smooth adherence to regulations.

Effectively allocating resources to different projects and ensuring operators have the necessary equipment pose a significant logistical challenge. Balancing these factors effectively is crucial to maintaining productivity and minimising costs. Implementing larger machinery, such as hydraulic shears and material handlers for stationary shears and transport boats, as well as developing a custom cutting robot for manual burning processes, has increased efficiency and facilitated resource logistics, allowing resources previously occupied with time-consuming processes to be redirected elsewhere. Another challenge associated with resource utilisation is that machinery may become a bottleneck during periods of high production. In the event of a machine requiring maintenance or repair, it becomes necessary to reevaluate and adjust the working methodology and approach, often with little notice and varying durations. Job cards are utilised to indicate the necessary working height and scissor size when planning for equipment rental and utilisation of in-house machinery. The methodologies rely on continuous planning through meetings and site inspections involving multiple disciplines, such as engineers, operations managers, planners, and health, safety, and environmental (HSE) personnel, to name a few. This process may result in priority changes due to better-than-expected production outcomes or the need to accommodate incoming projects.

4.3 Production Logistics in AF Environmental Base Vats

4.3.1 Lean Production Implementation at AF Offshore Decom

AF Offshore Decom has previously employed a staff member responsible for examining the implementation of Lean methodologies to enhance yard efficiency. This led to significant benefits, as the organisation gained a more comprehensive understanding of Lean principles and the cost savings associated with executing tasks correctly the first time. However, there was an increasing focus on closing actions rather than the value of having an action. Several measures have been implemented to enhance yard efficiencies, such as introducing shears for machinery enlargement, procuring stationary hydraulic shears, acquiring material handlers for replenishing stationary shears, and utilising transport boats. A designated cutting area for manual cutting and a cutting robot for more efficient burning have also contributed to increased efficiency.

Additionally, a friction frame has been implemented to enhance pulling force and direction when tilting large structures, bringing the structures down to the working height for machines. Previously, work was predominantly conducted at elevated heights, and sections were lowered one by one. Now, machines are used more effectively in combination with weakening to bring down the modules, allowing for the use of shorter and more powerful machines. This initiative also reduces the need for multiple cranes and minimises time spent working at height.

Another lasting impact from the lean employee is sorting gas cylinders near the washing hall and the overall labelling and storage areas. Kitting was also introduced, ensuring that tools were available in a designated area throughout the working period. Moreover, a daily morning meeting attended by all staff features a board displaying the layout and work assignments, providing a visual representation of the day's tasks and an overview of the yard.

4.3.2 Layout

AF Environmental Base Vats includes, as shown in Figure 10, a deep-water quay and a platform with a well-developed drainage system at a high level. Additional facilities include dormitories for operators working on a rotational basis and accommodations for guests. An administrative building houses a reception area, offices, sleeping quarters, and storage for protective equipment. A canteen is located between the reception building and the dormitories. A large, fenced storage area with an additional building can be found along the path from these structures to the quay. Access to the quay is granted only via access cards, ensuring a clear overview of individuals at the yard at any given time. Furthermore, there are workshops and storage halls for machinery. As one approaches the quay, a washing hall with a drainage system also stores materials and waste from front-running operations. The last building before the work area houses offices for logistics operators, engineers, and other yard supervisors. A small self-service kiosk and a lunch area are available for employees to take breaks. Major equipment includes cranes, excavators with shears, a stationary hydraulic shear, excavators with grapples, wheel loaders, forklifts, trucks, and cars.

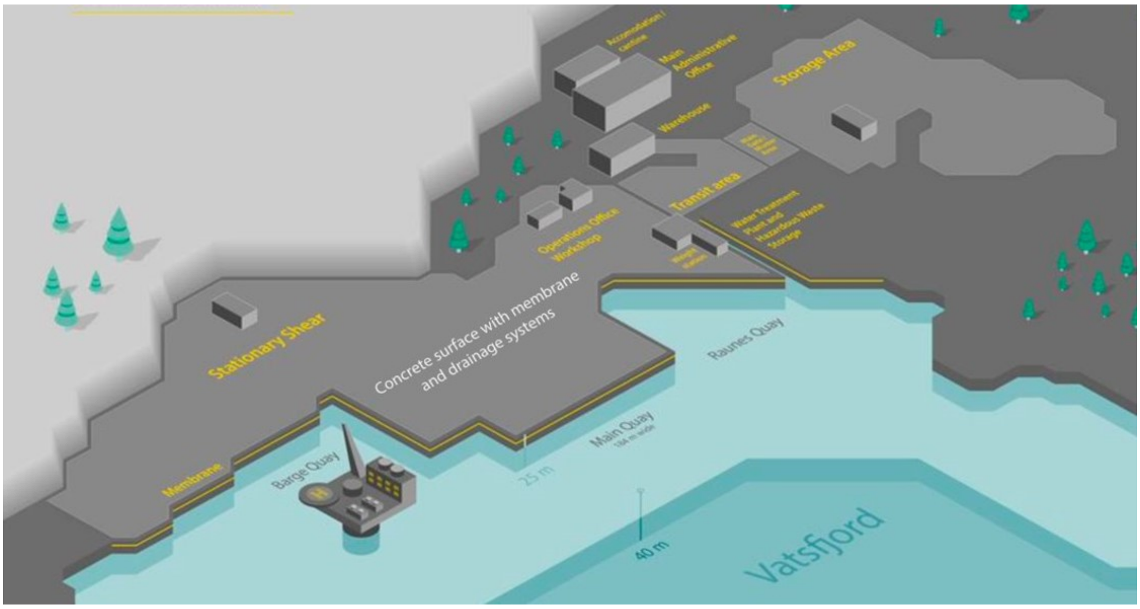

Figure 10: The Layout of AF Environmental Base Vats (Internal Source with Permission from AF Offshore Decom)

Based on the case study's findings, it can be inferred that the employees express overall contentment with the existing layout. However, there is a notable preference for larger facilities to accommodate their work-related needs, water storage, and other functional requirements. If the yard were designed today, they would prefer a more streamlined design based on assembly line production. In reality, the situation is more complex; however, Figure 11 illustrates a streamlined representation of the general processes at the shipyard.

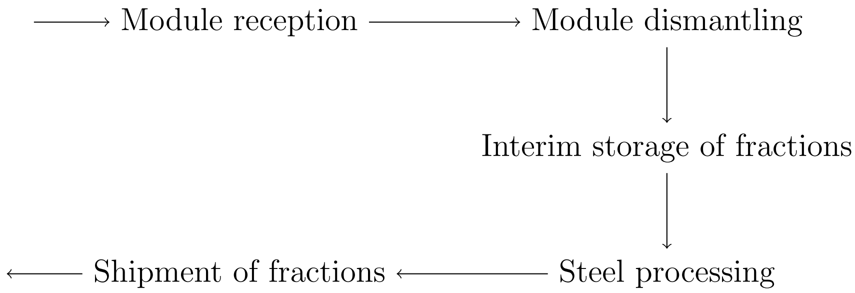

Figure 11: Streamline of Processes

Aspects that could optimize the yard's operations include:

- Increased quay capacity to accommodate larger structures
- Excavation of the rear area to create more space
- Anchor points to provide pulling capacity for skidding barges
- Conveyor belts for scrap and filling scrap boats
- Quays designed for vessels to directly lower topsides
- A dedicated transport system for moving smaller structures

5 Results

This chapter presents the findings that largely address RQ2 and RQ3. It begins by examining how the identified methods from the literature study can be applied in ship recycling. Subsequently, it explains the selection process of three methods that are further investigated and narrowed down for application at the AF Environmental Base Vats. Additionally, it presents AF Offshore Decom's response to the proposed methods.

5.1 Analysis of Principles, Theories and Methods from Production Logistics in Ship Recycling

After closely examining the data from the case study of AF Offshore Decom, several essential findings have been highlighted. These findings stem from a comprehensive review of relevant literature and the understanding of ship recycling through the case study. Production logistics is a broad subject area with many principles, theories, and methods. However, those selected in this research often appear in the literature relating to shipbuilding and construction, industries that have similarities with ship recycling. The decision to look at similar industries comes from the lack of current research focusing on production logistics in ship recycling. As a result of the conducted research, a compilation of theories, principles, and methods from production logistics deemed particularly applicable to this study has been assembled, as shown in Table 4. The theoretical foundations of these concepts were expounded upon in the theory chapter. In this section, however, the focus will shift towards exploring the practical application of each method within the specific context of ship recycling.

Lean Manufacturing	**Other Methods**
Kanban	Layout Optimization
CONWIP	Bottleneck Analysis
Takt Time	Kitting
Visual Management	
SMED	
Just-in-Time	
Total Quality Management	

Table 3: Identified Principles, Theories and Methods

5.1.1 Lean Manufacturing

In the process of collating relevant methods, seven have been categorized under Lean Manufacturing. It should be noted that the field of Lean is broad and diverse, with numerous concepts and principles. The selected seven have been recurrent in literature and have been chosen to maintain focus on the most pertinent. Following this, an exploration of how each term can be applied to ship recycling will be presented, and this exploration is rooted in the researcher's understanding of the ship recycling process.

Kanban

Kanban cards can yield various advantages; however, a careful assessment is necessary to determine whether they contribute to increased efficiency and clarity or introduce additional complexity. Within the context of ship recycling, there are several areas where the application of Kanban can be envisaged.

One approach could involve subdividing an entire project into numerous subtasks, and each assigned its own Kanban card. On a Kanban board, for instance, categories such as "to do," "in progress," and "completed" could be created. The card would be moved along the board as the task progresses, providing a highly visual and comprehensible status overview. In the context of simplifying the processes for illustration, a version is presented in Figure 12. Orange squares denote the tasks within the "Frontrunning" stage, while purple squares represent tasks in the "Cutting" phase. The "Post-Cutting" phase tasks are marked with blue squares. It is crucial to note that this depiction is purely exemplary, meant to showcase the application of the Kanban method, and thus, does not stem from a real-world case.

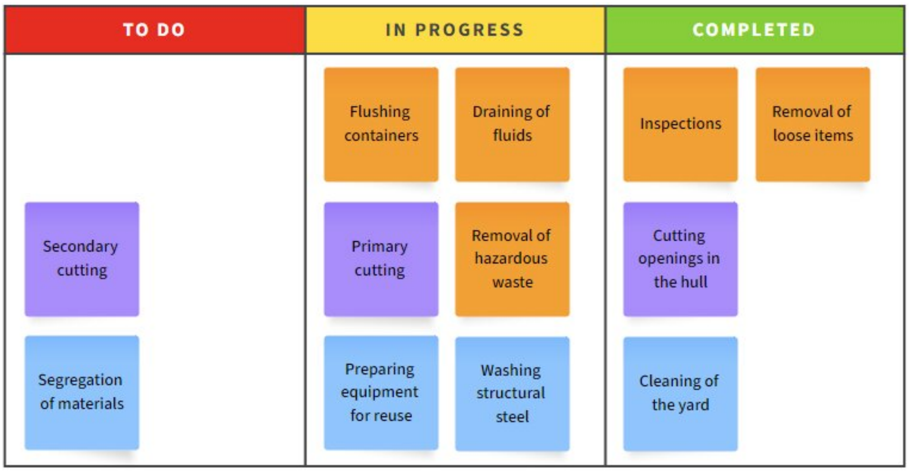

Figure 12: Kanban Solution

Maintenance of machinery is another crucial aspect of ship recycling. Production could reach a standstill if a critical piece of equipment fails. In this scenario, a board could be established where each machine is allocated its Kanban card. The card would then accompany the machine's status on the board, be it scheduled, ongoing, or completed maintenance. This tool could assist in maintaining a comprehensive overview of potential extended machinery downtime due to maintenance and ensure that all machines receive regular upkeep.

Kanban can also be employed to manage the inventory of materials extracted from the ship. Each material must be identified and assigned its own Kanban card. For instance, the card could be placed on the board once the material is ready to be shipped out of the base. Subsequently, the card can be moved once that material has been dispatched from the base. This would provide an immediate visual indication of which materials are abundant, and accordingly, arrangements for their transport could be ordered.

CONWIP

CONWIP bears many similarities with Kanban, making it conceivable to envisage its application within ship recycling operations. Initially, it was challenging to pinpoint the exact areas where CONWIP could be applied, primarily due to its distinct nature from Kanban, where it does not apply to specific products.

However, CONWIP could serve as an effective tool for managing storage space in a ship recycling yard. For instance, a storage area could be partitioned into sections, each capable of accommodating a specific tonnage. Each section could then be assigned a corresponding CONWIP card. Such a card denotes that the storage space can hold up to 50 tons. Once this space is emptied, due to the materials being dispatched from the yard or processed further, the CONWIP card can signify the availability of up to 50 tons of storage space.

This would result in a systematic and organized method of managing storage spaces and could be a valuable instrument for planning and coordination within the ship recycling operation. However, it is essential to note that the specifics of this approach would depend on the unique circumstances and requirements of each ship recycling operation.

Takt Time

The application of takt time in the ship recycling industry is challenging due to the industry's requirement for a certain degree of standardization and predictability, which are not entirely compatible with ship recycling. This is primarily due to the variability in the ship type received and the work's project-based nature. Furthermore, the high-energy tasks inherent in this industry necessitate a robust focus on safety. It would not be advisable if the imposition of takt time induces stress among the workers, as it may compromise safety.

Nonetheless, there are some potential applications of takt time. If a shipyard typically deals with a specific type of ship, standardization might be more feasible, allowing the implementation of takt time for different operations. Alternatively, takt time could be defined in terms of quantity, such as tons; for instance, a specific tonnage could be targeted for each shift. This strategy promotes steady workflow and enables more accurate predictions of project timelines. However, such measures must not be overly stringent to avoid safety compromises.

The definition of material flows within the shipyard might also facilitate setting takt time for each process a component must undergo. This approach can provide a consistent production flow and minimize the accumulation of interim storage.

While applying takt time in ship recycling is possible, the industry's unique characteristics necessitate a comprehensive evaluation of whether its benefits outweigh its drawbacks. Crucially, a safety analysis must be undertaken to ensure safety is not adversely affected.

Visual Management

Visual management holds immense significance within ship recycling, as it encompasses a fundamental concept of simplification and enhanced comprehension. This approach facilitates a comprehensive understanding and can be applied effectively across diverse industrial contexts. In ship recycling, visual management finds numerous practical applications, a selection of which will be further explored.

A noteworthy application involves creating a physical representation of the recycling yard using a combination of colour codes and modules to depict the current layout accurately. Given the size of these yards, such a tool can enhance visibility significantly, contributing to safety standards by enabling more informed decision-making. This model should not merely be an exhibit but incorporated into meetings where crucial decisions are made. Regular updates to this layout are crucial to prevent decision-making based on outdated configurations. A balance between detail and simplicity is essential in the model to prevent excessive complexity, which could negate its purpose.

Another potential utilisation of visual management lies in the management of inventory. Using large, colour-coded signs with clear text could aid in categorising and indicating stored items and their respective locations. This would allow for a quick overview of stock quantities.

Additionally, similar to the kanban cards' application, visual management could be used to maintain an overview of the status of various machines in the yard. With the range and diversity of machines typically present in a yard, a visual status representation can enhance planning and prevent production disruptions due to unexpected maintenance needs.

Upon examining the potential consequences of implementing visual management in ship recycling, it is evident that there will be initial time and resource costs associated with setting up the system, such as creating the physical yard layout. Employee training for system utilisation and integrating it into workplace culture are crucial considerations. Regular system updates will require a consistent commitment of resources. However, these are considered minor investments compared to the expected significant gains. It is crucial to ensure that visual management's implementation is universally understandable, regardless of individual backgrounds.

SMED

Single-Minute Exchange of Die (SMED) was initially devised to reduce changeover time in manufacturing. However, adapting this method for ship recycling is conceivable, as there are transitions between processes or tasks where the methodology can be applied. It is not necessarily a matter of changing a machine but rather transitions in processes or tasks.

One potential application of SMED could be the transition from one process to another, for instance, when steel cutting is completed, and the materials must be transported elsewhere for intermediate storage before being further reduced in size by other machinery. Implementing SMED here could entail having machines that will transport the material ready by clearing the storage area and performing all necessary preparations so that the material can be moved as soon as it is ready.

In addition, SMED can be implemented on machinery that frequently experiences downtime. This could involve undertaking preventive maintenance and stocking a supply of the parts that commonly break down on these machines. Furthermore, SMED could be applied to sorting various materials extracted from the ship, creating an efficient, standardised method for this process and employing equipment capable of simultaneously sorting different materials to avoid changeover time. This would prevent one type of material from waiting to be sorted while others are being processed.

SMED's primary focus is reducing unnecessary processes during machine operation. However, distinguishing between non-value-adding but safety-assuring processes and truly unnecessary ones is crucial. Training and making this philosophy a part of employees' everyday operations is vital to benefit from SMED genuinely. It should be noted, though, that any proposed changes must prioritise the safety of the workers.

Just-in-Time

Just-in-Time (JIT) focuses on enhancing efficiency and minimising waste by ensuring that resources arrive at their station exactly when required, negating extensive storage. Although applicable in ship recycling, it would be implemented differently than in typical manufacturing industries.

One potential application could be to mirror JIT in shipbuilding in reverse order; when materials are removed from a ship, they could be transported directly out of the yard. This method would eliminate the need for extensive on-site storage. However, finding a solution that prevents a continuous flow of half-filled transportation vehicles leaving the base is essential. If there is an option to accumulate materials before arranging transport, that would be recommended.

Another consideration involves machinery maintenance, which contradicts a previous SMED proposal. The proposition is to avoid maintaining an inventory of spare parts for machine maintenance instead of ordering them just before scheduled service or promptly when a machine malfunctions. A careful assessment is needed to determine whether it is more beneficial to maintain a parts inventory or to act swiftly when a requirement arises.

JIT could also be applied in the context of employee utilisation. Rather than keeping a large workforce engaged at all times, staff could be called upon right before their input is needed for projects. This approach is likely already practised to some extent in most places where the workload fluctuates throughout the year.

Generally, the successful implementation of JIT relies heavily on meticulous planning and seamless operations, as significant delays may occur if something scheduled to arrive just in time is delayed. The extraordinary effect of JIT may not be observed in ship recycling. Still, incorporating some elements of this philosophy, such as not possessing excessive, unnecessary resources before they are genuinely needed, may be beneficial.

Total Quality Management

The total quality management (TQM) approach, which seeks to enhance quality across all facets of an organisation by involving all stakeholders, can benefit any business where quality is a factor. This principle is undoubtedly applicable within various areas of ship recycling.

Primarily, the introduction of standard operating procedures is recommended. By providing clear, easy-to-understand ship-cutting and recycling procedures, operators would consistently follow the same methods, reducing accident risks and potentially boosting efficiency.

The philosophy of continuous improvement can also be embedded within the organisation. This approach emphasises the involvement of all stakeholders to ensure processes are as efficient, safe, and environmentally friendly as possible. It requires the evaluation of current practices, potential investments in new technology, and upskilling of employees to optimise their performance.

In addition, implementing quality checks between each process can be beneficial. It implies that an operator endorses the material before it is passed on to the next stage, reducing cases where material must be returned for rework or improvement.

Moreover, TQM emphasises customer satisfaction. In the ship recycling industry, close collaboration with customers receiving various materials can determine desired sizes and delivery methods. Although this might render the process less time-efficient, it could enhance the overall value chain's efficiency by integrating the customer into the value chain, potentially leading to heightened customer satisfaction and unforeseen benefits for the shipyard.

Overall, it is recommended that the TQM philosophy is firmly established within a ship recycling yard, as it is beneficial for any business to consistently focus on improving quality. This, of course, necessitates a gradual integration of these values across all operational levels.

5.1.2 Layout Optimization

Layout optimisation is a method that can significantly impact the operational performance of ship recycling facilities if previously underutilised. The potential benefits include enhanced efficiency, safety, and productivity on the shipyard premises. Multiple factors should be considered when modifying the layout of a ship recycling facility, some of which are discussed herein.

The focal point of layout optimisation is often material flow, a fundamental aspect that can significantly boost efficiency and productivity. A streamlined workflow can be achieved by strategically situating processes and workstations close to one another. Thus, the physical rearrangement of the shipyard can lead to an improved flow of work, which, in turn, improves the overall performance.

Another facet of layout optimisation pertains to safety enhancements. Clear demarcations of movement paths and delineating between machine-operated and personnel-operated areas can substantially reduce safety risks. Comprehensive analyses can be conducted to strategically position safety equipment around the yard, thus further promoting a safe working environment.

Additionally, layout optimisation can result in improved space utilisation within the shipyard. The layout's adaptability can be enhanced by repositioning equipment and facilities, offering more storage or workspace, or accommodating more projects.

In ship recycling, the incoming vessels vary significantly in shape and size, often necessitating substantial alterations to the process flow. Consequently, a flexible layout is beneficial, one where workstations are dynamic and can be adjusted to accommodate the specific requirements of each incoming project with minimal planning.

In essence, layout optimisation encompasses many aspects that require consideration in a ship recycling environment. Adopting digital tools can be invaluable in this regard, offering a means to explore and exploit the full potential of the shipyard and its operational capacities.

5.1.3 Bottleneck Analysis

In any manufacturing enterprise, it should be feasible to identify bottlenecks impeding overall efficiency. A bottleneck can take many forms, and during a bottleneck analysis, it is essential to remain open to the possibility that physical machines are not the only sources of constraints.

In ship recycling, conducting a bottleneck analysis is seen as highly advantageous. One approach could involve timing all operations, including those executed by different operators, and noting where materials predominantly accumulate when all operations are in progress.

Once bottlenecks are identified, strategic investments in newer and better machines can be made if a machine is found to be the source of the problem. Alternatively, reimagining material flow to prevent operations from directly obstructing others or overall productivity might be beneficial. If something outside the shipyard contributes to the bottleneck, advocating for rule changes and new principles could be a potential solution.

Within the ship recycling industry, the largest machines, which are responsible for undertaking tasks beyond the capabilities of smaller machines, may be designated as bottlenecks, particularly during periods of inactivity or when they are non-operational.

By conducting such an analysis, a shipyard becomes better equipped to make informed decisions when unexpected issues arise, distributing resources appropriately to maintain peak productivity. A bottleneck analysis could be highly relevant before potentially implementing any other methods proposed earlier.

5.1.4 Kitting

Kitting, a widely employed strategy in numerous industries, notably manufacturing, entails consolidating multiple smaller components into a comprehensive kit. When considering ship recycling, kitting's utilisation may deviate from its conventional application. Rather than assembling a multi-part product, ship recycling necessitates disassembly. Consequently, kitting in this context could encompass arranging requisite equipment and materials at the work location for the operator. Given the considerable expanse within a shipyard, consolidating necessary resources at the work site can facilitate time efficiency. The tasks within ship recycling are typically time-consuming, implying that any extra time invested in preparation could boost overall productivity. Moreover, the extracted materials from ships could be organised into kits; for instance, all electrical components could be compiled into one kit and then transported to the storage area for further sorting. This approach might optimise productivity by reducing the need for extensive sorting in the work area of the shipyard. Maintenance, another crucial aspect of ship recycling, could benefit significantly from having maintenance kits for the various machines. When a machine requires maintenance, the operator can easily retrieve the corresponding kit, reducing time gathering necessary items from different storage areas. Safety, with a consistent emphasis on ship recycling, could be improved using safety kits for various tasks. This ensures that all necessary protective equipment is readily accessible, reducing the chance of an operator potentially missing an essential safety element. Allocating time to prepare kits could yield long-term efficiency improvements, although the extent of this benefit would depend on the current practices within a particular shipyard.

5.2 Selection

The principles, theories, and methodologies identified in this study present a collection of tools and techniques that may have potential applicability within the context of ship recycling. Correct application of these tools could improve efficiency, productivity, safety, oversight, customer satisfaction, and quality, among other benefits. The scale of their impact will largely depend on the strategy used for their deployment. This section explains the reasoning behind choosing specific methodologies to answer Research Question 3 (RQ3). Subsequent chapters will propose how these methodologies could be effectively implemented at AF Environmental Base Vats, the associated shipyard of the case study company, AF Offshore Decom.

While these methods were identified by observing industries with similarities to ship recycling, it is essential to note that ship recycling is unique. Therefore, not all methods will have the same effect. Some are more relevant and offer greater potential benefits. The selection was influenced by the researcher's understanding of ship recycling, the operations at Vats, and the existing literature on these methods. After careful evaluation, three strategies have been chosen for further exploration: takt time combined with bottleneck analysis, visual management, and layout optimisation. These were selected due to their functionality and compatibility with the AF Environmental Base Vats. They address important aspects of ship recycling such as material flow pacing, bottleneck identification, clear communication, safety, and effective use of workspace.

Reasons will be given for why methods such as kanban, CONWIP, SMED, JIT, TQM, and kitting were considered less suitable, even though they may be valuable in certain situations. The selection process was guided by the need for solutions that would add the most value to the results of AF Offshore Decom. Some methods were excluded because the shipyard would not benefit from them, either due to having alternative solutions in place or because they had already been implemented.

The decision to select these specific methodologies allows for deeper exploration and the provision of tailored solution proposals for the shipyard. Although initially, it seemed challenging to associate takt time with the shipyard at Vats, its combination with bottleneck analysis could offer substantial benefits. These two could potentially ensure efficient resource use and steady workflow, which made them interesting to relate further to the operations at Vats. Visual management, currently in use and appreciated at the Vats shipyard, has the potential to be further optimised to enhance communication, safety, and overall efficiency. Layout optimisation is a logical choice for deeper exploration, considering the large workspaces typically associated with ship recycling, thus providing diverse opportunities for improvement.

The methods not chosen are considered less suitable. Kanban and CONWIP heavily rely on standardised work and even workloads, while ship recycling can be highly variable. SMED might have a beneficial impact in industries where tasks are highly repetitive by reducing changeover times. However, in ship recycling, the lengthy nature of the processes means the savings would not be significant. The evaluation encompassed kitting, JIT, and TQM, although AF Offshore Decom already implements a form of kitting. As for JIT and TQM, which are more overarching philosophies rather than immediately implementable solutions, they were considered less suitable for the Vats shipyard. Each method was therefore evaluated to ship recycling and its potential benefits for AF Offshore Decom.

5.3 Applicability of the Selected Principles, Theories and Methods in AF Environmental Base Vats

The following three outcomes stand out among the principles, theories, and methods the researcher identified, given their substantial potential for application at AF Environmental Base Vats. The researcher has tailored these methods to the Vats base, which in certain instances is based more on the methodology than a direct application thereof. The three outcomes presented consist of a combination of takt time and bottleneck analysis, followed by visual management and layout optimisation.

These results were presented in a workshop with AF Offshore Decom, attended by a project director and an engineering manager. The project director could perceive the outcomes from a macro perspective and correlate them with previous practices. At the same time, the engineering manager was able to directly link them to the current processes at Vats, where he is stationed. It was precious to verify the results and discuss their thoughts on applying the results, including the potential impact each might have. It is easy to undermine oneself, assuming one cannot improve a business that engages in these activities daily. However, it was reassuring to observe their recognition of the value of these methodologies. The researcher had them plot each result on a diagram examining effort against impact.

5.3.1 Takt Time Combined with Bottleneck Analysis

An extensive literature review has been conducted on applying takt time in manufacturing, particularly in production companies with multi-stage processes or assembly of multiple parts into a final product. This concept is often used in pull-production businesses, where the production relies on customer orders or forecasts based on prior demand. Takt time has proven to make the workday more predictable and transparent for those involved, as each station has fixed times or quantities to follow, establishing a pace to meet the demand. The simplicity of takt time lies in its calculation, which is the available production time divided by the customer's demand.

However, there is no immediate thought of where takt time could be applied for AF Environmental Base Vats. The primary reason is that they do not manufacture a product where a customer drives the demand. Their operation aligns more with push-production, where modules are dismantled into smaller steel pieces, with most being shipped to the smelting work in ”Mo i Rana”. This also applies to many hazardous materials, which require payment for the recipient to handle. Therefore, creating a takt time based on some form of demand would be challenging and potentially cause more logistical chaos than improved logistics.

Instead of discarding the idea, an examination explored ways to adapt the method to suit the yard in Vats. It was considered that factors other than demand could influence the determination of takt time, which sparked an interest in investigating this concept further. The possibility of conducting a bottleneck analysis and using it as the basis for setting the takt time for the yard emerged as an intriguing idea, prompting further exploration.

Bottleneck analysis is a methodology employed to identify the element hindering company production efficiency. Through conducting semi-structured interviews at the base, the research revealed that the base itself could be recognised as a bottleneck. The limited capacity of the yard to accommodate new modules and projects presents a bottleneck in production. The bottleneck's location is anticipated to shift as unforeseen events occur intermittently. Based on the site visit and understanding of the production operations, the stationary shear was identified as a potential bottleneck. It is generally recommended that the base in Vats allocate sufficient time for a comprehensive bottleneck analysis to obtain an overview that can inform future decision-making.

An outcome of the researcher's research on applying principles, theories, and methods from production logistics at AF Environmental Base Vats involves permitting the bottleneck (which, in this case, has been identified as the stationary shear) to establish the takt time for the initial processes. Suppose the stationary shear is capable of cutting a specific tonnage into pieces. In that case, the smaller excavators with shears must cut the same tonnage to consistently operationalise the stationary shear. Likewise, larger excavators with larger shears must dismantle the ship into parts to ensure the smaller excavators always have work. Presently, takt time is not utilised, and the ship is continuously cut up, with the steel segregated and stored in piles before the following process.

One positive impact of this combined approach of takt time and bottleneck analysis is that the storage piles on the ground will diminish. This is because the shear dictates the pace, eliminating the need to cut more than the shear can handle in a day. Rather than multiple interim storages around the ship and by the shear, there will be a more continuous flow with these processes to the extent possible. A side effect of this will be the creation of additional space on the platform where the work occurs. This additional space can enhance several areas, including efficiency, logistics, and safety, and may allow the consideration of taking on more projects.

The interim storages, previously several piles scattered about with a limit on how high one could stack, will remain on the ship until required within the takt time. This concept can be visualised through two highly simplified figures; Figure 13 represents the current practice, while Figure 14 illustrates the scenario following implementation, showcasing reduced inventory preceding the shear. This will result in storage in height, freeing up space in the work area. One could also argue that operators who cut can be flexibly deployed to other tasks, given that the amount they need to cut in a day is more or less predetermined.

Throughout the day, lesser amounts may be removed from the ship following the introduction of a set takt time, but the stationary shear will still cut the same quantities daily. Initially, the shear will have enough feed when the interim storages are emptied, allowing the operators cutting up the ship to be used elsewhere. Subsequently, all processes will align with the takt time, focusing on producing a specific tonnage during the day.

The extra time operators gain due to a lower ”cutting speed” can be utilised for equipment maintenance to prevent production halts. The safety aspect, where operators have more time to make sound decisions, and additional ground space making the production more transparent and even safer, can also be considered.

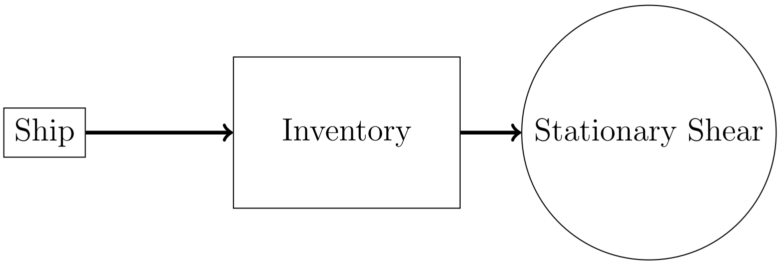

Figure 13: Process from Ship to Inventory to Stationary Shear. (AS-IS)

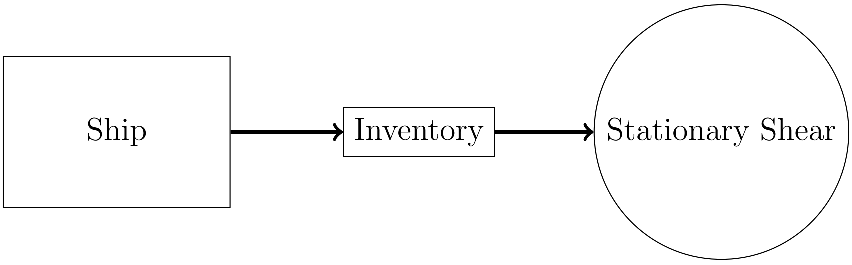

Figure 14: Process from Ship to Inventory to Stationary Shear. (TO-BE)

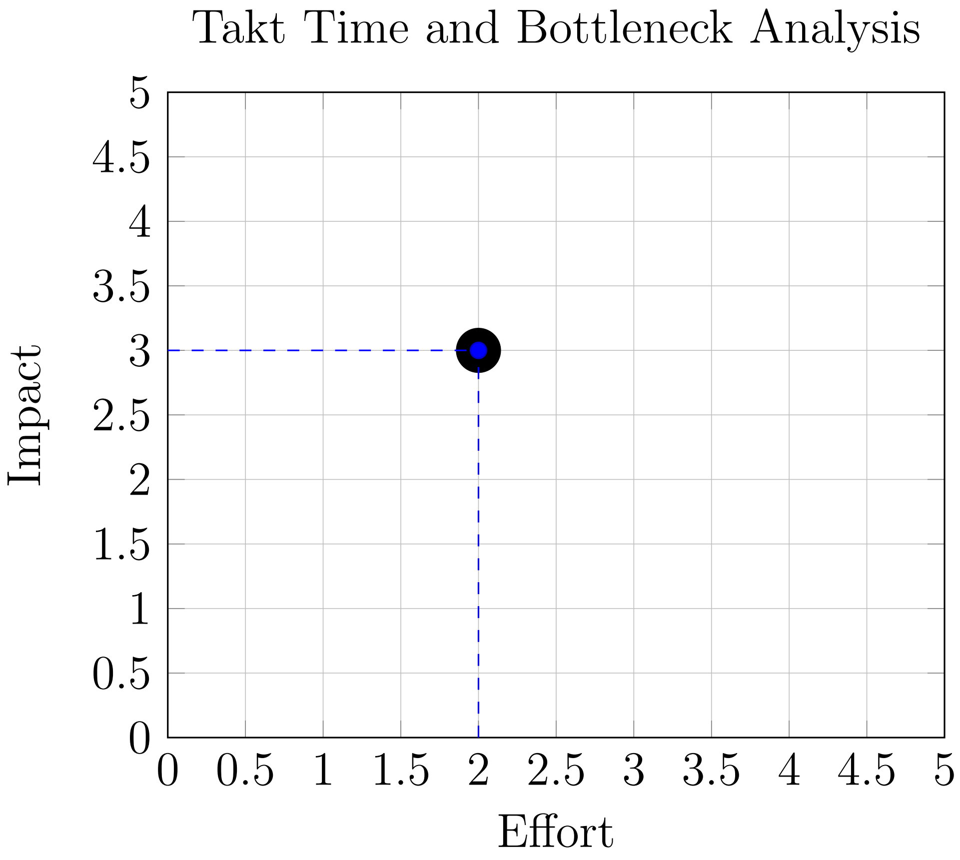

Figure 15: AF Offshore Decom's Response to the Proposed Takt Time Solution with Bottleneck Analysis: An Impact-Effort Graph

During the workshop with AF Offshore Decom, takt time and bottleneck analysis were presented as previously explained. There was consensus that the stationary shear could undoubtedly be regarded as a bottleneck but that several other machines could be categorized under this term. The most prominent white excavator with a shear was also seen as a bottleneck, as progress stalls when it sustains damage or requires maintenance. A critical aspect that specifically renders these machines bottlenecks is that not just anyone can perform the service; a company from Portugal is employed for this task. The need for this service becomes critical and could potentially result in a production halt rather than merely a bottleneck.

An approximate figure was provided for the amount the stationary shear can cut in a day, which was 500 tonnes. It was then discussed if this could serve as a reference number for the upstream steel-cutting processes. This was something they found interesting and worthy of further exploration. However, they noted a caveat: the amount that can be cut varies greatly depending on the specific material, making it challenging to consistently adhere to a set tonnage each day. Nonetheless, they were open to the possibility of introducing some form of established takt time.

There was also positivity towards conducting a more comprehensive bottleneck analysis to understand better what constitutes a bottleneck at any given time and how it impacts production.

As depicted in Figure 15, the proposed method was placed at 2 for effort and 3 for impact. This placement was justified because conducting a bottleneck analysis should not be excessively demanding, and the effect of implementing some form of takt time could be relatively significant. This is contingent, however, on minor adjustments to the proposed concept while preserving the essence of the idea. The most significant impact will likely be a reduction in ground storage space. However, it also clarifies the varying paces machines can maintain and increases statistical data on their operation.

5.3.2 Visual Management

Visual management, as previously mentioned, is not a method restricted to a specific industry or production. Instead, it is a strategy that all companies can implement to varying degrees. The fundamental concept is to utilise visual aids to communicate information as clearly and efficiently as possible. Often, extensive reports detailing forecasts and progress are commonplace, but the researcher's proposition is to convey this information in a visually intuitive manner.

There is a standard morning meeting at the shipyard, attended by everyone involved in that day's production. The operations manager presents the day's tasks and uses a board displaying the facility's layout with movable pieces for a comprehensive view. For challenging cases, a projector is used to review pictures and discuss solutions. These meetings naturally contain more details and are most time-consuming at the beginning of a shift when operators need to familiarize themselves with the project status at the shipyard. Towards the end of a shift, as operators have been doing the same tasks for several days, they are already familiar with their duties and what to consider. The morning meeting remains standard practice, but a detailed walkthrough is no longer necessary.

The second proposal on applying principles, theories, and methods from production logistics at AF Environmental Base Vats is to enhance these morning meetings with visual management. The physical layout board would be replaced with a 3D-scanned, digital representation of the shipyard, providing a comprehensive overview. The initial implementation may require considerable effort to develop the software, but updates should be straightforward and provide enhanced clarity once established.

Operators can be relocated within this digital representation, providing complete visibility of the day's tasks and areas requiring extra caution, such as high-traffic areas or areas with limited workspace. A substantial part of this solution involves the introduction or increased use of visual metrics, primarily for each project. Current forecasts and progress could be included in the representation, dividing each project into subcategories and measuring progress as a percentage.

Colour coding could indicate progress against plans, not exerting time pressure but as an aid in planning work. The goal is not to complicate but to provide an overview of the progress for anyone working at the shipyard. Operators performing the same tasks daily may lose sight of the bigger picture, and visual metrics could help them feel more included and take more ownership of projects.

Another metric to introduce is a capacity indicator for each storage area. At the wash hall, materials retrieved from front-running are stored, with liquids stored in secure containers and various loose materials stored in separate boxes. Instead of precisely measuring available space in each box, the total floor area could be measured, indicating the capacity for additional storage.

This percentage could be calculated from available floor space or weight of stored items, or both. Later in the day, an additional meeting could update the representation of where operators will be working in the final hours, offering a clear view for coordinating and making decisions where a status overview of the shipyard is required.

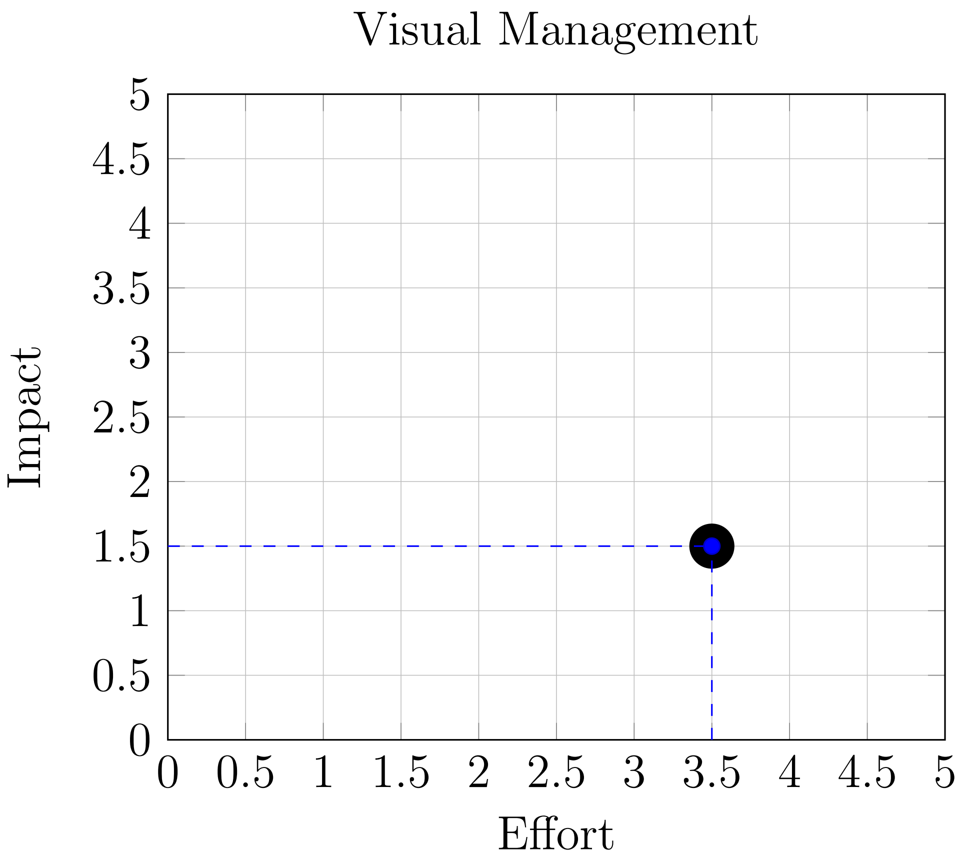

Figure 16: AF Offshore Decom's Response to the Proposed Visual Management Solution: An Impact-Effort Graph

Visual management was presented as described above during the workshop with AF Offshore Decom. The concept was well received and conveyed that the base had already been 3D scanned, suggesting that developing this representation should not be excessively challenging. There was also enthusiasm around including specific metrics, which should not prove difficult as extensive data is already available.

The workshop attendees disclosed that a similar tool is currently used offshore where several hundred operators need to be coordinated, and every minute must be utilised efficiently due to the high cost of maintaining much personnel offshore. This situation requires continuous dynamic planning to maximize labour against time constraints. They envisage that in the future, with increasing traffic at the shipyard, a similar arrangement could be beneficial on-site.

For such a visual representation to be effective, someone must be responsible for continuously updating it, and guidelines must be established to determine the frequency of complete updates. A proposed approach involves conducting a fresh 3D scan of the base before each shift, accompanied by incremental adjustments as needed.

As shown in Figure 16, they ranked the proposed method at 3.5 for effort and 1.5 for impact. The rationale for this is that even though much of the necessary data is available, creating an efficient representation will still be a demanding task. They are also satisfied with the current layout on the board during the morning meetings and do not anticipate a significant impact from this change, given the effectiveness of the existing system.

This system must function seamlessly and not be time-consuming for the benefits to be evident. In the future, with a potentially larger shipyard consuming more projects and a continuously full base, this tool could be considered as its impact could be more significant.

5.3.3 Layout Optimization

Layout Optimization involves analyzing the current layout and examining opportunities for improvement. There is not necessarily a definitive solution for how a layout should be designed, as it depends on the focus of the layout. Often, the goal is to enhance the flow of materials and increase efficiency, but the focus could also be on improving safety or ergonomics for operators. In the context of ship recycling, it involves considering the utilization of ground space, the organization of production equipment, and the movement of materials within the processes. The layout at AF Environmental Base Vats could be argued to be both a fixed position layout and a layout where the product moves. It is a functional layout insofar as it is divided into areas where different machines operate, such as the stationary cutter, dedicated burning area, and various excavation areas. This layout also has a fixed arrangement as the operators and machines go to the product rather than vice versa.

From semi-structured interviews with staff at the base, the impression is that most are satisfied with the current layout but could suggest minor improvements if necessary. A recurring concern is space limitations and steel transportation being time-consuming. The third identified outcome of applying principles, theories, and methods from production logistics at AF Environmental Base Vats involves optimizing the layout to enhance organization and improve material flow efficiency.

Despite being built 20 years ago, this base is still regarded as one of the leading offshore recycling bases in the world. This is largely due to the water renovation system beneath the platform and the ability to have complete control over all hazardous waste to prevent environmental pollution. This outcome considers the possibility of streamlining the logistics on the platform. Primarily, expanding the shipyard will open new opportunities to accommodate more projects and analyze how the setup should be based on the experience gained since the base's inception.

Apart from increasing the size of the base, the researcher suggested a solution to use conveyor belts for the intermediate transport of modules and loading of the transport ship. This would involve collaborating with a belt manufacturer to adapt them for the large steel pieces they need to transport and make them flexible enough for easy relocation for different uses. The researcher envisions these as a building set that can be assembled to the required length. For instance, if much steel is being cut up in one place that needs to go to the stationary cutter, a conveyor belt could be set up between these points to send parts continuously. This could create a smoother operation flow rather than having it come in batches. The belts could also be used for other tasks at the base, where a lot needs to be transported from one place to another. For loading the transport ship with steel, these belts could be employed. A conveyor belt could be set up from the intermediary storage area with pieces cut to the correct size and ready to be sent to a smelter, down to the quay where the transport boat docks. For a better understanding, the proposed solution is depicted in Figure 17.

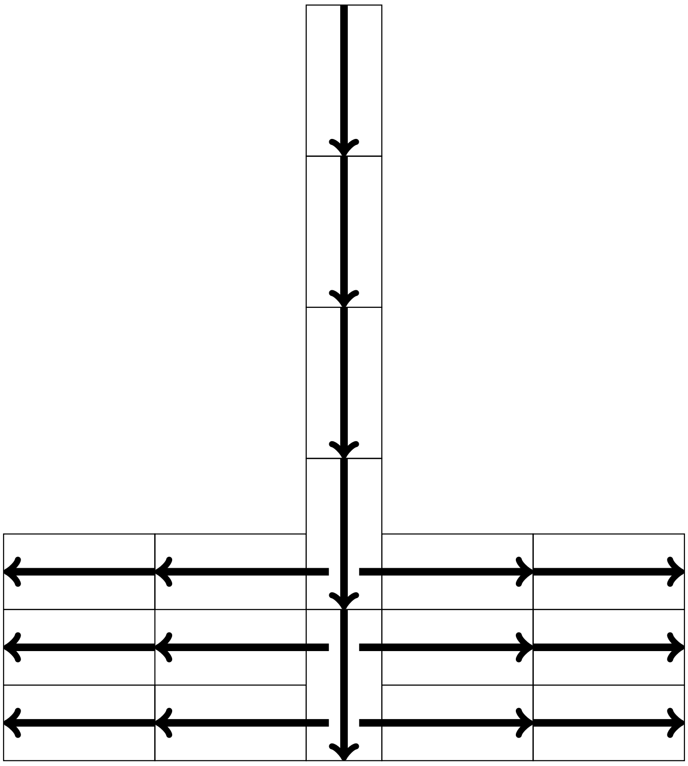

Figure 17: Conveyors for Transportation of Steel to the Main Quay

There will be challenges to avoid damage to the ship, so plenty of padding will need to be laid out both between the quay and the side of the ship and at the bottom of the ship's storage area. All proposed conveyor belt usage is to initiate a thought process, while the final solution must be defined in collaboration with the belt manufacturer to explore the possibilities and what cannot be done. An efficient system would eliminate much of the time spent on material transport, allowing that time to be used more productively. This solution could also integrate a scale at the end to measure how much has been stored and avoid taking pieces to other scales on the base.

Another aspect of the layout the researcher has considered is the potential to incorporate a slipway. The existing literature generally does not advocate for the use of slipways. However, in a shipyard where high standards are maintained, and emissions are well managed, the presence of a slipway for hauling smaller ships ashore could be feasible. This should not be perceived as the new method for ship arrival but rather as an option for accepting smaller projects during periods of reduced activity.

An additional consideration has been to achieve a more streamlined flow, not merely in processes but also the physical movement of steel. The concept involves receiving projects and storing them at the farthest end of the base, in proximity to the mountain, in order to move each steel element closer to the main quay gradually. From there, the steel is transported out of the base. From a production logistics perspective, this idea aims to achieve a unidirectional flow. However, it is important to consider that there may be practical challenges associated with implementing this approach. Limited space availability could pose constraints regarding receiving ships from the main quay and manoeuvring them through the entire base to reach the farthest point. One feasible option could be to use the main quay for receiving new projects, which is today's standard procedure. The steel can be cut up to the stationary shear, then accumulated by the quay further in. However, this approach would require adaptations to ensure the transport ship can dock. These adaptations would require land-based modifications and excavations from the bottom of the water to ensure that depth conditions do not pose a barrier.

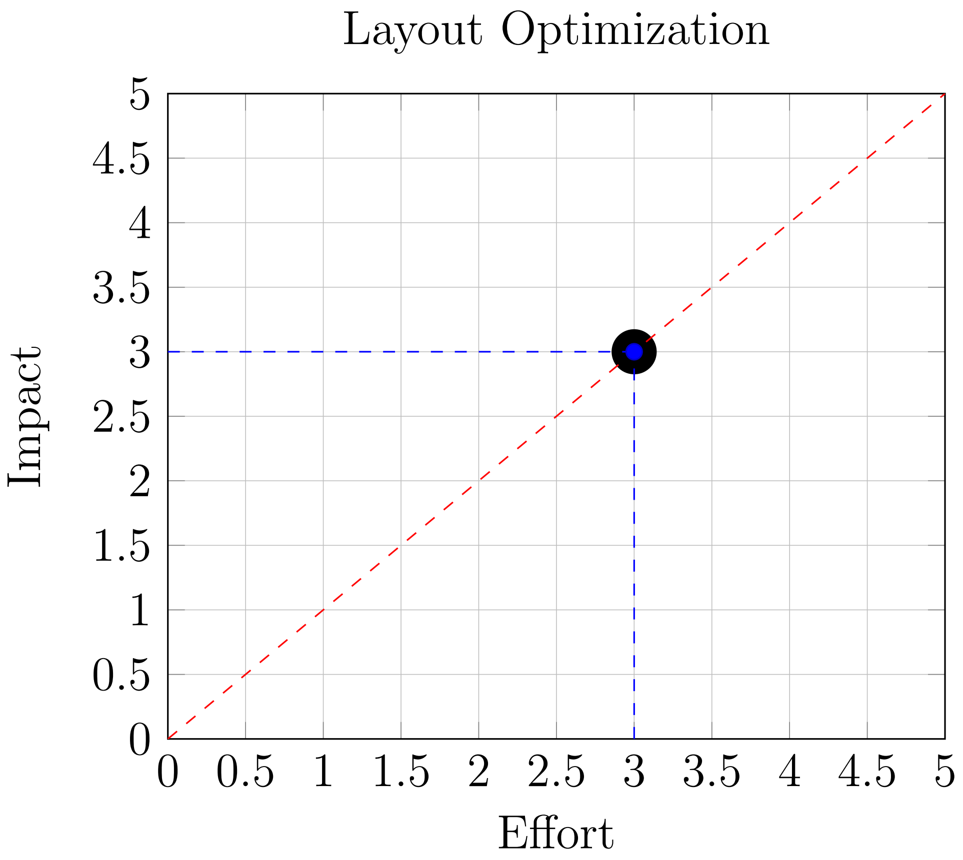

Figure 18: AF Offshore Decom's Response to the Proposed Layout Optimization Solution: An Impact-Effort Graph

During the workshop with AF Offshore Decom, the researcher emphasised the concept of Layout Optimization, highlighting the use of conveyor belts during the loading of the transport ship and focusing on achieving a more streamlined flow. Despite the spatial limitations, AF Offshore Decom emphasised their contentment with the current layout but acknowledged the potential for layout improvements. They expressed openness to the concept of conveyor belts. However, they faced challenges envisioning the practical aspects of loading the transport ship, particularly regarding heavy and large steel pieces that could pose risks of damage. While this is a critical consideration, the researcher envisions the feasibility of implementing automated solutions utilising conveyor belts and innovative approaches. Additionally, they were optimistic about the focus on streamlined operations but felt that starting with projects inside near the mountain would be challenging to implement in practice.

As seen in Figure 18, they placed the proposed method at 3 in effort and 3 in impact. There is also a red dashed line running linearly from 0 to 5. This reflects their feedback that the impact of layout optimization is closely related to how much effort they put into it. A minor layout optimization could yield a small effect, whereas a significant layout optimization could yield a substantial effect. The impression is that minor optimisations are entirely feasible, but a more significant optimisation should be carried out in line with a broader long-term plan for the base.

6 Discussion

In this chapter, the results are discussed directly, along with their application at the Vats facility, highlighting the implications that may arise. Furthermore, it shares insights and knowledge gained through the study. Finally, a section is dedicated to proposing suggestions for the future of the ship recycling industry.

6.1 Exploring the methodologies: A Deep Dive into Takt Time, Bottleneck Analysis, Visual Management, and Layout Optimization at AF Environmental Base Vats

Based on the results, exploring the potential the three methodologies can have for AF Offshore Decom is intriguing. AF Offshore Decom also confirmed this sentiment during the workshop where the results were presented. They recognised some challenges that could make direct implementation somewhat tricky, but they affirmed the potential and relevance of the methodologies.

Takt Time Combined with Bottleneck Analysis

Implementing takt time in combination with bottleneck analysis can, if appropriately applied, increase overall productivity by smoothing the work pace and optimising the use of yard space. However, the practical execution of a bottleneck analysis and setting a consistent work pace might be challenging. As mentioned during the workshop, the stationary cutter can handle approximately 500 tons daily. This figure can act as a set takt time. However, earlier cutting processes can vary tremendously, from approximately 50 to 1000 tons per day, depending mainly on the material being cut and the demands of that particular project phase.

Ships comprise different sections, and it is naturally faster and easier to cut the ship where there is only steel, without any extra considerations for other parts of the ship. However, it is a more complex process when dealing with an engine room, where much equipment could be resold, requiring special care.

While maintaining a continuous flow of processes and minimising ground storage may be beneficial, it could result in longer project durations if this ground space is not used for new projects or better resource utilisation. This could minimise the effect of such a strategy. The understanding is that a particular space is reserved for each incoming project, so this space is invariably designated for the ship.

One challenge in implementing takt time could be equipment maintenance. For example, if one of the significant bottlenecks, like the stationary cutter or the largest white excavator breaks down, very few service providers can fix them. Sometimes, a company from Portugal must be flown in for the repairs. If there were not enough intermediate storage of steel because the aim was to maintain a continuous flow from the white cut-up ship, then all the smaller machines would also stand idle. On the other hand, if there had been more intermediate storage, as is currently the case, they could continue working with this steel.

Other bottlenecks likely to have a more substantial impact on production are primarily related to the shipyard itself, as there is a limitation on the number of projects that can be concurrently managed due to the limited ground space available. As a result, the overall progress is constrained or regulated by the inability to accommodate additional projects.

The reception time for new projects emerged as another potential bottleneck. The workshop underscored the requirement to receive all projects between May and August, as adverse weather conditions during this period hinder offshore operations. If projects could be received evenly throughout the year, this would enable a more uniform overall operation and enhanced predictability.

Another challenge is getting projects onto land, which is currently only feasible by lifting them onto the shore. In the case of the FPSO project, one of the world's largest lifting ships had to be used to bring it ashore. This lifting ship, sourced from China, incurs significant costs. AF Offshore Decom had to wait up to two years until this ship was in Europe, and it became more cost-effective to commission it for the lifting of the FPSO ship compared to bearing the full cost of transporting the ship from China to Norway.

Predicting the exact impact of this methodology in practice is challenging, as testing must first be conducted to see the effects and to leverage the benefits it brings. As a primary recommendation, a more thorough bottleneck analysis should be conducted as it can serve multiple purposes and will not disrupt production more than the time taken to execute it. Whether more fixed work speeds should be established can also be considered. Given the nature of ship recycling and the need to maintain safety and avoid employee stress, continuing with the current processes may be preferable.

Visual Management

Visual management, the second method yielded from the study, is valuable for any business to consider, provided its benefits are fully leveraged. In ship recycling, it can help maintain safety and improve communication within the shipyard. Ship recycling is a fairly complex process, and visual management can help enhance understanding of overall operations, promote transparency in progress, and serve as a helpful tool for decision-making and coordination.

When it was presented during the workshop, AF Offshore Decom was receptive to this method. They possess some data that could be utilised without it being overly complicated. They already employ a form of visual management through a physical layout on a board discussed in every morning meeting. However, they acknowledge the potential value of developing this further, especially if the shipyard's workload increases in the future and necessitates enhanced control.

The implications of this method primarily revolve around creating a digital representation. Here, they could employ 3D scans already taken of the base. Someone would then need to create a simple representation of this, capable of efficiently moving operators within the depiction. This representation would also need regular updates to ensure accuracy and usefulness.

Regarding visual metrics, there are not many implications as they have extensive data on the progress of different processes that are measured daily. It is positive that everyone can follow this to get an insight into the total operation. The only question here is what to include: whether to keep it very high-level or delve deeper into individual tasks. One must remember that visual management should provide information at a glance, which necessitates limiting the level of detail included.

This would be a helpful tool, given the advancements in technology today. Although the current system works, it is anticipated that more can be obtained from a new system, especially if it is well integrated into the shipyard's culture and routines. During the workshop, it was noted that when working offshore on platforms to be recycled, a similar digital representation of all levels is used, detailing where various operators should work. Given the high cost associated with offshore operations, there is a pressing need to optimise time utilisation and implement meticulous planning. This system is already in use and should be possible to integrate into the shipyard.

Layout Optimization

The third approach discerned from the findings pertains to exploring opportunities for optimising the layout of the shipyard, for which several proposals were suggested. The shipyard in Vats has maintained the same layout since its inception approximately 20 years ago. Despite this, a high degree of satisfaction was observed among the employees during the researcher's site visit. Modifying the layout of the shipyard could enhance material flow, reducing the distance that materials need to be transported. Given the enormous volume of materials that need to be moved, which requires substantial resources, this optimisation could be particularly beneficial.

Designing an optimally efficient permanent layout presents a significant challenge due to the variability in the projects admitted into the base. As this is project-based work, ample space is required to ensure flexibility and the ability to devise dynamic solutions. Reevaluating the layout will inevitably consume resources, necessitating comprehensive analysis and potentially requiring machine learning and other modern technological tools. This would allow for the optimisation of space utilisation and facilitate the analysis of the optimal placement of incoming projects. Implementing a new layout will undoubtedly entail significant investment, accompanied by the risk of unforeseen issues not associated with the previous layout. However, the researcher's proposal revolves around evaluating layout optimization, where the actual implementation needs to be considered later.

A proposed recommendation within the scope of this study is the deployment of conveyor belts for material transit between various processes within the shipyard, as well as during the loading of transport vessels. Developing a system of flexible conveyor belts that could be assembled between locations where a large volume of material needs to be transported could substantially reduce the time and delays associated with moving materials, thus promoting a smoother flow. Workers who typically move materials could be reassigned to other tasks. Such a system could also enhance safety by eliminating the need to move and lift large steel parts. However, there are specific implications to consider, such as the cost and maintenance of the system, which would constitute a significant expense. The materials to be transported would also vary in size and shape, necessitating conveyor belts capable of handling these variations without jamming or spillage. This concept merits further consideration, and it would be beneficial to involve companies that supply these systems to customise them as much as possible for ship recycling.

In the case of using conveyor belts for loading transport vessels, there is a risk of damage to the ship if the materials fall directly onto the ship's bottom. Solutions must be devised to dampen the impact and prevent the materials from falling into the water or damaging the ship's side. This practice is currently in place so that it can be continued. The challenge lies in developing a reliable loading solution without stoppages or incidents of materials falling. If a reliable solution cannot be developed, the current loading method is preferable regarding safety and efficiency. Conveyor belts for transporting materials between locations on the ground are easier to implement in practice, so further consideration should be given to this possibility.

6.2 Key Insights and Knowledge Gained from the Study

Significant new insights into ship recycling have been obtained throughout this investigation, enriching the comprehension of its processes and the application of production logistics within this industry. While ship recycling was a focal point in the project assignment, the complexity and magnitude of the industry were only fully appreciated after personally visiting a shipyard.

The study identified specific methods scarcely documented in the literature about their use in ship recycling, enriching their analysis and potential application in this context. One key finding was the identification of bottlenecks. Initially, the assumption was that a machine represented the physical bottleneck, but the study unveiled that space limitations at the shipyard and project intake timelines posed a more significant hurdle. This led to the understanding that bottlenecks could shift and that their identification was crucial, given their profound impact on overall production.

Another critical insight emerged from the proposal to introduce a transparent and comprehensible representation of the shipyard's operations. Such visualisation could enhance communication and coordination, leading to a more modern approach to visual management. While an effective existing system was in place, the study found that proactively preparing for potential future increases in production and complexity could be beneficial. The significant finding here is incorporating more visual metrics and new technology to improve the existing solution.

Furthermore, the study addressed the advantages of performing a layout optimization of the shipyard. Despite the shipyard's layout remaining unchanged for an extended period and functioning effectively, applying technology could further optimise the shipyard's utilisation. One suggestion involved using conveyor belts to improve material transport within the shipyard, promoting continuous flow and reducing reliance on operators for material movement. This could lead to safer operations and increased efficiency.

Other knowledge from the study includes a more detailed understanding of the processes and the possibilities of practising a safety-oriented industry like ship recycling. It is clear that production logistics principles, theories, and methods, although not directly associated with ship recycling, can yield positive effects. However, utilising these methods seems less about their direct application and more about an adaptation based on these methods. The study emphasises the importance of continuous improvement and the exploitation of the potential for productivity, safety, and efficiency enhancement. Furthermore, the degree of method implementation is shown to correlate with the effectiveness of the results.

6.3 Recommendations for the Ship Recycling Industry

Through this master's study, the researcher has developed extensive knowledge and interest in ship recycling and envisions a significant transformation of the industry in the future compared to its current state. The following are some recommendations for the ship recycling industry.

1. Maintain high standards: Ship recycling yards should always strive to maintain the best workplace conditions, considering environmental preservation and employee safety. Adherence to international regulations should be the minimum requirement, and efforts should be made to push for even stricter standards to ensure a safer and more secure industry.

2. Invest in new technology and explore the application of production logistics methods: It is evident that regulations will become more stringent, and ship owners will prioritise yards that uphold high standards. Herefore, early investment in new technologies and methods that enhance efficiency and safety is wise. Technology can mitigate some of the inherent risks associated with ship recycling, making it a more secure operation in the future.

3. Share experiences and knowledge: The ship recycling industry should continue to promote knowledge sharing and collaboration across yards and borders. Despite the competition, collective efforts to enhance safety and efficiency can benefit the entire industry, given the inherent risks involved in ship recycling.

4. Continuous improvement and employee training: The culture of continuous improvement should be fostered within every ship recycling yard. Regular training and ongoing development of employees are essential to ensure they are equipped with the latest and best work practices and feel confident in performing their tasks safely.

5. Establish a unified international regulatory framework: Authorities, such as the EU, ILO, IMO, NGOs, and other relevant stakeholders, should consistently review and enhance the regulatory framework for ship recycling. The goal should be to establish a system to incentivise choosing a ship recycling yard with higher standards. Transparent and enforceable regulations are fundamental, and efforts should be made to promote transparency within the industry.

6. Increased research and development: Ship recycling yards, where possible, should seek opportunities to collaborate with universities and research organisations. By engaging with researchers and utilising future technologies, new methods and practices can be developed to address the challenges of ship recycling. Furthermore, proactive marketing efforts are needed to raise awareness and attract more attention to the ship recycling industry.

These recommendations, if implemented, can contribute to the overall improvement of the ship recycling industry, leading to safer, more efficient, and environmentally conscious practices.

7 Conclusion

This chapter concludes the master's thesis. It begins with a summary of the thesis, followed by a response to each research question, outlining where they were addressed in the thesis and summarizing the findings. Furthermore, it presents the contributions of the thesis to the industry, discusses the study's limitations, and provides suggestions for future research.

This master thesis explored the complexity of ship recycling processes from a production logistics perspective. It examined the challenges involved and assessed how different production logistics principles could improve the operations at one of the highest standard ship recycling yards. This led to a deeper understanding of the processes and challenges and offered insight and a practical walkthrough of methods for the industry. The implications of this study extend beyond the single yard that was the focus of the investigation, serving as a valuable reference for further improvements in the efficiency and productivity of the entire ship recycling industry.

7.1 Research Questions

7.1.1 RQ1: How is ship recycling carried out from a production logistics perspective?

This question was addressed through a comprehensive elucidation of the ship recycling processes, as seen from a production logistics perspective. The research was underpinned by the insights gathered during a two-day visit to AF Environmental Base Vats and the subsequent ongoing communication with representatives from AF Offshore Decom. The investigation revealed that ship recycling comprises a sequence of meticulously planned tasks and multifaceted activities. Essential tasks included the front-running operations, the actual cutting of the ship, segregation of materials, material storage, and the disposal of hazardous waste and recycling or repurposing of materials.

From a production logistics viewpoint, these tasks need to be coordinated and executed in a manner that optimally utilises the available resources, minimizes waste, and prioritizes safety. This necessitates effective material flow management, adept inventory control, efficient waste management, and comprehensive internal and external transportation logistics.

The research also unveiled several critical challenges within these processes. Notably, the size of the shipyard posed physical limitations, the stringent processes required for handling hazardous waste (a standard likely not matched in developing countries' yards), and a window of approximately four months for accepting projects. These challenges illustrate areas where applying production logistics principles can contribute significantly to more efficient, sustainable, and safe ship recycling practices.

7.1.2 RQ2: Which principles, theories and methods from production logistics can potentially be applicable at ship recycling yards?

In response to this research question, the study embarked on an in-depth exploration and characterization of various principles, theories, and methods from production logistics, assessing their potential applicability within ship recycling. This analysis was drawn from a comprehensive review of the literature on these concepts, coupled with the enhanced understanding of ship recycling processes gathered through the site visit and addressing RQ1. Given the scant existing research specifically focused on applying these concepts in ship recycling, the literature review included studies from industries with similar characteristics - high variability and project-oriented operations, such as shipbuilding and construction.

Multiple concepts were identified as potentially beneficial for ship recycling, as detailed in Table 4. Depending on the unique circumstances of a given shipyard, several of these methods could improve material flow, increase oversight, enhance resource utilization, boost efficiency, reduce waste, and generally uplift productivity.

Lean Manufacturing	**Other Methods**
Kanban CONWIP Takt Time Visual Management SMED Just-in-Time Total Quality Management	Layout Optimization Bottleneck Analysis Kitting

Table 4: Identified Principles, Theories and Methods

Implementing all the identified methods in ship recycling operations is feasible. However, some would require more significant adaptation to fit the unique context of ship recycling rather than a direct application. For some, integrating the underlying philosophy into the shipyard's operations might yield more significant benefits than merely applying the method. While there is potential for adaptation, for some methods, the unique characteristics of ship recycling may limit the extent of benefits realized, potentially resulting in a lower return on investment. Consequently, it is imperative to carefully evaluate each method's applicability and potential benefits within the specific context of a ship recycling yard.

7.1.3 RQ3: How can the most suitable principles, theories and methods identified from production logistics be utilised at AF Environmental Base Vats?

Applying the principles, theories, and methods identified in RQ2 within the context of ship recycling at the AF Environmental Base Vats forms the foundation of the response to this question. Drawing from the findings in RQ1 and RQ2, three methods were determined to have significant potential for implementation at the base in Vats: takt time combined with bottleneck analysis, visual management, and layout optimization.

Takt time combined with bottleneck analysis: This principle was most relevant for enhancing efficiency, productivity, and space utilisation at the Vats base. A smoother flow of work can be achieved by setting a pace for processes based on identified bottlenecks. While the standard application of takt time, as driven by customer demand, may not align with the nature of tasks in ship recycling, substituting the customer demand with the pace set by the bottleneck is recommended for further exploration. Moreover, conducting a bottleneck analysis can provide additional benefits, such as improved coordination and better decision-making in the face of unforeseen events.

Visual management: A part of the lean management philosophy, visual management was highlighted as an essential tool for increasing transparency among all parties involved at the Vats base. It can facilitate better coordination and planning of tasks. By visually representing vital information, such as the status of operators, and the progress of different projects and sub-projects, the shipyard can enhance the overall understanding of operations among workers. This promotes engagement and fosters a culture of continuous improvement. Modern technology to facilitate visual management is highly recommended to meet the demands of future shipyards and firmly establish this tool in the shipyard culture.

Layout optimization: Improving the layout can potentially significantly increase efficiency and safety. Using flexible conveyors for moving large amounts of material around the shipyard can improve flow, free up manual labour for use elsewhere, and provide a safer means of transport. Layout optimization should be considered with new technology to maximize workspace utilization.

These proposed solutions should be adapted to the specific shipyard they are to be implemented. The key lies in integrating these principles into the shipyard's culture and ensuring a continuous strive for efficiency while maintaining or enhancing safety. The findings suggest a dynamic process of adaptation and improvement, where new ideas are tested, evaluated, and refined in light of practical experience at the AF Environmental Base Vats.

7.2 Contribution

This study contributes novel research to an area where previous scholarly work is notably scarce, thereby deepening our understanding of ship recycling from a production logistics perspective. It provides insight into one of the world's premier recycling yards and demonstrates the feasibility of carrying out such a complex and hazardous industry professionally. The most significant innovation lies in this study's comprehensive examination of how production logistics can be applied in ship recycling, an exploration not found to the same extent in previous research. It further elucidates the potential impacts this could have on the ship recycling industry.

7.3 Limitations

This study, similar to other research, inevitably has certain limitations. It focuses solely on a single ship recycling yard, which may not comprehensively represent the entire ship recycling industry. Furthermore, the applicability of the identified principles from production logistics could considerably vary across different ship recycling yards due to disparities in practices, local surroundings, and process execution. A significant portion of the knowledge gathered in this thesis is based on observed data and interviews, which might introduce an element of bias.

7.4 Future Research

While this thesis provides a novel contribution and valuable insights, ample opportunities remain for further research. Foremost among these could be expanding the scope to include multiple ship recycling yards, broadening the understanding of the industry. It would also be of considerable interest if future studies conducted case studies where multiple identified principles are implemented and their effects measured. Additionally, research into incorporating new technologies in tandem with these methods, and assessing their impact upon implementation in the yards, would present intriguing prospects.

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