Bridging Operations and Management on the Shipyard Production Floor

The application of FRAM within a shipbuilding environment

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by

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Preface

What you have in front of you is the final effort towards officially concluding my life as a student. In the summer of 2018 I started with a Bachelor's degree in Mechanical Engineering in Eindhoven, followed by a Master's degree in Maritime Technology in Delft. Although this switch was not obvious at the time, it made sense to me. I grew up on and around the water, often finding myself working on boats both small and large, and already back then I must have experienced the craftsmanship involved in building and maintaining them. At the same time, I have always been deeply intrigued by the rapid development of technology and the challenge of discovering how it can be applied. The many hours I spent watching the TV-series "How It's Made" as a child certainly fed this interest. In this thesis, I have tried to combine those two interests.

The overarching goal of this thesis is to contribute to practical and operational shipyard environments. It explores how technology can be implemented in ways that respect the craftsmen who ultimately realize each vessel, and how managerial intentions can be bridged with the realities of work on the production floor. By analyzing both "work as imagined" and "work as done", I hope to offer insights that are directly applicable to shipyard practice.

I am grateful to the many people who made this journey possible. First, I thank everyone that welcomed me during this project, be it through site visits, office ambushes or informal conversations. The overall openness and willingness to share insights provided an essential foundation for the work presented here. I also acknowledge the individual craftsmen on the shipyards who passionately explained their daily realities. These perspectives ensured that the analysis remained anchored in actual operational practise.

A special word of appreciation goes to Floorganise. Throughout the project, I have recognized in the colleagues at Floorganise the same ambition that drives this thesis; the commitment to support real shipyard operations with a healthy sense of reality. Without the trust, support, and network of Floorganise, this thesis would not have been possible in its current form.

Finally, I sincerely hope to remain close to actual shipyard operations in my further professional life. The promise to myself, and to those who I encountered in this past year, is that I will not lose sight of the practical realities of shipbuilding, nor the craftsmanship that continues to inspire me.

Björn Visser
Delft, May 2025

Summary

This thesis explores the persistent misalignment between formal managerial processes and actual operational practices within shipyard production environments. The central aim is to investigate how a socio-technical approach can enhance the alignment of work systems in shipbuilding, ultimately improving operational effectiveness and productivity. To achieve this, the study applies the functional resonance analysis method (FRAM), enriched with an abstraction hierarchy, to systematically compare work as imagined (WAI) with work as done (WAD) in a case study for an abstracted major European shipyard.

The research is grounded in the observation that the shipbuilding industry is facing significant challenges due to market volatility, technological complexity, labor shortages, and an increasing dependence on subcontractors. Shipyards operate under engineering-to-order (ETO) conditions, characterized by concurrent engineering (CE), bespoke vessels, and high variability. These factors result in a dynamic environment in which formalized processes frequently fall short of capturing the real work performed on the production floor.

A core finding of this study is the clash between top-down control mechanisms and bottom-up operational flexibility. While managerial systems aim for standardization, traceability, and efficiency through techno-centric tools like enterprise resource planning systems (ERP) and manufacturing execution systems (MES), the reality is that production relies heavily on tacit knowledge, informal coordination, and ad hoc decision-making. This misalignment contributes to inefficiencies such as rework, delayed feedback, and ineffective implementation of innovations.

The methodological contribution of the thesis is the development of a novel framework that uses FRAM in combination with an abstraction hierarchy to model and analyze WAI and WAD. Through detailed data collection, formal process documents for WAI and field observations combined with informal interviews for WAD, the method enables multi-level analysis of work functions, their interdependencies, and emergent variability. The comparative analysis reveals that WAD involves more functions and connections, including multiple feedback loops, absent in the WAI, indicating a richer and more adaptive operational reality.

Two specific discrepancies exemplify the misalignment: the absence of explicit operational management functions and proactive material expediting from WAI. Their omission implies that critical functions are informally performed yet formally unrecognized, leading to a lack of support in digital systems and inadequate performance monitoring.

This thesis offers actionable recommendations for both shipyards and software providers like Floorganise. For shipyards, these include formalizing operational management roles, adopting socio-technical frameworks such as the plan-do-check-act (PDCA) cycle and Hale's rule management model, and improving knowledge transfer through the socialization, externalization, combination, internalization (SECI) model. For Floorganise, the research recommends tailoring tooling to reflect WAD, supporting adaptive planning practices, and expanding consultancy services to help clients integrate socio-technical considerations.

In conclusion, the study demonstrates that sustainable productivity improvements in shipbuilding require bridging the gap between WAI and WAD. By adopting a socio-technical lens and systematically modeling operational realities, shipyards can better align managerial intentions with shop floor execution. The proposed method and findings extend the application of FRAM beyond safety domains into general industrial operations, offering a replicable approach for tackling similar challenges in other complex production settings.

The summary was generated using OpenAI's ChatGPT 4o language model and subsequently edited and verified by the author.

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Nomenclature

Below, all abbreviations that are used within the thesis are defined. Abbreviations are also introduced in text in their first use.

Abbreviations

Abbreviation	Definition and explanation
AI	*Artificial intelligence*
ATO	*Assembly-to-order*
BPM	*Business process management*
BPMs	*Business process modeling systems*
CE	*Concurrent engineering*
Cobots	*Collaborative robots*
ERP	*Enterprise resource planning*
ETO	*Engineering-to-order*
EU	*European Union*
EVM	*Earned value management*
FRAM	*Functional resonance analysis method*
GFCF	*Gross fixed capital formation*
HSEQ	*Health, safety, environment, and quality*
I4.0	*Industry 4.0*
IoT	*Internet of things*
IT	*Information technology*
KPI(s)	*Key performance indicator(s)*
MES	*Manufacturing execution system*
MTO	*Make-to-order*
PDCA	*Plan-do-check-act*
PLM	*Product lifecycle management*
SECI	*Socialization, externalization, combination, internalization*
SEUS	*Smart European Shipbuilding*
VR/AR	*Virtual reality / augmented reality*
VSM	*Value stream mapping*
WAD	*Work-as-done*
WAI	*Work-as-intended*

1 Introduction

The shipbuilding industry is a key sector for Dutch and European society, having a great societal role [1] and responsible for a significant turnover, also involving numerous industrial partners and component manufacturers [2]. Traditionally performed as a craft, Western European shipbuilding is now approached as a production network [3], characterized by its engineering-to-order (ETO) nature [4] and concurrent engineering (CE) practices [5] that enable the development and production of highly specialized vessels. These practices, while essential to meet customer demands, introduce unique challenges that hamper competitiveness [6]. The industry operates under high pressure to meet customer demands and regulatory standards while continuously adapting to technological advancements and market changes.

High competition exerts a significant pressure on shipbuilders to perform efficiently and cost-effectively. Profit margins are generally low, making cost control a primary driver of business decisions [6]. This financial pressure is compounded by the capital-intensive nature of the industry, where significant investments are required for infrastructure, equipment, and technology [7]. In addition, the industry faces major labor shortages [8], particularly in operational roles, adding to the challenges of maintaining productivity and meeting project deadlines. In the context of this research, the labor shortage arguably has an adverse effect on the level of tacit knowledge within operational organizations. In general, the shipbuilding market is tight, with intense competition and numerous external pressures influencing the industry's dynamics. These pressures challenge the market and introduce risks to the shipbuilding process.

The operational environment in shipbuilding is inherently dynamic, characterized by high degrees of autonomy and reliance on the craftsmanship of workers [3, 9]. Shipbuilding requires a large amount of tacit and contextual information, which is often not formally documented but is crucial to successful project execution [10]. This reliance on tacit knowledge highlights the importance of effective communication and knowledge transfer within the industry. Traditionally, shipbuilding has relied heavily on personal relationships and informal networks to facilitate collaboration and problem solving [3]. However, there is a shift towards more corporate collaboration, driven by the need for standardized processes and improved efficiency. This transition presents both opportunities and challenges for shipbuilders as they navigate the balance between maintaining personal connections and adopting more formalized and automated approaches.

'Floorganise' is a Dutch software provider for the marine industry, specialized in operational planning software. Floorganise's goal is to dictate the state-of-the-art in software for operational planning in shipbuilding [11]. With major clients across multiple continents and expanding, they fulfill their promise of increasing shipyard productivity through increased control. As a company, Floorganise has a deep interest in gaining a deep understanding of innovations in ship production, the drivers, and its constraints. The initiation of this thesis research is an example of the thought leadership that Floorganise strives for. With an intrinsic understanding of its clients' operations, Floorganise is able to deliver more effective solutions.

This thesis addresses the issue of disconnect between operations and management within shipyards. Following this disconnection, one can expect that there will be a clash between the various approaches and technological improvements available to the shipbuilding industry. This will be further investigated using socio-technical principles to analyze a work system within operational shipbuilding. The focus of this thesis is on shipbuilding production activities. Here, design and engineering, and later commissioning project phases are outside of the research scope. The ultimate goal of the research is to coordinate and perform shipbuilding operations effectively and efficiently, optimally utilizing technology in socio-technical work environments.

The structure of this thesis is as follows: chapter 2 provides an introduction to the shipbuilding industry, its current challenges, and existing innovations. It concludes by introducing a socio-technical perspective and exposing the research gap that is to be studied. chapter 3 expands on the methodology used in this research, including the use of the functional resonance analysis method (FRAM) in combination with abstraction hierarchy, as a modeling method for complex socio-technical work systems. chapter 4 presents the results of an FRAM analysis on a case study and discusses the key findings. chapter 5 extends the findings to recommendations made specifically for this case study, as well as toward shipbuilders in general and towards Floorganise as a software solution provider. chapter 6 reflects on the research findings and discusses the findings from the perspective of existing research. chapter 7 concludes the thesis by summarizing the key points and discussing the potential impact on the shipbuilding industry.

2
Shipbuilding

2.1. Shipbuilding industry challenges and strategy

The shipbuilding industry is a crucial sector within Dutch and European societies. It provides national security and strategic autonomy, ensures the availability of naval vessels, and is essential in reducing reliance on foreign suppliers. The industry drives technological innovation in the maritime domain and supports economic stability through high-skilled jobs and related sectors [2]. In addition, it ensures control over maritime trade routes, which is vital for countries with significant maritime activities, such as the Netherlands. The industry is transitioning from a craft-based trade to a structured and specialized production network, integrating multiple industrial partners and component manufacturers into its supply chain.

The shipbuilding industry is characterized by external and internal influences that pose challenges to the market and require the development of strategies to navigate this complex environment, resulting in substantial exposure to risks [6]. Principal influences are identified through a review of the existing literature, in which their individual impacts on the industry are laid out, alongside the fundamental mechanisms employed by the industry to address these challenges. These market influences are not extracted systematically, but are identified from recurring themes in the literature. Upon identification, a general market challenge taxonomy is developed based on these individual influences. This market challenge taxonomy was validated with multiple stakeholders within the industry, such as scientific researchers, shipyard managers, and workers. In the early stages of research, the author of this thesis spent a lot of time visiting multiple Dutch shipyards and meeting with several scientific researchers specialized in the shipbuilding industry. The taxonomy was recognized as broadly representative and serves as a basis for further research within this thesis. Due to the diverse nature of different shipyards, certain influences have a more pronounced impact on some shipyards compared to others. The diverse nature only further confirms the dynamic characteristic of the shipbuilding industry.

The following subsections detail the distinct market influences, the strategies that the industry adopts, and their consequences. This is followed by a synthesis of the different influences and challenges to generate a holistic perspective on the industry. This is further elaborated in terms of information management by integrating industry case studies with academic literature.

High competition

The shipbuilding industry faces intense global competition, with market pressures that require on-time delivery, cost efficiency, and high-quality output [6]. These drivers are equivalent to the main market drivers defined by the iron triangle [2, 12]: time, cost, and quality. Globalization has intensified this competition, introducing players from new regions that challenge established shipyards. Although some countries are making an effort to support shipbuilders by providing state aids and thus improving the competitive position of shipyards, the effectiveness of such aids is limited and has disturbing long-term effects [6]. As a result, European shipbuilders have differentiated themselves by focusing on specialized markets, offering complex, high-tech vessels with advanced onboard systems [2]. Despite this specialization, competition remains fierce due to low customer lock-in and a demand-driven market. Furthermore, Asian shipyards have also recently entered the market of complex vessels.

Low profit margins

The profit margins are low, as a result of the high competition in the shipbuilding market. These low profit margins are amplified by volatility in demand and supply chain costs [6, 13]. To maintain financial stability, shipyards employ rigorous cost control measures that extend to operational departments, such as the implementation of rigid enterprise resource planning (ERP) systems [14, 15]. This results in strict oversight of these operational sectors, accompanied by the desire to reduce operational flexibility as a strategy to mitigate uncertainty and risk [16].

Capital intensive

The shipbuilding industry requires substantial capital investments [7], with a higher capital stock-to-employment ratio than what is typical for the manufacturing industry [6], this is visualized in Figure 2.1 where the capital-to-employment ratio is presented in several global sectors. To maintain capital liquidity and secure assurances, responsible financial management is essential. Given the labor intensive nature and significant capital absorption during the construction phase, careful hourly budgeting is crucial to effectively manage total project expenses [10]. The need to reduce the overall project throughput time is further driven by capital intensity, as it causes capital to be absorbed over shorter durations. Intermediate payment milestones are commonly agreed on to ensure liquidity. However, these milestones often do not correspond to the actual costs incurred in the project timeline.

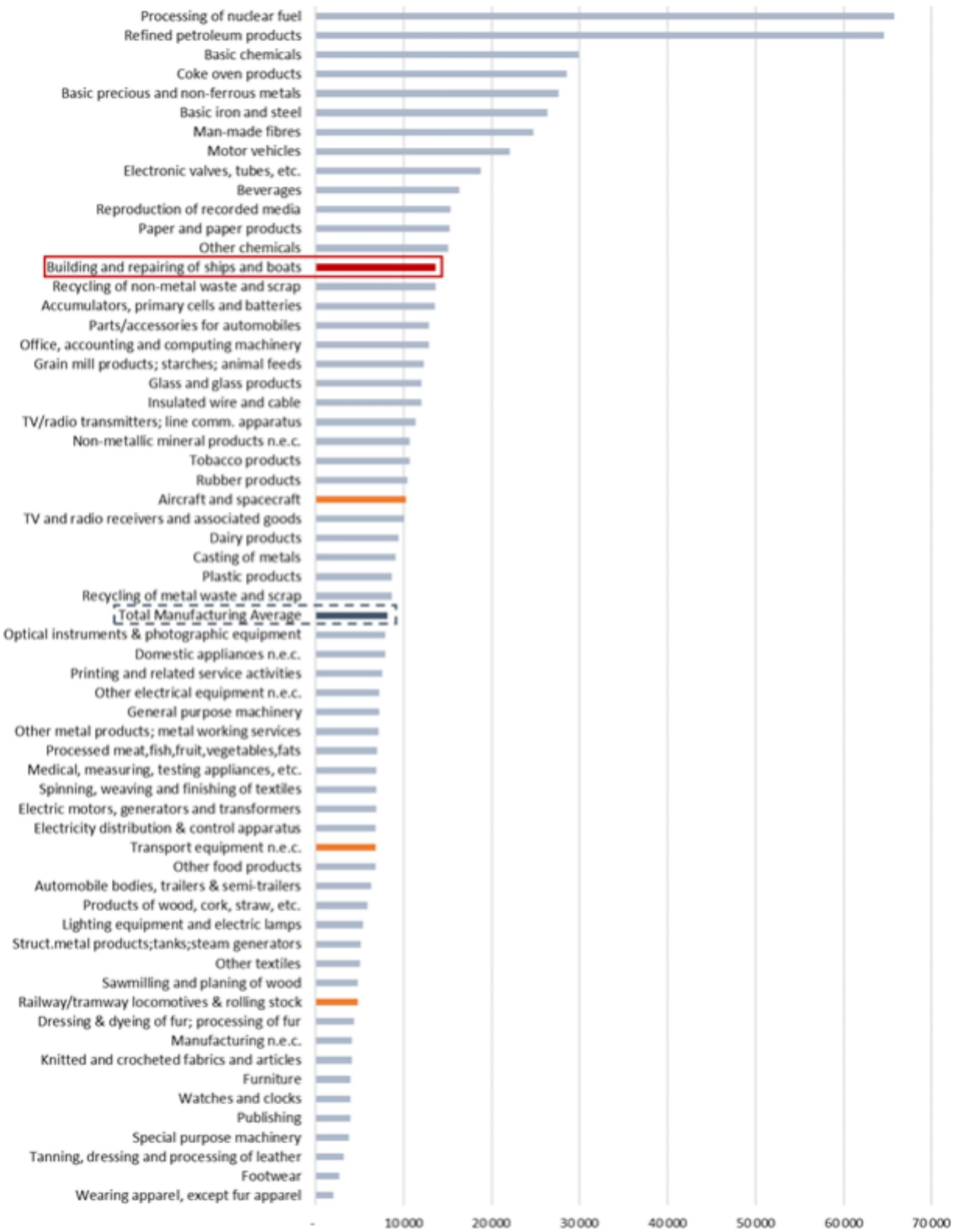

Figure 2.1: Ratio of Gross Fixed Capital Formation (GFCF) over Employment, illustrative capital intensity across sectors [6]

Concurrent project execution

Considering that the delivery time plays a primary role in the project tendering [6, 17, 18], it is crucial to focus on the lead time in project execution. Shipyards implement extensive strategies to reduce lead time [7, 18, 19]. Typically, project phases overlap deliberately with each other, relying on concurrent project execution practices [5, 16]. An example of such practises is the release of engineering drawings towards production before the complete engineering scope is finished, with the risk that later engineering activities may lead to a revision of a scope that is already in production. In the industry this specific example of concurrent project execution is known as concurrent engineering (CE). As a result of concurrent project execution, tighter collaboration is required between departments. Although formal collaboration and handovers are accounted for in project organization, in practice different cultures and work environments, with different moral codes, must collaborate intensively [3].

Western Europe: Product innovation

European shipbuilding is specialized in highly complex and high-value vessels [2, 9] that are dense in on-board systems. Focusing on one-off or limited-production run vessels. These shipbuilders employ market diversification strategies based on product innovation as a coping mechanism against high competition. A great example in this regard is Royal IHC, a Dutch shipbuilder specialized in dredger vessels. This shipyard explicitly names product innovation as a company value [20].

The integration of advanced systems, or novel design elements, differentiates the vessel from competitors. Within this specialized industry, customer satisfaction, intimacy, and product customization are key. The characteristic of the described industry originates in craftsmanship-like approaches. This approach to specialization helps avoid direct competition with foreign low-wage countries [9]. This market feature challenges standardization efforts, as the specifics are different for each vessel/project delivered. In addition, it toughens long-term investments, as applicability to new projects is unknown, and write-off periods are often limited to single projects.

Engineering to order (ETO)

The specialized shipbuilding industry is inherently an ETO field, with production organized around particular projects and where the project phases are only executed after an order is signed [4, 16]. The specialized industry, as described in the previous subsection, requires the deployment of ETO strategies [4]. On the other hand, shipyards focused on more standarized vessels, with larger production runs, are able to employ make-to-order (MTO), or even assembly-to-order (ATO) strategies to optimize operations [4]. Meaning that ETO shipyards intrinsically have to employ other strategies than non-ETO shipyards, limiting the extent to which these shipyards can be taken as an example.

The ETO characteristic hampers operational continuity by having fluctuating demand cycles, and uncertain production conditions [4]. Furthermore, general standardization is difficult due to the temporary nature [3, 21]. Because future purchasing volumes are uncertain, it may be impractical to enter into long-term agreements with suppliers. Consequently, shipyards often rely on temporary partnerships with suppliers and subcontractors.

Continuously changing standards

The shipbuilding sector is tightly regulated [22, 23], with technological progress driving the adoption of innovative construction techniques and the implementation of novel materials in ship design. This is especially valid for the specialized European shipbuilding industry, where customer requirements push product innovation. This innovation results in evolving standards, complicating the application of strict procedures, requiring ongoing reassessment and validation of standards, and the need to adapt to new ones [23].

Labor shortages

There is a noticeable demand for skilled workers in the technical field, with a particularly high requirement in the shipbuilding industry [2, 8]. There are especially shortages for workers in hands-on production roles, such as welding or pipe fitting. An increasing number of temporary workers are being brought in from other countries to work in the Netherlands and other European countries [2]. The cyclicity of the market and the aforementioned low profits limit shipyards in making long-term investments in, and comitting to production personnel [8]. In general, the shortage means that the labor market is extremely tight and competitive to employers. Marine industry employers confirm this and perceive labor shortages as a major obstacle to operations, as presented in Figure 2.2. The reputation surrounding shipbuilding is that it is considered a dirty industry to be employed in, which discourages potential new workers from enrolling in it. The general pressure on available labor drives advances in productivity improvements and promotes automation.

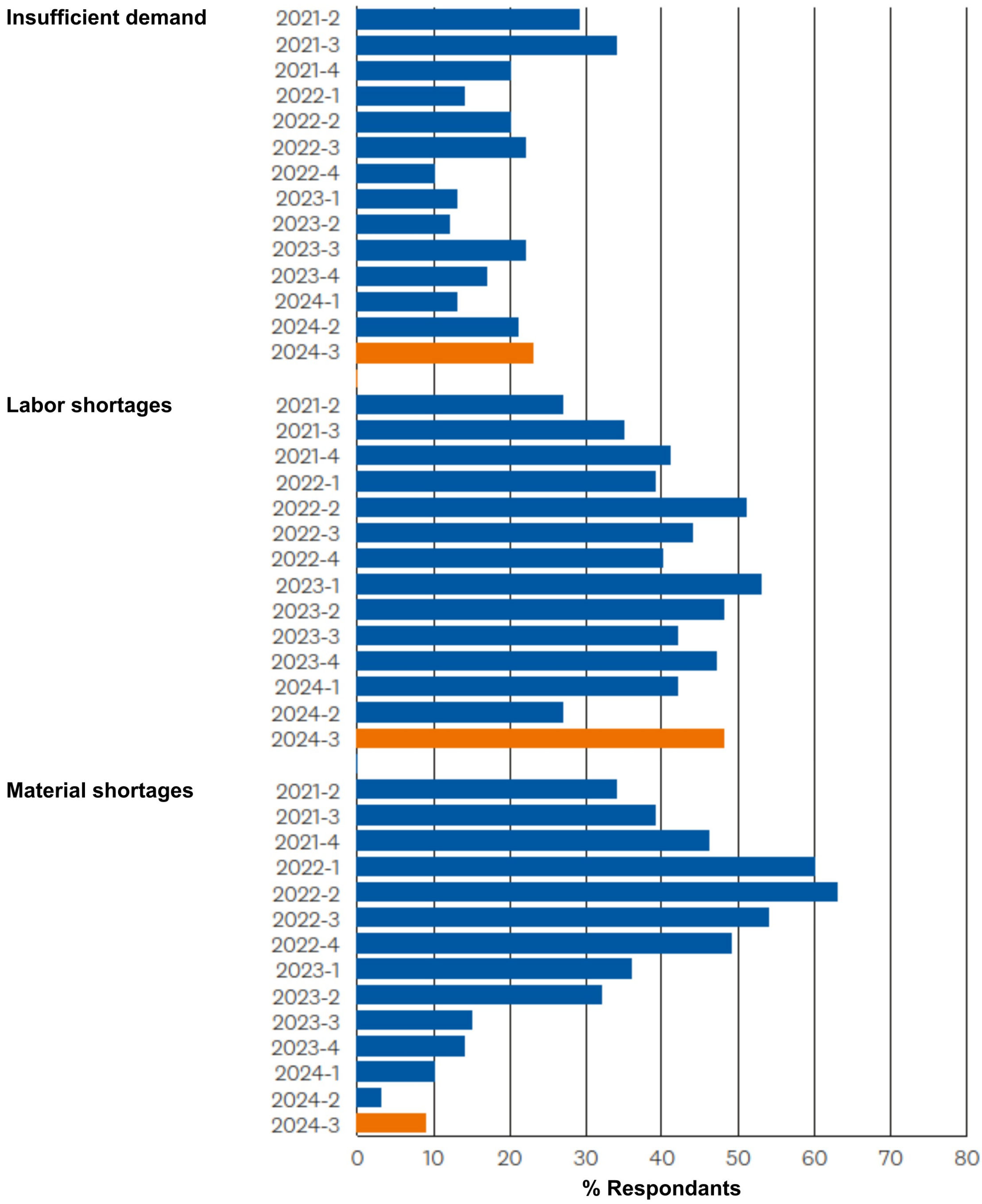

Figure 2.2: Perceived market obstacles by the Dutch marine manufacturing industry in Q3 2024, by the author based on [24]

Shift towards subcontractors

Subcontractors represent a significant portion of the total value of shipbuilding projects [25]. This increasing stake is in accordance with the specialization of the industry in Western Europe. For a significant portion of the project, dependence on expertise outside the typical domain of shipbuilding is required [3, 4, 25]. For example, utilizing advanced hybrid propulsion systems rather than conventional internal combustion engines demands a more integrated system design and, consequently, requires closer cooperation with subcontractors, as subcontractors responsible for onboard systems realize an increased portion of the value [4, 25]. Additionally, European shipyards tend to outsource hull production activities to hull production shipyards in low-wage countries, outsourcing the labor intensive production scope of a project. At the same time ,the main shipyard continues to oversee the prime contract and is held accountable towards the customer.

This results in an increased number of high-value independent contracts that require management [25]. Moreover, while there is a desire for long-term collaboration, true enduring partnerships are limited [3], potentially due to the previously mentioned ETO characteristic. In the context of a production floor, this implies that many external workers are involved in the shipbuilding process, and their tasks must be integrated with the primary shipbuilding activities or allocated specific slots in the planning [10]. In practice, it often relies heavily on the cooperation of employees of various companies and subcontractors [3].

Condensed market challenges

The shipbuilding industry is shaped by a diverse set of influences that define its operational structure. Shipyards operate within a complex production environment that combines traditional craftsmanship with increasingly industrialized and digitalized workflows. The following synthesis consolidates the identified influences into a unified perspective. The operational levels of organizations are characterized by tacit knowledge and informal collaboration with great flexibility. These act as a coping mechanism for the highly dynamic shipbuilding environment. Simultaneously, operational margins are compressed due to the high financial and temporal pressures. These pressures drive explicit, rigorous control strategies to maintain profitability and ensure the sustainability of the business.

The resulting overview of the industry influences is visualized in Figure 2.3. The main interactions between individual influences are also laid out. From this figure alone, it is evident that the shipbuilding industry is intertwined and complex.

In the next subsection, the challenge of managing information flows within such a complex production environment is elaborated.

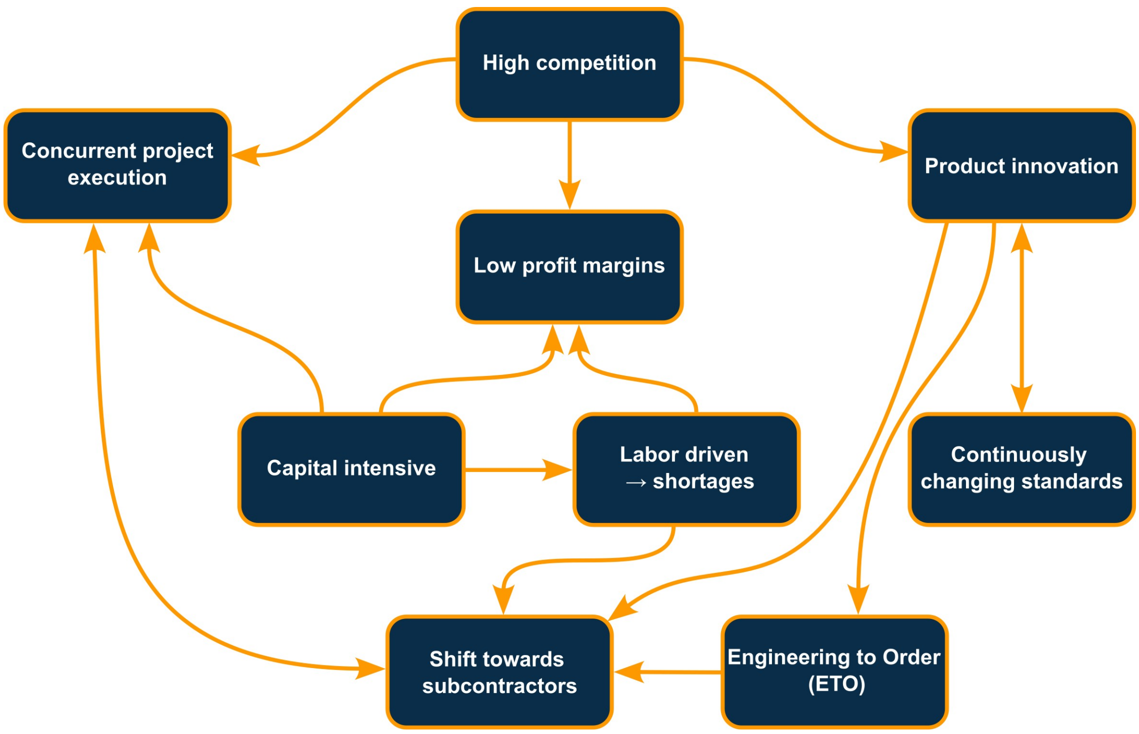

Figure 2.3: Abstracted influences to the shipbuilding industry, together with their main interactions as provided by the section

Information management challenges

Information management is an essential operational challenge in shipbuilding. Large amounts of information are created and distributed throughout the complete shipbuilding process. Managing the correct and timely creation and distribution of this information is key to enabling efficient shipbuilding [25]. There are challenges specifically related to the management of information and knowledge. Several studies have examined these issues [21, 25–27], emphasizing the crucial role of information management in shipbuilding projects. The findings from the authors in these studies are consistent with industry observations, aligning both with one and another.

This subsection presents findings from both scientific literature and industry to provide an accurate depiction of the current state and challenges of information management in shipbuilding. First, two industry examples are introduced, followed by a discussion and comparison of multiple scientific studies with industry observations.

As a first example, 'Royal IHC', a large dutch integrated shipyard specialized in dredgers, a has implemented the ERP software from software solution provider 'IFS' across its organization [14]. While publicly available information on the implementation process is limited, the author is aware of the ongoing challenges Royal IHC continues to face as a result of this transition. More than five years after its original adoption, the shipyard is still working towards the effective integration of the software into its operations. Although the need for more data-driven operations and decisionmaking was recognized at first, the effort required for successful implementation was significantly underestimated, as evidenced by the persistent challenges observed today.

Another example is 'Damen', a dutch shipbuilding conglomerate, which recently implemented software solutions from information technology (IT) provider 'SAP' across its organization [28]. A local shipyard manager noted that the initial post-implementation phase was less smooth due to the introduction of additional process steps. He explained: "For smaller tasks, we are gradually developing a new approach where we can easily share documents with each other through a 'SharePoint' environment. That suffices for small tasks. For larger, truly complex tasks, it becomes a significant challenge, and precise document control becomes a necessity. That's when we realize this approach doesn't sufficiently support the process. For this challenge, we use 'Shipbuilder Software' as a handy tool to provide support." [15]. Here the adoption Shipbuilder software is an unforeseen addition to the tooling, highlighting that the expected solution, SAP alone, did not fully meet operational needs as initially intended.

The importance of information management in the shipbuilding context is well-documented in literature. For instance, So [27] highlights the complexity of information flow in shipbuilding projects, emphasizing the numerous information holders involved, each with distinct origins and destinations. Similarly, McKendry [21] conceptualizes shipbuilding information management within the framework of product lifecycle management (PLM) and explores its implementation in the ETO shipbuilding context. This study further discusses the key considerations necessary for the successful adoption of PLM systems in ETO shipbuilding companies.

Garcia-Agis [25] explores the general needs, challenges, and opportunities associated with digital shipbuilding. This study highlights the importance of shipyards developing a comprehensive understanding of what digitization entails for their overall business and operations, while also acknowledging the current deficiencies in this regard. Similar to the research by So [27], Garcia-Agis presents a potential digital tooling landscape for shipyards, emphasizing the complexity of these digital environments and the necessity for thorough evaluation before their implementation.

A key finding in Garcia-Agis' research, similar to the digital implementations at Damen and Royal IHC, is the identification of challenges at 'Ulstein' shipyard. These challenges closely resemble those observed in other shipyards, highlighting the broader industry struggle to effectively address information management issues. The study further emphasizes the difficulty in mitigating these challenges efficiently. Figure 2.4 presents an overview of the specific challenges identified in this study.

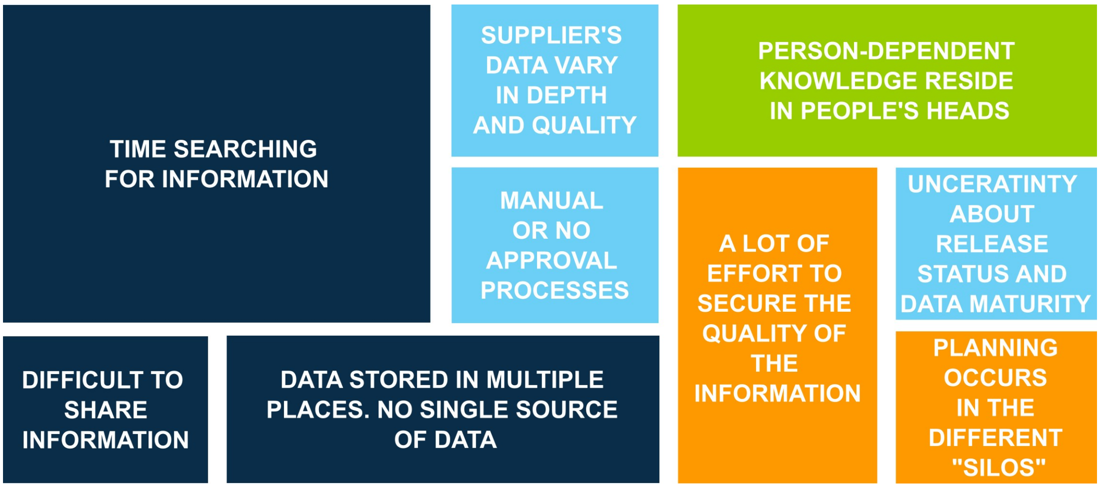

Figure 2.4: Challenges identified on current data and project management practises at Ulstein, extracted and derived from the research of Garcia-Agis [25]

Industry observations align with findings from the scientific literature that confirm the significant impact of inadequate information management. In practice, shipyards often recognize the consequences of poor information management and tend to adopt a technical approach to address these issues. However, root causes are often overlooked, leading to incomplete or ineffective solutions that are implemented. These challenges, which continue to hinder overall control of ship production and significantly limit operational productivity, are systemically exposed in this thesis, particularly focusing on the counterproductive mechanisms regarding the implementation of new technologies in the shipbuilding industry.

The point illustrated by these industry examples and literature findings is not that ERP implementations are inherently ineffective. Rather, the complexity of integrating such deeply embedded IT systems is often underestimated for complex ETO industries, requiring significantly more effort and time than initially budgeted. Furthermore, decision-making during the implementation process should be continuously reassessed and adjusted to align with evolving operational needs. Together, these factors suggest that shipyards struggle to fully grasp the fundamental importance of information management and its deep-rooted impact on operations.

The next section dives into the solutions available to the shipbuilding industry. It examines how these solutions can solve for the challenges that the industry experiences, but also how technological solutions have practical limits.

2.2. Available Innovations

Throughout the industry, a variety of toolkits and solutions are provided to address the complex shipbuilding environment, as detailed in section 2.1, and to increase overall productivity. This section outlines the solution landscape. Commonly implemented solutions and state-of-the-art solutions are handled. As well as the development and trends surrounding these solutions. Having a clear view of the routes available for innovation within shipbuilding enables effective discussion and well-considered decision making. First examples of such solutions and innovation paths are industry 4.0 (I4.0) solutions, implementation of lean methods, or the introduction of systems engineering and production [29, 30].

In general, a lot of potential solutions are available to the shipbuilding industry. The large amount of available solutions complicates the process of selecting an appropriate solution. This is reflected in literature, for example in the study of Schulze and Dallasega, where they attempt to sort the available solutions and innovations within ETO context [19]. Since each innovation impacts the shipbuilding process in its own way, pinpointing the precise effects of a particular innovation or the interaction between multiple innovations is challenging, adding a layer of inherent complexity.

In addition to the large amount of available solutions and potentially relevant technologies, also multiple paths for innovation can be recognized within the shipbuilding industry, as well as shipbuilding literature. To sketch an example for clarity: A systems engineering approach to shipbuilding is highly dependent on explicit definitions of the product and connected processes. It does so by detailing the complete scope of requirements, functions and physical definition of said product in preparation of actual production operations. This way risks and conflict can be identified and mitigated in early project phases. This approach contrasts with agile approaches. Agile processes rely on iterative evolution of product specifications and operational flexibility to deal with changing, or unknown specifications in operations. If systems engineering and agile approaches are used mutually, the interaction between the approaches should be well considered and understood to avoid conflicting goals. Reflecting back on the available paths of innovation, it means that innovations do not necessarily support each other. It is possible that they work against each other.

Besides the different general paths of innovations, This thesis coins that available solutions can be categorized in and contribute to roughly two domains. The first being productivity-enhancing technologies, and the second being control-oriented technologies.

Productivity-enhancing technologies focus on streamlining operations, reducing manual workload, and optimizing resource utilization. They include digital tools and methodologies that enable workers to perform tasks more efficiently. For example, innovations such as automated production systems, digital applications for real-time task management, and virtual reality / augmented reality (VR/AR) environments for on-site training can transform traditional craftsman operations into automated and agile processes [31]. Examples of emerging technologies in this domain include the integration of collaborative robots (cobots), internet of things (IoT) based workflow management systems, and wearable technologies that improve workers' performance on-site [13, 31]. These advancements not only boost output, but also facilitate a more adaptive and responsive production environment.

In contrast, control-oriented technologies are designed to maintain oversight, ensure process consistency, and protect quality and compliance. They enable managers to monitor operations, make informed decisions, and address potential issues. Tools such as digital twin simulations, integrated ERP systems, and advanced data analytics platforms can provide real-time insights into production performance [13]. Looking ahead, innovation paths for control include infrastructure for secure and synchronized information sharing outside of the own organization, automated progress control based on smart measuring, and the introduction of artificial intelligence (AI) in the synthesis of acquired data. These innovations enable decision-makers to fine-tune operations and mitigate risks while preserving the flexibility needed on the production floor.

Both productivity-enhancing and control-oriented solutions can strengthen shipyard operations, yet they also expose an ongoing tension in shipbuilding: the necessity of top-down control versus the bottom-up autonomy required on the production floor. Adopting more advanced technologies can sharpen this tension if the system's design does not accurately reflect the everyday realities of complex shipbuilding activities. Indeed, although technical innovations are developing rapidly, practical implementation often lags behind. Several studies note that shipyards face frequent organizational hurdles [32], such as a shortage of skilled labor [8] or a reluctance to alter well-established work practices [3, 25].

Subsidies for researching and implementing holistic paths of innovation within the marine industry are available. For example through European Union (EU) funded Horizon programs [33], or the recently started dutch initiative ”maritieme maakindustrie” [1]. These subsidiaries are available to support in the development of a sustainable marine industry, one that is economically viable, socially responsible, and environmentally sound. This highlights the recognition of the need for a transformation of and innovation within the industry. A great example of such a subsidized project, is the SEUS project, financed from the Horizon program [33]. The SEUS project has the goal to enable time savings throughout the shipbuilding project at European shipyards and proposes to do this via efficient integration and use of the computational tools included in the framework [34]. In Figure 2.5, the project vision of the 'Smart European Shipbuilding' (SEUS) program is presented. Here, different tooling and working methods are proposed for each of the shipbuilding project phases. Within the figure, the importance of human collaboration is emphasized through the large amount of human workers visualized in the illustration, as well as within ”impact 6, Human-centric shipbuilding”. These are signals that the socio-technical relevance is recognized within the main scope of the research.

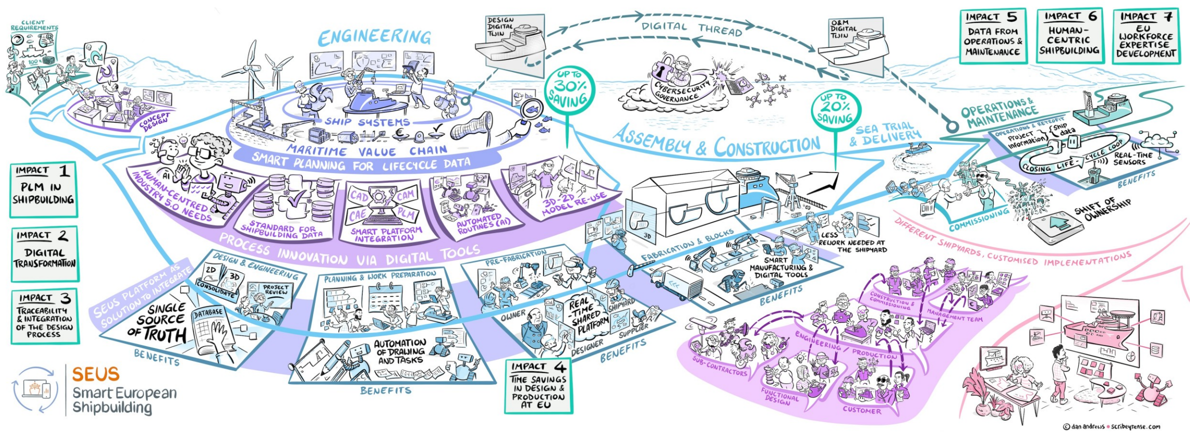

Figure 2.5: Smart European Shipbuilding (SEUS) project vision [34]

In addition, different scientific studies underscore the relevance of available technologies for the shipbuilding industry. For example [27] describes a potential complete digital transformation for the shipbuilding industry. An interesting observation is that there seem to be geographic differences in the attention the topic of digital transformation receives. Asia appears to be leading the way with digitization and automation, aligning with the taxonomy of the shipbuilding industry as described in the previous chapters. Asian shipyards face different challenges and do not face cultural and organizational challenges in the same way European shipyards do. It would therefore be worthwhile to examine the theoretical approaches applied in Asian shipyards and to assess whether these can be transferred to the European context.

Meanwhile, numerous companies offer innovative tools to support shipyards. For example, automation providers such as 'Kranendonk' or 'ABB' focus on production efficiency, while major IT vendors like 'Siemens' [35] and 'Dassault' [36] address digital design and lifecycle management. Floorganise also contributes by delivering a state-of-the-art manufacturing execution system (MES) and operational planning IT solution that promises broad operational improvements for shipbuilders. What distinguishes Floorganise is its emphasis on worker empowerment and effective interfacing with third-party software. Floorganise ensures strong shop-floor implementation through the recognition of craftsmanship. Although Floorganise has successfully realized this vision in collaboration with its clients, a scientific understanding of how worker empowerment and shop floor collaboration add value remains limited in the context of shipbuilding. One of the few examples is the research of Emblemsvag, who developed and implemented a lean planning methodology at a Norwegian shipyard [32].

Ultimately, the shipbuilding sector is equipped with a robust technical toolbox of potential improvements, from lean methodologies to advanced digital twins. However, choosing and implementing these solutions requires a careful review of yard-specific workflows, cultural norms, and existing technological infrastructure. As the following subsection illustrates, recurring market disruptions and organizational constraints often make it difficult for shipbuilders to fully realize the benefits of these innovations, ultimately doubting the effectiveness and feasibility of the techno-centric solutions that are available.

Synthesis of available innovation

Technical solutions are readily available and have been available for a long time already. For example, the report by Andritsos [37] from 2000 tediously describes advanced production techniques and opportunities of digitization and automation within shipbuilding. Even today, a quarter of a century later, a lot of the considerations described in this report are still considered state-of-the-art for the industry. Meanwhile, technical innovations are being developed within science, iterating on the state-of-the-art described in this report. However, implementation efforts are trailing. Within this thesis, the stance is taken that technical solutions are being developed faster than they are implemented, creating a trend where science moves away from industry. Empirical research around I4.0 implementations in the context of the ETO and the shipbuilding industry supports this position [13, 19].

In addition to the recognition of innovations in the shipbuilding industry, it can also be argued that lack of continuity and general volatility hamper continuous innovation efforts, thus limiting effective implementation. This topic is handled in the research of Solesvik [23], arguing that shipyards should employ different innovation strategies in different phases of the general shipping cycle. Although western European shipyards generally value innovation highly, and policy makers make efforts to support in enabling said innovation, adopting effective innovation strategies is difficult and requires more attention.

While analyzing available innovations, it becomes clear that most solutions within the shipbuilding industry are predominantly technical in nature, techno-centric in that sense. These include both tangible tools and software platforms designed to increase efficiency, standardize outputs, or enhance traceability, like traditional ERP for example. However, the implementation of technically feasible solutions often clashes with the actual complexity of shipyard environments. A solution that enhances oversight or formalizes procedures may improve control from a managerial perspective, yet simultaneously reduce flexibility and autonomy on the shop floor. In this way, an intervention aimed at addressing one part of the system can inadvertently create new frictions elsewhere. This tension is particularly present between top-down control and bottom-up execution. This reflects a broader misalignment between the technological focus of current innovation toolboxes and the organizational and cultural realities in which they are deployed. Although shipbuilding science and, for that sake, the shipbuilding industry tend to frame challenges in technical terms, wider academic research points to cultural and behavioral dimensions as equally important levers for improvement; see the example of Floorganise where deep understanding and recognition of a clients individual work environment and culture contributes to successful software implementation. The prevailing assumption that increased control necessarily limits agency and adaptability is also questioned in recent organizational studies, arguing that formal structures can, in fact, support autonomy when designed well [38]. This suggests a persistent gap between shipbuilding-specific innovation approaches and broader socio-technical insights, and although this gap is implicitly recognized at times, like in the SEUS project [34], explicit research output often neglects this topic. This is a gap that must be acknowledged and explored if innovations are to contribute meaningfully to improved production outcomes.

Making this insight more specific to this research; the available solutions, whether they seek greater productivity or better control, all promise to positively transform shipbuilding operations. However, they also expose the inherent tensions within shipbuilding. On the one hand, top-down mechanisms, characterized by centralized control systems and structured management practices, offer clear guidelines and consistency. On the other hand, bottom-up approaches, driven by worker empowerment and agile methodologies, foster flexibility and rapid responsiveness on the production floor to adapt to dynamic demand. This divergence creates a dynamic in which prescribed methods and actual practices often collide. The enforcement of top-down controls can clash with the practical insights and adaptive behaviors that drive daily operations, setting the stage for the conflicting mechanisms discussed in the next section. It describes where this clash originates and how it manifests within ship production. The section exposes how the imbalance between directive control and delegative execution can lead to operational challenges, misalignment and inefficiencies. By understanding both the potential and the limitations of available innovations, one can better appreciate the complex and often conflicting forces at work in modern shipbuilding. This understanding and mutual recognition are the foundation for strategies that bridge this divide.

2.3. Clashing mechanisms in ship production

The industry taxonomy presented in section 2.1, combined with insights into available technologies discussed in section 2.2, highlights a critical gap in both the literature on shipbuilding and industry practices regarding social and organizational impacts on ETO shipbuilding operations. Central to this gap is the lack of alignment between the intended processes and the actual execution of the work, or as these concepts will be later introduced as 'work-as-intended' (WAI) and 'work-as done' (WAD). This section contextualizes the shipbuilding industry through the lens of social and organizational considerations, using relevant literature from domains outside of shipbuilding.

Building on Trist's socio-technical theory [39], this section examines shipbuilding as a socio-technical environment in which technology, people and organizational structures must be understood as interdependent. Although various technological challenges have been addressed in previous chapters, the organizational dimension remains underexplored. In practice, directive and delegative approaches frequently collide, revealing a top-down versus bottom-up tension in daily operations. At one extreme, management departments perceive shipbuilding projects as controllable through formal processes and metrics. On the other hand, front-line workers see their tasks as crafts that require skilled flexibility. Recognizing this tension highlights the need to take into account not just advanced technologies and technical hurdles, but also the human and cultural factors that shape their implementation.

Each of the market influences identified in section 2.1 is identified as a driver for directive control or delegative approaches. The resulting clashing mechanism is distilled by following this reasoning and expanding on the findings of previous chapters. First, a brief introduction is provided to the relevant theory on socio-technical systems.

Socio-technical systems

Work system analysis has a long history, and socio-technical systems are recognized as a crucial subfield where technology and people intersect. As early as 1981, Trist [39] noted that modern work environments are characterized by higher levels of interdependency, complexity, and uncertainty that push beyond the limits of what purely hierarchical top-down approaches are designed for. Consequently, Trist argued that robust socio-technical systems must integrate top-down and bottom-up mechanisms [39].

Subsequently, the work by Vicente [40] explored the dynamic of these mechanisms by contrasting the concepts of 'instruction-based' and 'constraint-based' working methods. The difference between the two is how the actual work is managed and controlled. In the case of instruction-based methods by prescribing exact instructions and mitigating all edge-cases (similar to a systems engineering approach), or in the case of constraint-based methods by setting an objective and allowing for flexibility within defined boundaries (like agile working methods).

Building on these concepts, Hale [41, 42] expands on this topic by defining two models for the interpretation of rules and procedures in the context of safety management. The first model being a directive, instruction-based (Hale's instruction-based model 1), and technical approach to rules and regulations. The second model argues that rules and regulations are delegative, constraint-based, and open to expert interpretation (Hale's expertise-based model 2). Hale investigated the strengths and weaknesses of each model. These are summarized in Table 2.1. Hale concluded that an effective work system leverages the strengths of both models [41]. Using the paradigm of the two models, a comparison is made with the shipbuilding industry and its management and operations mechanisms.

Table 2.1: Summary of main strengths & weaknesses of models 1 and 2, as provided by Hale [41]

Model 1	**Model 2**
Strengths: - Makes rule-making explicit & easy to audit - Makes consequences of rule violation explicit - Emphasises competence in rule-making & role of subject experts - Logical, rational, engineering approach - Works well for novices - Proven effectiveness for simple, 'golden rules' (Behavioural Based Safety) - Emphasises the role of organisational complicity in rule violation	- Recognises operators as experts central to rule making - Recognises social processes as key to rule use - Sees rule-making as a continuous, dynamic process - Links rules to the crystallised competence of organisational memory - Recognises the importance of managing exceptions & their link to violations - Recognises the centrality of experience
Weaknesses: - Sees operators as robots, lacking competence & social motivation & needing imposed rules - Encourages a blame culture & negative view of rules & violations Sees rule-making as a one-off, static process, until accidents trigger rule modification - Fails to deal adequately with exceptions except as triggers for rule book growth - Tendency to bureaucracy & gap between rules & reality	- Rule-making & modification process lacks transparency for auditing and for novices learning the skills - Undervalues the need for the organisation to explicitly manage rule development & use - Hides differences of interpretation & competence

In the next subsections, the shipbuilding environment is placed in the context of these seemingly opposing socio-technical models using the industry taxonomy defined in section 2.1. In the end, an abstracted conflict is presented that is typical of the current ETO shipbuilding environment.

Drivers of top-down control

In the current shipbuilding market, several factors converge to motivate a directive control approach. High competition in terms of cost, delivery times, and quality requires efficiency optimization and quality assurance, implying strict process control. These requirements are typically met through standardization and directive control methods.

Low profit margins and the capital intensive nature of shipbuilding further raise the need to optimize efficiency and productivity. In this environment, losses in one department cannot be easily offset by gains in another, so stringent performance metrics become essential for monitoring operations. Variability as a whole is considered problematic as it reflects a lack of control. Negative deviations can cascade and lead to significant consequences. Directive control measures, rooted in data-driven and engineering-based decision making, are thus used to minimize variability, although they may sometimes overlook specific contextual factors.

Additionally, the prevailing labor shortage in the operational domain drives a greater dependence on directive control. Labor shortages drive the need for automation, which in turn requires clearly defined and explicit processes for effective implementation. Such processes are more easily established within a controlled, directive environment. Market volatility further discourages shipyards from investing in long-term personnel relationships, increasing their dependence on temporary hires, which often require more direct supervision and who inherently do not have as much experience as seasoned own personell.

Overall, the combination of high competition, low profit margins, capital intensity, and labor shortages creates a tightly constrained, cost- and time-driven market. These factors collectively motivate the adoption of directive control approaches, aligning with the principles outlined in 'model 1' by Hale [41] which is elaborated on later in this section.

Drivers of bottom-up operations

A specialized ETO shipbuilding industry inherently carries substantial uncertainty at every stage of the project. Allowing front-line teams and departmental managers a degree of autonomy offers the flexibility to handle emerging issues on the spot, preventing small disruptions from cascading throughout the project.

Additionally, product innovation strategies, which are common in specialized shipbuilding, push the limits of existing rules and regulations. Consequently, these regulations must be updated or interpreted again for each project, creating a constantly changing landscape of requirements. In such a dynamic environment, delegative approaches enable the workforce to adapt quickly, ensuring that evolving regulations and standards are adequately addressed without bottlenecks and rework.

Concurrent project execution amplifies interdependencies among the different project phases. Because multiple disciplines work in parallel and iteratively share critical information in real time, it becomes difficult to prescribe exact working methods for every task. Assigning responsibilities at the departmental or individual level, rather than enforcing rigid directives, allows skilled personnel to make agile decisions and maintain project momentum.

Increased reliance on specialized subcontractors adds another layer of complexity. As the industry moves toward outsourcing non-core activities, managing a diverse network of external partners becomes essential. Granting subcontractors a measure of trust and autonomy encourages collaborative innovation and effective decision making. Distributing authority between multiple parties allows companies to take advantage of subcontractor specialized expertise, while mitigating delays caused by redundant managerial oversight. With the goal to prevent entanglement in corporate subcontract management in which focus shifts to legal disputes, instead of operational collaboration.

In summary, these industry strategies produce an inherently dynamic shipbuilding environment that advocates craft-based delegation approaches. Implementing such approaches fosters operational flexibility, reduces response times to emerging issues, and leverages the specialized skills of all parties involved, thus improving overall project performance, aligning with the principles outlined for model 2 by Hale [41], elaborated in the next subsection.

The clash

Although both directive and delegative drivers serve legitimate objectives within shipbuilding, balancing them is challenging. On the one hand, strict process controls and uniform metrics provide a sense of predictability, enabling managers to track performance and contain cost overruns. However, sharp-end workers and subcontractors often require on-the-spot decision-making authority to address unforeseen technical issues in a timely manner. When top-down directives override local expertise, misalignments in workflows and communication quickly arise. In reverse, when bottom-up initiatives are not well-communicated across the organization, decision making may not happen at the right level. The resulting conflict and its underlying causes are illustrated in Figure 2.6.

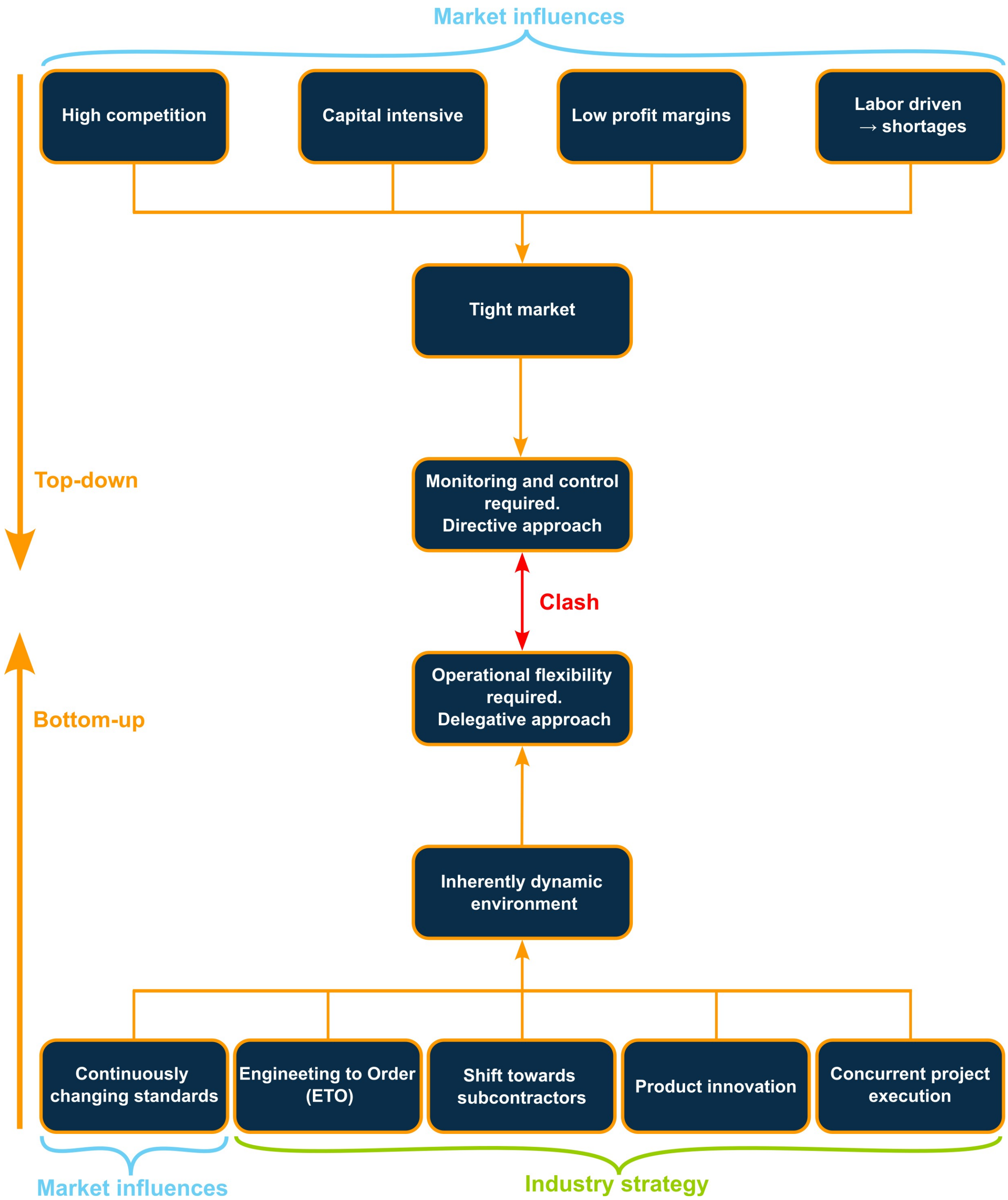

Figure 2.6: A visualization of the clashing mechanism

During the past decade, shipyards that aim to increase operational control have escalated directive approaches, placing greater emphasis on standardized metrics, digital dashboards, and automated data collection. Basically, following the reasoning behind model 1 of Hale[41]. The cases of Royal IHC and Damen earlier on are exemplary of this trend. Although these efforts were intended to reduce uncertainty and improve predictability, they often failed to deliver on their promises. Essentially, experiencing the weaknesses stated for model 1. Relying heavily on metrics alone tends to overlook the fact that ETO shipbuilding is a socio-technical environment: production depends not just on standardized procedures, but also on tacit knowledge of workers and collaborative improvisation. When sharp-end involvement in designing and implementing these tools is minimal, solutions risk being ill-suited to daily realities, only adding to the "disconnect" between top-level plans and on-site practices. The need for effective socio-technical considerations is strengthened by the labor shortage; there is an urge for rapid and fluid transfer of tacit knowledge.

Also research in the business process management (BPM) domain recognizes the tension and general need for the adoption of socio-technical considerations. For example, the work of Beerepoot et al. recognizes the current limitations and challenges (comically visualized in Figure 2.7) within BPM and states that the barriers to solving these are often socio-technical in nature.

Figure 2.7: The future graveyard of business process management (BPM) problems [43]

This tension is not purely theoretical; it manifests itself in real-world inefficiencies such as recurring rework, scheduling delays, or unplanned downtime. Projects relying heavily on strict adherence to a static plan may fail to adapt when engineering changes occur or when unexpected complications arise during concurrent tasks. Similarly, digital transformations can become too rigid if they do not accommodate dynamic processes and evolving standards.

Ultimately, any practically feasible solution must treat shipbuilding as a socio-technical production system, integrating both top-down strategic direction and bottom-up operational freedom. This requires continuous feedback from production teams, iterative refinement of formal processes, and an open framework for stakeholders across all levels to contribute expertise without getting buried in corporate procedures. Harnessing the benefits of data-driven innovation while acknowledging the complex and evolving nature of shipbuilding can reduce these systemic bottlenecks, helping shipyards strike a sustainable balance between directive control and delegative adaptation. Succeeding in this leverages the strengths and weaknesses of Hale model 1 and model 2 presented earlier in Table 2.1.

Implications

The tension between top-down directive control and bottom-up adaptive execution has practical effects that extend throughout entire production operations. On the one hand, extensive formal documentation and structured work instructions are intended to standardize essential tasks, accommodate regulatory demands, and serve as a stable basis for financial oversight and reporting. On the other hand, these prescriptive methods do not fully capture the fluid nature of day-to-day shipbuilding, where on-site teams must improvise around missing information, unexpected technical complications, or short-notice design changes. This mismatch sometimes remains hidden in formal progress metrics, but ultimately manifests itself in unplanned rework, scheduling bottlenecks, or lost opportunities to optimize resource usage.

The resulting dynamic underscores the need to reconcile directive control with the flexible, context-specific knowledge that experienced craftsmen contribute. Without adequate attention to the realities of concurrent engineering and the limits of prescriptive oversight, even well-intentioned technologies and management practices can exacerbate communication gaps. The specialized nature of shipbuilding creates nearly constant engineering surprises, unforeseen constraints, and last-minute client changes. Sharp-end operators, including welders, fitters, and installation workers, must improvise on the spot to keep the project from stalling, often under severe time pressure. Because these bottom-up adjustments remain difficult to incorporate into the formal planning framework (which presumes stable inputs and outputs), 'unofficial' workarounds, extra quality checks, and ad hoc tasks proliferate in the margins. Strains when management discovers these gaps too late or does not recognize them at all, leading to frustration over rework or administrative inconsistencies. Consequently, reconciling the two approaches becomes a prerequisite for improving overall production efficiency: formal processes establish essential guidance and structure, but genuine success depends on how well they integrate with localized learning and adaptive decision-making on the shop floor.

With the context and base environment of the research now established, the overall research question is constructed that addresses this ambiguity. This is handled in the following section.

2.4. Research questions and objectives

Considering the complex socio-technical nature of shipbuilding, there is an inherent challenge to innovation within this industry. Simultaneously, the market demands innovation to be competitive. section 2.3 revealed that the conflict between top-down and bottom-up approaches is a significant factor hindering successful innovation. This is particularly relevant to information management, as detailed in the last subsection of section 2.1. Shipyards typically have formal process flows available. However, actual operations are different from these formal processes, given the dynamic nature of shipbuilding. This makes it difficult to establish effective requirements and boundaries for the envisioned solution. This challenge is made even more difficult because of the high number of available solutions and the confusing contradictions some solution paths show, as explained in section 2.2.

Currently, there is a gap in shipbuilding literature regarding how the clash applies to the industry. The available literature acknowledges the general challenge of solution implementation, but does not systemically analyze work environments and the effect of potential solutions on these work environments. In addition, socio-technical considerations are not explicitly addressed within the shipbuilding literature. Therefore, also the solution toolbox is limited to primarily techno-centric solutions. These techno-centric solutions have at best a limited positive effect if the social and organizational dynamics are not regarded, as pointed out in section 2.3.

At the same time, shipyards attempt to solve for their challenges primarily using top-down mechanisms, pinning down bottom-up practices and thus sustaining the clash described in section 2.3. This conclusion is logical because the available literature approaches the shipbuilding industry as a techno-centric environment as well. Overall, it exposes a gap between the industry's operational challenges and the effective solutions available to solve these.

Said research gaps are visualized in Figure 2.8, together with the envisioned research goal. As can be seen in this figure, the main research goal is to combine the different aspects within literature and industry, mainly by opening the topic of socio-technical considerations within operational shipbuilding.

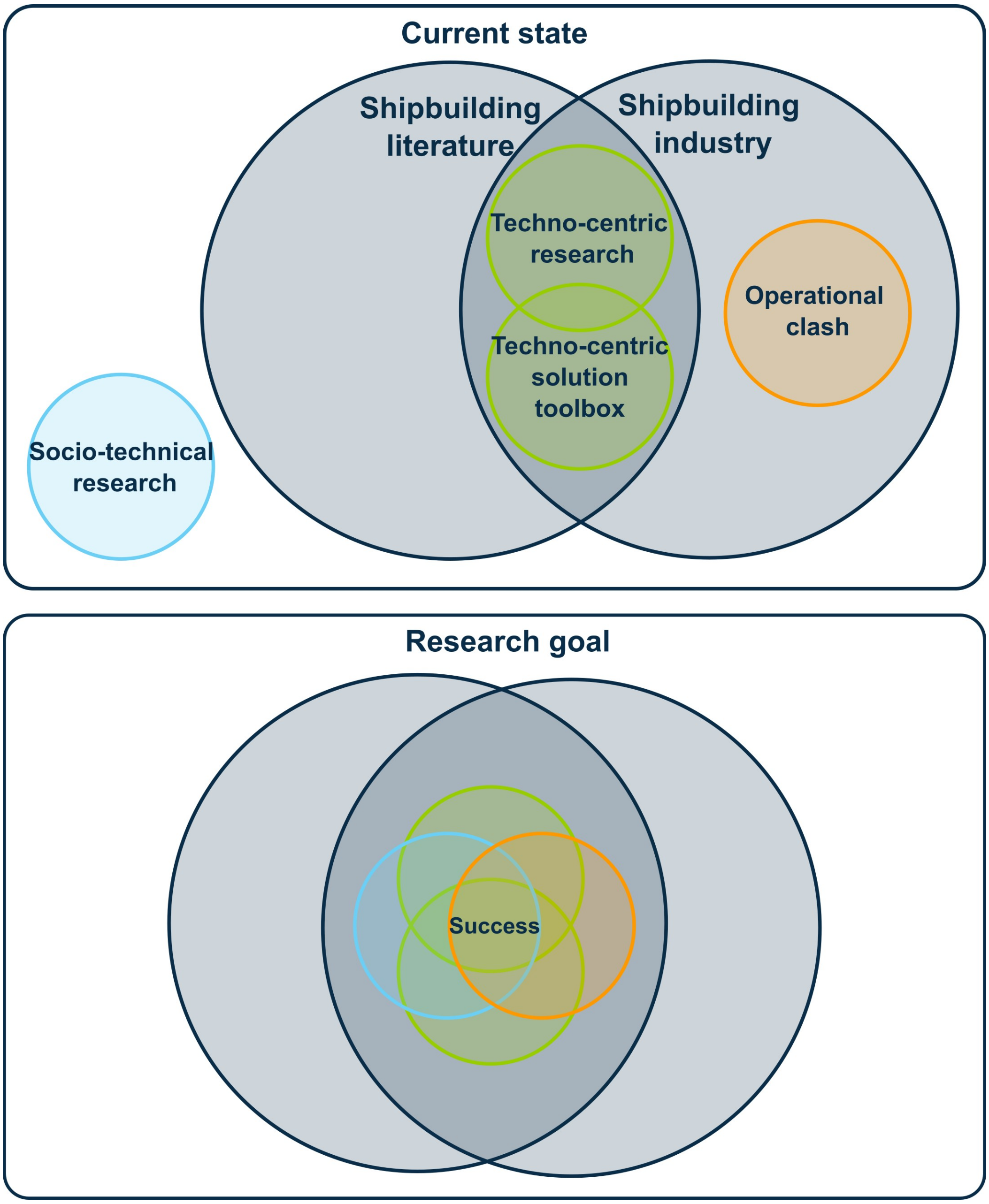

Figure 2.8: Visualized current state research gaps, together with the envisioned research goal

The succeeding research aims to address these gaps by providing an interface between literature and industry through answering the following main research question: "How can a socio-technical approach to shipbuilding be used to align the work system for improved operational effectiveness and productivity?" (RQ.1)

Within the framework of the primary research question, the context and origin of the main research is already addressed in chapter 2. To support the answer to the main research question, the following secondary research questions are set up:

1. How can a socio-technical approach be used to systematically compare and analyze the work system? (RQ.2)
2. How can a socio-technical understanding of the work system support in effective implementation of techno-centric solutions? (RQ.3)
3. How can a socio-technical understanding of the work system be supported in the effective organization of work? (RQ.4)

These subquestions are answered in chapter 3 to chapter 6. Here, RQ.2 is handled in chapter 3, RQ.3 in chapter 4, and RQ.4 in chapter 5. Together, the answers to these research questions formulate an answer to the main research question (RQ.1). This answer is formulated in chapter 5 and concluded in chapter 7.

3

Methodology

3.1. Method considerations

The clash between directive management controls and directive operational activities was described in section 2.3. Despite the presence of supportive industry examples and scientific literature, there remains a lack of understanding on how to systematically expose and address this issue. As outlined in section 2.4, having a structured approach to uncover practical conflicts is beneficial because it not only highlights discrepancies in greater detail but also aids in the process of choosing and adopting effective solutions. It enables Navigating and resolving the industry's challenges and complexities. The derived method provides an answer to RQ.2, specified in the previous chapter.

Innovations can only be effectively implemented by having insight and deep understanding of the formal processes and actual performed work, as well as knowing the limitations of both, as concluded in section 2.2. Therefore, the chosen methodology should be able to dive into this difference in perceived and actual working methods. The specifics of each should be valued. This requires a method that details working environments and work activities within that environment, while being able to abstract these to higher levels that can be used for setting up innovation requirements that support effective implementation

With the ship production domain being identified as a socio-technical environment in section 2.3, it is key that the chosen method captures the socio-technical context of this environment. There is little shipbuilding literature available that explicitly approaches the shipbuilding industry as a socio-technical environment. With this evident, it is clear that the method must be able to reason from the socio-technical perspective, while still providing a systemic way to reason. The main challenge here is to have a method available that is able to handle both the dynamic nature of actual operations, while at the same time being able to make a systemic comparison with the set formal process. This way, an effective contribution can be made, extending the understanding of the shipbuilding industry within socio-technical context.

Traditional lean approaches, such as value stream mapping (VSM), and standardized business process modeling systems (BPMs) tools, are often employed to enhance operational efficiency in manufacturing and shipbuilding environments. VSM, for instance, excels at visualizing sequential flows of materials and information. Nevertheless, these approaches were originally conceived for relatively linear production contexts and tend to focus on explicit process steps rather than the broader socio-technical setting in which work is carried out. In contrast, shipbuilding exhibits high complexity, non-linear task interdependencies, and extensive involvement of craft-based decision-making. Recent studies therefore underscore that traditional methods frequently fail to capture the nuanced variations between formally prescribed processes and the genuine, evolving practices that emerge on the shop floor. As a result, they may overlook the key socio-technical factors that strongly influence real-world workflow dynamics. Examples are workforce autonomy, concurrent engineering activities, and shifting external requirements. These limitations are collectively acknowledged in BPM literature [43], indicating the need for a framework that can represent non-linear relationships, account for dynamic changes, and incorporate tacit human knowledge alongside formal procedures.

Table 3.1 highlights that while VSM and BPMs brings structure and clarity to well-defined or repetitive work, they inherently rely on relatively predictable process flows. As a result, none adequately addresses the real-world variability and non-linearity that exemplify shipyard production, nor do they account for the organizational or tacit dimensions of how work is actually done. This gap motivates the need for more adaptive socio-technical modeling techniques, capable of distinguishing between abstracted work instructions and the fluid, iterative nature of practical execution on the shop floor.

Based on Hollnagel's FRAM, a central idea is that both successful and unsuccessful processes share fundamental similarities, which Hollnagel coins as the principle of equivalent of success and failures [44]. Rather than describing what an element of the system "is," FRAM focuses on modeling what it "does" by defining its functions [44]. Each function can exhibit variability in how it is carried out, reflecting natural differences in real-world execution. While most of this variability has no significant impact on outcomes, occasionally it is sufficiently large to yield a result that diverges from what was anticipated, either positively or negatively. This inherent variability is distributed unevenly across functions, highlighting the importance of understanding which functions are more prone to unexpected behavior. Within this framework, WAI represents only a snapshot of how activities are believed to occur, whereas WAD captures how they actually unfold, embracing the notion of relative ignorance that stems from acknowledging the system's fundamental intractability. By comparing WAI and WAD, it becomes possible to gain insight into these differences and thus reduce the relative ignorance surrounding the system's true operational patterns. Analogous to VSM and BPMs, the main characteristics of FRAM are captured in Table 3.1.

Table 3.1: Comparison of methods in research context

Method	Core focus	Advantages	Limitations
BPMs	Formalizing and documenting process steps	Offers clarity on official workflows and responsibilities	May oversimplify complex interactions and miss tacit knowledge critical for large, custom projects
VSM	Visualizing sequential material and information flows	Effective at identifying lead-time bottlenecks in stable, linear processes	Struggles to handle non-linear feedback loops and socio-technical variability
FRAM	Modeling socio-technical systems by capturing both variability and emergent interactions	Supports a deeper socio-technical perspective on why actual practice may diverge from official procedures	Requires detailed qualitative data collection and can be labor-intensive to set up

The exploratory nature of the research makes quantitative research methods neither feasible nor effective at the moment. It should be noted that quantitative research can provide solid evidence, but at the moment the available data within the shipbuilding industry are not reliable and detailed enough to perform a useful quantitative analysis on this topic.

In alignment with the features listed in Table 3.1 and the criteria defined by the research objective, FRAM has been chosen as the method for use. It is deemed the most appropriate for application. Currently, FRAM has not been applied to the shipbuilding domain. Neither has it been applied extensively to industrial production environments yet. These features position FRAM as both novel and state-of-the-art when it comes to the analysis of general industrial production networks, with a particular emphasis on shipbuilding.

FRAM centers on identifying the key functions within a system, analyzing the relationships among these functions, and capturing the variability that inevitably arises in real operations. By modeling both WAI and WAD, FRAM makes it possible to compare the formally prescribed processes with actual practices and to pinpoint where and how performance and functionality may deviate. Additionally, the functionality of FRAM can be extended by using an abstraction hierarchy, as proposed by Patriarca et al. [45], which enables analysts to navigate different levels of system complexity without losing sight of how individual components interact. Together, these capabilities help address the known challenges in BPM, such as model subjectivity or fixed granularity [43].

The application of FRAM within shipbuilding context by itself provides a scientific contribution. Another novelty is the application of FRAM to reason with the goal to increase productivity. While FRAM is widely recognized in safety domains, originating from 'Safety II' approach, its application to production efficiency and organizational improvement in a shipbuilding, or even general industrial setting is still unexplored. Together, this creates new potential for the application of FRAM and possibly integrates safety theory with general operational management theory.

To conduct an effective FRAM analysis, it is essential to collect data from multiple environments, each characterized by distinct assumptions and work practices. Because these contexts produce datasets that are not directly comparable, a range of data-gathering techniques is necessary to obtain sufficiently detailed and representative information for the models. In the next section, a more comprehensive discussion of these methods is drafted.

3.2. Data collection and preliminary modeling

This study adopts FRAM to investigate the misalignment between WAI and WAD in a shipbuilding context. The data collection for this study follows two main streams. First, formal process descriptions are collected to set up the WAI model. Subsequently, empirical data and insights of actual practises are gathered through field observations and informal discussions, or 'coffee talks', to establish the WAD. The following paragraphs discusses the two streams of data collection in more detail.

The formal process descriptions serve as the starting point for understanding how tasks are officially documented and anticipated to be executed. When necessary, these are complemented with insights from process managers, supplied through informal conversations and general background materials on shipbuilding. This will only be done in case the available formal process descriptions do not describe the researched scope. Such an approach offers a structured baseline for modeling the WAI, but it also demands interpretative efforts to align abstracted processes descriptions with the approach of describing functions and connections according to FRAM.

In contrast, the data substantiating the WAD originates from field observations and unstructured, informal coffee talks. These capture the fluid nature of day-to-day operations. The shipyard environment relies heavily on tacit knowledge and personal relationships. Clearly communicating the study's objectives and clarifying how the insights fit into the research fosters transparency and builds trust. Trust that is necessary to raise more sensitive subjects. An example of such a topic is skipping quality control steps in order to meet deadlines. Without a trust base, the answer to a predefined question would become appeasing and shallow. However, with a solid trust base and transparency, a real discussion can be held, exposing deeper reasoning and insights. These characteristics make standardized, semi-structured interviews less effective.

Observations create an extra layer of understanding, as the workers have a practical background and may have difficulty verbally explaining their activities. Here the observations provide an extra verification for the researcher, as well as exposing the wider context of working

While this informal approach encourages openness and spontaneity, the administration of findings is challenging. In this study, rough notes were drafted based on the coffee talks and observations. However, no verbatim records were kept documenting all the conversations and observations but considering the huge amount of exploratory data, field nodes were used instead. Given the explorative nature of the data collection within this research, this is not seen as a showstopper, as long as the final models are representative of the environments they describe. Though, it should be noted that for future research, exceeding the requirements of a master thesis, optimally structured interviews or even verbatim records should be documented and traceable, with the possibility to be consequently analyzed by qualitative coding.

The dynamic way of data collection as described in this section matches with the dynamic environment that shipbuilding is. The WAI and WAD originate from two completely different environments with different drivers and social codes. Therefore also the suitable methods are different. The data sources for the two different models are visualized in Figure 3.1.

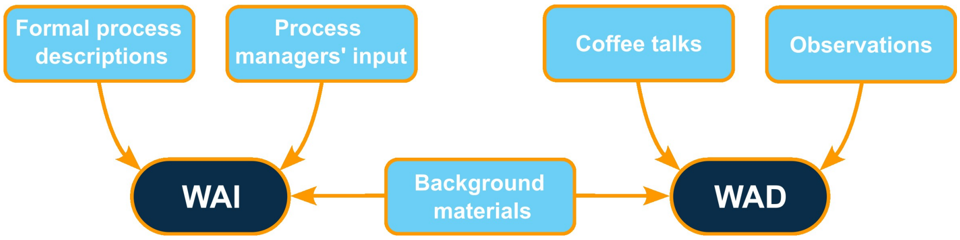

Figure 3.1: Schematic overview of the applied data sources

3.3. Methodological Steps

In this section, the methodological background and the method steps are elaborated. The different theoretical concepts around which the methodology is shaped are explained and put in the context of this research. This is followed by a detailed description of the method steps.

Building on the work of Beerepoot [43], the challenge of selecting a suitable level of granularity to model business processes and applying that level of granularity consistently becomes particularly clear when analyzing complex socio-technical systems. FRAM, combined with abstraction hierarchy theory, offers a structured approach to address this challenge by ensuring that the analyzed processes are neither overly simplified nor burdened with excessive detail. Specifically, by converting the WAI and WAD processes to a similar level of granularity within FRAM, functional interactions can be compared while still capturing critical variances that lead to unexpected outcomes.

The FRAM method consists of four main steps. These are presented in Figure 3.2. All key elements of FRAM are included in these main method steps.

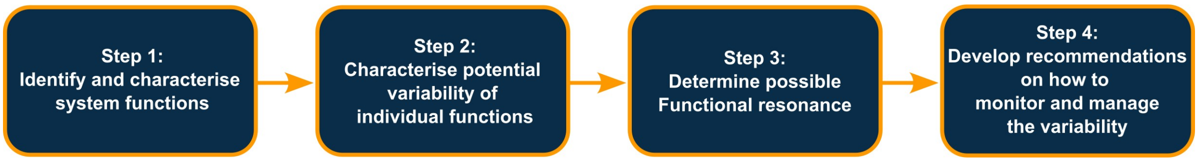

Figure 3.2: FRAM conceptual methodology steps [44]

To model the functions and their connections, FRAM prescribes a hexagonal model visualization where the hexagon represents a function, and each of the corners represents a specific aspect of that function. By drawing arrows between the outputs of a function and one of the other aspects of the other function, a connection between the functions is identified.

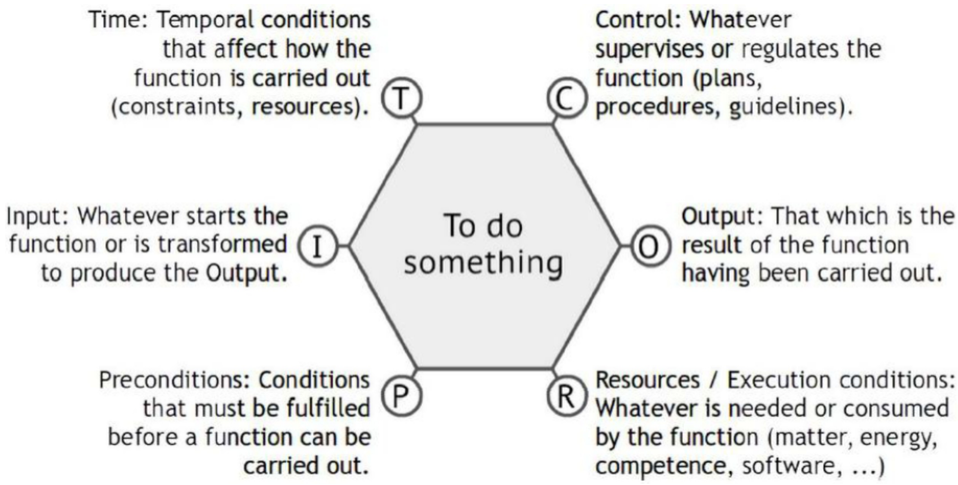

Figure 3.3: Definition of a FRAM function with its aspects [46]

A key theoretical pillar for achieving consistent and meaningful levels of abstraction is the hierarchy-based method presented by Patriarca [45]. This approach leverages the means-end structure first articulated by Vicente [40], in which originally five principal tiers of hierarchy are distinguished. The five levels of abstraction hierarchy are presented in Figure 3.4. The work of Vicente states that the exact definition of each level and the amount of levels relevant to a particular work system depend on the work system itself and the depth of the required analysis. In this study, the abstraction levels similar to those redacted by Patriarca and Vicente are used.

At the top of the hierarchy of Patriarca is the functional purpose, which describes what the system aims to achieve within its broader environment. In a shipbuilding context, this can be as general as “deliver a completed vessel that meets specified requirements”. Below that is the abstract function level, in which a generalized causal network outlines intended states and interactions, such as the flow of information between engineering, planning, and production departments. Next comes the generalized function level, which defines the overarching operational processes that govern system behavior above the level of individual specific tasks, capturing how various tasks and resources come together in practice. The definition for each of the levels is defined by Vicente [40].

By systematically assigning each activity or subsystem to one of the three levels of abstraction hierarchy, the resulting model balances high-level goals with the operational details necessary to reflect the real world complexity. In contrast, the physical function and physical form tiers focus on short-term activities and events that may or may not occur, given the local circumstances. They offer less analytical value for understanding how overarching processes unfold over time. Consequently, the bottom tiers are excluded here to maintain emphasis on the broader functional and organizational dynamics that drive system behavior. However, these or other levels can be added for different purposes. For example, if the analysis requires detailing of specific tasks of individuals within the work system. For clarity, the hierarchy levels that were defined by Vicente and Patriarca are listed in Figure 3.4. There, the levels that are not used within this study are greyed out.

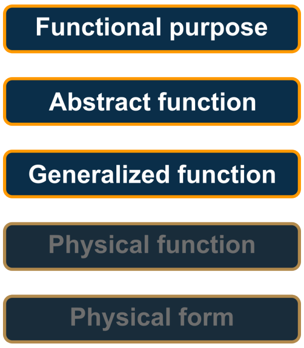

Figure 3.4: Hierarchy levels as defined by Patriarcia [45] with the levels not applied within this research greyed-out

The modeling workflow progresses in two primary phases. First, the WAI model is established at the abstract function level, based on available formal process documentation. Since the WAI depicts how processes are formally described and anticipated to unfold, its connections mirror those specified in official procedures, guidelines, or project plans. The WAD model is then constructed at the generalized function level by incorporating empirical data. As specified in section 3.2, this data is gathered through conversations and observations that capture how tasks are actually performed in shipbuilding projects. The following two subsections, respectively, explain the method to derive the representative WAI model and the representative WAD model.

Deriving the WAI model

To derive the WAI model, the first step is to distill the relevant functions directly from the formal process descriptions. Subsequently, the interrelations among these functions are determined using FRAM's functional connections, using the same process documentation as the primary source. Based on the approach of Patriarca et al. [45], each function is then assigned to an appropriate tier of abstraction hierarchy. With input from process managers and guidance from relevant literature, functional systems are further elaborated to encompass both the levels of 'functional purpose' and 'abstract function'. Where multiple levels are present, aggregated connections are used to link higher-level functions, while additional detail and the actual connection is defined at the lower abstraction level.

Through this iterative mapping of functions and their interrelations at both high and more granular levels, a coherent WAI model emerges that aligns with the work abstraction hierarchy, as well as FRAM function and connection definition. A visual representation of this derivation is presented in Figure 3.5

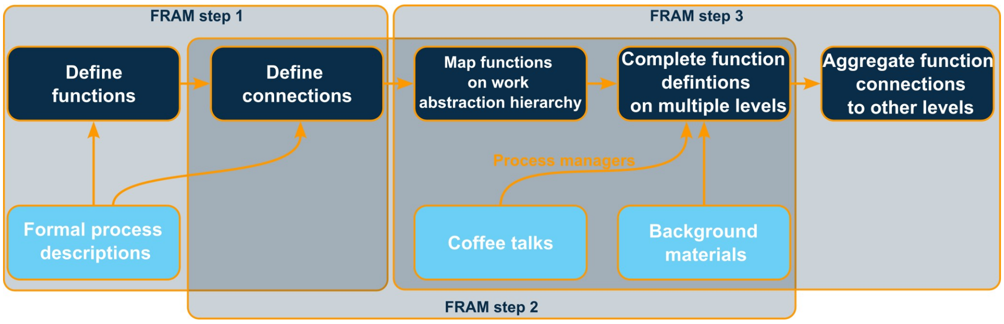

Figure 3.5: Schematic method representation for the construction of a WAI FRAM model using work abstraction hierarchy

Deriving the WAD model

The development of the WAD model takes a different approach than the WAI. It starts by defining the initial functions and relationships through observations made on the work floor, alongside informal conversations with both production staff and supervisors. The construction of a comprehensive WAD model is then informed by best practices, anecdotes, real observations of day-to-day operations, and dialogues regarding operational matters. The resulting WAD perspective is verified with shipyard workers and supervisors along the way, again through conversation and observation focused around the operational scope that needs verifying.

Once the unstructured WAD model is defined, its functions are aligned with the abstraction hierarchy levels of the work system. Then, it is assessed whether a function has a means-end relationship with any function identified for the WAI at a higher level. It is also conceivable that a WAD function is functionally analogous to one already specified for the WAI. Alternatively, the function may operate independently of those described for the WAI. In such cases, similar to the WAI, the functional systems are further detailed to identify both the functional purpose and the abstract function level. This analysis provides a contextual definition of the WAD functions relative to the WAI.

To obtain FRAM models at the different abstraction hierarchy levels, the connections of the previously defined WAD are now mapped and aggregated on the respective hierarchy level of which the function is now a part.

To construct FRAM models across various abstraction levels of work, the previously established connections of the unstructured WAD are now introduced back into the model. This results in the mapping of connections at and across the different levels of abstraction hierarchy. The mapped connections at lower levels can then be aggregated to higher levels, defining aggregated functional connections.

Employing this method, the WAI and WAD functions are mapped to each other, enabling systematic comparison of FRAM instances at the different abstraction hierarchy levels.

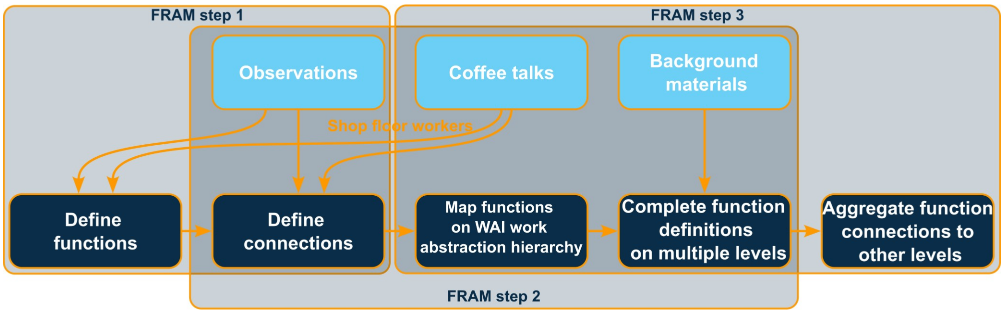

Figure 3.6: Schematic method representation for the construction of a WAD FRAM model mapping on a defined WAI

Model analysis

Having representative models for WAI and WAD allows for a deeper comparison of the situations at hand. It shows different types of limitations, risks, possible disturbances, and different coping mechanisms that are identified between the WAI and observed WAD. The models serve as a verification of preliminary findings (suggestions, causes, and observations), as well as exposing new findings.

In the process of constructing the models, generalized functions that lack a designated abstract function are identified. Such discrepancies indicate either a need to refine the WAI so that it accounts for real-world variations or a requirement to integrate new process elements altogether. Similarly, the emergence or elimination of inter-function connections during this mapping indicates processes that might be more (or less) coupled in practice than expected. Ultimately, these gaps and misalignments between WAI and WAD offer concrete and documented evidence of the tension between formal work instructions and real-world operational demands.

The model comparison is structured around three principal analyses. The first analysis is a systematic examination, emphasizing the technical characteristics of the models, such as the amount of functions and direct comparisons between functions and connections. The second analysis offers a socio-technical interpretation of the work system models, contextualizing them within the framework of Hale's models [41], as introduced in chapter 2. The third analysis provides a detailed and practical assessment of the functions and properties specific to this case study, closely evaluating the distinct differences between WAI and WAD for specific functions and their connections in the work system. Employing these three distinct analytical perspectives demonstrates the ability of the proposed method to facilitate both comprehensive and specific evaluations of the work system.

The combined model analysis provides insight in the limitations of current tooling and requirements of effective tooling within the analyzed work system and extends this to the general level of ETO shipbuilding.

The final stage of the research involves developing recommendations tailored specifically to the insights derived from the various analyses. For instance, in cases where multiple connections identified within the WAD bypass the formal communication channels in the WAI, the implementation of new collaborative tools or the formalization of existing informal interactions may be advisable. At this stage, considerations discussed in section 2.2 are integrated into the reasoning and the formulation of these recommendations. In this context, technical aspects are primarily represented by the WAI model, whereas organizational and socio-technical aspects are captured by the WAD model. Utilizing these representative models, a deeper comprehension of shipbuilding operations within an ETO environment is achieved. The overarching aim is to reduce the 'relative ignorance' of the system, as conceptualized by Hollnagel [44]. In practical terms, it is essential to recognize that WAI models, at best, serve as generalized representations of the system. Perfect compliance with WAI is neither practical nor realistically feasible. The resulting structure for model comparison is visualized in Figure 3.7.

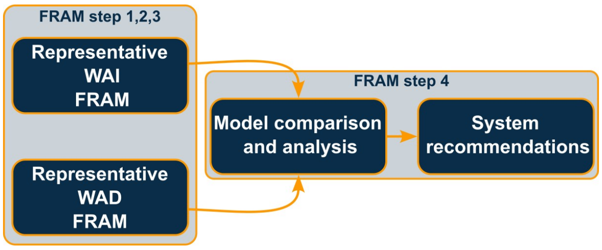

Figure 3.7: Visual representation of how the FRAM perspectives combined enable effective analysis

3.4. Resulting method

Building on the preceding subsections, this section consolidates the methodological choices into a final structured framework to analyze the observed clash between formal procedures and actual work practices. The goal is to detail the implications of this clash and the systemic mechanisms that shape it, setting the stage for the concrete application of the method in the next chapter.

The Functional Resonance Analysis Method (FRAM), combined with the work abstraction hierarchy, offers the requisite rigor and flexibility to navigate these socio-technical dynamics. As described earlier, FRAM centers on identifying and connecting system functions, rather than just sequentially listing tasks, while accounting for the inherent variability of human and organizational factors. The accompanying hierarchy helps to manage the level of detail, thereby avoiding the granularity pitfalls typical of other approaches. By mapping WAI and WAD to the same hierarchical structure, divergences between formal definitions and actual practices can be identified and examined.

The modeling itself is performed in FRAMify (previously DiaFRAM), a web-based FRAM modeler developed by Pieter Bots, a TU delft associate professor at the faculty of Technology, Policy and Management [47]. The FRAM models are exported from FRAMify and graphically edited in Inkscape for further processing.

This dual model approach, as visualized in Figure 3.8 creates a 'stacked' view of the system, showing how higher-level functional purposes and lower-level abstract functions interact and compare between WAI and WAD. Such an arrangement highlights missing or extra links and functions, which in turn clarifies where top-down and bottom-up approaches might need realignment. Although the ultimate intention is to reduce the mismatch between WAI and WAD, it must be recognized that no single solution fully stabilizes every point of variability. Instead, FRAM provides a means to identify realistic intervention points, guiding shipyards in choosing solutions that fit their unique organizational context.

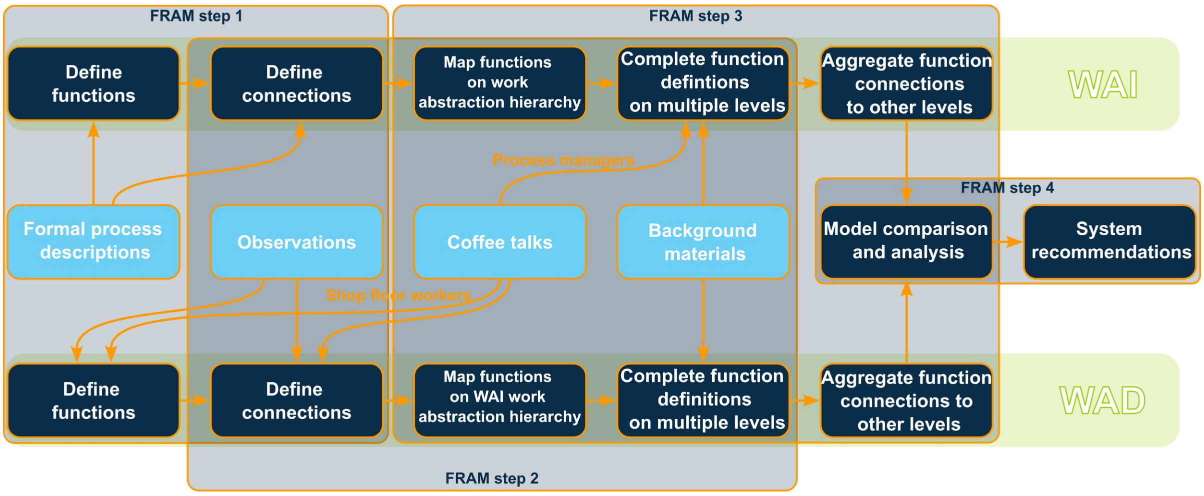

Figure 3.8: Complete method overview with FRAM stages identified

In sum, applying the means-end hierarchy method within a FRAM framework exposes the tensions between formalized procedures and daily operations. It also provides a systematic way to address the 'granularity problem' of Beerepoot et al. [43] raised in section 3.3, ensuring that neither oversimplification nor excessive detail obscures the real functioning of the system. By systematically mapping the generalized functions onto the abstract ones and then comparing and creating department or tool oriented cross-sections, shipyards gain both the structural clarity and the practical insight needed to refine their processes. These refinements are anchored in concrete, observed practices, rather than assumptions. The proposed method consolidates an answer to RQ.2; by using FRAM in combination with abstraction hierarchy, a systematic comparison and analysis can be performed on the work system.

The next chapter, chapter 4 delves into the actual execution of this final method with empirical data, revealing how FRAM-based modeling can pinpoint the specific information gaps and their origins that disrupt the production flow. There, actionable recommendations are constructed to bridge the divide between formal and actual work, using the resulting FRAM models.

4 Results

4.1. Case-study introduction

This research employs a generalized case study of a major European shipyard to illustrate how information gaps manifest themselves in real-world operations and how they influence the implementation of new tools and methods. Although shipyard identities must remain confidential and are not relevant to the findings of this study, the characteristics align closely with the taxonomy introduced in Chapter 2. In particular, it operates in an ETO environment, is subject to volatile market conditions, and adopts innovative technologies in an effort to increase both productivity and managerial control.

Recent changes at this shipyard include the introduction of new IT systems designed to offer enhanced business oversight. These initiatives exemplify the broader trend in large European shipyards toward digital transformation and automation. However, preliminary observations indicate that the expected benefits, such as seamless data exchange, greater transparency, and tighter resource planning, are not fully realized in practice. This resonates with the challenges documented by Garcia-Agis [25], who notes that shipyards often struggle with inconsistent data quality, slow adoption pace, and limited workforce participation when implementing new software systems.

The main operational scope of this case study focuses on the production department, specifically the hull construction and section building activities. Other shipyard functions, such as the engineering phase and the outfitting processes, are considered only as they intersect with these core production tasks. Within this scope, increased attention is given to understanding which IT tools are actually in use and how effectively they support daily operations. The departments most relevant to this analysis include construction engineering, production management, production planning, and the production workforce itself. The scope is schematically projected on the formal process documents in Figure 4.1.

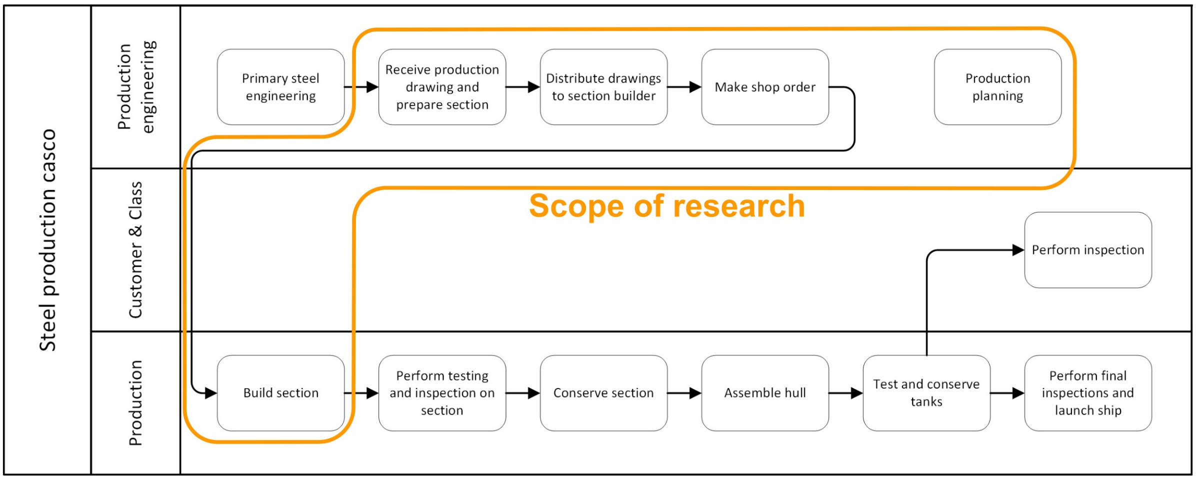

Figure 4.1: Scope of research visualized in the overview of formal process descriptions

The important hypothesis underpinning this study is that the 'top-down versus bottom-up' conflict, described in section 2.3 as a clash between formal processes and real-world operational demands, plays a central role in the current operational challenges of the yard. While management seeks more detailed metrics and tighter oversight through newly introduced IT solutions, the workforce often relies on experience-based, flexible methods to meet immediate production objectives. The case study suggests that formal business process descriptions do not always reflect how work is performed effectively, leading to uncoordinated approaches, unexpected interruptions in workflow, and unplanned rework. These patterns are evident in the hull section-building stage, where any missing information or poorly aligned tasks tend to propagate downstream, amplifying time and cost overruns. Be aware that these patterns are not limited to this shipbuilding stage. It is argued that they apply to all practical stages of shipbuilding.

The data for this investigation were collected primarily through direct observation on the shop floor and through informal conversations (coffee talks) with workers, supervisors, and planning personnel, as laid out in section 3.2. More structured interviews were found to be less effective, in part due to worker hesitancy and the sensitive nature of discussing operational inefficiencies. However, multiple days of participation produced a sufficiently detailed account of WAD, revealing noteworthy gaps between actual practice and formal WAI. These mismatches inform the subsequent discussion of how information gaps originate, how they spread through the production network, and how current IT tools do or do not address them. An example is provided in Figure 4.2. In the conversation surrounding this quote, the supervisor explained that direct supplier contact is not according to formal processes but often works best if there is an urgence to it, bypassing formal procedures. This quote is exemplary of why the informal conversation is in this case effective to gain insight into actual operations. These statements are only made when the organization is actually subject to the described situation at that moment, and thus the statements are reliable sources for the WAD.

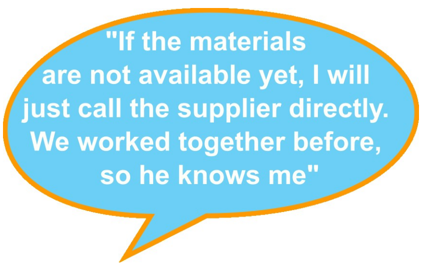

Figure 4.2: A production supervisor explains his routine for material handling

In summary, this case study provides a tangible illustration of the challenges associated with implementing new digital technologies in a complex shipbuilding environment. The examples provided with the findings will be recognizable to many medium- to large-sized European shipyards. Although formal documents and process descriptions exist for activities such as section-building, the reality is much more variable than those descriptions imply. The empirical findings highlight the importance of investigating the social and organizational context behind the yard's efforts at digital transformation. This reinforces the argument that technological tools, however advanced, may fail to deliver their promised benefits unless they are closely aligned with actual operational demands. Practical recommendations will be made to the contacted yards and towards Floorganise as a software provider based on the elaborated case study.

In the next sections, the case study is executed. First, in section 4.2, the respective FRAM models are constructed on the different abstraction hierarchy levels. Next, in section 4.3 the models are analyzed in detail. The content of this chapter provides a base for the construction of recommendations in chapter 5.

4.2. Representative FRAM models

This section presents the representative FRAM models that are developed using the data gathered as outlined in section 3.2, and following the approach detailed in section 3.3. The organization of this section mirrors the format shown in section 3.3.

Deriving the WAI model

This subsection explains the construction of the representative WAI model and presents the resulting FRAM model. The model is derived from the formal process descriptions outlined in Appendix A. These formal process descriptions are hierarchal BPM representations of the work system. The current process description is acknowledged as outdated and has been updated last time during the implementation of new IT tooling. Since then, the technical environment has evolved. Although new process descriptions are needed, the task of updating the process descriptions is resource intensive and only limited resources are available. Operational departments are unaware of the process descriptions themselves. The current processes were developed with minimal input from those in charge of carrying them out. It remains unclear how new processes will be established and maintained, as there is currently only a proposed meeting structure. The original process descriptions used to construct the WAI model are presented in Appendix A. The WAI process serves as the foundation for the implementation of IT systems and fundamentally contributes to the structure of the architecture of these systems, which should improve operational oversight and traceability.

Following the method steps as described in Figure 3.5, first the functions and connections are defined based on the aforementioned formal process descriptions. The identified functions and the corresponding connections can be found at the start of Appendix B.1 and Figure B.1, respectively. The FRAM model presented in Figure B.1 does not account for the different levels of the abstraction hierarchy of work and, therefore, cannot be directly used for systemic comparison. Each function defined for the WAI is then categorized to the appropriate level of abstraction hierarchy. The result of this is found in Figure B.2. There, the granularity issue described by Beerepoot [43] is explicitly exposed because the identified functions have different tiers in the hierarchy levels. Subsequently, new functions are derived to complete the levels of abstraction of work using the theory of means-end relationships described by Vicente [40]. The levels are completed to ensure that all originally identified functions are represented on both the functional purpose level and the abstract function level. The enrichment of functions is an interpretation of the work system and is not a direct representation of the formal process descriptions.

In Figure 4.3 the top two levels of abstraction hierarchy are presented, being the functional purpose and abstract function level. For each abstraction level, a FRAM model represents the work system. Given that the functional purpose level model is a projection of the model at the abstract function level, they are essentially seen as stacked models, where both models can be used for independent analysis.

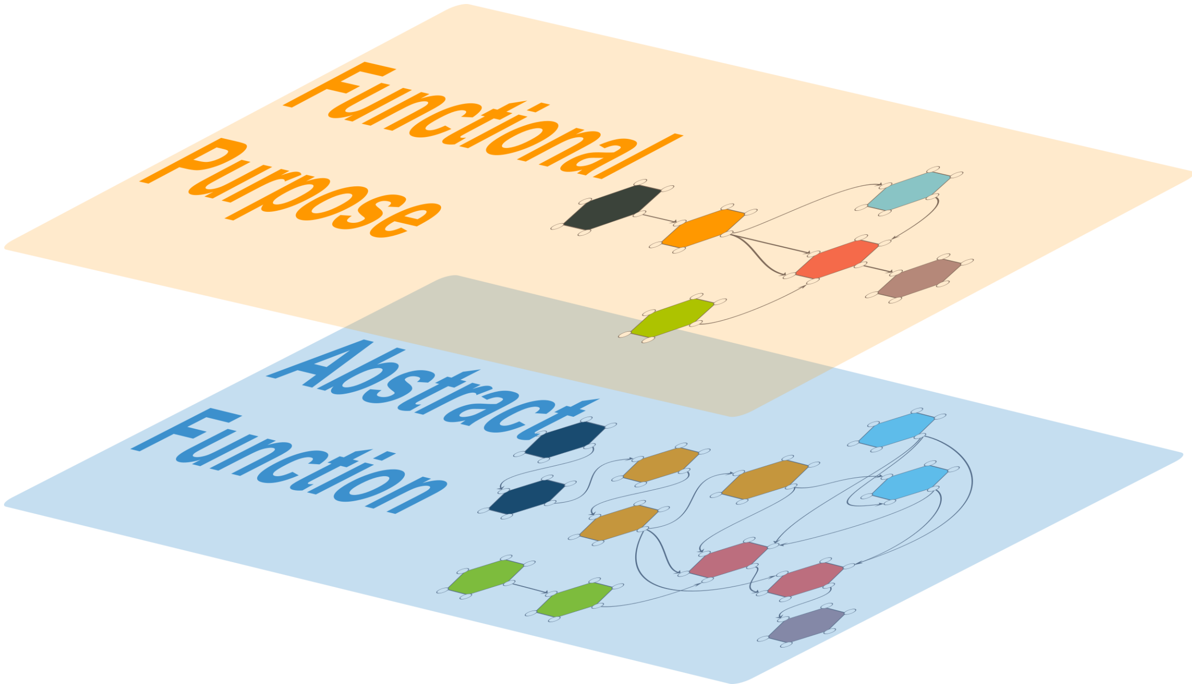

Figure 4.3: Conceptual representation of FRAM WAI models for the two stacked layers of abstraction hierarchy

The resulting set of functions, with accompanying means-end relations, is presented in Figure B.3. With the functional levels fully described for the scope of research, now the connections of the FRAM model without the work abstraction hierarchy are projected on the functional purpose level and the abstract function level. The resulting FRAM models for the levels are presented in Figure 4.4 and Figure 4.5. These two models are now representative for the WAI on the two levels of work abstraction hierarchy and can be used for further analysis.

Within Figure 4.4 and Figure 4.5, identical colors of functions define a means-end relationship between the functional purpose and abstract function hierarchy levels.

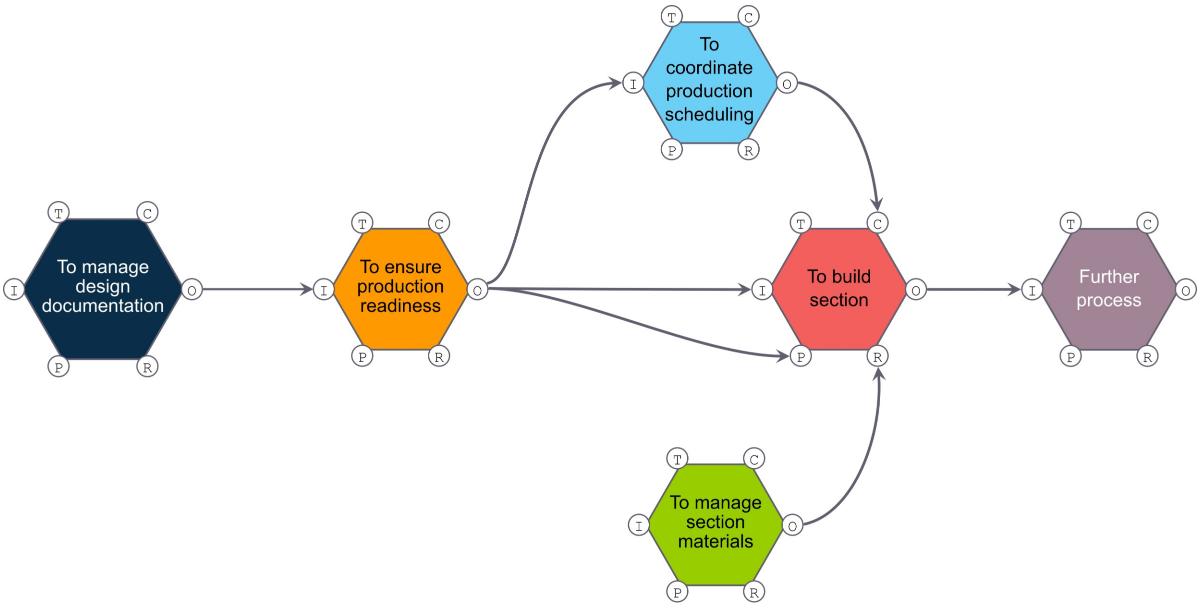

Figure 4.4: WAI FRAM representation at functional purpose level

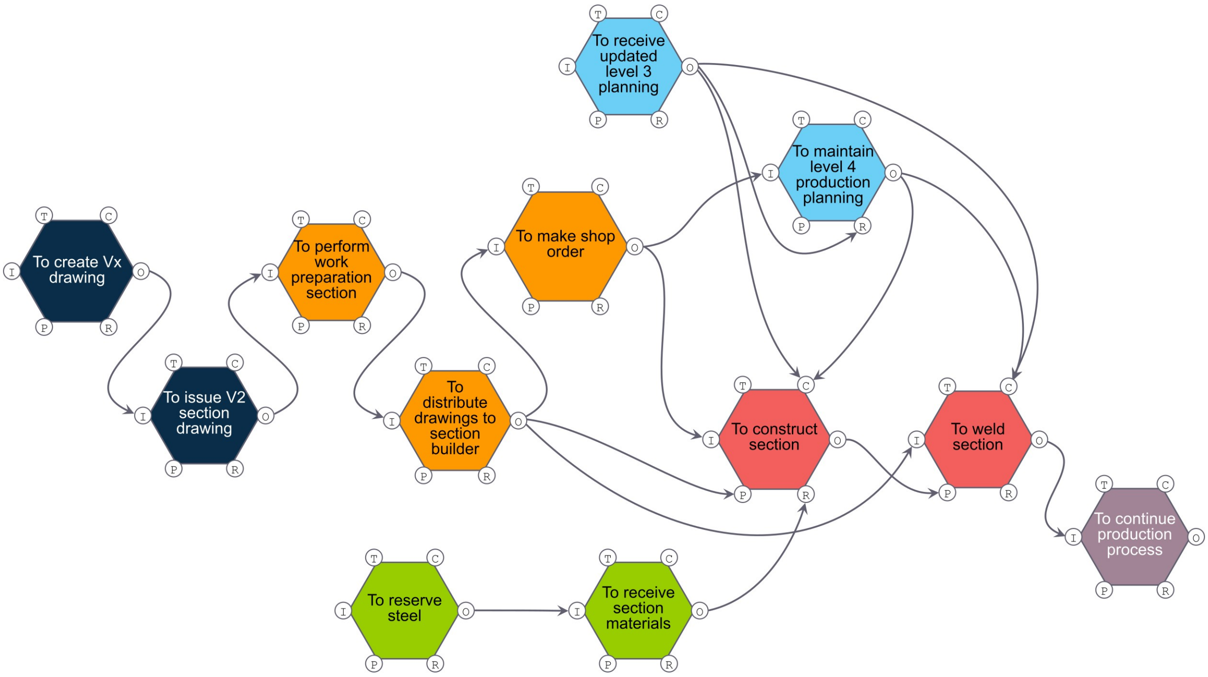

Figure 4.5: WAI FRAM representation at abstract function level

An initial observation of these representative FRAM models already exposes the linear characteristic of the WAI at both hierarchal levels. Another observation is that the representation of FRAM at the abstract function level is more complicated than the representation at the functional purpose level. This is expected since the FRAM representation at the functional purpose level is an aggregate of the FRAM at the abstract function level. In section 4.3, the WAI FRAM representations are analyzed in further detail, extending on these initial observations.

Deriving the WAD

Now, the representative WAD models are set up. The origin of the models are primarily observations and information extracted from the coffee talks. The information was extracted empirically and then generalized to identify the relevant functions of the actual work within the scope of the research. This generalized perspective was verified through conversations with workers and supervisors and through new observations. The stories and findings of the actual work are highly dynamic and fluid. Also, the identified functions vary a lot in definition and in the connections they have to other functions.

Following the method steps as described in Figure 3.6, first the functions and connections are defined based on the empirical findings. The identified functions and the corresponding connections can be found in Appendix B.2 and Figure B.4, respectively. The FRAM model presented in Figure B.4 does not account for the different levels of abstraction hierarchy. Subsequently, the WAD functions are mapped onto the already existing categorization of WAI functions, using the three distinct options described in Figure 3.3. A visualization of the resultant categorization of WAD functions is presented in Figure B.5. With the functional levels fully described for the scope of research, now the connections of the FRAM model without the abstraction hierarchy are projected on the functional purpose level and the abstract function level. The resulting FRAM models for the top two levels are presented in Figure 4.6 and Figure 4.7. These two models are now representative for the WAD on the two levels of abstraction hierarchy. Similarly to WAI FRAM models, the matching colors of the functions between Figure 4.6 and Figure 4.7 represent means-end relations between the functional purpose and the abstract function level. Additionally, matching colors are used between the WAI and WAD models for identical functions at functional purpose levels. The representative FRAM models, with their colors, will be used for further analysis in the next section, section 4.3 analysis.

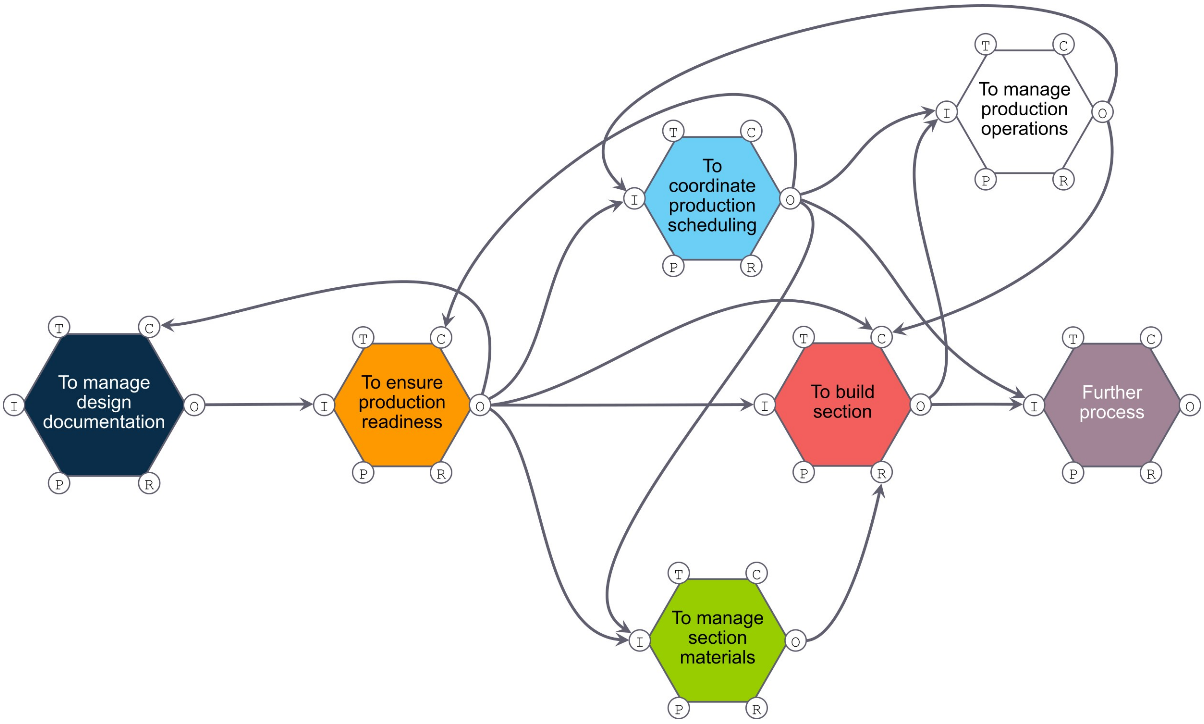

Figure 4.6: WAD FRAM representation at functional purpose level

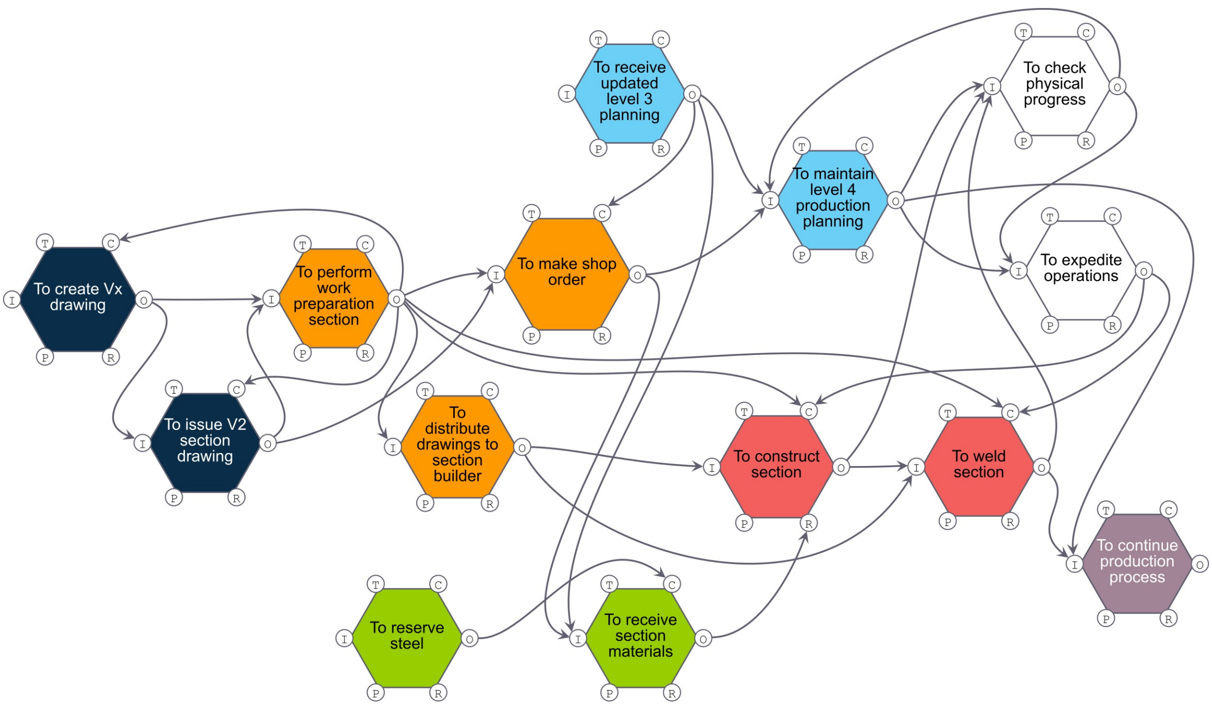

Figure 4.7: WAD FRAM representation at abstract function level

4.3. Model analysis

This section presents an analysis of the FRAM models and their associated empirical findings in relation to the main research question. The analysis highlights the gap between top-down and bottom-up approaches, providing detailed insights into the results obtained from the FRAM models, and offering guidance on their interpretation. These findings exemplify how a socio-technical understanding can facilitate the effective implementation of techno-centric solutions, thus addressing RQ.3.

Initially, a systemic comparison is conducted between the representative WAI and WAD models. This comparison reveals quantitative and factual differences between the models without incorporating specific contextual considerations. This systemic comparison can be characterized as an engineering approach. Subsequently, a socio-technical analysis is performed within the context of Hale's model theory [41]. This analysis highlights similarities between characteristics defined by socio-technical science and those observed in the representative FRAM models. Finally, two cases specific to these models are examined in greater detail to identify unique characteristics relevant to this particular operational context, thus adopting a practical perspective. Collectively, these three analytical approaches represent distinct yet complementary perspectives that can be employed when analyzing the representative models or socio-technical environments in general.

Systemic comparison

A systemic comparison of the two representative FRAM models (see Figure 4.4, Figure 4.5 for WAI and Figure 4.6, Figure 4.7 for WAD) shows that the WAD at both the abstract function level and the functional purpose level has more function definitions than the WAI. For instance, the WAD uncovered several tasks that were never recorded as discrete functions in the WAI, confirming that the actual functional work is more extensive and subdivided than the formal process suggests.

Another finding is the higher number of connections for the WAD. These extra WAD connections indicate that operational flexibility can prevent disruptions before they escalate. At the same time, more dependencies highlight the need for tighter collaboration and intensive interaction between functions. These extra connections are a form of connection variability in parallel paths between the functions. Without resiliance, undesirable variability will cascade and is only identified in validation moments, like the WAI assumes. In fact, workers already catch and solve for a lot of poor quality or missing information, as reflected in the WAD by the connection variability. WAI, on the other hand, does not capture variability at all. There, only ideal flow is represented with formal issue management handled outside of regular production. At the same time, this high variability experienced in WAD increases the complexity of ensuring consistent and organization-wide visibility into production progress. The amount of functions and connections of each of the models, as well as the differences between WAI and WAD are summarized in Table 4.1.

Table 4.1: Comparison of WAI and WAD number of functions and connections

	Abstract function level		**Functional purpose level**	
	no. functions	no. connections	no. functions	no. connections
WAI	12	17	6	7
WAD	14	30	7	15
Difference	2	13	1	8

Feedback loops are instances where downstream functions converge with upstream functions, resulting in iterative function activation and reinforcing functional dynamics. Figure 4.8 and Figure 4.9 present examples of, respectively, direct and indirect feedback loops. There are no direct or indirect feedback loops present in the WAI FRAM representations. At the same time, WAD models show multiple feedback loops at both the functional purpose and abstract function level.

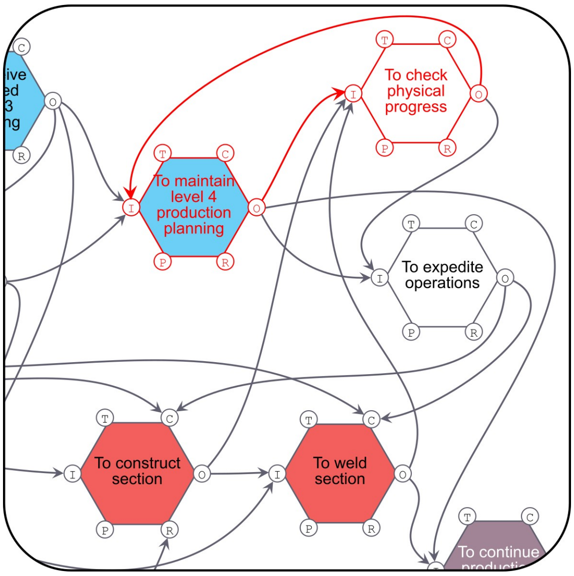

Figure 4.8: A case direct functional feedback in the WAD FRAM at functional purpose level

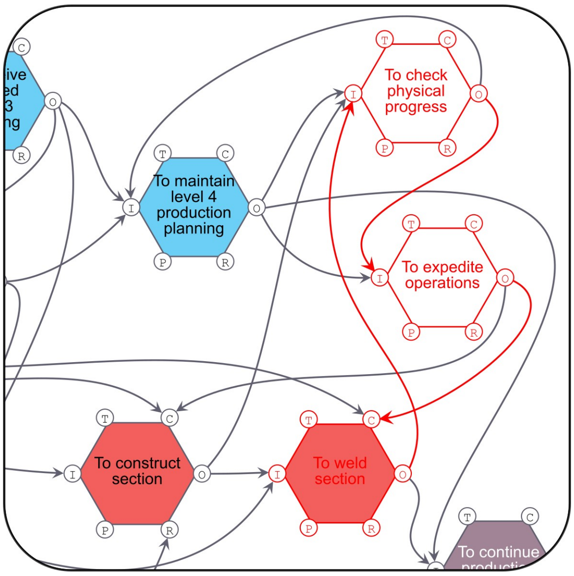

Figure 4.9: A case of indirect functional feedback in the WAD FRAM at functional purpose level

Extending this to practise, the models reveal that WAI typically depicts a more linear and sequential workflow. This can be explained by the fact that the process steps in the formal documentation also connect linearly and sequentially. The outputs from one function feed directly into the inputs of the next, under the assumption that all required information is both complete and timely. In contrast, WAD models show significantly more interdependencies and, in general, a much more complex functional network. Workers on the production floor, along with supervisors, frequently engage in unplanned or ad hoc communication and work activities to address unexpected challenges, such as missing technical documents or delayed materials. Unforeseen incidents that were not included in the initial planning documents require problem solving on the spot. These informal approaches establish a denser and more adaptable web of interconnections among functions.

Applying Hale's model theory

Many currently implemented technologies and systems create simplified artificial relations that do not fully capture the nuanced reality of shipyard operations. This limitation is inherent, as no system is entirely capable of representing the complexity present in actual operations. The WAI model developed within this research clearly exhibits characteristics similar to Hale's Model 1 [41], which is grounded in an engineering or techno-centric approach to rule-making, favoring explicit, easily understandable rules. Many newly developed technologies and information systems tend to replicate and iterate on these same artificial and abstract relationships, which fail to fully represent the nuanced and complex dependencies present in actual shipyard operations. A typical example are ERP systems. These systems often fail to adequately deal with exceptions or unexpected disruptions, a shortcoming explicitly recognized by Hale [41]. As illustrated in Table 2.1, the inability of overly abstracted models to address operational exceptions limits system flexibility and creates a persistent gap between intended rules and actual practice. This phenomenon is precisely observed within the context of the studied shipyard. A clear example is the dynamics around the issued drawings which follow a purely sequential path, according to the WAI. Within this path, drawings are only issued once complete and work preparation begins only after the drawing is issued. The WAD does not follow this sequence, as detailed in the next paragraph.

In contrast, the constructed WAD model closely aligns with Hale's Model 2 [41], emphasizing the importance of social processes and interactions. Here, the social interactions among the operators largely determine how the rules are interpreted, adapted, and ultimately executed. This model acknowledges the inherent variability in operational processes and recognizes the crucial role that social interaction plays in the definition of actual operations. Nevertheless, weaknesses attributed to Hale's Model 2 are also evident. For example, there is often a lack of transparency due to the informal and ad hoc nature of operational interactions, complicating the accurate modeling of actual practices. The fact that a lot of time was spent gathering the information is exemplary of this. Additionally, establishing a representative WAD model requires significant effort and detailed understanding, reflecting Hale's identified weakness of Model 2's complexity and opacity. Exhibiting the same example as for the WAI, the issued drawings are already shared before official drawings are issued, and work preparation for a section already starts. This enables downstream disciplines, like production engineering or even production themselves, to provide feedback to engineering departments, anticipating the official drawings issue. Within these dynamics, there is an intensive collaboration between departments where information is shared iteratively until complete and of good quality.

A truly effective operational system for shipyard management would take advantage of both Hale's models, explicit and clear guidelines from the WAI approach, coupled with the operational flexibility and responsiveness inherent to the WAD model, while actively mitigating their respective weaknesses. The approaches to accomplish this integration are further elaborated in chapter 5, where concrete recommendations will be presented to bridge these differences and to adopt a sustainable method for the organization of work. In the case of drawing issuing, an example would be to implement a workflow that distinguishes official traceable releases (WAI) from working copies to preliminarily share information and request feedback (WAD), and to have workers understand the difference in value and purpose these versions have.

Case-specific findings

The previous subsections identified general aspects inherent to any WAI and WAD comparison, highlighting universal gaps for environments with clashing top-down management and bottom-up operations. This subsection further specifies and analyzes findings unique to the scope of the case by examining two explicit examples. Each case is chosen because of its significant impact on shipyard productivity, reflecting the core operational processes observed within the scope of the investigation.

The first example relates to operational management functions. Specifically, the WAI fails to explicitly identify the function 'To manage production operations' at the functional purpose level, as illustrated in Figure 4.10. In contrast, this function is clearly represented within the WAD model. The absence of this function in the WAI implies an underlying assumption that explicit management of production operations is unnecessary, as formal communication channels and predefined frameworks are presumed sufficient for establishing and managing priorities. In contrast, the findings of the observations and coffee talks indicate that explicit operational management is necessary. Regular progress monitoring and proactive operational adjustments are consistently undertaken to ensure alignment of production activities with current planning priorities. This observed management function exemplifies self-regulation within the operational environment, addressing and mitigating negative variability effects. Variability that is not anticipated by the WAI model. Consequently, the operational management function remains invisible in the WAI, despite its critical role in maintaining effective production operations.

This discrepancy not only reflects a misalignment in theoretical understanding but also practically implies that formal documentation alone inadequately addresses real operational needs. Thus, it emphasizes the need for adaptive managerial frameworks capable of responding flexibly to operational realities.

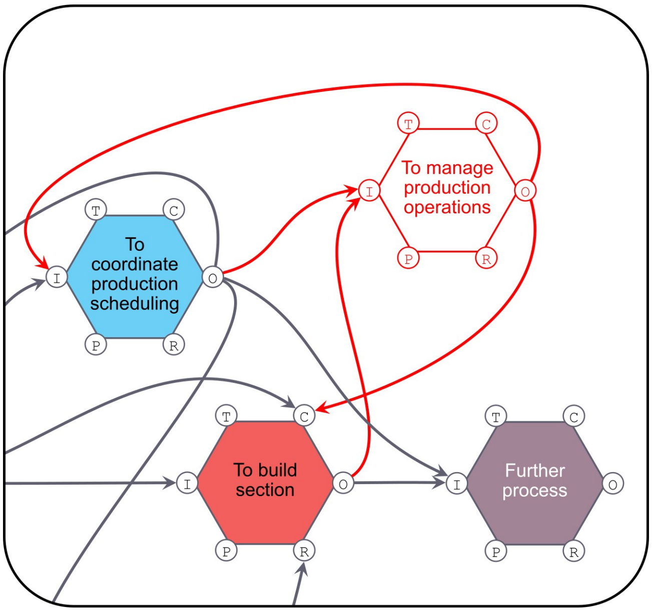

Figure 4.10: The function ”To manage production operations” highlighted in the WAD on functional purpose level

The second example concerns material delivery management. The WAI model assumes that once materials, particularly cut steel packages, have been reserved, no further management of deliveries is necessary. In this model, timely receipt is guaranteed. However, the WAD model reveals a different operational reality, where active expediting is essential. Specifically, on the abstract function level, material receipt is connected with functions such as ”To make shop order” and ”To receive updated level 3 planning.” The updated level 3 planning, together with the activated shop orders, triggers the function ”To expedite material deliveries”. A visualization of these differences is presented in Figure 4.11. Operational practices, as identified through empirical research, demonstrate that the timely receipt of materials frequently requires proactive measures. These measures include expediting actions by designated personnel. This expediting either ensures that materials arrive according to the schedule or is required to acquire precise updates when deviations occur.

This finding highlights that formal process models (WAI) neglect crucial real-world functions. Specifically, the active management needed to cope with delivery uncertainties and schedule adjustments. The discrepancy emphasizes the need for formal processes to explicitly acknowledge these real operational activities, as their absence from formal documentation limits the ability to effectively monitor, communicate, and coordinate during deviations.

Additionally, the detailed analysis at the generalized function level (presented in Figure 4.12) reveals that registrations of material deliveries are not necessarily synchronized with the actual management of stored materials. Consequently, ERP material flows, in this case, are not inherently aligned with operational practices. The ERP material registration, in this case only controls how the management of the stored materials is executed. Please note that in this case, only an isolated representation at the generalized function level can be made. The generalized function level is not functionally complete for the scope of the case study.

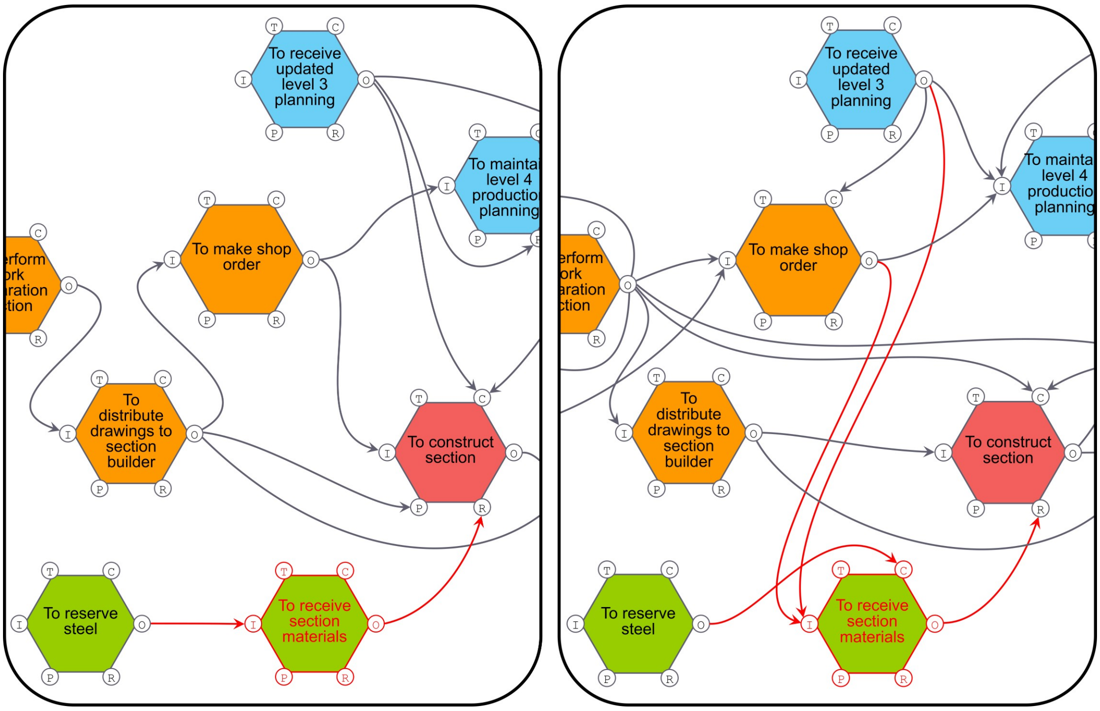

Figure 4.11: "To receive material deliveries" and its connections higlighted for WAI (left) and WAD (right)

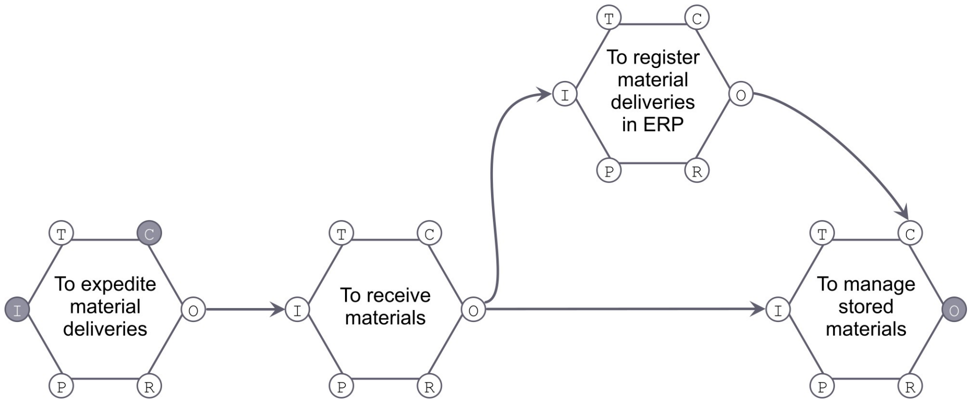

Figure 4.12: FRAM representation for WAD, isolated for "To receive section materials" at generalized function level

5
Recommendations

This chapter synthesizes the insights derived from the FRAM model analysis described in section 4.3 of the previous chapter, presenting targeted recommendations aimed at bridging the identified gap between WAI and WAD, providing for a further answer to RQ.3. By exploring various control mechanisms and proposing actionable interventions to the work system, the recommendations also address RQ.4 formulated in section 2.4: "How can a socio-technical understanding of the work system be supported in the effective organization of work?"

The recommendations come mainly from socio-technical science and best practices within the socio-technical domain. Explicitly searching for possible improvements and solutions outside of typically recognized solutions within the shipbuilding literature and the shipbuilding industry. Some recommendations also originate from shipyard workers and supervisors themselves, following on the conversations around the FRAM analysis results.

The recommendations are structured into three sections: Case-specific recommendations, general shipyard recommendations, and recommendations to Floorganise (or other software providers). This structure ensures clear distinction in to whom and to what case a recommendation is most relevant, guiding shipyards and solution providers towards effectively balancing directive control mechanisms with operational flexibility.

5.1. Case-specific recommendations

A critical finding of the comparative analysis between the WAI and WAD models was the absence of explicit operational management functions within formal processes. To address this gap, it is essential to clearly define operational management roles within formal documentation and explicitly incorporate these into process descriptions. The introduction of operational management roles follows logically from the current failure to recognize these in formal processes. Additionally, the job descriptions for these functions should be updated to reflect actual requirements and expectations for this position, as is confirmed by management science. For example, the study of Switasarra emphasises the explicit need for clear and up-to-date job descriptions to control work systems [48]. Raju even argues that job description quality has a direct relation to operational performance [49]. The clarity of defined roles enables operational managers to effectively request relevant operational data and establish representative key performance indicators (KPIs) that reflect their specific operational responsibilities, moving beyond abstract metrics. An example of an operations-focused KPI that is man-hours per tonne, a commonly employed measure of shipbuilding production efficiency. Here, it is key that the KPIs are only complementary to the findings and reasoning of operational controllers and managers. Another recommendation is to explicitly define roles and responsibilities across various organizational levels, such as operational managers or supervisors, and to include these roles in the definition of the work system (in this case being process descriptions). This ensures that personnel have the appropriate authority and support to promptly address operational issues, aligning their practical tasks with formally documented responsibilities. Clearly defining these roles not only provides formal leverage, but also fosters an environment where informal collaboration is acknowledged and valued within organizational social hierarchies.

A practical recommendation emerging from these insights is the introduction of a formalized ”andon responder”, whose sole responsibility is to provide immediate support and short-term solutions to operational issues. This individual should be empowered to bypass or override formal processes and structures when necessary to effectively resolve operational disturbances. Consequently, routine production operations can continue uninterrupted under the guidance of supervisors and operational managers, with the andon responder stepping in only in exceptional circumstances. Andon originates from lean theory [50], where it is introduced as a tool to quickly solve for emergent disturbances. This recommendation is exemplary of how potential solutions from different disciplines (like lean) can be effectively implemented once an adequate understanding of the work system is established.

Further analysis of the WAD model highlighted the critical role of actively expediting material deliveries, a function completely absent from the WAI model. To mitigate this issue, it is recommended that explicit processes for material management be established, clearly assigning responsibilities for expediting material deliveries. Formalizing a dedicated role or department responsible for proactively managing and expediting materials, as well as maintaining consistent communication with suppliers, will enhance visibility and control, thus effectively aligning operational realities with formal planning structures. Additionally, explicitly recognizing these material management activities allows for targeted technological and IT support, such as collaborative platforms to facilitate interaction between shipyards and suppliers. The specific recommendation of formalizing these functions originate directly from case study findings. As a current shipyard worker was struggling with their current responsibilities and lack of formal recognition of these responsibilities. Additionally, analogous considerations apply as for the operational management functions.

These recommendations provide practical measures specifically tailored to the case study, demonstrating that actionable strategies can significantly improve the work system and support the effective implementation of innovative solutions. As mentioned in section 4.3, operational management and materials expedition represent only two examples of potential improvements. Given the current substantial misalignment between WAI and WAD, it is advised to continue with an extensive detailed analysis of this work system to uncover further areas requiring alignment and improvement.

5.2. General shipyard recommendations

This research highlights that shipyards should explicitly explore socio-technical solutions, recognizing that technical innovations alone cannot fully resolve operational variability and information gaps. Relying solely on formal process descriptions has proven insufficient for effectively organizing work. Intentionally adopting socio-technical frameworks that recognize WAD, such as the FRAM approach utilized in this research or similar methodologies, enables shipyards to better identify and manage inherent complexity within their operational processes.

To address the identified reliance on tacit knowledge within shipyard operations, structured knowledge management techniques that recognize the socialization, externalization, combination, internalization (SECI) process, illustrated in Figure 5.1, are recommended. The SECI concept originates from research of Nonaka in the domain of innovation science [51]. The concept sets out four quadrants, each representing a mode of information processing. Being, (S)ocialization, (E)xternalization, (C)ombination, and (I)nternalization. These modes form a continuous spiral, facilitating the transformation between tacit and explicit knowledge. Socialization involves the sharing of tacit knowledge through shared experiences. Externalization converts tacit knowledge into explicit concepts. Combination systematizes explicit knowledge into more complex sets, and internalization turns explicit knowledge back into tacit knowledge through learning-by-doing. This model underscores the iterative and interrelated nature of organizational knowledge development.

Formalizing the capture and transfer of tacit knowledge through clearly defined processes can significantly improve information management and operational responsiveness. This approach mitigates the risks associated with informal knowledge exchanges and improves overall transparency and access to knowledge throughout the organization. Practically, this could involve creating continuously updated and project-specific best-practice documentation, actively involving specialists from all organizational layers to ensure effective extraction and dissection of critical knowledge beyond individual social networks. The discipline of knowledge management in general is complicated due to its ambiguity and large data demands; What knowledge do we want to capture exactly, and how? Potentially solution providers, like Floorganise, can support the development of effective (software) tools to support shipyard knowledge management.

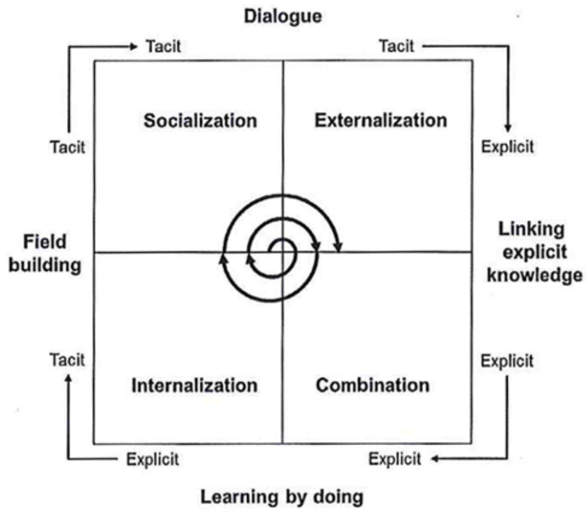

Figure 5.1: The SECI process derived from the research of Nonaka [51]

To apply the SECI process to practice, it can be integrated in a mechanism based on the plan-do-check-act (PDCA) cycle. This mechanism is based on the improvement science literature that roots from the Deming wheel, and later the Model for improvement [52]. The iterative approach of the PDCA cycle fosters continuous learning and adaptation informed by operational realities, effectively externalizing tacit knowledge and embedding socio-technical principles into daily practices. Such a mechanism promotes sustainable alignment between top-down control mechanisms and bottom-up operational requirements. A general outline of this approach in the context of this research is provided in Figure 5.2.

Figure 5.2 proposes a potential control mechanism for shipbuilding project environments. This framework distinguishes between top-down control and bottom-up operations, analogous to the clashing mechanisms illustrated in Figure 2.6 and discussed in section 2.3. To ensure effective control, the framework emphasizes the need for reliable input from operational departments. This input must be made explicit to ensure that all parties understand the information on which decisions are based. The decision-making process is supported by various forms of analysis and its results should be translated into clear outputs oriented to operations. These outputs serve as input for operational departments to execute their tasks. In return, operational departments provide feedback based on their activities and requirements, which then informs subsequent top-down decision-making. The mechanism resembles a PDCA structure in that the output from operations functions as a check on the effectiveness of prior decision-making. Based on this feedback, further action can be taken by conducting more detailed analyses and updating the decision-making process accordingly. These updated decisions are then planned and communicated to the operational departments, which subsequently carry out operations based on the revised plan.

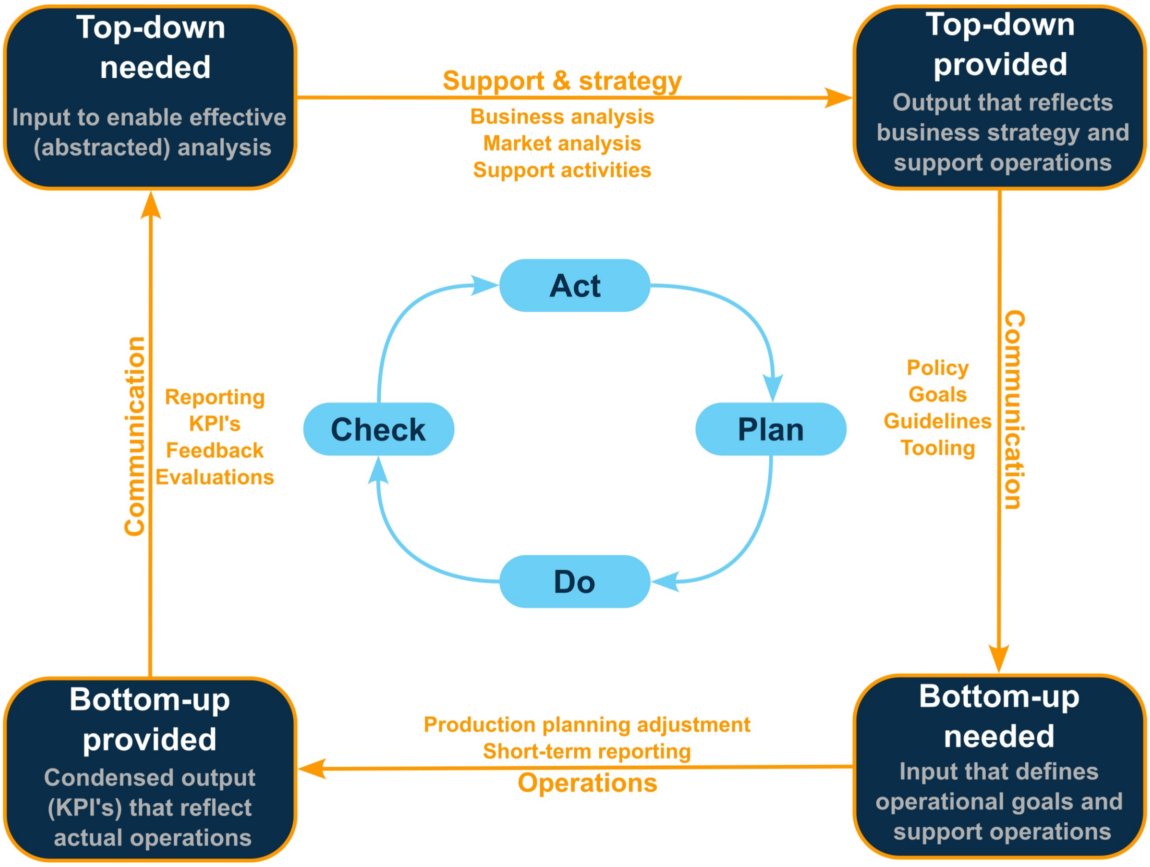

Figure 5.2: PDCA-based mechanism proposal to bridge the gap

Considering the complexity inherent to shipyard operations, solutions specifically aligned to distinct domains of the production process are essential. Each domain, such as hull construction, outfitting, or system integration, has unique data requirements and varying demands for information granularity and complexity. Thus, solutions should be customized accordingly to ensure that they precisely match the real-world operational needs. Adopting dynamic planning methodologies such as the Last planner system, derived from lean theory and also proposed in Emblemsvag's research [32], would improve operational responsiveness and facilitate prompt identification of disruptions. This is particularly applicable to section-building activities (like the case study) characterized by job-shop processes.

Shipyards should proactively develop adaptive capabilities within their workforce. Training and educational programs should explicitly integrate socio-technical concepts, ensuring that workers and managers comprehend both technical and social aspects of operational improvements. This comprehensive understanding facilitates smoother implementation of innovations and better integration of changes into operational culture. Despite high technical expertise among personnel in the current craft-based environment, socio-technical considerations remain largely unfamiliar to operational workers.

Hale, in a subsequent paper expanding on his initial models [42], proposes a mechanism to align Model 1 and Model 2. Given the analogy between the findings of this thesis and Hale's models, applying Hale's proposed framework, illustrated in Figure 5.3, could provide a structured context for testing and implementing solutions in a controlled and manageable manner. This framework identifies nine explicit steps for effective rule management, taking into account both intended and actual work processes. The mechanism focuses specifically on effective implementation of rules/processes. The mechanism emphasises verifying that actual practices align with the goals the rules are meant to achieve, rather than merely confirming compliance with the rules themselves.

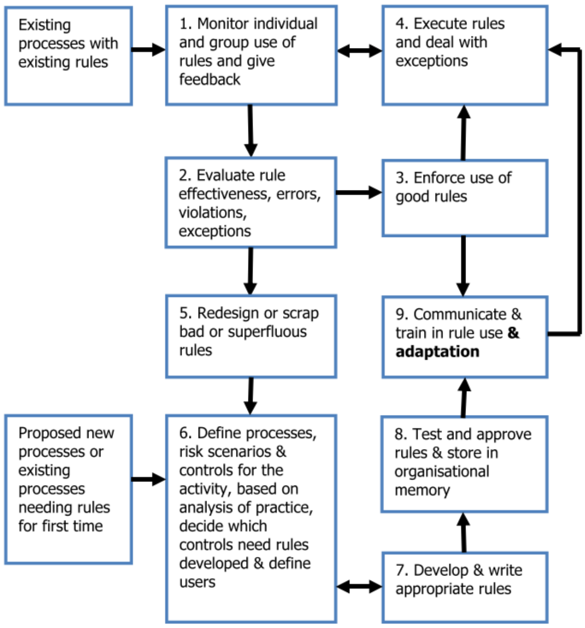

Figure 5.3: Framework of rule management proposed by Hale [42]

Besides the need for recognition of socio-technical aspects within shipbuilding, shipyards must remain cautious about excessively detailing or overfitting solutions and project practices, to which the linear process approach is exemplary. Instead, operational risks should be mitigated using strategies such as front-end loading, recognizing that effective implementation requires significant interdepartmental iterative collaboration. Data-driven collaboration platforms can support this objective, breaking down information silos and fostering cohesive efforts. Operational departments should receive sufficient budgeting for early proactive preparations. This approach aligns with the reality of extensive dependencies and numerous feedback loops evident in WAD. Corresponding tooling and practices must be designed to support this complex iterative interaction, as purely sequential handovers alone do not sufficiently accommodate such complexity, although they may be beneficially combined with iterative approaches for progress tracking. This research found that current processes and tooling do not sufficiently support in this, therefore there is a need for the development of new tooling that recognizes the complex environment of shipbuilding.

Collectively, these recommendations underscore the necessity of integrating directive control with operational flexibility through structured socio-technical methods. Their successful implementation requires deliberate organizational transparency, clearly defined roles, continuous feedback systems, and appropriately tailored technological solutions, ultimately bridging the identified gaps between formal processes and actual operational practices within shipyards. These recommendations provide an example of how socio-technical insights can support effective implementation of techno-centric solutions (RQ.3), by aligning technology with human workflows, creating a shared understanding across hierarchical levels, and enabling adaptive responses to dynamics on the production floor. Additionally, examples are provided detailing how a socio-technical understanding of the work system can be supported in the effective organization of work (RQ.4). Such as the introduction of the PDCA mechanism applied to the context of shipbuilding, or by proving the analogy to Hale's rule management framework, which originates from the socio-technical domain.

5.3. Recommendations to Floorganise

Floorganise operates as a software provider that specializes in MES and planning solutions for shipyard production management. The research confirmed that it is essential for Floorganise to avoid overly constraining the shop floor operations through introduction of rigid processes in IT tooling. Currently, their software aligns well with this principle, supporting the existing company culture that emphasizes flexibility and go-get mentality. An effective strategy employed by Floorganise to bridge top-down control mechanisms with bottom-up operational processes includes leveraging the Last Planner System in combination with earned value management (EVM). This integrated approach has already proven successful in practice, while it is only scarcely recognized in shipbuilding literature [10].

Additionally, a deep understanding of local shipyard circumstances enhances the software's capability to provide solutions that better fit specific client requirements. Shipyards exhibit varying operational profiles and adopt diverse market strategies, necessitating distinct KPI's. Consequently, Floorganise tooling should accommodate multiple types of information aggregation and customization. Although operational data such as budgets, labor hours, and progress metrics generally remain consistent across different shipyards, the methods of interpreting and applying these metrics can vary significantly, underscoring the importance of flexible, scalable and adaptable software solutions. This is especially true as Floorganise's client shipyards becomes increasingly diverse due to their worldwide expansion efforts.

In practical application, an analogy can be drawn between the abstraction hierarchy and the level of detail in operational planning, highlighting the importance of clearly defining the cut-off point for detailed input based on each shipyard's specific identity. A great example in this regard is the deep rooted integration of ERP systems, drawing on data points with high level of detail, while actual operations (WAD) are not reflected back in these detailed data points. This approach was proven to be ineffective through the misalignment of WAI and WAD. Therefore, the recommendation is made to first set up a proper reflection of WAD with all its inherent dynamics, before mapping this into predefined structures. This way, tooling is better able to support actual operations and there is the additional transparency about what is lost in the aggregation of data. This consideration and insight is particularly relevant to Floorganise, as their goal is to support operations through software solutions. Meaning that a focal point of their offered software should be to represent the WAD, such that it can be used for operational management and support, aligning with the core purpose of MES systems.

Literature consistently emphasizes that software without proper implementation is ineffective, reinforcing the necessity for close collaboration between shipyards and Floorganise. Findings from FRAM indicate discrepancies between intended and actual work systems, underscoring the challenge of controlling operations and realizing innovation that is faced by shipyards. Additionally, shipyards suffer from lack of experience with implementation strategies. Consequently, Floorganise is well-positioned to actively guide shipyards through the implementation process, utilizing their software, complementary tools, and proven practices to establish effective operational processes that fill the gap between WAI and WAD. In turn, it is expected that this approach will result in long-term customer lock-in and ensures customer satisfaction in both the short and long term.

Floorganise can be in the lead regarding combining technical solutions with socio-technical considerations. Given their current focus on customer intimacy and excellence, they are perfectly fit to adopt this new identity of advising shipyards in this regard. Already, although implicitly, they have helped shipyards in mapping their processes and optimizing for them, using consultancy knowledge and implementing solutions through their IT products. Expanding consultancy services will not only support sales of the current IT product, it will also broaden the perspective on future solution opportunities, each guided by a clear customer narrative. Consequently, developing new solutions must rely on more than theoretically sound but inapplicable abstract shipbuilding literature. The development requires practical and directly applicable insights.

Specifically, Floorganise can facilitate the effective implementation and further advancement of sophisticated operational planning methods. Research efforts such as those by Emblemsvåg [10] can be leveraged; The lean planning method that is introduced can used as a benchmark to the current practices of Floorganise. Additionally, it is essential for Floorganise to critically review current practices in customer collaboration to identify implementation blind spots. Evaluating that WAD is sufficiently integrated into solution offerings should be a priority, alongside investigating existing organizational limitations within shipyards. Identifying these areas for improvement will allow Floorganise to customize their solutions more accurately and provide targeted advisory services, thereby enhancing shipyards' overall capability to fully leverage Floorganise products.

To support in these activities, it is advised to employ explicit mechanisms like the proposed PDCA-based mechanism in Figure 5.2, or a derivation of the Hale's framework in Figure 5.3. This way Floorganise can develop a proven method to holistically improve shipbuilding operations of their customers through a combination of software solutions and optimized practical work practices.

6 Discussion

This thesis studied operational challenges in shipbuilding by applying FRAM, in combination with abstraction hierarchy, to explore the misalignment between WAI and WAD. The analysis prerequisite to the FRAM identified a consistent pattern of techno-centric solutions dominating current practices, often neglecting the socio-technical realities of shipyard operations. The FRAM findings revealed clear misalignment between formal planning and actual production operations, demonstrating the need to consider both social and technical dimensions in operational management, confirming the earlier analysis.

The application of FRAM exposed systemic gaps that do not stem from the absence of technological tools, but from insufficient integration of these tools within existing organizational contexts. This indicates that many of the inefficiencies in shipbuilding arise due to a lack of alignment between intended procedures and real-world practices. The socio-technical perspective provided a nuanced understanding of how informal workarounds, tacit knowledge, and organizational dynamics shape production behavior. Especially the relevance of socio-technical literature, like Hale [41], was key to understanding the shipbuilding environment. These findings support the claim that technological success in complex industries relies on the ability to adapt innovations to local work systems and practices. something that is only briefly touched upon in shipbuilding literature, like in the research of Garcia-Agis [25] and Emblemsvåg [32].

The findings have several important implications. First, they demonstrate the necessity of socio-technical integration in both academic research and industrial practice. While technological innovation remains critical, its effectiveness is conditional upon worker engagement, organizational culture, and social structures. These factors all are typically underrepresented in current shipbuilding strategies. This study also introduces possible methods that recognize and include these factors in the work system design.

The study underscores the need for closer integration between traditionally separated domains. specifically, between efficiency driven methodologies like Lean, and safety-oriented disciplines such as health, safety, environment, and quality (HSEQ). Merging these perspectives through a socio-technical approach can enable organizations to reconcile performance and resilience objectives, which are often viewed as competing priorities. Within science, an analogous integration of domains is required. Namely between shipbuilding research (arguably even general ETO manufacturing research) and socio-technical research.

Additionally, the research highlights the practical value of methods such as FRAM for exposing operational complexity. Compared to common process mapping and analysis tools, like VSM or BPM, FRAM provided additional insight by supporting the mapping and comparison of both WAD and WAI. Beyond safety applications, socio-technical tools in general can be applied to support tooling decisions, guide process improvements, and align high-level planning with shop-floor realities. This approach enables a more comprehensive understanding of operational variability, supporting holistic strategies that are both technically robust and practically feasible. The proposed method for combining FRAM with abstraction hierarchy to perform systematic work system analysis also pushes the development of FRAM in general.

Together, these research findings answered the research questions of section 2.4. Providing a significant contribution in closing the research gap visualized in Figure 2.8, in the same chapter.

While the study offers valuable insights, several limitations should be acknowledged. The FRAM analysis was based on a specific operational scope within the shipbuilding process, which may limit the ability to generalize the findings across other production phases or industrial (ETO) sectors, which each deal with their own unique characteristics. Moreover, reliance on qualitative data and direct observations introduces a degree of subjectivity that could affect the interpretation of results. This is the result of practical challenges related to the extensive time and effort required to gather and model WAD data. The absence of formalized procedures for socio-technical analysis within industry environments further complicates replication and transferability. Finally, as the research was conducted by a single investigator, researcher bias cannot be fully excluded, despite efforts to verify findings with scientific and industry stakeholder input.

Building on these insights, future research should pursue several directions. First, there is a clear need to formalize WAD data collection methods, improve scientific reproducibility, and reduce reliance on individual interpretation. This could be achieved through structured knowledge management, automated data capture, or simplified modeling techniques. Secondly, longitudinal studies that observe the implementation of technological solutions over time, particularly in relation to socio-technical alignment, would provide valuable insights into the conditions for successful innovation. These studies could also help generalize findings across different shipbuilding phases or comparable high-complexity domains. Thirdly, further development and adaptation of socio-technical frameworks like FRAM for non-safety contexts is recommended. This includes expanding their use in tooling design, and organizational development.

7 Conclusion

This study demonstrates that a socio-technical analysis can effectively uncover and mitigate disconnects between WAI and WAD in shipbuilding. By examining the hull production phase of shipbuilding, including preceding work preparation, the research exposed systemic misalignments in intended working processes and actual execution, and illuminated their impact on operational performance. The central ambition was to bridge the top-down intentions of managerial control with the bottom-up realities of day-to-day work. Ultimately providing an answer to the question: ”How can a socio-technical approach to shipbuilding be used to align the work system for improved operational effectiveness and productivity?” (RQ.1)

A novel method was developed to map and compare the different work system perspectives. This method iterates on the existing socio-technical theory on FRAM, combined with abstraction hierarchy. This method allows for a systematic approach that enables a multi-perspective analysis. The developed method supports systemic, socio-technical, and case-specific analyses by enabling consistent multi-level comparisons within the work system. This systematic comparison framework not only answers RQ.2, but also contributes a transferable modeling approach for analyzing complex socio-technical production systems.

Having established a method for systematic analysis, its application revealed several insights into the actual dynamics of shipyard work environments. The case study research exposed a significant blind spot of operational functions in formal documentation. In particular, critical planning and control actions, such as progress reporting, drawing validations, and material coordination, are poorly documented, despite their central role in daily operations. As a result, formal information systems do not adequately support workers, increasing reliance on manual expediting and informal coordination practices, represented by extra connections in the WAD models. These informal mechanisms, although effective in the short term, suffer from a lack of tooling support and formal recognition. These findings illustrate how the lack of formal recognition for operational practices weakens system transparency and limits operational control, gaps that the proposed socio-technical method was able to surface systematically.

Additionally, the approach provided additional insight on the inherent dynamic characteristic of ETO shipbuilding. The socio-technical framing helped reposition operational variability not as a human failure, but as a natural and systemic outcome of ETO work environments, in line with socio-technical research [44]. This inherent variability holds advantages as well, adding to work system flexibility and resilience.

These insights carry implications for organizational design and control in shipbuilding. Traditional control-oriented models struggle to capture the fluidity and interdependence of modern shipyard operations. Socio-technical methods, like the one applied in this thesis, provide a more nuanced perspective to assess system performance and resilience. Moreover, the findings underscore the enduring value of informal practices and tacit knowledge within highly structured and rule-bound environments. Together, these insights support the effective implementation of techno-centric solutions within a ship production environment (RQ.3).

The recommendations illustrate how socio-technical considerations can be sustainably embedded in the effective organization of work (RQ.4). For instance, PDCA-based approaches, or more elaborate frameworks such as the rule management method proposed by Hale [42], can provide structured support for aligning formal processes with operational realities.

A conclusive answer to the main research question can be formulated. FRAM, when combined with abstraction hierarchy, effectively exposes misalignment between multiple work system perspectives, and supports effective analysis of the work system. The insights gained by this analysis includes social and organizational considerations, extending beyond the techno-centric scope of commonly applied technical solutions. To support the sustainable integration of such analysis in the organization of work, PDCA-derived, or the work organization model as proposed by Hale [42] can be employed.

Future research should extend the methodology to other stages of the shipbuilding process and specific shipyard case-studies to test the applicability of the proposed work organization mechanisms. Additionally, the data collection methods should be formalized to sustain scientific reproducibility, as this was a challenge in this research project. To effectively advance this aspect, closer collaboration is needed between the scientific domains of shipbuilding and socio-technical systems. To the industry, continued WAD analysis is essential to maintain feedback mechanisms and close the loop between management and operations. Ultimately, sustainable operational improvement in shipbuilding depends not just on better tools or tighter controls, but on fostering socio-technical alignment that respects the complexity of real work. This presents a timely opportunity for shipbuilding solution providers, such as Floorganise, to support their clients in effectively innovating their shipbuilding work environments.

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A

Formal processes - input to WAI

This appendix contains the formal process descriptions that were used as input to the the case-study. These formal process descriptions closely resemble processes as they are available at a combination of major Western-European shipyards. The process within the scope of research has a hierarchial structure, where one process block in Figure A.1 actually represents a more detailed process as detailed in Figure A.2 to Figure A.6.

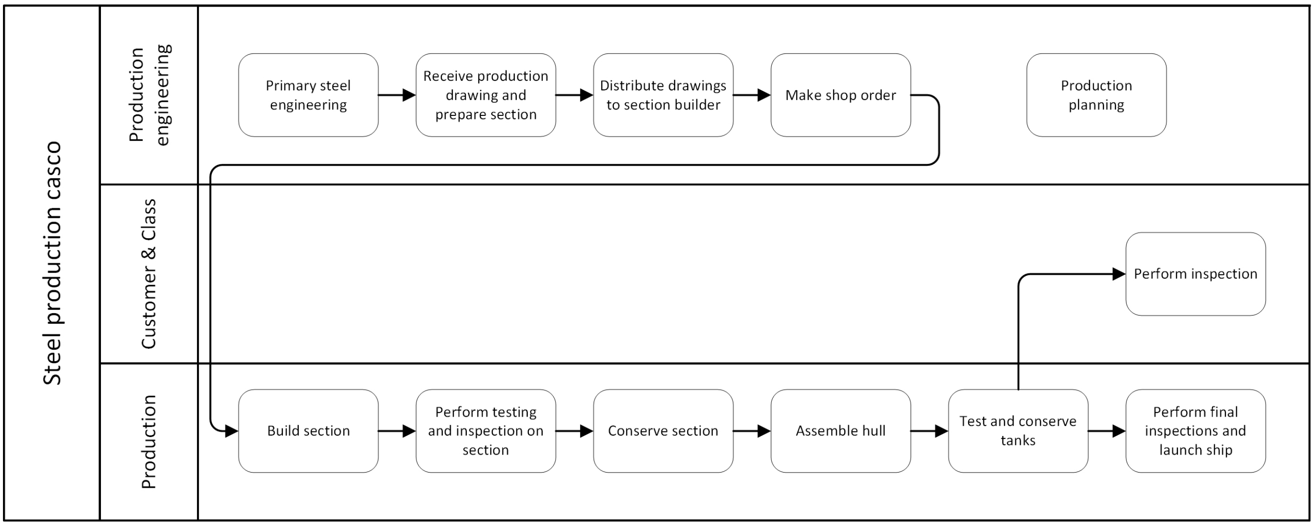

Figure A.1: Hull production - complete flow

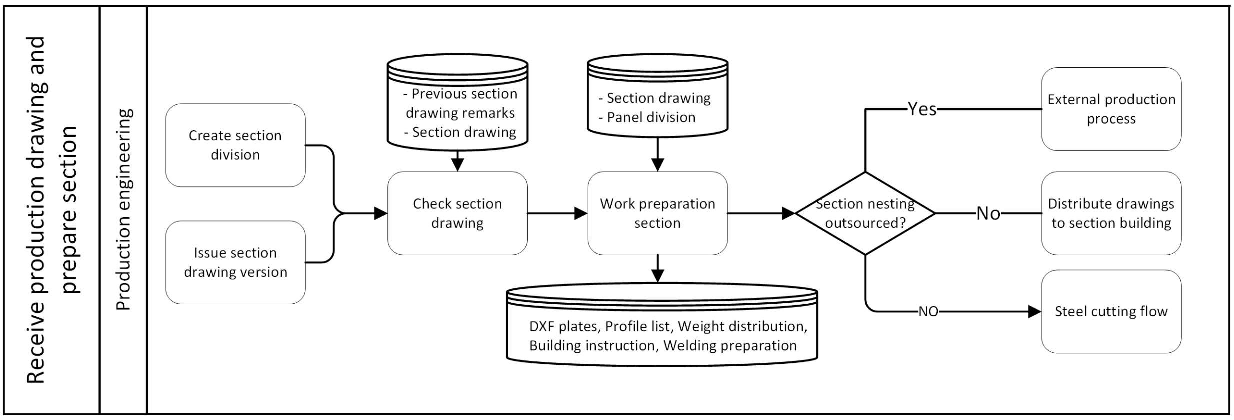

Figure A.2: Hull production - Receive production drawing and prepare section

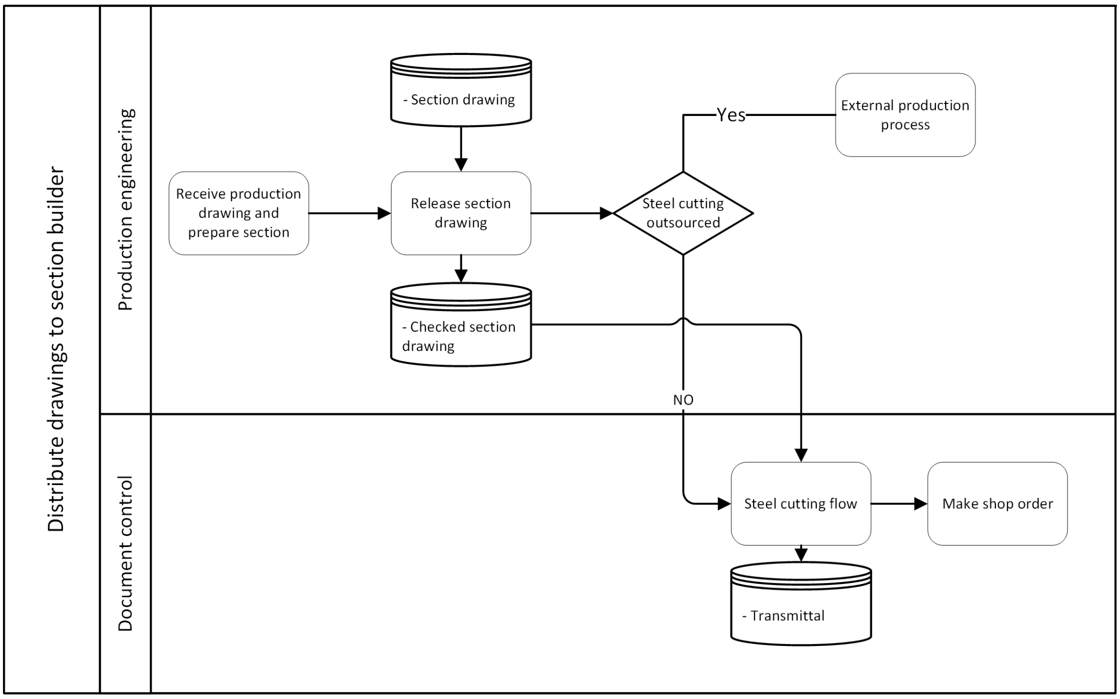

Figure A.3: Hull production - Distribute drawings to section builder

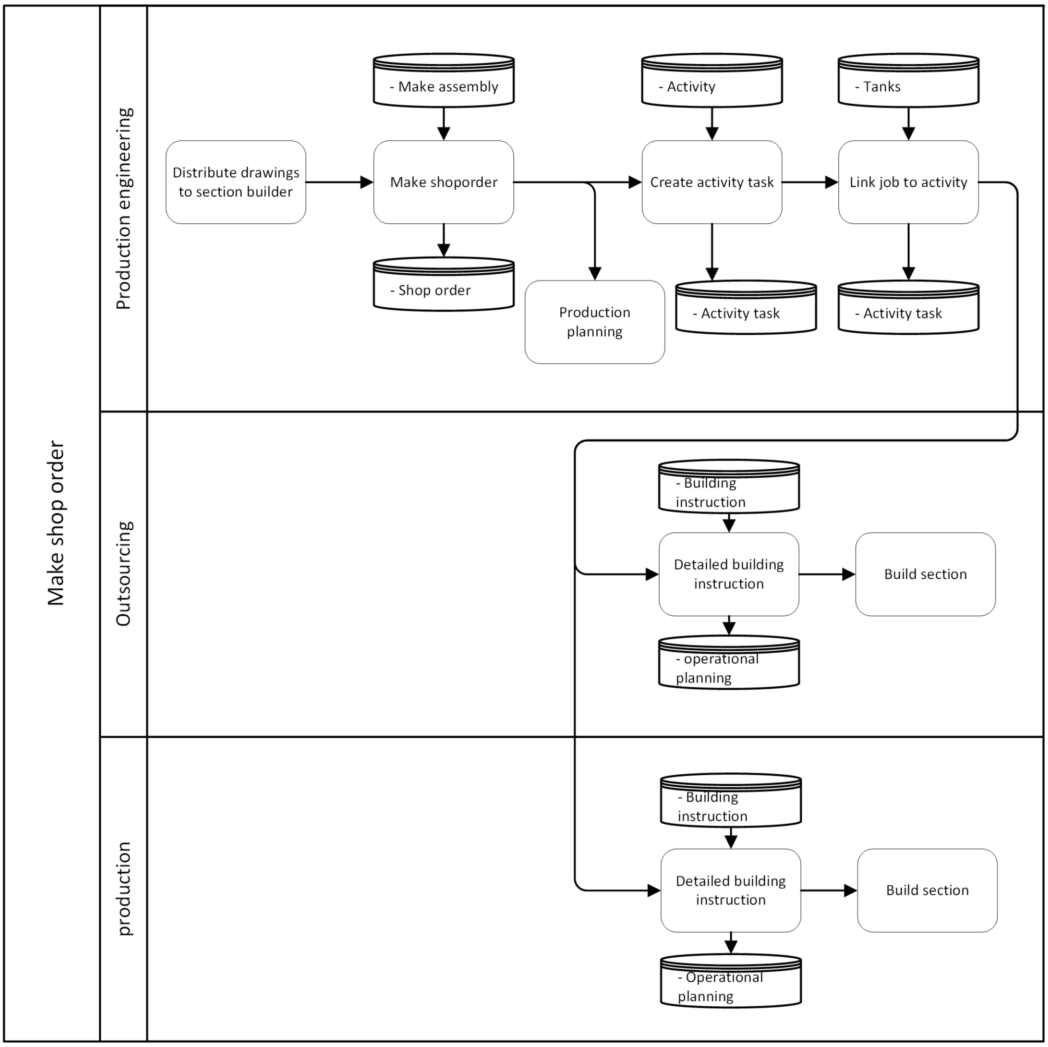

Figure A.4: Hull production - Make shop order

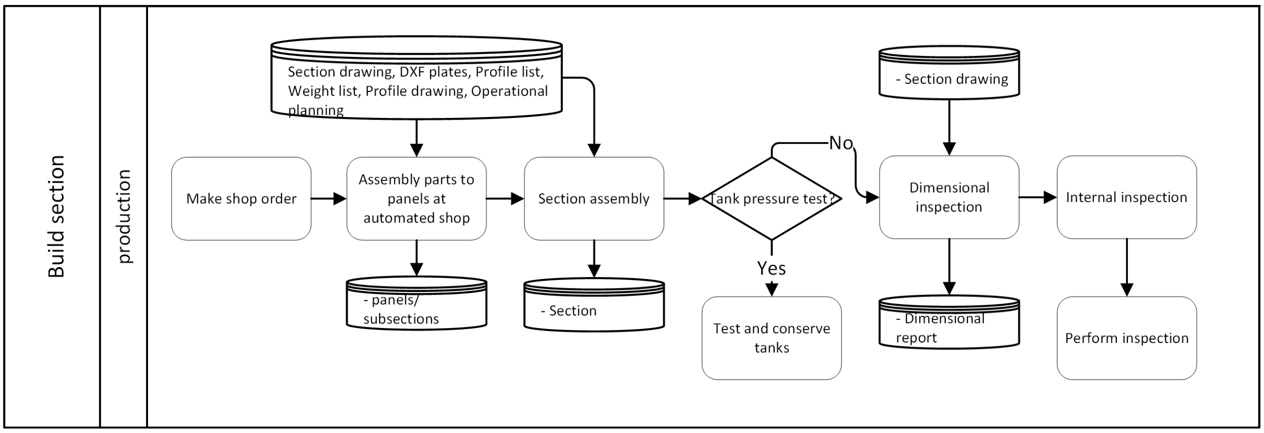

Figure A.5: Hull production - Build section

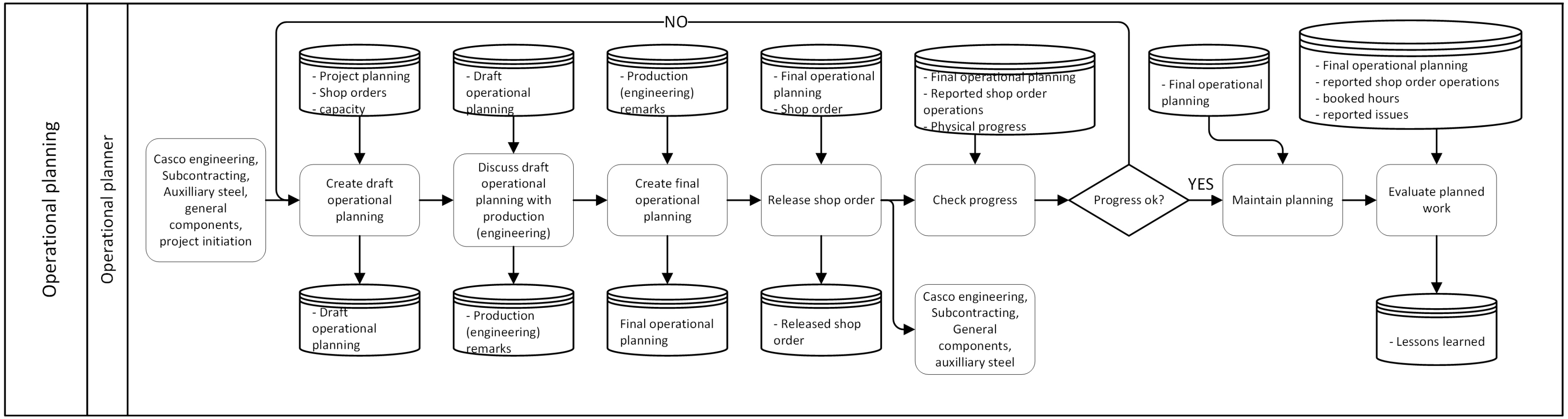

Figure A.6: Project management - Operational planning

B

Resulting FRAM models

In this appendix, the intermediate products following from the FRAM analysis and abstraction hierarchy method are presented. These intermediate models were used to construct the final FRAM models presented in the main report.

B.1. WAI

Identified WAI functions

- To issue V2 section drawing
- To create Vx drawing
- To build section
- To perform work preparation section
- To distribute drawings to section builder
- To maintain level 4 production planning
- To make shop order
- To receive updated level 3 planning
- To reserve steel
- To receive section materials
- Further process

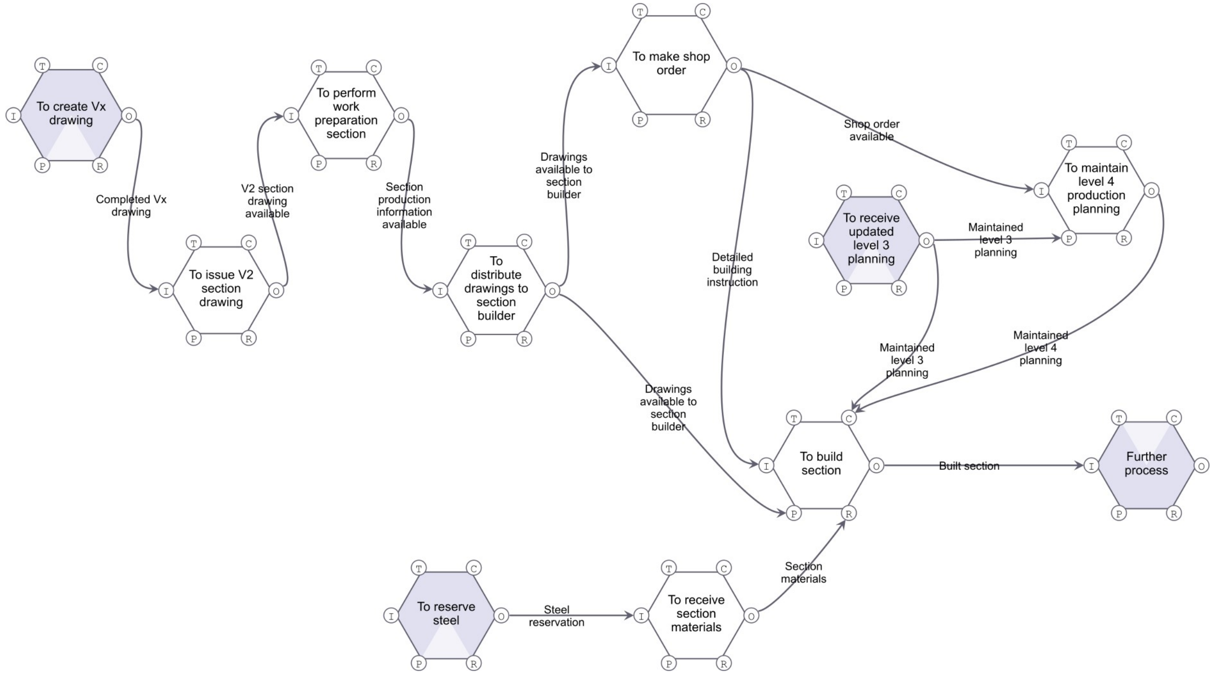

Figure B.1: WAI FRAM model without work abstraction hierarchy applied

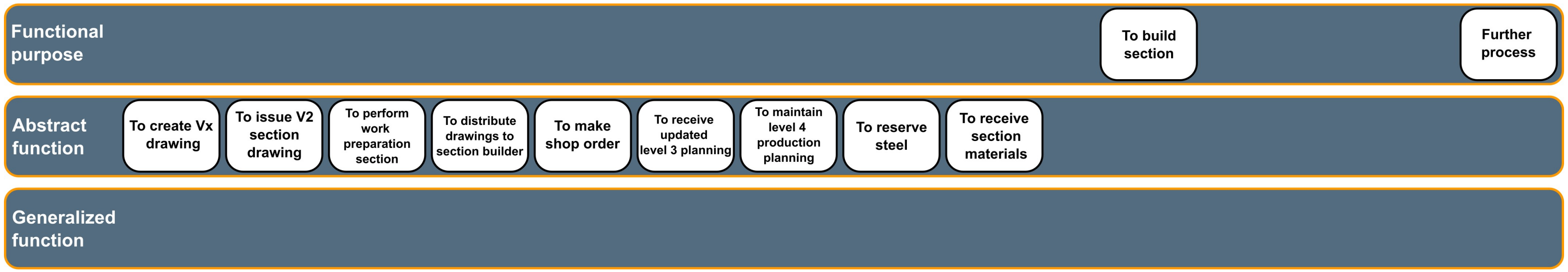

Figure B.2: Identified WAI functions categorized in work abstraction hierarchy levels

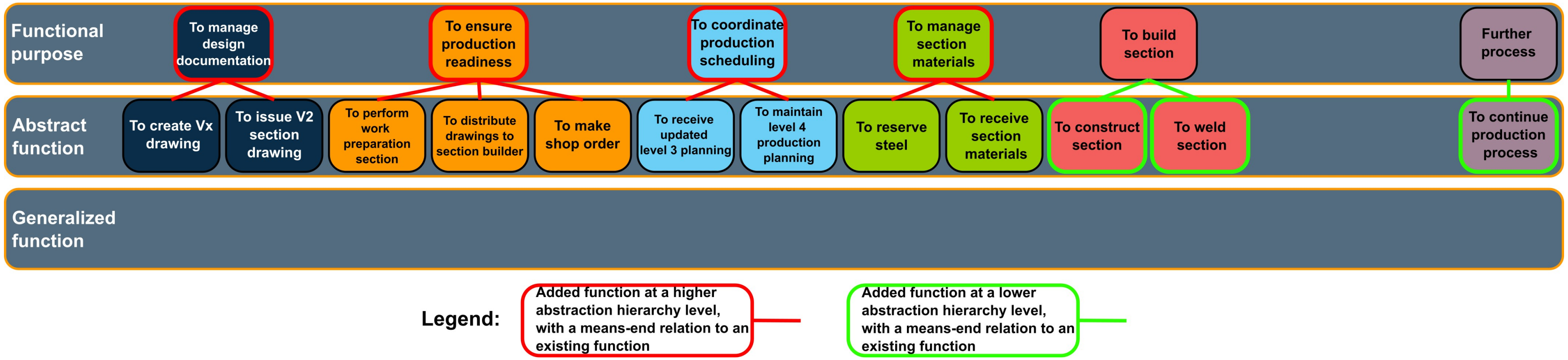

Figure B.3: Categorized WAI functions complemented with functions to ensure complete representation at functional purpose and abstract function level

B.2. WAD

Identified WAD functions

- To define shop order
- To activate shop order
- To define build order
- To prepare building instructions
- To check section drawing
- To distribute drawings to section builder
- To create Vx drawing
- To issue V2 section drawing
- To construct section
- To weld section
- To expedite operations
- Tocheck physical progress
- To receive updated level 3 planning
- To check available resources
- To make initial level 4 planning
- To allocate resources
- To plan activities
- To release shop order
- To register progress
- To finish shop order
- To reserve steel
- To expedite material deliveries
- To receive materials
- To register material deliveries in ERP
- To manage stored materials
- To continue production process

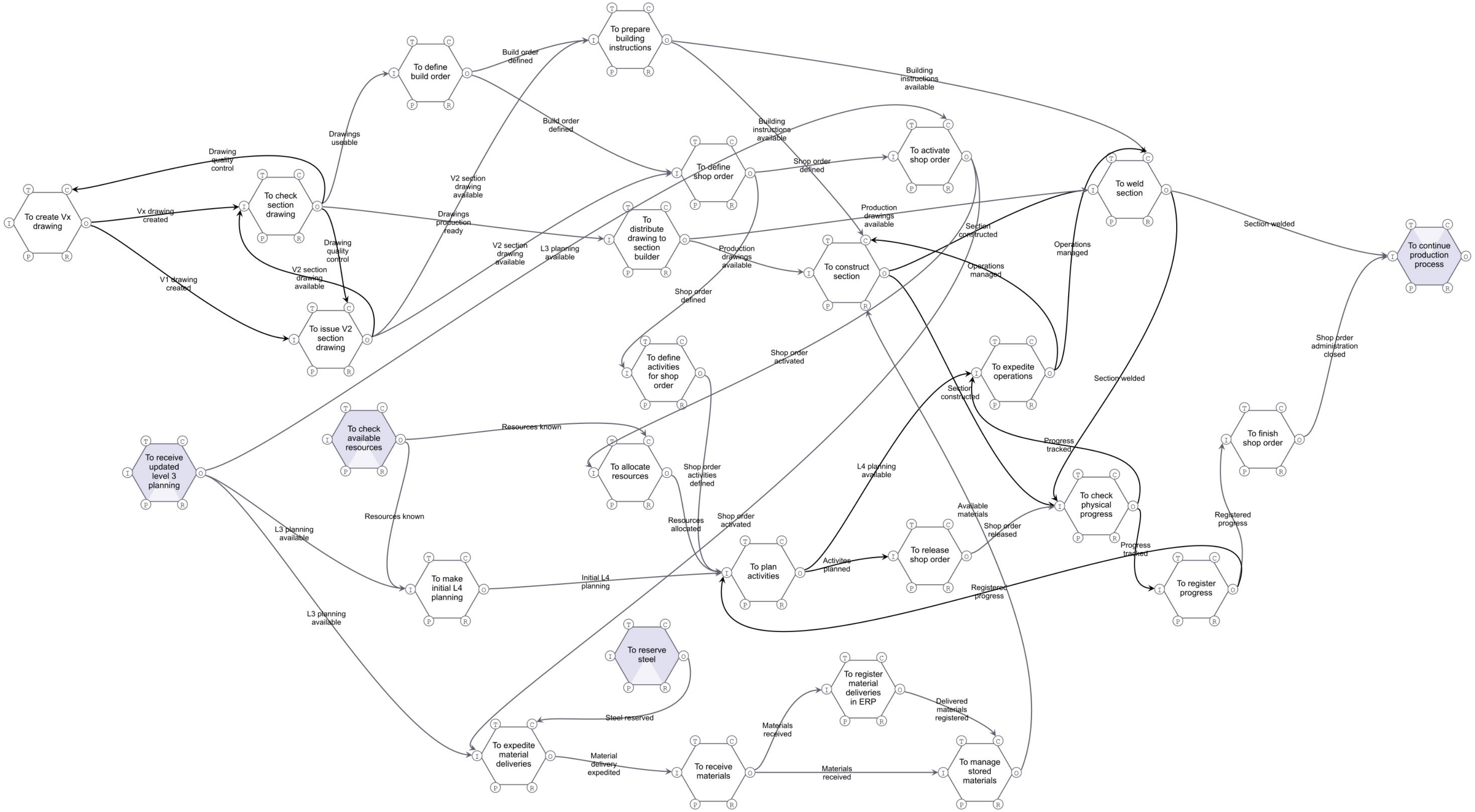

Figure B.4: WAD FRAM representation without work abstraction hierarchy applied

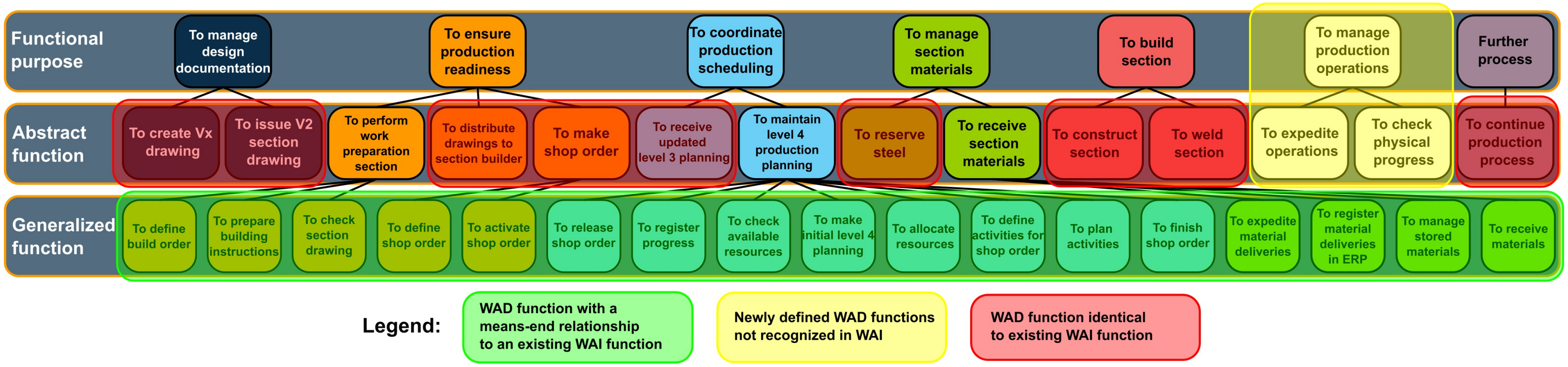

Figure B.5: WAD functions categorized in work abstraction hierarchy framework of WAI