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Next Generation Maritime Workforce Planning: Smart scheduling for remote-controlled ships

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Abstract. The evolving landscape of maritime autonomous surface ships (MASS) is marked by prolonged transitions through various autonomy stages, which necessitate changes in crew composition and qualifications. As crew costs represent a significant portion of operational expenses, quantifying the impact of varying autonomy levels on crew sizes and future qualification requirements is becoming increasingly critical for both system providers and ship operators. This paper introduces a framework designed to evaluate crew demand and scheduling onboard and in fleet operation centers (FOC´s) based on operational concepts such as partially or fully remote-controlled vessels. While few existing studies address this topic, they typically focus on specific aspects of ship operations, such as mooring and watchkeeping, often overlooking the overall workload. In contrast, this paper adopts a holistic approach to represent onboard workload and assess crew demand comprehensively. The framework has been applied to current cargo and cruise liners, providing robust decision-making support in manning strategies. Utilizing mathematical modeling and tailored algorithms, it calculates optimal crew demand and schedules specific to individual ships, voyages, and operations. A task-based methodology incorporates in a holistic manner workload, crew qualifications, and voyage-specific factors, while sorting algorithms generate schedules that comply with complex regulations regarding rest hours and organizational maintenance protocols. The algorithms are tailored to take advantage of the problem structure and scale fast. Companies like Carnival Maritime GmbH have leveraged this tool to optimize crew configurations in response to dynamic operational challenges, such as reduced passenger capacity during the COVID-19 pandemic and the reassignment of ships to new routes. This work demonstrates how the framework can be adapted to offer informed decision support in the MASS sector, particularly for remote-controlled vessels. It outlines how existing information systems can delineate tasks and requisite skills for remote operations, facilitating clear identification of responsibilities transitioning to shore, tasks becoming obsolete, or those undergoing transformation. Furthermore, the paper discusses the integrated holistic planning of ship and shore crews, offering substantial decision-making support for automated vessel providers and FOC operators. Finally, it explores the potential of this model to assess the economic impact of varying levels of automation.

1. Introduction

The journey towards maritime autonomous surface ships (MASS) is marked by prolonged transitions through various autonomy stages [1], necessitating changes in crew composition and qualifications. Manning issues have so far mostly been considered in the context of cost savings, as crew represents a significant portion of operational expenses; enhanced safety due to human-error minimization [2]; [3]; and the opportunity to alleviate the shortage of seafarers and address the imbalance between seafarer demand and supply. Most works and studies on this topic focus heavily on the strategic-economic and human-centered aspects of crew reduction on board. The ability to quantify the impact of varying autonomy levels on crew sizes, future qualification requirements, and general setup, as well as the detailed scheduling of shore personnel, is becoming increasingly critical for both system providers and ship operators as the operationalization of higher autonomy levels moves forward.

A holistic framework is needed to calculate crew demand and scheduling, addressing the manning challenges of transitioning to remote-controlled vessels and further on to fully autonomous vessels. While few studies focus on specific ship operations like mooring and watchkeeping, this paper adopts a comprehensive approach through the SCEDAS Framework, which has been applied to cargo and cruise liners, offering robust decision-making support for manning strategies. Utilizing mathematical modelling and tailored algorithms [4], it calculates optimal crew demand and schedules for individual ships and voyages. A task-based methodology incorporates workload, crew qualifications, and voyage-specific factors, while sorting algorithms generate compliant schedules with rest hour regulations. Companies like Carnival Maritime GmbH have used this tool to optimize crew configurations in response to dynamic challenges, such as reduced passenger capacity during the COVID-19 pandemic and the reassignment of ships to new routes.

The adopted SCEDAS Framework is supposed to deliver well-founded decision support by:

- breaking down the workload onboard into chunks called tasks and providing a modular information system to represent the dependencies between tasks and operational procedures as well as the qualification requirements of the crew;
- quantifying the effects of different levels of automatization based on tasks and adopted requirements on qualifications by:
    - identifying which tasks with which qualifications requirements need to be shifted on shore and which ones are obsolete
    - and representing /translating new operational concepts into tasks and defining their time and qualification requirements.
- calculating crew schedules on a detailed level for ship and shore by assigning tasks related to the specific voyage /operation of the ship and by considering rest hours regulations as well as further company specific procedures;
- assessing the overall crew demand (ship and shore e.g. for remote operation centres (ROC)) based on the detailed crew schedules;
- and enabling the fast calculation of various strategic and operational scenarios of interest.

Reliable scheduling of onshore personnel is crucial for secure ship operations. Rapid responses to dynamic changes are essential for both safety and commercial viability. Harsh working conditions at sea pose significant health risks to seafarers, who often work over 12 hours a day, seven days a week, leading to chronic fatigue and underreported overtime (Bhatia, 2024).

Furthermore, seafarers face long separations from family, limited communication, and lack of privacy onboard. External factors like severe weather and piracy exacerbate these risks. The compromised well-being of seafarers increases the likelihood of maritime accidents, as human factors contribute to most marine incidents [5]. Transitioning to remote operation centers can enhance working conditions by providing a safer environment. However, remote-controlled ships still require 24/7 operation, and a clear path to "no crew onboard" remains uncertain. Effective scheduling of shore personnel, integrated with onboard crews and tailored to operational demands, will be essential for high-quality service.
The framework presented in this paper addresses this important aspect and can be utilized for onshore crew scheduling by considering its strong dependence on the operational concept, fleet structure, setup, and specific company needs and strategies. When planned accurately and customized, remote ship operations can create a win-win situation for both shipping companies and seafarers. This framework can facilitate a smooth transition in this complex field and provide decision support for evaluating the economic and operational impacts of varying levels of automation and operations.

The paper is organized as follows: chapter 2 give an overview of current related approaches to this topic from research and ongoing work from the industry as far as known. Chapter 3 provides a detailed description of the framework and its applications. Chapter 4 describes how this framework can be adopted to provide well-founded decision support for remote controlled operations and beyond. Chapter 5 concludes with the main findings from this wok and provides the reader with an outlook for next possible steps.

2. Related works

This section outlines key developments in the literature on crew-related topics for Maritime Autonomous Surface Ships (MASS). It is important to note that this literature review is not exhaustive; rather, it focuses on selected studies that are particularly relevant to the authors' research. Unlike many existing studies that concentrate on skills development for automation, our approach differentiates itself by emphasizing the translation of these skills into specific tasks for shore personnel and providing tools to calculate scheduling for remote controlled centers (ROCs). This focus is crucial for ensuring safe and effective remote operations, addressing a gap that is often overlooked in the current body of research.

2.1 Current research

Most research on crew-related topics for Maritime Autonomous Surface Ships (MASS) emphasizes skills development for future automation. Recent studies, like [6], identify essential skills needed for the maritime workforce in autonomous shipping. These studies highlight the necessity of a comprehensive skills framework covering technical, digital, operational, higher-order thinking, and interpersonal skills. However, there is less focus on translating these needs into specific tasks for qualified shore personnel to ensure safe remote operations. Few studies, such as [7], examine this, focusing mainly on aspects like mooring and watchkeeping while often neglecting overall workload.

Kooij's study investigates the impact of automation on crew size and composition for a 750 TEU container vessel, using a heuristic to find cost-effective crew compositions for two automation scenarios: navigation and mooring. This approach is closely tied to specific case studies and

requires manual adjustments for other scenarios. In contrast, the SCEDAS Framework offers a holistic, flexible method to assess onboard workload and crew demand comprehensively.
A task-based approach for representing the workload onboard, as utilized in SCEDAS, was previously introduced by [8]. This approach serves as the foundation for the SCEDAS Framework, enabling the calculation of crew demand and scheduling while adhering to rest hour regulations mandated by the STCW Code [9]. One of the few studies employing a similar task-based method to analyze the transition from manned to unmanned ships in a structured manner is by Carmen Kooij and Robert Hekkenberg [10] Their research identifies various tasks performed on ships and proposes a systematic approach to automate these tasks, thereby establishing a logical sequence for reducing crew size. The tasks are categorized into groups such as navigation, maintenance, and mooring. The study presents a method for determining the most economically viable tasks to automate, focusing on the order of replacement to maximize crew reduction while ensuring safety and operational efficiency. In contrast to SCEDAS, which is based on over a decade of data collection through tools and expert interviews across various shipping companies, including container ships, tankers, and cruise liners, Kooij's study relies on a limited number of expert interviews. While Kooij proposes a structured implementation path specifically for unmanned ships, SCEDAS offers a flexible framework for decision support in crew scheduling and planning, underscoring the adaptability of task management in diverse operational contexts. Unlike SCEDAS, Kooij's study does not address the scheduling of shore personnel, which is crucial for the current and mid-term developments of remote-control-based approaches. Overall, this research provides a structured framework for advancing toward unmanned autonomous ships, highlighting the significance of task automation and strategic planning in crew reduction.

2.2 State-of-the-art in the industry

This section highlights selected developments from companies that have moved beyond the proof-of-concept stage and now offer remote vessel control as a service, although it does not claim to be exhaustive. The focus on remote-controlled ships is intentional, as they are already commercially utilized, unlike fully autonomous vessels. The study [11] indicates that Maritime Autonomous Surface Ships (MASS) can achieve significant cost savings compared to traditional vessels, primarily by reducing manning costs through remote operation centers (ROCs) as indicated in Figure 1 in [12]. The potential for economies of scale increases as more vessels are managed from a single ROC.

Some companies are testing and piloting autonomous vessels for specific tasks; however, widespread commercial deployment is still in its early stages. Additionally, remote-controlled ships can exhibit varying levels of autonomy, along with a blurred transition between these levels, which is important for addressing crew demand and scheduling challenges, ultimately providing valuable insights for autonomous vessels.
Ocean Infinity has become the first company to receive approval from DNV (Det Norske Veritas) for remote vessel operations [13]. This significant achievement enables Ocean Infinity to perform remote operations with its Armada vessels, improving operational efficiency and safety in marine environments. The approval marks a notable advancement in the adoption of remote technology within the maritime sector. The Armada vessels are 78-meter ships designed for partial remote operation and will be staffed by a crew of 16 while undertaking tasks that would typically require a crew of 50 [14].

Recent news [15] indicates that the German shipping company HGK Shipping has received approval to conduct a six-month trial for the remote operation of a cargo ship along a major German canal, with the vessel being controlled from a remote center located 400 km away. The trial involves the ship "Niedersachsen 2" ("Lower Saxony 2"), which will be navigated remotely using radar, radio communications, and joystick controls from an office in Duisburg, western Germany. The remote control and navigation technology is provided by SEAFAR, a company that now offers this service commercially. One of Germany's largest logistics players, Rhenus, is planning to develop and implement its own remote navigation system for its fleet [16]. A primary motivation for this initiative is to address the impending shortage of seafarers and create more attractive job opportunities in the maritime industry. These developments are still in the so-called trail and fail phase as the business models are undergoing transformation and are subject to continuous review, drawing on past experiences with various systems and operational strategies. Automation, however, entails higher maintenance and servicing efforts. that needs a smart integration into the operational strategy. This intersection between technical feasibility, personnel optimization, and cost-effectiveness is precisely the "sweet spot" that must be addressed for the successful commercial implementation of ROC concepts.
Smaller companies, such as CargoKite [17], are also working to deliver innovative ships with high levels of autonomy. They have utilized the SCEDAS Framework to assess crew demand and refine their concepts for operational realization, analyzing the added value for future customers.

In summary, advancements in remote-controlled and autonomous vessel technologies are transforming the maritime industry, particularly concerning crew demand and qualifications. As companies like Ocean Infinity and HGK Shipping innovate, the need for skilled personnel to manage remote operations is increasingly critical. To address crew shortages while ensuring safety and efficiency, it is essential to develop effective concepts for remote ship operations, along with training programs for crew members. Additionally, there is a pressing need for tools to accurately schedule crews and assess demand in this new operational landscape. As the industry evolves, a well-trained workforce supported by advanced scheduling tools will be key to navigating the complexities of modern maritime operations and fostering a sustainable future in shipping and logistics.

3. The SCEDAS Framework and Applications

SCEDAS (Ship Crew Demand Assessment System) is a framework designed to evaluate and analyze crew demand for maritime operations. It aims to optimize the management of crew resources by assessing various factors that influence crew requirements, such as vessel type, operational tasks, and levels of automation. Its key features can be summarized as follows

1. Crew Demand Analysis: SCEDAS provides tools to quantify the number of crew members needed for specific operations, considering different levels of autonomy and operational complexity.

2. Operational Realization: The framework helps organizations understand how changes in vessel operations such as the introduction of remote or autonomous technologies—affect crew requirements.

3. Training and Qualification: SCEDAS emphasizes the importance of crew training and the necessary qualifications for operating advanced maritime technologies, ensuring that personnel are adequately prepared for their roles.

4. Decision Support: By integrating data and providing insights, SCEDAS assists maritime companies in making informed decisions about crew scheduling and resource allocation.

5. Adaptability: The system can be tailored to various vessel types and operational contexts, making it versatile for different maritime stakeholders.

Overall, SCEDAS plays a crucial role in optimizing crew management in the maritime industry, especially as remote and autonomous technologies become more prevalent. The framework has been applied to current cargo and cruise liners, providing robust decision-making support in manning strategies. Utilizing mathematical modeling and tailored algorithms like the ones presented in [18] and [19], it calculates optimal crew demand and schedules specific to individual ships, voyages, and operations. A task-based methodology incorporates in a holistic manner workload, crew qualifications, and voyage-specific factors, while sorting algorithms generate schedules that comply with complex regulations regarding rest hours and organizational maintenance protocols. The algorithms are tailored to take advantage of the problem structure and scale fast. Companies like Carnival Maritime GmbH have leveraged this tool to optimize crew configurations in response to dynamic operational challenges, such as reduced passenger capacity during the COVID-19 pandemic and the reassignment of ships to new routes. Cruise operations pose high demands in terms of automation heterogeneity, integrated maintenance planning (exceeding 3,500 scheduled tasks annually per vessel), and the synchronization of multiple onboard departments with up to 1,600 crew members. These characteristics offer a rigorous framework for evaluating and adapting ROC-related methodologies in complex maritime operations

4. The SCEDAS Framework for ROC

The SCEDAS Framework offers versatile applications for providing decision support in crew scheduling and planning within the field of autonomous shipping, particularly in the design, planning, and implementation of remote-control operation centres. Central to the information model are tasks that provide significant flexibility and facilitate the evaluation of relationships between workload, automation levels, and operational concepts. The tasks that have already been gathered and defined regarding qualification requirements (specifying which positions, including the necessary crew and their priorities, should perform each task) and time constraints lay a strong foundation for further detailing and categorization. The loosely coupled architecture enables the seamless transfer of tasks between ship and shore, allowing for the development of a unified crew schedule that encompasses both aspects. In collaboration with an industry partner transitioning toward the implementation of remote-controlled vessels, we have conducted initial calculations for a work schedule that integrates both shipboard and shore-based operations. The foundation for this approach is the consideration that, in the medium term, the combination of task complementarity (tasks that are not yet fully automatable but can be enhanced) and the deepening of automation presents the most promising strategy to enhance productivity in shipboard operations.

For a Remote Operation Center (ROC), the primary objective is to develop and enhance existing remote support services by transitioning the most economically viable tasks to a centralized shore-based facility overseeing an entire fleet. Fundamentally, the tasks that can be included in a ROC's service portfolio can be categorized according to the navigational or engine department responsibilities of a vessel.
While the workload associated with supporting a single vessel can be relatively straightforward to determine—regardless of the degree of partial, full, or non-automation—the situation becomes significantly more complex when a ROC supports multiple vessels. These vessels may operate at different levels of automation and be subject to varying contractual service level agreements. This complexity is illustrated in Figure 1, using a simplified example of two vessels in a fleet.

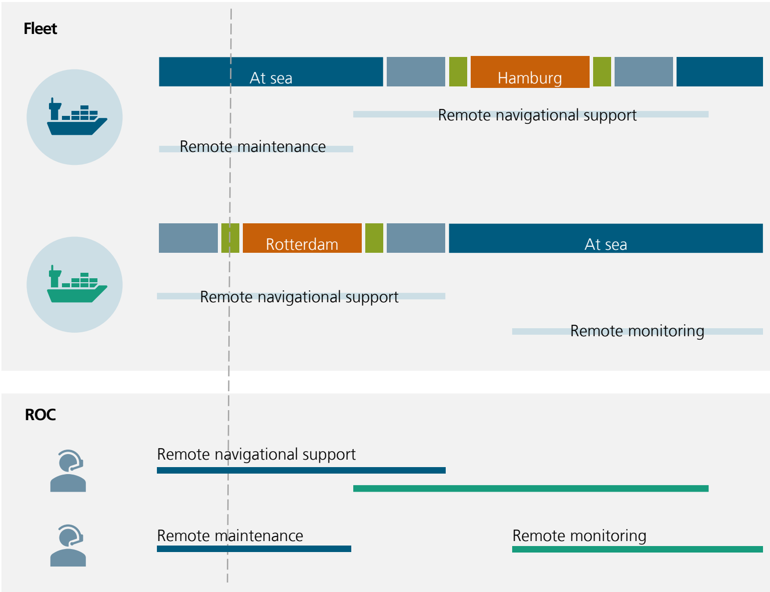

Figure 1: Distribution of task packages between the ROC and vessels at different stages of the voyage

At a given point in time, both vessels are at different stages of their voyage and are supported by the ROC in varying task packages. One vessel is in transit, while the other is navigating coastal waters during a pilot boarding operation prior to port entry. This example demonstrates the dynamic and time-sensitive distribution of workload, particularly for navigation-related tasks. The workload at the ROC would increase substantially if both vessels were to arrive at the next port simultaneously. Comparable assumptions can be applied to remote maintenance tasks, depending on the requirements imposed by the vessels' current routes.
For a deeper analysis, we examine the implications of transferring navigational responsibilities to the ROC for a specific shortsea container vessel. This vessel measures 100 meters in length and has a gross tonnage of 3,999 GT. It is operated by a crew of 11 seafarers, including four deck officers, four deck ratings, two engine officers, and one cook.

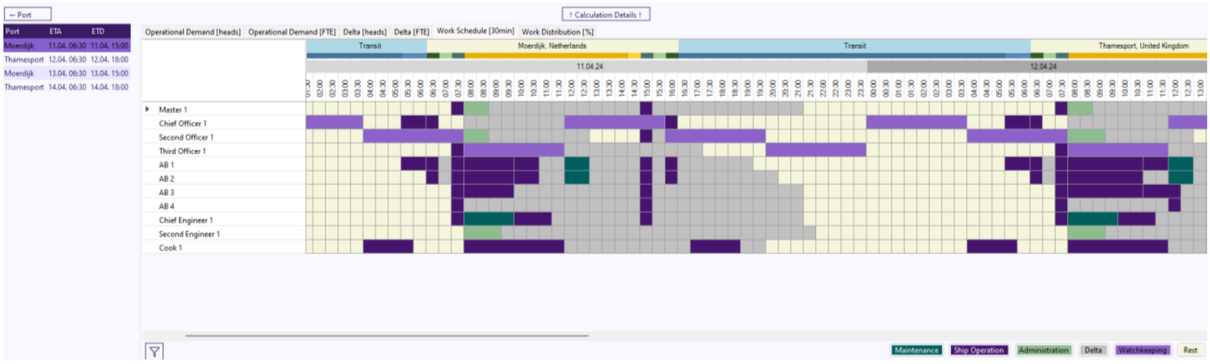

Figure 2: Work schedule on a half-hourly basis for all ship-operation-essential tasks for a container vessel in short-sea shipping

Figure 2 illustrates the crew schedule for the ship during its standard voyage when the crew is onboard. This schedule encompasses essential tasks for safe ship operation, including watchkeeping, berthing, and mooring, as well as maintenance activities, while also adhering to the work and rest hour regulations mandated by STCW [9]. Figure 3 presents the resulting workload distribution for each crew member during a typical voyage. The calculations have been conducted by using the latest release of the SCEDAS Framework on a common computer with following resources 11th Gen Intel(R) Core(TM) i7-11850H @ 2.50GHz , 16GB RAM and Windows as operating system. The programme took less than 10 seconds to achieve the presented results.

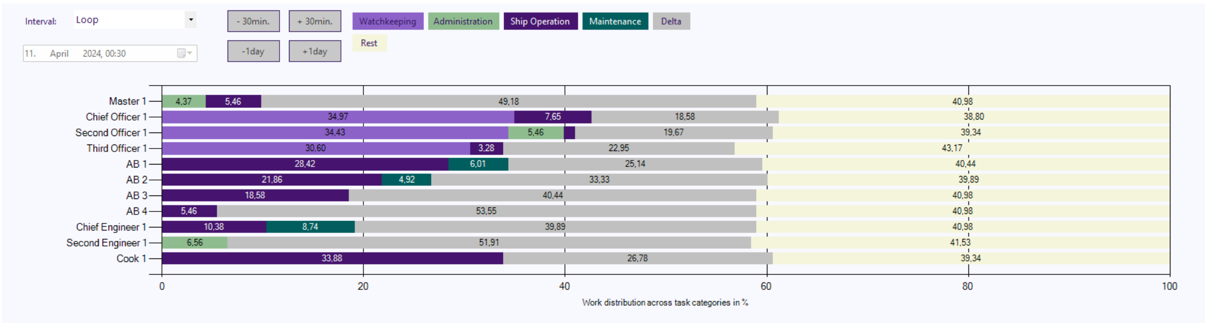

Figure 3: Resulting onboard workload per position, clustered by task categories

If navigational tasks are fully assumed by the ROC, the required personnel shifts to a configuration comprising three ROC officers, two onboard deck officers, two engine officers, four deck ratings, and one cook—resulting in a total of 12 personnel.

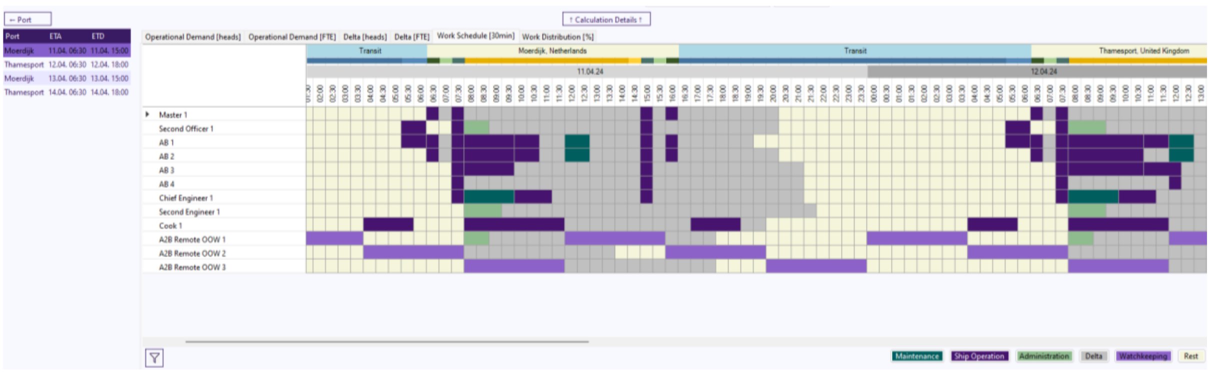

Figure 4: Work schedule on a half-hourly basis for all ship-operation-essential tasks, with watchkeeping duties transferred to a Remote Operation Center (ROC)

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Figure 4 presents the overall schedule. The shift system for watchkeeping and the rest hours are kept the same. The associated workload distribution for this scenario is depicted in Figure 5.

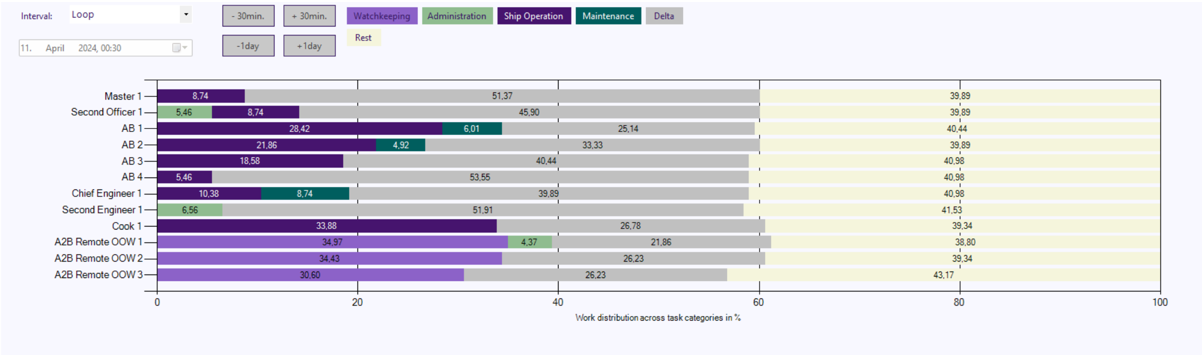

Figure 5: Resulting workload in the ROC and onboard the vessel per position, clustered by task categories

Focusing further on the implications for the onboard deck officers, we note that two officers—the Master and the Second Officer—remain part of the crew of nine essential seafarers, even though all navigational watchkeeping duties have been transferred to the ROC. Nevertheless, responsibilities in the domain of ship operation—such as oversight of pilot boarding procedures or maneuvering supervision—still need to be conducted by the Master and Second Officer in parallel, based on current technological and regulatory frameworks. While their workload is significantly reduced, these roles cannot yet be fully substituted. It is certainly debatable whether further delegation of deck officer responsibilities—particularly under advanced automation concepts such as watch-free bridges—could be technically feasible. However, from a regulatory and insurance standpoint, it is unlikely that the role of the Master can be removed from onboard operations in the medium term.

This implies that the transition to ROC-supported operations of one vessel does not necessarily reduce the number of onboard personnel and instead results in one additional individual being involved overall. A further consideration in the evaluation of remote operation efficiency lies in the inherent availability of onboard crew members. Seafarers are continuously present on the vessel and can flexibly respond to ad hoc or short-notice tasks as they arise – a factor that, in economic terms, often represents "anyway-costs", as their availability does not incur additional labor planning or financial expenditure. In contrast, ROC personnel must be scheduled in advance within shore-based shift systems, making them less flexible and potentially more cost-intensive for short-notice interventions. This difference in structural availability must be considered when comparing operational efficiency and crew planning between ship-based and shore-based task execution.

Closely linked to the question of which tasks remain onboard—and thus the required number of deck officers—is the economic evaluation of the capital and operational costs associated with the remote monitoring and control systems. These costs must be weighed against the personnel-related savings. Moreover, the additional onboard efforts for supervising and maintaining the control systems must be considered, alongside any potential ROC-side expenditures for system monitoring and maintenance to ensure operational safety. Additionally, the ROC personnel might require more advanced/adapted skills than traditional onboard seafarers leading to cost increase that can be estimated by the gap between the high and low positions as estimated in [20]. These factors—while not yet fully accounted for—must be integrated into the overall task and workload analysis.As outlined schematically in Figure 1 and examined in more detail in both onboard and shore-based task analyses, the highest sensitivity in ROC-integrated operations emerges in situations where multiple tasks must be performed simultaneously by several individuals. A ROC will only realize its full potential if it succeeds in minimizing personnel effort during such peak load periods. In other words, it is necessary to define a minimum safe manning standard for a ROC based on a clearly defined service portfolio and scope of responsibility, supported by a task-based analysis and scheduling framework.

5. Conclusion and Outlook

The main driver for adopting deeper levels of automation and remote services remains cost efficiency for shipowners and operators. However, these changes must be carefully balanced with regulatory requirements and operational safety.

The analysis presented demonstrates that the integration of ROCs and the advancement of shipboard automation significantly impact crew size, crew consistency, and operational costs. The application of a Decision Support System (DSS) like SCEDAS in crew planning has already proven to be an effective tool in addressing the challenges of the past decade in ship management. Particularly in manning strategies, the DSS has supported the definition of optimal crew size and consistency under conflicting objectives of economic pressure from charterers and the legal constraints imposed by flag states, port state regulations, and international standards for working and rest hours.

By employing a task-based methodology, it is possible to evaluate and quantify the effects of increased levels of automation both onboard and ashore. This includes:

- Automation: Tasks that can be fully automated or remotely supported using AI-driven tools (e.g., administrative routines).
- Task Complementarity: Tasks that are not yet fully automatable but can be enhanced through remote assistance (e.g., bridge watch support).
- Enhanced Automation: Further productivity gains in areas already partially automated (e.g., unmanned machinery space).
- Emergent Tasks: New roles and responsibilities arising as a direct consequence of automation and remote integration.

In the medium term, a hybrid approach combining task complementarity with deeper automation appears to be the most effective strategy for increasing productivity in ship operations. As automation advances, it becomes essential to analyze the correlation between changes in crew size and composition and the associated cost implications.

Future research should aim to establish a correlation matrix linking crew configuration adjustments with operational costs and regulatory compliance. This will also facilitate the identification of future skill requirements for both onboard and shore-based personnel operating in increasingly automated environments.

Furthermore, it is recommended that scheduling algorithms be implemented to support the identification and optimal distribution of workloads when managing multiple vessels within a ROC. Such algorithms can assist in balancing parallel task demands, accounting for different automation levels, service agreements, and voyage stages across a fleet. Their integration is a prerequisite for achieving efficient workload planning and sustainable personnel deployment at the ROC.

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Ultimately, the insights gained from such analyses should inform the development of a revised and task-oriented service portfolio for ROCs. This portfolio would define not only the range of responsibilities a ROC can effectively assume but also serve as the foundation for establishing a minimum safe manning standard for remote operations—optimized for workload distribution, technical feasibility, and economic viability.

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