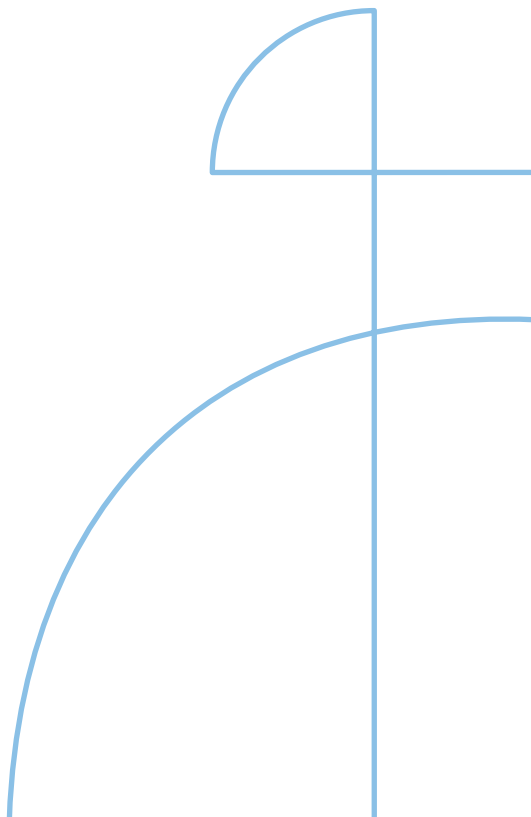


Doctoral Thesis in Vehicle and Maritime Engineering

A systematic approach to seakeeping evaluation

MARION ZU

KTH ROYAL INSTITUTE OF TECHNOLOGY



A systematic approach to seakeeping evaluation

MARION ZU

Academic Dissertation which, with due permission of the KTH Royal Institute of Technology, is submitted for public defence for the Degree of Doctor of Philosophy on Friday the 18th of September 2026, at 14:00 in D3, Lindstedtvägen 5, Stockholm.

Doctoral Thesis in Vehicle and Maritime Engineering
KTH Royal Institute of Technology
Stockholm, Sweden 2026

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TRITA-SCI-FOU 2026:24
ISBN 978-91-8106-685-2

Printed by: Universitetsservice US-AB, Sweden 2026

To Abba

Abstract

Marine vessels operate as moving work environments, and vessel motions can affect the safe and effective performance of onboard tasks. By influencing crew balance, perception, control, and the handling of materials and equipment, vessel motions can compromise safety and operational performance. Such limitations should be addressed early in vessel design and procurement through seakeeping evaluation. However, conventional seakeeping evaluation practices often rely on generic motion criteria that do not adequately capture the relationship between vessel motions, onboard task demands, and crew performance.

The aim of this thesis is to develop a systematic approach to seakeeping evaluation that aligns seakeeping performance with functional requirements, onboard tasks, and end-user needs. The research combines literature reviews, semi-structured interviews, focus group discussions, onboard observations, and numerical simulations. It identifies key limitations in conventional seakeeping evaluation practices and develops a systems-oriented, vessel-specific, and task-based framework for seakeeping evaluation. The framework is demonstrated through two case studies of the Swedish Coast Guard vessel KBV 202 and the Swedish Maritime Administration fairway maintenance vessel Fyrbjörn, showing that task-based evaluation yields substantially different operability assessments from conventional generic approaches. A task-informed motion-induced interruption estimator is also developed, enabling the prediction of interruption rates without prescribed stance geometry or orientation.

The findings show that seakeeping evaluation should extend beyond routine generic procedures towards vessel-specific and task-based approaches that better support the safe and effective performance of onboard work. The proposed framework provides a structured and defensible basis for translating functional requirements and end-user needs into relevant seakeeping evaluation criteria.

Keywords
seakeeping evaluation, seakeeping criteria, crew performance, motion-critical tasks

Sammanfattning

Fartyg är rörliga arbetsmiljöer och fartygsrörelser kan påverka ett säkert och effektivt utförande av arbetsuppgifter ombord. Genom att påverka besättningens balans, perception, kontroll samt hantering av material och utrustning kan fartygsrörelser försämra säkerheten och den operativa förmågan. Sådana begränsningar bör beaktas tidigt i fartygsdesign och upphandling genom utvärdering av sjöegenskaper. Konventionella metoder för utvärdering av sjöegenskaper baseras dock ofta på generiska rörelsekriterier som inte i tillräcklig utsträckning fångar sambandet mellan fartygsrörelser, arbetskrav ombord och besättningens prestation.

Syftet med denna avhandling är att utveckla en systematisk ansats för utvärdering av sjöegenskaper som kopplar fartygs sjöegenskaper till funktionskrav, arbetsuppgifter ombord och slutanvändarnas behov. Genom att kombinera litteraturöversikter, intervjuer, fältobservationer och numeriska simuleringar identifierar studien centrala begränsningar i konventionell praxis för utvärdering av sjöegenskaper och utvecklar ett systemorienterat, fartygsspecifikt och uppgiftsbaserat ramverk för sådan utvärdering. Ansatsen demonstreras genom två fallstudier av Kustbevakningens fartyg KBV 202 och Sjöfartsverkets farledshållningsfartyg Fyrbjörn och visar att uppgiftsbaserad utvärdering ger väsentligt annorlunda operabilitetsbedömningar än konventionella generiska metoder. Därutöver utvecklas en uppgiftsinformerad estimator för rörelseorsakade avbrott som möjliggör prediktion av avbrottsfrekvens utan att förutsätta någon given kroppsgeometri eller hållning.

Resultaten visar att utvärdering av sjöegenskaper bör utvecklas mot fartygsspecifika och uppgiftsbaserade angreppssätt som bättre stödjer ett

säkert och effektivt utförande av arbete ombord. Den föreslagna ansatsen utgör en strukturerad och försvarbar grund för att översätta funktionskrav och slutanvändarbehov till relevanta kriterier för utvärdering av sjöegenskaper.

Nyckelord

Sjöegenskapsutvärdering, sjöegenskapskriterier, besättningens prestation, rörelsekritiska arbetsuppgifter

Acknowledgements

The journey of being a PhD student is, at its core, a process of learning how to do research. At the time of writing this, I can confidently say I have fully committed myself to that process. One of the key lessons I walk away with is that successful research is not sustained by intellect alone. It requires a particular set of skills, foremost among them is what I have come to call the "mastery of time".

By "mastery of time", I do not mean traditional time management. Rather, I refer to the ability to translate internal and external resources such as funding, mentorship, support from industry partners and colleagues, and opportunities for personal and professional development into productive and focused time. When properly engaged, these resources create space for research to progress within the often strict and limited timelines of research projects. In this sense, mastery of time is about making those resources work in one's favour, so that time becomes not just something one spends, but something one shapes.

I began this journey a little over six years ago, and although it now feels as though it passed in an instant, it is now drawing to a close. I have grown, excelled, and, most importantly, learned from my failures during this period. One thing this journey made clear to me is that I could not have completed it alone. I have had my supervisors, Karl Garme, Anders Rosén, and Magnus Boström, guide me through every stage of this process and shape my growth as an independent researcher. For their patience, support and steady guidance, I am deeply grateful.

I would also like to express my sincere gratitude to the industrial partners in this project from Maritime at RISE, especially Nicole Costa and Magnus Wikander, for their support, engagement, and collaboration.

I am also grateful to my predecessors, Pahansen de Alwis, Meng Zhang, and Harsha Cheemarkuthy, for their friendship, for teaching me how to make this journey bearable and sustainable, and for being exemplary pacesetters. I am equally grateful for the friendship and encouragement of Maria del Mar Vizcaino, Charitha Vaddamani and Aldo Téran Espinoza. Thank you for making this journey lighter. Later in this journey, Ogechukwu Nwafor and Hauwa Yunusa joined the Naval Architecture group; having other African women around and no longer feeling like I was carrying my experiences alone meant more than words can fully express. You have been like sisters to me. Thank you for bringing warmth, familiarity, and a sense of home, even when home was a continent away.

I am deeply grateful to my dear parents, my siblings and my inner circle of friends for their love, prayers, support, and constant encouragement throughout this journey. Their support carried particular meaning because so many of them live the very lives my research is about: my husband and most of my closest friends are seafarers, and my dear father was once a seafarer too. They kept me close to the real people and the working lives behind this research, and their belief in me carried me further than they know.

Especially to my husband, who saw the tears, the disappointments, and the times when I had almost given up, thank you for pushing me to show up day after day. Thank you for insisting that we celebrate even the small wins along the journey, and for reminding me, through your own daily experiences, why it mattered. *Melɔ̃ wò*

Marion Zu,

Stockholm, September 2026.

Declaration on the Use of Generative AI

ChatGPT, Claude and Grammarly's rewriting features were used as writing-support tools during the preparation of this thesis. They were used to organise and structure text, improve clarity and flow, support reviewing and editing, and suggest alternative formulations. They were not used as sources of factual information, research results, or conclusions. The research design, data collection, theoretical and contextual framing, analysis, interpretation, and conclusions are my own, and I take full responsibility for the content of this thesis.

List of Publications

This thesis consists of the following appended papers:

Paper A

Zu, M., Garme, K., & Rosén, A. (2024). Seakeeping criteria revisited. Ocean Engineering, 297. https://doi.org/10.1016/j.oceaneng.2024.116785

Paper B

Zu, M., Garme, K., Rosén, A., & Costa, N. (2022). Specifying seakeeping criteria for efficient task performance. 15th International Symposium on the Practical Design of Ships and Other Floating Structures, 894–909.

Paper C

Zu, M., Garme, K., Rosén, A., Boström, M., & Costa, N. (2026). Translating functional requirements into seakeeping evaluation metrics for marine vessel design. Proceedings of the Institution of Mechanical Engineers, Part M: Journal of Engineering for the Maritime Environment. https://doi.org/10.1177/14750902251412460

Paper D

de Alwis, P., Boström, M., Zu, M., & Garme, K. (2026). Characterisation and synthesis of motion-induced interruptions – A systematic literature review (Submitted for publication)

Paper E

Zu, M., Garme, K., & Rosén, A**.** (2026). A task-informed approach to predicting motion-induced interruptions for seakeeping evaluation (Submitted for publication)

Division of work between authors

Paper A.

Zu, M. and Garme, K. conceived the study. Zu, M. designed the literature search and analysis, conducted the review and wrote the manuscript. Garme, K. and Rosén, A. supervised the work and contributed through critical review and editing of the manuscript.

Paper B.

Zu, M. conceived and designed the study, performed the simulations and analysis and wrote the manuscript. Garme, K. and Rosén, A. contributed through supervision, scientific discussions, and critical review and editing of the manuscript. Costa, N. contributed through review and editing of the manuscript.

Paper C.

Zu, M. conceived and designed the study, developed the framework and task analysis procedure, conducted the interviews and observations and wrote the manuscript. Garme, K. supported the empirical work on KBV 202. Garme, K. and Rosén, A. contributed through scientific discussions and interpretation of the findings. Garme, K., Rosén, A., Boström, M. and Costa, N. contributed through critical review and editing of the manuscript.

Paper D.

de Alwis, P., Boström, M., and Garme, K. conceived and designed the study, carried out the systematic literature review, analysed the included articles and wrote the manuscript. Zu, M. contributed through critical review and editing of the manuscript.

Paper E.

Zu, M. conceived and designed the study, developed the estimator, and wrote the manuscript. Garme, K. and Rosén, A. contributed through scientific discussions, support in developing the estimator, and critical review and editing of the manuscript.

List of abbreviations

FSA	Formal Safety Assessment
GBS	Goal-based Standards
HTA	Hierarchical Task Analysis
HTO	Human Technology Organisation
IMO	International Maritime Organisation
ISO	International Organisation for Standardisation
MIF	Motion-induced Fatigue
MII	Motion-Induced Interruptions
MSI	Motion Sickness Incidence
RAO	Response Amplitude Operators
SSRS	Swedish Sea Rescue Society
TD	Task Decomposition

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1 Introduction

1.1 Background

Marine vessels operate not only as transportation platforms but also as moving work environments, where mission success depends on the crew executing tasks safely and effectively in actual sea conditions. Vessel motions resulting from wave excitation turn the deck into a dynamic workspace where the direction and magnitude of accelerations vary with time. In such motion-rich environments, motion exposure challenges balance control, spatial orientation, manual control and manual materials handling, perception, and attention, which are directly relevant to the safe execution of tasks (Duncan et al., 2012, 2018, 2020; Rumawas et al., 2016; Wertheim, 1998).

This focus on safe task execution is particularly important for vessels whose operational value is determined by their sustained capability in non-ideal sea conditions. On such vessels, the practical question is not whether motions will be present, but rather whether work can continue effectively and safely despite the motions. A vessel's motions, in response to wave excitation in the sea environment, influence multiple dimensions of its performance. These motions may compromise perceived comfort and habitability (Çakıcı et al., 2015; Riola & García de Arboleya, 2006; Rumawas et al., 2016; K. Sariöz & Narli, 2005; G. Wang et al., 2020), safety (Domnisoru, 2020; Jamal et al., 2020; Jiao & Huang, 2020; NATO, 2018), and survivability (Bonci et al., 2019; Cui et al., 2019). They can also degrade workability (Bruijn et al., 2019; Domingos et al., 2024; Feikens et al., 2011; Smith et al., 2022) and reduce operability (Ghaemi & Olszewski, 2017; Gutsch et al., 2020; Mauro & Nabergoj, 2020).

Vessel motions also impose loads on the hull (Faltinsen, 1993, 2006; Salvesen et al., 1970) and can cause cargo damage and losses (Acanfora et al., 2017; Dallinga et al., 2018; Öztürk, 2024). For the crew on board, exposure to these motions can reduce task efficiency and accuracy, increase physical demand and fatigue, and increase the likelihood of slips and falls or handling and control errors during the execution of tasks and other activities (Bridger & Pisula, 2012; Crossland et al., 2007; Duncan et al., 2020; Duncan, Hickey, et al., 2018; Duncan, MacKinnon, et al., 2018; Stevens & Parsons, 2002; G. Wang et al., 2020).

These effects propagate beyond the crew to system outcomes; for example, task interruptions and reduced human performance can translate into downtime, layovers, delayed operations, increased operational risks, and reduced mission effectiveness. A vessel's seakeeping, therefore, acts as a determinant of whether the vessel, as designed, is fit for purpose, underscoring the need to prioritise its analysis and evaluation in vessel design. This is particularly important for vessels with motion-critical operations, where seakeeping performance must support safe and effective task execution.

Determining whether a vessel's seakeeping is suitable for its intended purpose requires the following: information on the existing wave conditions in operational routes or areas, a tool to predict the vessel's responses to these environments as designed, and metrics for evaluating whether a vessel's seakeeping compromises its performance (Couser, 2000; Crossland & Johnson, 2001; Lewis, 1988; Lloyd, 1998).

1.2 Problem statement

Approaches for the analysis and evaluation of a vessel's seakeeping are extensively covered in the scientific literature and in industrial practice (Dhavalikar, 2011; Fonseca & Guedes Soares, 2002; Ghaemi & Olszewski, 2017; NATO, 2018; Olszewski & Ghaemi, 2018; E. Sariöz, 2012; K. Sariöz & Sariöz, 2006; Tello et al., 2011). Although the approaches and methods for analysing and evaluating seakeeping exist and continue to develop, challenges remain in their implementation; namely, complexities of wave modelling and realisations (Holthuijsen, 2007), the fidelity of motion prediction tools (Dhavalikar, 2011; el Moctar et al., 2021; Faltinsen, 1993; Salvesen et al., 1970), and the metrics for determining whether a vessel's seakeeping performance is acceptable (Zu et al., 2024). These factors introduce inaccuracies and

uncertainties, making seakeeping less of a priority in the design and reassignment of vessels to other services.

Despite these challenges, the goal of seakeeping assessment remains the same: to ensure the efficacy, safety, and comfort of a vessel in service. Seakeeping assessments are an integral part of the vessel or platform design process, justifying design choices against design specifications and functional requirements. For passengers, this means a comfortable passage; for the crew, motions manageable enough to work effectively and efficiently; and for owners, an operable vessel that delivers acceptable operational and economic performance. However, reports of suboptimal experiences regarding vessel motions, evident in crew accident statistics and occupant discomfort surveys, indicate that improvements are needed in the seakeeping design of vessels (Riola & García de Arboleya, 2006; Stevens & Parsons, 2002; G. Wang et al., 2020; J. Wang et al., 2005).

Ultimately, seakeeping assessments must address end-user satisfaction. Although it is the vessel's seakeeping that is being assessed, it is indirectly the end-users' needs that are being met and assured. However, current seakeeping evaluation methods, including established criteria and standards, tend to be biased towards hull performance and integrity, with less structured concern for occupants. Additionally, there is limited guidance for structuring a vessel-specific seakeeping evaluation, particularly in determining whether a vessel's seakeeping performance meets end-users' needs.

In summary, while tools exist to predict vessel motions, the field lacks a systematic, transparent way to map functional requirements and end-user needs to tailored evaluation metrics, such as task-based performance metrics. This gap limits the transparency, reproducibility, and decision value of seakeeping evaluations as a basis for functional and safe vessel designs when the objective is to support crew safety and mission effectiveness. There remains a need, therefore, for seakeeping evaluation to be tailored to a vessel's functional requirements, one that accounts for variability across vessel types and supports efficient, functional design of vessels and offshore platforms.

1.3 Research aim

This thesis aims to develop a systematic approach to seakeeping evaluation that aligns vessel seakeeping performance with functional requirements, onboard tasks, and end-user needs.

1.4 Research objectives

To achieve the overall aim, the thesis pursues the following objectives:

i. Clarify and critique current seakeeping evaluation practices and identify limitations
ii. Develop a systematic, vessel-specific approach for determining tailored seakeeping evaluation metrics
iii. Develop methods for identifying and quantifying these metrics

1.5 Research questions

This research advances the following research questions:

i. What limitations arise in current seakeeping evaluation practices?
ii. How can seakeeping evaluations be structured as a systematic, vessel-specific process that maps functional requirements and end-user needs to a communicable and defensible set of evaluation metrics (including task-performance indicators)?
iii. How can the identified evaluation metrics be predicted efficiently for a seakeeping evaluation?

1.6 Research contributions

This thesis makes the following contributions, each traceable to the research questions:

i. A clarified account of current seakeeping evaluation practice and its limitations for crew-centred vessel assessments.
ii. A structured, systems-oriented framing of seakeeping evaluation that integrates functional requirements, end-user needs and safety considerations.
iii. A unifying framework that maps functional requirements to tailored seakeeping evaluation metrics.
iv. A task-informed estimator for addressing motion effects on occupant activities in early-stage design.

Together, these contributions support vessel-specific seakeeping evaluation, enabling assessments not only of predicted vessel motions, but of the vessel's capacity to sustain safe and effective task execution under expected sea conditions.

1.7 Papers included in the thesis

Paper A: *Seakeeping criteria revisited* reviews and critiques seakeeping criteria and evaluation practices, with emphasis on evaluation purpose and limitations when considering end-user needs.

Paper B: *Specifying seakeeping criteria for efficient task performance* develops a basis for translating operational needs into performance-relevant criteria.

Paper C: *Translating functional requirements into seakeeping evaluation metrics for marine vessel design* formalises and demonstrates a tailored seakeeping evaluation approach through task-based metrics.

Paper D: *Characterisation and synthesis of motion-induced interruptions – A systematic literature review* structures the motion-induced interruption concept through definitions, indicators and quantification approaches.

Paper E: *A task-informed approach to predicting motion-induced interruptions for seakeeping evaluation* proposes a task-informed estimator for predicting motion-induced interruptions without prescribed stance geometry or orientation.

1.8 Thesis organisation

This thesis is organised into six chapters.

Chapter 1 introduces the motivation, problem formulation, aim, objectives, research questions, contributions, and the thesis structure.

Chapter 2 provides the frame of reference, including core concepts in seakeeping assessments, the vessel as a socio-technical system and related safety perspectives, motion effects on humans, and the positioning of these effects within task-based seakeeping evaluations.

Chapter 3 describes the research approach and methods used across the thesis.

Chapter 4 presents a thematic synthesis of the research work conducted and the key results across papers, consolidating the findings into coherent areas.

Chapter 5 discusses the implications for practice and critically addresses limitations and broader considerations, including sustainability and diversity.

Chapter 6 concludes the thesis by answering the research questions, summarising contributions, and outlining future research directions.

2 Frame of Reference

2.1 Seakeeping assessment

Seakeeping is commonly understood as the motion response behaviour of a vessel in waves and the consequences of that behaviour for its performance at sea (Comstock & Keane, 1980; Couser, 2000; Lloyd, 1998; Lloyd et al., 1991; Nordforsk, 1987). In this thesis, the term seakeeping assessment denotes the overarching process of understanding how a vessel responds in a specified sea environment and whether the response is acceptable for its service. Seakeeping assessment comprises two closely related concepts: seakeeping analysis and seakeeping evaluation. Seakeeping analysis concerns the prediction of wave-induced motions and related response quantities. Seakeeping evaluation concerns the judgement of the acceptability of those responses against specified criteria (Couser, 2000; Ghaemi & Olszewski, 2017; Nordforsk, 1987; K. Sariöz & Narli, 2005).

This thesis builds on established seakeeping analysis methods and focuses on how predicted motions are interpreted with respect to crew performance and safety. Seakeeping is thus addressed not only as a hydrodynamic phenomenon but also as a factor in operational performance.

2.1.1 Seakeeping analysis

Seakeeping analysis refers to the prediction or estimation of how a vessel will respond to a specified sea environment, characterised by waves and wind, for given operating conditions. Its purpose is to describe vessel behaviour quantitatively in terms of motion responses. Seakeeping analysis requires defining or estimating (i) the relevant sea states or environmental conditions in

the specified operational environment and (ii) the associated vessel responses (Couser, 2000; Lewis, 1988).

The sea environment is complex, irregular, and never repeats a pattern. Its detailed surface, therefore, cannot be predicted deterministically, and it is treated as a random process (Lewis, 1988; Lloyd, 1998). It is commonly represented statistically, through spectral and probabilistic models, and, under linear wave theory, as a superposition of regular component waves. Over short periods, a sea state may be treated as statistically stationary, allowing irregular waves to be described using idealised wave spectra and wave scatter diagrams (Bertram, 2012; Lewis, 1988). These representations provide the basis for predicting vessel responses.

A well-established range of methods exists for predicting vessel motions. The choice of method depends on the design stage, the required fidelity, and the purpose of the analysis. These methods include simplified linear approaches, such as strip theory; more detailed numerical methods, such as computational fluid dynamics; and experimental approaches, such as model testing (Dhavalikar, 2011; el Moctar et al., 2021). Regardless of the method used, the aim is to estimate the vessel's responses under defined sea conditions.

Seakeeping analysis alone does not determine whether the predicted response is acceptable, whether a motion level is tolerable, or whether it is safe to continue operations. That further step belongs in the domain of seakeeping evaluation.

2.1.2 Seakeeping evaluation

Whereas seakeeping analysis concerns prediction, seakeeping evaluation focuses on interpretation and decision-making. Seakeeping evaluations answer the question of whether the predicted motion responses permit a vessel to fulfil its intended purpose, support the required activities on board, or remain within acceptable safety and performance limits (Crossland & Johnson, 2001; Ghaemi & Olszewski, 2017; Lloyd et al., 1991; NATO, 2018; Nordforsk, 1987; K. Sariöz & Narli, 2005).

Predicted motion responses do not convey meaning on their own. A predicted roll angle, or vertical or lateral acceleration, becomes relevant only when interpreted against a reference, such as a design requirement, an operational objective, a human tolerance limit, or a regulatory requirement (Karppinen, 1987; E. Sariöz, 2012; K. Sariöz & Narli, 2005; K. Sariöz & Sariöz, 2006). Seakeeping evaluation, therefore, builds on the predicted motion responses

obtained from a seakeeping analysis and depends on two linked elements: the metric used to express the significance of a predicted response, and the threshold, or acceptance limit, against which the metric is judged. This thesis maintains an explicit distinction between these two elements. Seakeeping evaluation is thus a purposive process that links predicted motion responses, expressed through metrics, to operational meaning.

Seakeeping evaluation may be focused on different aspects of vessel performance, including operability, workability, habitability, survivability, and safety. Operability refers to the percentage of time a vessel's crew can fulfil the intended functions in the specified seaways, assessed over a yearly or seasonal period (Karppinen & Aitta, 1986; Nordforsk, 1987). Workability refers to whether specific tasks can be performed under the sea conditions prevailing at a given time, within defined operational windows (Domingos et al., 2024; Feikens et al., 2011). Although operability and workability are often used interchangeably in practice, this thesis maintains the distinction between them. Habitability concerns how tolerable the onboard environment is for the crew and is commonly associated with vibration, noise, motion sickness, and general physical discomfort from exposure to vessel motions (Grech et al., 2019). Survivability concerns the vessel's ability to withstand and recover from severe or extreme wave loads, including situations when the hull's integrity is compromised. Safety concerns whether the motions remain within acceptable levels for the safe execution of tasks, and this is discussed further in Section 2.3.

These aspects are not independent and may overlap. For example, a vessel may be operable, in that the crew can perform its intended functions, while the prevailing conditions still compromise safety. Given such overlaps, a seakeeping evaluation may need to consider several aspects together rather than in isolation. The relevant aspects shape how the evaluation is conducted: which motions are considered, which criteria are applied, and which acceptable limits are set. This thesis places particular emphasis on the safety and operability aspects of seakeeping evaluation.

2.2 The vessel as a socio-technical system

A vessel, as built, cannot carry out its operations or execute its missions on its own. While autonomous and remotely operated vessels are an emerging exception, most vessels rely on a crew whose work, supported by the onboard

technical systems, is essential to operations. This makes such a vessel, in practice, a socio-technical system (Grech et al., 2019). Seakeeping evaluation is therefore approached here not only from a hydrodynamic perspective but also by considering how these hydrodynamic effects influence the people on board and the installed technical systems. A vessel may, in principle, remain afloat, stable, and operable; however, its motion responses could impose conditions that degrade task performance, increase workload, and compromise safety margins for the crew (Matthews et al., 2007; Mccauley & Matsangas, 2005; Stevens & Parsons, 2002).

Treating the vessel as a socio-technical system means that seakeeping evaluation is not limited solely to the vessel's motion responses but also extends to the safe and effective execution of work on board. Wave-induced motions influence more than just the dynamic behaviour of a vessel's hull (Pattison & Sheridan, 2004). From the crew's perspective, these motions also influence balance control, perception, coordination, access to technical equipment, the manual handling of materials, the timing of operations, and how tasks are adapted (Domingos et al., 2024; Duncan et al., 2013; Duncan, Hickey, et al., 2018; Grech et al., 2019). What matters, therefore, is not only the magnitude of the motions but also who is exposed to them, and how they affect the task, the technical equipment involved, and the conditions under which the mission is carried out. Seakeeping evaluation must account for how motions act on the crew and the technical systems together, not on the hull alone.

2.2.1 HTO, Extended HTO, and the Septigon Model

The vessel, understood as a socio-technical system, can be examined through established models such as the Human Technology Organisation (HTO) (Berglund et al., 2020; Karltun et al., 2017), the Extended HTO Framework (Eklund, 2003), and the Septigon model (Grech et al., 2019). These models differ in scope and emphasis, but they share the premise that a system's performance cannot be understood by examining technical components in isolation from the people who use them and the organisational context in which they function (Berglund & Karltun, 2007; Eklund, 2003; Grech et al., 2019; Karltun et al., 2017).

The HTO model (Berglund et al., 2020; Karltun et al., 2017) highlights the interaction between the human or personnel, the technical system, and the organisational setting. Following the HTO framing, the human refers to the crew on board; the technical system comprises the vessel, its general

arrangement, the installed machinery (e.g., propulsion and navigation systems) and other relevant support systems (e.g., fire-fighting systems); and the organization comprises the work procedures, operational routines and management structures that define how missions are executed. This framing shows that the consequences of vessel motions are mediated by the interactions among the elements of the vessel system, rather than determined solely by the hull.

The Extended HTO framework (Eklund, 2003) broadens the HTO model by incorporating the surrounding environment as an additional element and emphasising the interdependence of these elements. This framework is especially relevant to seakeeping, since the marine environment is not passive but the source of the wave-induced motions that shape the work environment on board. The environment here encompasses not only waves and wind, but also the local motion conditions at the specific locations on the vessel where tasks are performed.

The Septigon model (Grech et al., 2019) provides a wider socio-technical scope representing system performance as arising from interactions among seven elements: society and culture (the socio-political and economic environment); the physical environment (e.g. ship motions, vibration, air quality, noise); practice (informal rules and customs); technology (the vessel, machinery, tools, manuals); the individual (e.g. sensory or physical limitations, physiology, psychology, skills, experience, workload); the group (interactions between crew members); and the organisational environment (onboard or shore management). Within the scope of this research work, the full Septigon model is not required. However, it reinforces the idea that vessel operations or missions are embedded in a wider system of constraints, expectations, and working conditions. For the work presented, the interactions of concern are those between the technology (the vessel and its installed machinery), the physical environment (motions), and the individual or group (the effects of motions on the crew performing a task)(see Figure 2.1).

In this thesis, the HTO model, the Extended HTO framework, and the adapted Septigon models were used as complementary conceptual tools for framing the vessel as a socio-technical system and to support the development of the research approach. The HTO model was used to establish the relationship between the crew, the hull and its technical systems, and the operational setting in which work is performed. The Extended HTO framework was useful

in contexts where the sea environment and local motion conditions also had to be considered, particularly in seakeeping applications.

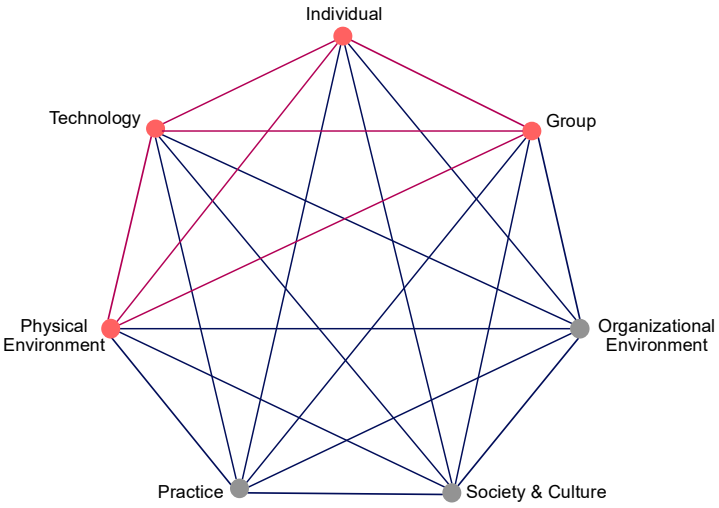


Figure 2.1. Septigon model (Grech et al., 2019) adapted for addressing seakeeping evaluation (interactions in purple) within the context of this research work

The adapted Septigon model provided a broader conceptual basis for understanding that seakeeping evaluation is influenced not only by motions but also by operational, organisational, and contextual factors. Together, these models informed the conceptualisation of the vessel system, stakeholder perspectives, and task-related evaluation needs.

2.2.2 Stakeholders, functional requirements and end-user needs

Viewing the vessel as a socio-technical system also highlights the stakeholders whose perspectives shape seakeeping evaluation. Three stakeholders are especially important: the vessel owner, the naval architect, and the crew as end users of the vessel in operation (see Figure 2.2).

The vessel owner is primarily concerned with the vessel's mission and operational capability, including expectations regarding productivity, safety, regularity, and the ability to execute under anticipated sea conditions. The naval architect is responsible for translating these expectations into design decisions and assessment approaches, including decisions on which motions to predict and which criteria and standards to apply to judge vessel suitability for purpose. The crew, by contrast, experience the vessel as a moving work

environment. Their perspective highlights task demands, physical and cognitive workload, postural balance requirements, and the practical conditions under which operations must be executed.

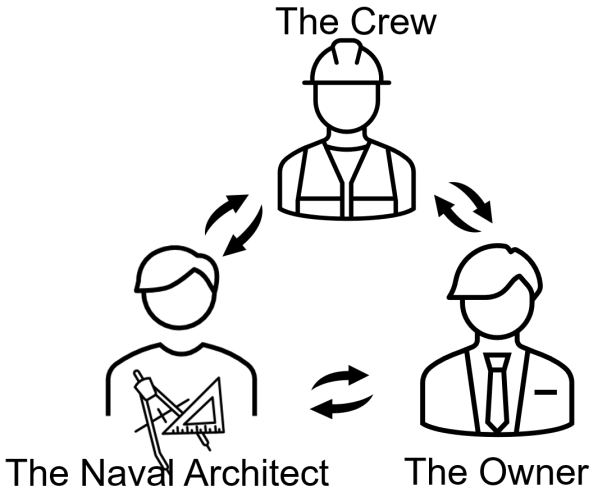


Figure 2.2. Stakeholders of seakeeping evaluation

These stakeholders' different viewpoints matter because they influence what counts as acceptable seakeeping performance. A vessel may satisfy technical performance expectations from a design perspective, yet generate motion responses that hinder safe and effective task execution. The end-user (crew) perspective is therefore particularly important here. Seakeeping assessments should not be limited to whether the vessel can operate in waves, but should also assess whether the resulting platform motions support the crew working on board.

These stakeholder perspectives bring two concepts central to this thesis into focus: functional requirements and end-user needs. Functional requirements are understood here as requirements linked to what the vessel must be able to do in service, rather than what it must withstand structurally or achieve hydrodynamically. End-user needs, in turn, are understood as the operational and safety-related conditions required for the crew to perform their tasks effectively on board. Together, these concepts provide the basis for a tailored understanding of seakeeping evaluation, in which the vessel's function, the nature of work on board, and the end-users' needs inform the choice of seakeeping evaluation metrics. This forms an important conceptual basis for the research approach detailed in Chapter 3.

2.3 A safety-oriented perspective on seakeeping evaluation

The socio-technical view of the vessel system offers several interpretive lenses for seakeeping evaluation, including safety, operability, workability, and human performance. In this thesis, safety is used as a primary lens because it directs attention to whether vessel motions support or constrain safe task performance on board.

In the maritime domain, safety is not a simple, singular concept; it is shaped by the different interests of the stakeholders involved (Veiga, 2002). Safety is generally understood as the absence of accidents, incidents, and near misses (Hollnagel, 2014; Hollnagel et al., 2015). While this understanding is intuitive, it is insufficient within maritime contexts, where safe operations are influenced by a wide range of stakeholders, expectations, and regulatory structures. Depending on the stakeholder and context, maritime safety may be associated with preventing injury and loss of life, protecting cargo and the marine environment, maintaining the integrity of the vessel's hull, ensuring operational continuity, or addressing the economic implications of a failure (Veiga, 2002).

A further challenge lies in how maritime safety is governed (Kristiansen, 2005). Safety at sea is addressed not only through conventions, rules, and operational practice (Stefan, 2012), but also through structured approaches such as the Formal Safety Assessment (FSA) and Goal-Based Standards (GBS) (IMO, 2010, 2011, 2013). FSA frames safety in terms of risk assessment and the evaluation of risk-control options, while GBS frames it in terms of goals, functional requirements, and verification of compliance with regulations. Together, the FSA and GBS approaches show that maritime safety is understood not only as the absence of accidents, but also as the way acceptable performance is defined, justified, and maintained in practice. The concept of safety, therefore, needs to be clarified before it can serve as an interpretive lens for seakeeping evaluation.

2.3.1 Safety-I, Safety-II, and Safety-III

There are three concepts or perspectives of system safety in the literature: Safety-I, Safety-II, and Safety-III (Aven, 2022; Leveson, 2020). These safety perspectives are not treated in this thesis as mutually exclusive, but rather as distinct interpretive lenses that emphasise different aspects of what it means for a system to be considered safe.

Safety-I views safety as achieved when things do not go wrong (Aven, 2022; Hollnagel et al., 2015). It is associated with the prevention of accidents, incidents, failures, and other undesired events (Hollnagel et al., 2015). Within the Safety-I perspective, safety management tends to focus on deviations, hazards, non-compliance, and the control of expected risks. In a seakeeping evaluation context, a Safety-I perspective will place focus on identifying motions that lead to unacceptable events, such as injury, loss of control, or exceedance of criteria thresholds. Thus, the central concern is whether vessel motions remain below the thresholds for unacceptable outcomes.

Safety-II shifts the emphasis from preventing failure to ensuring that things go right (Aven, 2022; Hollnagel et al., 2015; Leveson, 2020; Provan et al., 2020). Rather than viewing safety only as the absence of undesired or adverse events, the Safety-II perspective focuses on the capacity of a system to function successfully under varying conditions (Hollnagel et al., 2015; Provan et al., 2020). With this perspective, it is acknowledged that in complex settings, the successful performance of systems depends on continuous adaptation to disturbances, constraints, and changing environmental conditions. Within the context of seakeeping evaluation, a Safety-II perspective would consider whether the vessel system can continue to support effective task performance despite platform motions. The focus, with this perspective, would therefore extend beyond exceedance and failure to include operability, workability, and the crew's capacity to adapt to platform motions while maintaining acceptable performance.

Safety-III may be viewed as a systems-theoretic perspective that treats safety as an emergent property of the whole system, controlled through system design, constraints, and the wider organisational and regulatory context (Aven, 2022; Leveson, 2020). In a maritime context, this perspective highlights that safety is influenced not only by actions on board, but also by design choices, organisational arrangements, procurement priorities, and regulatory structures.

These three perspectives imply different emphases in seakeeping evaluation. A Safety-I perspective asks when motions become unacceptable. A Safety-II perspective asks whether work can continue safely and effectively despite platform motions. A Safety-III perspective asks how the vessel system is configured to sustain performance across varying conditions. This difference in emphasis matters because it influences what is measured, how criteria are interpreted, and what is regarded as meaningful in a seakeeping assessment.

In this thesis, safety is viewed from a Safety-II perspective, since the central concern is whether vessel motions support task performance under varying sea conditions. The interest, therefore, lies in how the vessel system functions in practice as a moving work environment, and whether the conditions created by vessel motions permit tasks to be carried out. Defining safety in this way does not imply that conventional safety concerns, such as injuries, accidents, or hazardous exposures, are disregarded. Rather, such undesired outcomes are interpreted within a broader understanding of safe operation. A condition on board may be a safety concern even before it causes an injury or accident, for example, if it disrupts task execution, increases reliance on compensatory actions for postural control, or reduces operational margins. This broader perspective is particularly relevant for vessels whose crew must work through the motions, where mission success depends on the crew's continued ability to perform operationally significant tasks despite prevailing sea conditions.

Though primary, safety is not treated as the only interpretive lens in this thesis. The adopted Safety-II definition provides a suitable basis for linking vessel motions to the safe execution of tasks, while still allowing for connection to other evaluative perspectives, such as operability, where appropriate. A Safety-II-oriented approach to seakeeping evaluation also requires attention to the crew who must work in these motion-rich conditions to perform tasks efficiently.

2.4 Crew-centred design – introducing ergonomics into seakeeping evaluation

In the scientific literature, the effects of motions on human performance have been categorised as general and specific. General effects influence performance through discomfort or demotivation, biomechanical interruption, or fatigue, and are commonly referred to as motion-induced interruptions (MII), motion-induced fatigue (MIF), and motion sickness. Specific effects, by contrast, interfere with particular human functions such as perception, motor skills, and cognition (Wertheim, 1998).

The negative impact of platform motions on the crew is a research topic of interest in the aircraft, automobile, and maritime industries. Compared with the others, however, research on the effects of platform motions in the maritime industry is limited and warrants greater attention (Duncan, Hickey, et al., 2018), particularly regarding vessel occupants. Most of the earlier

research on the effect of platform motions on vessel crew was carried out by naval establishments and focused primarily on military or naval personnel (ABCD Working Group on Human Performance at Sea, 1995; A. E. Baitis et al., 1984; Colwell, 1989, 2004; Crossland et al., 1994; Graham et al., 1991; O'Hanlon & McCauley, 1974). Although research on non-military occupants is limited, some of the available knowledge can still be drawn upon. It can be translated into an understanding of how motion exposure affects the crew and other occupants during daily tasks and operations, as well as in transit.

Knowledge of the effects of motions on the crew in their daily work tasks aligns with the International Maritime Organization's (IMO) goal of integrating *ergonomics*[1] in the design of the vessel and work tasks to promote performance and safety, i.e. considering the human element in vessel design (Antão et al., 2014; IMO, 2003, 2011, 2013; Schröder-Hinrichs et al., 2013). Integrating human factors and ergonomics into the maritime industry, specifically into the design of vessels, is presently a growing topic of interest (Costa et al., 2015; Grech et al., 2019; Mallam et al., 2015; Mallam & Lundh, 2013; Praetorius et al., 2015; Rumawas et al., 2016; Schröder-Hinrichs et al., 2013). In the context of vessel design, there are several aspects where ergonomics could be integrated or applied, e.g., in the general arrangement, the design of machinery spaces, and the bridge (Grech et al., 2019), and in the design of vessels that produce motions favourable for the crew's tasks aboard.

In seakeeping evaluation focused on crew performance and safety, as in this thesis, integrating ergonomics involves understanding what the crew is expected to do in their daily work, and how motions affect them. This understanding is pursued by adopting a *crew-centred design*[2] approach, an ergonomic approach that aligns with the principles of Safety-II.

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[1] *Ergonomics* (or human factors) is "the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance" (International Ergonomics Association (IEA), 2000).

[2] *Crew-centred design* is "a design practice where the focus is on human capabilities and limitations, and where ships and ships' equipment in appreciation of these design parameters is explicitly designed with human operator usability as an integral part of the design process and mindset" (Praetorius et al., 2015, p. 2825).

3 Research Approach and Methodology

3.1 Research positioning

This thesis proposes a systems view of seakeeping evaluation. The vessel is treated as a socio-technical system in which technical, human and organisational elements together shape how a vessel's platform motions are experienced and managed during operations. Interactions between the sea environment and the vessel hull are governed by physical laws and can be described using hydrodynamic models. However, the effects of the resulting motions on crew performance depend on human capabilities and limitations, task demands, workplace culture and operational practices.

To clarify the basis for the research design and methods, this section briefly outlines the ontological and epistemological positioning of the thesis. Ontology concerns assumptions about the nature of reality and what exists within the research domain, while epistemology concerns how knowledge about that domain can be developed and justified (Audi, 2011; O'Leary, 2017). These questions are relevant here because seakeeping evaluation in this thesis is approached not only as a hydrodynamic prediction problem, but also as a socio-technical one.

3.1.1 Ontological stance

Ontologically, this thesis assumes that waves, vessel responses, and human performance outcomes exist as real phenomena that can be observed, described and approximated. Vessel motions are treated as physical processes that can be represented by mathematical models and quantified using response transfer functions and spectra. However, when it comes to crew

performance, the effects of vessel motions on workload, productivity, and operational constraints cannot be measured directly in the same way as vessel motions. Even so, these effects must be treated as real and consequential outcomes within the vessel system.

3.1.2 Epistemological stance

In this thesis, knowledge about seakeeping performance is built through a combination of observations, experiments, governing equations, numerical models, and experience-based accounts. Hydrodynamic theory, response functions, and human response models provide structured, quantitative descriptions of vessel motions and their effects. In parallel, crew experiences, interviews, focus group discussions, and operational documents offer qualitative insights into how motion is perceived, how tasks are adapted, and what is considered acceptable performance on board.

The thesis adopts a post-positivist stance. It recognises that models and measurements are simplifications of reality and that uncertainty is inherent, yet assumes that these tools can still provide useful, progressively refined knowledge of seakeeping and its implications for crew performance. Subjective experiences are not treated as opposed to objective data, but rather as an important source of evidence for understanding, for example, which aspects of motion matter, how criteria should be formulated, and which operating conditions should be considered acceptable in practice. This view underpins the mixed-methods and interdisciplinary design presented in the remainder of this chapter.

3.1.3 Systems and safety perspective

The research work is further positioned within a systems-oriented, Safety-II-informed perspective. As elaborated in Chapter 2, the focus is not only on whether vessel motions exceed prescribed thresholds, but also on whether the vessel system supports the continued safe execution of work under varying sea conditions. This perspective defines how the research study was conducted, what counted as evidence and how findings were interpreted.

This means the research does not focus exclusively on traditional hull-centred performance measures. Instead, the focus is on motion exposure at relevant work locations on deck, its implications for task execution, and how these effects can be translated into evaluation metrics meaningful for design and seakeeping assessment. It also means that the crew's experiences and other

stakeholders' perspectives are relevant inputs to the seakeeping evaluation process, rather than secondary. The systems and safety perspectives, therefore, inform both the design of the research and the interpretation of the results.

3.2 Research design

The research design was shaped by the specified Aim and Objectives in Chapter 1. This research aims to develop a systematic approach to seakeeping evaluation that aligns vessel seakeeping performance with functional requirements, onboard tasks, and end-user needs. Achieving this required more than applying existing motion prediction methods and seakeeping criteria. It required a critical examination of current seakeeping evaluation practices; the development of a structured approach (framework) to translating vessel functional requirements and task demands into tailored seakeeping evaluation metrics; and the identification of methods to consistently and efficiently predict these metrics. The stated Objectives of this research study, therefore, motivated a mixed-methods and interdisciplinary research design.

3.2.1 Mixed-methods design

This thesis employs a mixed-methods design (Creswell, 2014; Leedy & Ormrod, 2016) because neither quantitative modelling nor qualitative interpretation is sufficient to address the problem. While modelling is necessary for predicting vessel motion responses and quantifying motion exposure, it does not, by itself, establish which aspects of motion are most relevant to a vessel's purpose, crew performance, or acceptable operating conditions. Addressing these also requires familiarisation with current seakeeping evaluation practices, engagement with stakeholders, especially the crew as end-users, and the development of a conceptual basis for selecting and interpreting seakeeping evaluation metrics.

This research combines quantitative and qualitative approaches. The quantitative approaches include seakeeping analyses, operability-related calculations, and the application or development of evaluative metrics and estimators. The qualitative approaches include semi-structured interviews, focus groups, literature reviews, observations, and video recordings. These methods were used to critique current seakeeping evaluation practices, identify

task-relevant concerns aboard vessels, and support the development and interpretation of tailored seakeeping evaluation metrics.

Both quantitative and qualitative methods used in the research design are treated as interrelated rather than independent. The qualitative methods employed help identify what metrics should be evaluated and how they should be interpreted or applied, while the quantitative methods help determine how the resulting metrics can be predicted and applied consistently. The mixed-methods design thus supported both problem clarification and methodological development.

3.2.2 Interdisciplinary approach

The interdisciplinary approach of the thesis follows directly from the nature of the research problem it addresses within seakeeping assessment, and more particularly within seakeeping evaluation. As established in Chapter 2, seakeeping analysis concerns the prediction of vessel responses in waves, whereas seakeeping evaluation concerns the judgement of whether those responses are acceptable for the vessel's intended purpose. The gap addressed in this research work lies in the latter. Specifically, it concerns the limited ability of current seakeeping evaluation practice to translate functional requirements and end-user needs into a communicable and defensible set of evaluation metrics.

This identified gap cannot be resolved solely through conventional seakeeping assessment logic. A predicted response becomes meaningful only when interpreted in relation to what the vessel must enable in service, what the crew must do on board, and what conditions are acceptable for safe task execution. The problem is therefore interdisciplinary because it requires integrating knowledge of physical responses (vessel-wave interactions), crew performance, and engineering judgement within a single framework.

This research, therefore, draws on seakeeping assessment in naval architecture, as well as human factors/ergonomics and biomechanics. Seakeeping assessment provides the basis for representing the environmental conditions, predicting motion responses and characterising motion exposure at relevant onboard locations. Human factors and ergonomics provide concepts for understanding task demands and the vessel as a motion-rich work environment. Biomechanics contributes to understanding the physical mechanisms underlying human responses to postural demands and balance. These disciplinary perspectives are methodologically intertwined in this

research to support the development of a more systematic and crew-centred approach to seakeeping evaluation.

3.2.3 Research progression

The progression of work in this thesis follows the three research questions introduced in Chapter 1. The first research question addresses the limitations of current seakeeping evaluation practice. This is approached through a critical review and synthesis of existing criteria, standards, and evaluative practices, as well as a focused review of concepts and quantification approaches for the effects of motions on human physiology. The second research question concerns how seakeeping evaluation can be structured as a systematic, vessel-specific process that maps functional requirements and end-user needs to a defensible set of evaluation metrics. This is addressed through conceptual formulation, framework development, and the use of qualitative data to clarify what should be evaluated and why. The third question concerns how the identified metrics can be predicted efficiently. This is addressed through quantitative modelling, metric formulation, and the development of an efficient motion-induced interruption estimator.

This logical flow is reflected across the five papers appended to this thesis. Paper A critiques and clarifies current seakeeping criteria and evaluation practice. Paper B develops the conceptual basis for translating operational needs into performance-relevant criteria. Paper C formalises and demonstrates a tailored approach for translating functional requirements into seakeeping evaluation metrics using two case-study work vessels. Paper D systematically reviews and structures the concept of motion-induced interruptions. Paper E develops a task-informed estimator that predicts MII rates at the resolution of individual tasks. The remainder of this chapter details the workflow and methods used to carry out this progression.

3.3 Quantitative methods

The quantitative methods used in this research provide the technical basis for predicting vessel motion responses, characterising motion exposure at local deck positions, and quantifying seakeeping evaluation metrics. This includes the calculation of response quantities at specified locations, such as local accelerations and model-based indicators (e.g., motion sickness incidence),

needed to assess whether predicted motions are acceptable given the vessel's mission and the associated work on board and in operational sea conditions.

3.3.1 Motion prediction

Motion prediction was primarily based on linear strip-theory methods. In the appended papers, where applicable, motion responses were predicted using the KTH in-house strip-theory code, KTH Strip. This strip-theory code provides motion responses for specified wave conditions, vessel speeds, and headings for a given hull geometry. The responses were generally represented by response amplitude operators (RAOs), which form the basis for estimating vessel motions in the relevant degrees of freedom.

Irregular sea conditions were typically represented using standard spectral descriptions, primarily the two-parameter ITTC wave spectrum (Lewis, 1988), defined by significant wave height and zero-crossing period. Where relevant, the specified sea environment was further represented through wave scatter data or specified combinations of significant wave height, characteristic wave period, speed, and heading. This approach allows vessel responses to be evaluated under isolated conditions across operationally relevant ranges of sea states, including the influence of forward speed, using encounter-frequency formulations derived from wave frequencies, where relevant.

This motion-prediction approach served as the quantitative backbone of the research studies. Particularly in Papers B, C, and E, this approach was used to predict vessel responses required as input for application of the framework, operability assessments, and MII-related estimations.

3.3.2 Point motion response modelling at task-relevant locations

Given the crew-centred seakeeping evaluation focus, predicted rigid-body vessel motions were, where relevant, transformed into local motions at task-relevant onboard locations. This included calculating quantities such as local accelerations, which provided the motion-exposure basis for evaluating the implications of motion for onboard tasks. By moving from global vessel response to local motion responses (point motions), the evaluation could better reflect how predicted motions relate to task execution, postural demand, and other operationally relevant effects of motions.

Point motion response modelling was especially relevant in Papers B, C, and E.

3.3.3 Quantification of seakeeping evaluation metrics

The quantification of seakeeping evaluation metrics was based directly on predicted motion responses or on models that translate motions into more operationally meaningful indicators. This included established evaluative quantities or criteria models drawn from the scientific literature and standards (Graham, 1990; Graham et al., 1991, 1992; ISO, 1997), as well as modified or newly formulated quantities developed to support vessel-specific seakeeping evaluation, as in Papers B, C, and E. Accordingly, predicted vessel response quantities served as inputs to these criteria models or were expressed in forms relevant to the seakeeping evaluation question being addressed.

3.3.4 Operability-related calculations

The quantified metrics were used in operability-related seakeeping assessments. The relevant calculated metrics were compared against defined standards, thresholds, or acceptance limits to determine whether a particular condition, task, or operational requirement was satisfied. This quantitative analysis supported the judgement of vessel suitability, as designed, for its intended purposes under expected sea conditions.

Operability assessments were used particularly in Papers B and C, where selected criteria were applied in case-study contexts to assess whether the vessels could support required tasks on board under specified sea conditions.

3.4 Qualitative methods

The qualitative methods used in this research supported the critique of current seakeeping evaluation practice and the development of a more systematic and crew-centred approach to seakeeping evaluation. These methods highlighted how motion is experienced at sea, which aspects of vessel motion are considered critical for operations, and how task performance is understood in motion-rich work environments, such as on board a vessel.

3.4.1 Literature-based inquiry

A substantial part of the qualitative methods used consisted of literature-based inquiry. This included the review of scientific literature, such as existing seakeeping criteria, and other written sources on seakeeping evaluation and the effects of motion on human (crew) performance. These literature materials

were used to identify how seakeeping evaluation has been approached in previous studies, which criteria and standards have been commonly applied, and where limitations or gaps remain when vessel purpose, task performance, and crew needs are considered.

Literature reviews formed the basis of the studies, particularly in Papers A, B, and D. In Paper A, the literature review served as the primary source of information for critiquing prevailing seakeeping criteria and evaluation practices. In Paper B, it supported the development of a method for specifying seakeeping criteria to support efficient task performance on board. In Paper D, a more structured and systematic literature review was employed to review how motion-induced interruptions have been defined, represented, and quantified in the scientific literature.

The literature-based studies also supported the clarification and structuring of concepts relevant to the research, including the effects of motions on crew task performance and how such effects could be translated into evaluation metrics.

3.4.2 Interviews and focus groups

Interviews and focus group discussions were conducted with relevant stakeholders and guided by structured questions (see Appendices B, C and D). Basic demographic information was also collected from participants at the start of the interview (see Appendix E). These interviews and focus group discussions were used to obtain experience-based insights into how vessel motions are perceived and managed in practice, which tasks are particularly sensitive to motion exposure, and what defines acceptable operating conditions. These stakeholder engagements included both end-user perspectives from crew working aboard work vessels and designer or naval architect perspectives relevant to vessel design and seakeeping assessments.

Several interviews and focus group inputs supported various aspects of the research. Focus group discussions with naval architects and design engineers informed Paper A, facilitating the identification of practical challenges in current seakeeping evaluation practice and motivating the subsequent literature review presented in the paper. Interviews with crew aboard work vessels informed the broader critique of current practices and supported the development of Papers B and C by identifying motion-critical work tasks and practical concerns related to motion exposure. Prior to the focus group discussions in the Paper C study, the questions were informally piloted with

seafarers known to the researcher in order to assess their clarity and comprehensibility.

The goal of the interviews and focus groups was to capture concerns that cannot be captured through literature reviews and seakeeping analyses. The interviews and focus group discussions, therefore, informed the critique of existing seakeeping evaluation practice, the interpretation of vessel-specific and crew task-related concerns and the development of a seakeeping evaluation framework, presented later in this thesis. Together with the literature-based inquiry, these stakeholder engagements helped clarify what should be evaluated, why certain metrics were needed, and how results should be interpreted when conducting a seakeeping evaluation focused on vessel purpose and end-user needs. The final versions of the interview and focus group guides are included in the Appendices B, C and D.

3.4.3 Onboard observations and supporting visual documentation

Where relevant, onboard observations and supporting video recordings were included. These were used to complement the interviews by providing direct insight into task execution. This approach was particularly important in Paper C, where onboard observations and video recordings were used alongside focus group interviews to support Hierarchical Task Analysis and Task Decomposition. These helped identify motion-critical tasks for the particular case studies, clarify how tasks were performed in practice, and support translation into seakeeping evaluation metrics.

3.4.4 Interpretation and methodological role of qualitative approaches

Across the thesis, the literature reviews, stakeholder interviews, focus group discussions, and onboard observations were qualitatively interpreted to identify concerns and gain insight into stakeholder perspectives relevant to seakeeping evaluation. In Paper A, the focus group discussions were exploratory and semi-structured, documented through summary notes and interpreted directly to surface the concerns and priorities that stakeholders associated with vessel motions and task performance. This served to scope and orient the research, shaping the problem formulation and the identification of practical concerns. In Paper C, the qualitative inputs, comprising interviews, focus groups, and onboard observations, were analysed more systematically through Hierarchical Task Analysis and Task Decomposition to identify and structure motion-critical tasks. The exploratory interpretation in Paper A

served to orient the research and inform the development of the framework, rather than to provide reproducible findings. The framework's evaluative and predictive claims rest on its own logic and on the quantitative methods and structured task analysis, with their transparent, repeatable procedures.

The qualitative methods were not a substitute for the quantitative methods. They contributed directly to the formulation of the research problem, the critique of current practice, the clarification of the operational meaning of motion effects, and the development and application of the vessel-specific seakeeping evaluation framework.

3.5 Methods by research question and paper

The research methods employed in this thesis were applied across the appended papers to address the specific question each paper was intended to address. This section summarises the methodological role of each paper in relation to the research questions.

3.5.1 Paper A – *Seakeeping criteria revisited*

Paper A addressed the first research question by critically reviewing existing seakeeping criteria and evaluation practices. The study was motivated by focus group discussions with naval architects and semi-structured interviews with crew members from vessels with motion-critical operations (see Appendices B and C). These focus group discussions and interviews highlighted practical challenges, including the lack of criteria for small vessels and operationally demanding vessel types, the lack of standardised criteria for passengers and crew, and broader difficulties in seakeeping evaluation practice. These empirical inputs then shaped the literature study that became the paper's primary method.

Methodologically, Paper A was based on a literature review explicitly informed by stakeholder input. The literature study was conducted using existing knowledge of commonly used seakeeping criteria, keyword searches in Web of Science and Scopus, and tracing relevant cited references. The literature review led to the identification and selection of relevant papers based on Paper A's research question and objective, as well as on themes related to the development of seakeeping criteria and the negative effects of vessel motions.

In this thesis, Paper A provided the basis for critiquing the current seakeeping evaluation practice and for identifying the need for vessel-specific and crew-centred seakeeping evaluation approaches.

3.5.2 Paper B – *Specifying seakeeping criteria for efficient task performance*

Paper B addressed the second research question by developing a method for specifying seakeeping criteria to support task performance. Methodologically, the study presented in Paper B was shaped by literature-based inquiry, preliminary stakeholder interviews, and a quantitative case study in the form of an operability assessment. The literature study provided insight into the effects of motion on crew and system performance, including motion-induced interruptions, motion-induced fatigue, and motion sickness. This was complemented by preliminary interviews with crew aboard work vessels, with the main aim of mapping working conditions on board to identify motion-critical tasks and capture practical concerns related to work performance in such motion-rich work environments.

Based on inputs from the literature and interviews, a structured framework for specifying criteria considering vessel type, mission, and motion-critical tasks was developed and presented in Paper B. The framework was then applied in a case-study context using selected criteria from established sources to demonstrate how such a procedure could be implemented within a seakeeping evaluation for operability assessments.

Paper B contributed methodologically by establishing the basis for linking vessel function and onboard task demands to the specification of seakeeping criteria.

3.5.3 Paper C – *Translating functional requirements into seakeeping evaluation metrics for marine vessel design*

Paper C addressed the second and third research questions. The paper was framed around the challenge of selecting criteria that reflect the actual tasks and operations performed on board, and proposed a task-analysis-based methodological framework to bridge the identified gap.

The paper combined framework development, task analysis, qualitative fieldwork, and quantitative case-study application. The framework was structured into three linked stages: identifying motion-critical tasks from functional requirements; translating the decomposed motion-critical tasks to

inform the selection of seakeeping criteria and standards; and evaluating compliance under specified sea conditions.

Motion-critical tasks were identified and decomposed using Hierarchical Task Analysis and Task Decomposition, supported by semi-structured focus group interviews and onboard observations. The interview questions (see Appendix D) were used to identify which tasks the crew performed, how these tasks were sequenced during operation, which tasks were motion-critical, and how motions affected their execution. Informal observations and video recordings were used to complement the interviews and support the task decomposition. The translation step of the method was based on criteria and standards available in the literature, or where these were lacking, on predictive models of motion-induced effects. The compliance evaluation was conducted through operability calculations.

Paper C extended the contribution from Paper B by introducing and demonstrating the use of task-analysis methods for identifying motion-critical tasks for vessel-specific applications in seakeeping evaluations.

3.5.4 Paper D – *Characterisation and synthesis of motion-induced interruptions: A systematic literature review*

Paper D addressed the first and third research questions through a structured literature review of motion-induced interruptions. The paper was motivated by the lack of consistency in how motion-induced interruptions are defined and quantified in the literature and aimed to identify definitions, indicators, and quantification approaches, and to clarify gaps relevant to seakeeping evaluation.

Methodologically, the paper was based on a systematic search and review process using Scopus. A broad search strategy was employed to include both explicit and implicit applications of the MII concept across fields. The review process involved literature identification, screening, and synthesis, with the included articles examined in relation to definitions, indicators and quantification methods. The articles were screened by title and abstract against predefined relevance criteria. Additional records were included from the references cited in the initial relevant articles from the screening phase.

Paper D thus provided a more structured basis for considering motion-induced interruptions as a crew-centred seakeeping evaluation metric.

3.5.5 Paper E – *A task-informed approach to predicting motion-induced interruptions for seakeeping evaluation*

Paper E addressed the third research question by developing a task-informed estimator to predict motion-induced interruption rates at the resolution of individual tasks. The paper was motivated by the practical limitations of existing MII prediction models, particularly their dependence on prescribed stance geometry and body orientation, which cannot be reliably specified for a general crew in early-stage vessel design.

The estimator was derived as a systematic reduction of Graham's resultant tipping and sliding conditions. In this reduction, the rotational inertia terms arising from the rigid-block body idealisation were removed, and the geometric tipping coefficient was replaced by an empirically derived, task-specific threshold. The resulting estimator predicts MII rates from the ratio of in-deck-plane resultant accelerations to the vertical acceleration at a specified task location, without requiring prescribed stance geometry or orientation. Vessel motion inputs were obtained from strip-theory seakeeping analysis, with local accelerations derived from RAO-based stochastic time-series reconstruction and MII rates calculated by counting threshold upcrossings in the time domain. Applying the estimator to three onboard tasks under identical vessel motions produced markedly different interruption rates, demonstrating that the predicted MII rate is a property of the task, and not only of the vessel motion.

Paper E contributed methodologically by providing a practical, task-resolved basis for MII prediction that places task specificity into an empirically grounded threshold, rather than an assumed stance geometry.

3.6 Quality, validity and scope

The quality of the research design in this thesis depends on how appropriately the selected methods support the research aim, how transparently these methods are used and how clearly the scope of the resulting claims is defined (Leedy & Ormrod, 2016; O'Leary, 2017). Since this thesis combines quantitative and qualitative approaches, quality is considered here in relation to both the technical basis for seakeeping evaluation and the evidence used to critique current practice, interpret crew needs and support the developed seakeeping evaluation framework.

3.6.1 Validity of quantitative methods

The validity of the quantitative methods used in this research is considered primarily in relation to their "fitness for purpose" within the objectives of the research (Leedy & Ormrod, 2016). The main quantitative approach of this research was to predict vessel responses, derive motion quantities at defined locations, and quantify evaluation metrics in a form useful for assessing vessel suitability for a defined purpose. Linear strip-theory-based seakeeping analysis, implemented through KTH Strip, provided an appropriate and consistent basis for generating vessel motion responses across different sea states, headings, and operating conditions.

The use of RAO-based response predictions, standard wave spectral descriptions, and local point-motion calculations was also appropriate to the stated objectives, since the focus was on translating the predicted motions into evaluation metrics relevant to onboard work. The validity of this approach, therefore, rests on its ability to provide a transparent and practical basis for comparing vessel hull designs in seakeeping evaluation contexts. This thesis does not claim that these methods capture every aspect of real vessel behaviour in waves. Linear strip theory rests on simplifying assumptions, including slender-hull sectional geometry, linearity of the response, and, as applied here, unidirectional long-crested waves and an empirically represented roll damping that potential-flow theory does not predict.

These assumptions were judged acceptable for the comparative, structured evaluation pursued here. The interruption estimator depends on lateral, in-deck-plane accelerations, to which roll contributes, so the predicted interruption rates are sensitive to the roll-damping assumption in particular. The value was applied consistently across all cases, so that the comparative findings, particularly the demonstration that predicted interruption rates differ markedly between tasks under identical vessel motions, do not depend on the absolute roll-damping value. The absolute interruption rates should, however, be interpreted with this limitation in mind. The methods are therefore used as appropriate tools to support the structured, crew-centred, vessel-specific seakeeping evaluation pursued in this research, with an emphasis on comparative evaluation rather than absolute prediction accuracy.

3.6.2 Trustworthiness of qualitative methods

In qualitative research, validity is commonly understood in terms of the accuracy of findings, and related concepts such as trustworthiness, authenticity

and credibility are widely used in place of validity in its narrow quantitative sense (Creswell, 2014). In this thesis, trustworthiness of the qualitative methods is considered in relation to the appropriateness of the sources used, the transparency of their role in the research, and the extent to which they support credible interpretation and the development of the seakeeping evaluation framework.

The use of multiple qualitative sources strengthened the research by allowing key concerns to be examined from different perspectives. Creswell (2014) recommends the use of multiple approaches to enhance the researcher's ability to assess the accuracy of findings and to employ triangulation across different data sources as a way of building coherent justification for interpretation. This approach was particularly important in Paper C, where literature-based inquiry, focus group interviews, onboard observations, and supporting video recordings were used together to support task decomposition and the application of the proposed framework.

In this thesis as a whole, the claims supported by the qualitative methods are interpretive and developmental. Their role is to strengthen the relevance, grounding, and practical orientation of the proposed seakeeping evaluation approach, developed through Papers B and C. The exploratory elements are conceptual and orienting rather than intended to yield identically reproducible findings, whereas the structured task analysis in Paper C follows a transparent, documented procedure. The framework's evaluative and predictive claims rest on the quantitative methods and this structured analysis.

3.6.3 Scope of the research

The scope of this research is defined by its focus on seakeeping evaluation. More specifically, the research concerns how vessel platform motions can be evaluated in relation to functional requirements, end-user (crew) needs, and the safe execution of tasks on board. This thesis, therefore, does not seek to establish universally applicable seakeeping criteria and standards for all vessel types and all operational contexts. Instead, it seeks to contribute a systematic basis for defining, structuring, and quantifying tailored seakeeping evaluation metrics and to inspire and guide future research.

The research is also bounded by its emphasis on crew-centred and task-relevant motion effects, particularly in relation to work vessels and motion-critical operations. Although hull responses and conventional criteria (e.g., slamming, green water on deck, propeller emergence, maximum roll angle,

voluntary and involuntary speed reduction) remain important, this thesis gives special attention to evaluation metrics linked to human (crew) performance and operational capability.

While several motion effects are considered, this thesis does not attempt to cover all possible seakeeping consequences in equal depth. Instead, the selected metrics and case-study applications are used to develop and demonstrate the proposed approach. The scope of this thesis should therefore be understood as methodological and framework-oriented, with case-based demonstration rather than universal standard-setting.

3.7 Ethical and practical considerations

The research presented in this thesis includes both analytical work and qualitative engagements with human participants. Ethical considerations therefore arose regarding the interviews, focus group discussions, and observations on board the case-study vessels. These considerations were addressed through participant information and consent procedures developed in the early stages of the study (see Appendix A). Participation was voluntary, permission to record discussions was requested, participants were informed of their right to withdraw, and the content of the interviews (including recordings and notes) was treated with attention to confidentiality and anonymisation. Care was also taken to handle participant perspectives responsibly, particularly where they related to professional experience, organisational practice, or operational insight.

The research was also shaped by practical considerations. These included access to vessels, naval architects in relevant organisations, and crew members; the availability of vessel data required for seakeeping analysis; and the feasibility of carrying out interdisciplinary research within the timeframe of a PhD project. In some cases, qualitative engagement relied on interviews, discussions, observations, and available supporting material rather than direct access to all relevant operational contexts. These practical constraints do not undermine the value of the work, but define the context within which the research design should be understood.

4 Towards Vessel-Specific and Task-Based Seakeeping Evaluation

4.1 Mapping motion-critical work: Findings from preliminary crew interviews

The research presented in this thesis did not begin solely from abstract concerns about seakeeping evaluation. It was also shaped by practical questions about how vessel motions are experienced on board, how they influence work and operations, and what seakeeping evaluations must capture to ensure sustainable and safe vessel designs. These questions motivated the empirical starting point of this research: mapping working conditions on board different types of work vessels through semi-structured interviews.

These interviews were conducted with crew and operators on vessels belonging to the Swedish Maritime Administration (Sjöfartsverket) and the Swedish Sea Rescue Society (SSRS, Sjöräddningssällskapet). They focused on mapping everyday working conditions on board, identifying operations that became difficult or unsafe to perform in motion-rich conditions, and clarifying whether existing seakeeping criteria reflected the realities of work on board vessels. The interviews showed that seakeeping is experienced on board not simply as a matter of vessel motions, but as a condition that influences the crew's ability to carry out tasks safely and effectively while meeting the required physical demands. Table 4.1 summarises the main findings from the interviews with the crew and operators from the Swedish Maritime Administration and the SSRS.

As shown in Table 4.1, the preliminary interviews indicated that the operational significance of vessel motions is closely linked to the vessel's

function and the nature of work activities carried out on board. A key finding was that similar motions could have very different consequences depending on the task being performed and the vessel type. The interviews also revealed that the same vessel could be acceptable in one operational situation but limit operations in another because of the motions, particularly on vessels where mission success depends on the safe execution of distinct tasks. This provided early empirical support for the view that seakeeping evaluation should be task-specific rather than based solely on global vessel motions. These findings were important because they shifted the seakeeping evaluation problem away from purely response-based descriptions of the vessel towards answering whether the vessel could still support its intended functions under realistic operational conditions.

The significance of these preliminary interviews extended beyond the empirical mapping itself. They also influenced the subsequent direction of the research. The recurring indication that vessel motions were of operational concern during specific tasks or work situations on board raised broader questions about whether existing seakeeping evaluation practices were adequate to represent such task-dependent realities. This question informed the next phase of the research, including the focus group discussions with naval architects and designers, and laid the foundation for the critical review of seakeeping criteria and current practice presented in Paper A.

4.2 Limitations of current seakeeping evaluation practice

The preliminary crew interviews raised a broader question: whether current practices are adequate to capture and represent the operational realities onboard during seakeeping evaluations to assess vessel designs. This question motivated focus-group discussions with naval architects, which later provided the scientific grounding for the critical review of seakeeping criteria. While the preliminary crew interviews revealed how vessel motions interfered with concrete onboard tasks, the focus-group discussions revealed that seakeeping evaluation practices are inadequate for systematically incorporating task-based considerations.

A central point emerging from the discussion was that seakeeping was understood primarily in terms of operability and that clients often expressed concerns about seakeeping only indirectly through operational requirements.

Table 4.1. Main findings from the preliminary crew and operator interviews

Context	Motion-critical work moment(s) identified	Limiting motions and conditions	Consequence for safe and effective task execution
Pilot transfer operations	Pilot embarkation and disembarkation at the pilot ladder; manoeuvring alongside larger vessels; maintaining a workable relative position during transfer.	Relative heave at the transfer interface; locally disturbed wave conditions around the larger vessel; manoeuvre-related motions when the pilot boat is alongside the larger vessel.	Safe transfers become strongly dependent on timing, vessel manoeuvring control, and local conditions.
Fairway maintenance operations	Crane operations with suspended loads; station-keeping; push-on or beaching; stepping onto lighthouse ladders and other fixed aids for navigation in the fairway.	Roll, lateral accelerations, heave, and local wind conditions.	Motions limit the ability to hold a position, control crane work, and transfer safely onto fixed navigational structures in the fairway.
Hydrographic survey operations	Real-time survey monitoring; instrument-dependent measurement work, computer-based work and post-processing of data during survey operations.	Roll, pitch, heave, and yaw; weather and wave-height limits; motions and accelerations in enclosed workspaces contributing to motion sickness.	Motions disturb computer-based and instrument-based work, reducing the continuity and quality of survey operations.
Sea rescue operations	Deck-based rescue work, bridge-based navigation and communication during high-speed transit, towing and line-handling alongside other distressed vessels.	Slamming loads in choppy seas when approaching distress sites, local motion during close-contact rescue support and towing.	Motions affect mobility on deck, increasing the risk of slips and falls, manual handling, and task disruption during rescue activities.

A key limitation identified, however, was that current seakeeping evaluation practice was insufficiently developed for human-centred evaluation. Seakeeping assessments in design practice were described as used mainly to support decision-making in hull form design, structural design, equipment and machinery arrangement, survivability, and habitability, whereas the implications of seakeeping for crew task performance were only weakly represented. The discussion therefore highlighted the need for the crew, machinery/equipment and hull to be considered together, rather than treating vessel motions only as a response problem related to hull form or structural integrity.

A further concern was the lack of suitable evaluation criteria. The discussions suggested that there were relatively few criteria available for smaller vessels and high-speed craft and that standardised criteria explicitly directed towards human performance on board were largely unavailable. Reference criteria such as those of Nordforsk (1987) were recognised as useful but also as limited, particularly in relation to trained and experienced crew and specialised operational scenarios. The focus group also provided useful indications of what improved or new criteria would need to look like. Rather than being framed as generic fixed values detached from practice, they need to be objective, measurable, and verifiable, and relate to different aspects of vessel performance. Most importantly, the focus-group discussion highlighted the need to determine which motions are critical for individual onboard tasks. This implied that the limitation of current practices lies not only in the limited availability of criteria but also in the absence of a sufficient logic for linking criteria selection to vessel function and task demands.

Another limitation raised concerned the practical conditions under which seakeeping evaluation is performed. The discussions suggested that seakeeping analyses were often perceived as complex and expensive, which contributed to their neglect or non-prioritisation, particularly in projects involving smaller vessels or limited budgets. This matters because it shows that the underlying problem with current seakeeping evaluation practices is not only methodological but also procedural. Additionally, even when seakeeping is considered important, the absence of clear, usable criteria may weaken its role in design and decision-making.

Altogether, these findings indicate that the limitations of current seakeeping practice are not simply a matter of the limited availability of seakeeping criteria. More fundamentally, they reflect a weak connection between existing

evaluation approaches and the task-dependent operational realities through which seakeeping becomes significant on board. Current practice appears better developed for describing vessel response than for judging whether the vessel, as a motion-rich working environment, can still support its specified functions under realistic sea conditions. This highlights the need for a more defined approach to specifying seakeeping criteria based on vessel functions, onboard tasks, and operational demands.

The concerns raised in the focus-group discussions made it necessary to examine whether the available seakeeping criteria were adequate, transferable, and aligned with specialised vessel functions and task demands, thereby motivating the critical review of seakeeping criteria conducted in Paper A. The review catalogued existing seakeeping criteria and standards, traced their original sources, clarified the scientific basis on which they were developed, and identified the vessel types and aspects of vessel performance these criteria addressed.

The review primarily showed that although a range of seakeeping criteria is available in scientific literature, they are not standardised and do not cover all vessel types. This shortcoming creates particular difficulties in early-stage design, where seakeeping evaluations are expected to support decisions on whether a vessel can safely fulfil its intended mission. Paper A therefore reinforced that the limitation of current practice is not simply the absence of criteria, but also the difficulty of knowing which criteria are appropriate for a given vessel, mission, or operational context.

Established criteria sets such as the Nordforsk (1987), NATO STANAG 4154 (NATO, 2018), ISO 2631-1 (ISO, 1997), US Coast Guard Cutter Criteria (A. Baitis et al., 1994), IMO Second Generation Intact Stability Criteria (IMO SDC, 2017), and the criteria for fishing vessels suggested by Tello et al. (2011) each address particular vessel types, subsystems or performance aspects. Merchant, naval, fishing and offshore vessels and some fast small craft are covered to varying degrees, but there are no well-established criteria for vessels whose operational value depends on the safe and efficient execution of mission-specific tasks. This was especially relevant in the context of this research, since such vessels present as motion-rich work environments.

Paper A also showed that the knowledge base underpinning many commonly used standards is more limited than might be assumed. A considerable number of the standards reviewed could be traced to a relatively small set of older full-scale studies (Aertssen, 1968) and their subsequent reinterpretations

(Karppinen, 1987; Karppinen & Aitta, 1986). Some standards were developed through field surveys (Aertssen, 1968; Lawther & Griffin, 1986, 1987, 1988; Sheinberg et al., 2003, 2010), experiments (Alexander et al., 1945b, 1945a, 1945c), simulations (Pattison & Bushway, 1991), and focus-group- or interview-based judgements (Karppinen & Aitta, 1986; Pattison & Bushway, 1991), while others have relied partly on assumptions or educated guesses. These findings highlight that standards are often vessel-specific, task-specific, or case-specific. Careful consideration is needed before applying them outside the contexts for which they were originally developed.

Conclusions drawn from the critical review highlight opportunities to improve seakeeping evaluation in relation to crew well-being and safety within a systems context. In effect, the critical review presented in Paper A substantiated the findings from the preliminary interviews with crew and the focus-group discussions with naval architects and design engineers: that seakeeping evaluation practices are insufficiently equipped to represent the task-dependent nature of work onboard and the varying contexts defined by vessel type and function. Paper A clarified that the current challenge with seakeeping evaluation is not merely that more criteria are needed; rather, what is lacking is a defensible basis for selecting criteria in relation to vessel type, mission, onboard tasks, and end-user needs.

4.3 Towards specifying vessel-specific criteria for seakeeping evaluations: a task-based systems framework

The limitations identified in current practice suggest that improving seakeeping evaluation is not simply a matter of expanding the list of available criteria. More fundamentally, it requires a clearer basis for deciding which criteria are relevant for a given vessel and its intended purpose or mission context. Since current evaluation practice does not adequately reflect how vessel motions affect onboard tasks, criteria should be specified based on those tasks. Therefore, a methodological framework encompassing the vessel system is proposed to perform structured, vessel-specific, task-based seakeeping evaluations.

Conceptually, the proposed framework is grounded in Safety-II, with the objective of ensuring that vessel functions and onboard tasks can be carried out successfully under varying sea conditions. Seakeeping evaluation is therefore viewed not only as a technical appraisal of vessel motion responses

but also as a broader safety assessment of whether the vessel system can function as intended in its operational environment. Methodologically, the framework is informed by a risk-based logic (see Figure 4.1). The link to risk management (Aven, 2016; Harms-Ringdahl, 2013; Leveson, 2015) follows naturally from the Safety-II perspective adopted in this research. If safety is understood not only as the avoidance of failure but also as the ability of the vessel system to function successfully regardless of surrounding conditions, then seakeeping evaluations must address both what threatens successful performance and the conditions or limits required to maintain acceptable performance. Once the solution is framed this way, a logical approach to seakeeping evaluation follows a risk-management progression: identifying motion-critical tasks; analysing how motion may affect them, and how they are linked to undesired events and limiting conditions; and translating them into seakeeping evaluation criteria and standards. Paper A already pointed in this direction by proposing that a Safety-II perspective could provide a basis for improving the specification of seakeeping criteria.

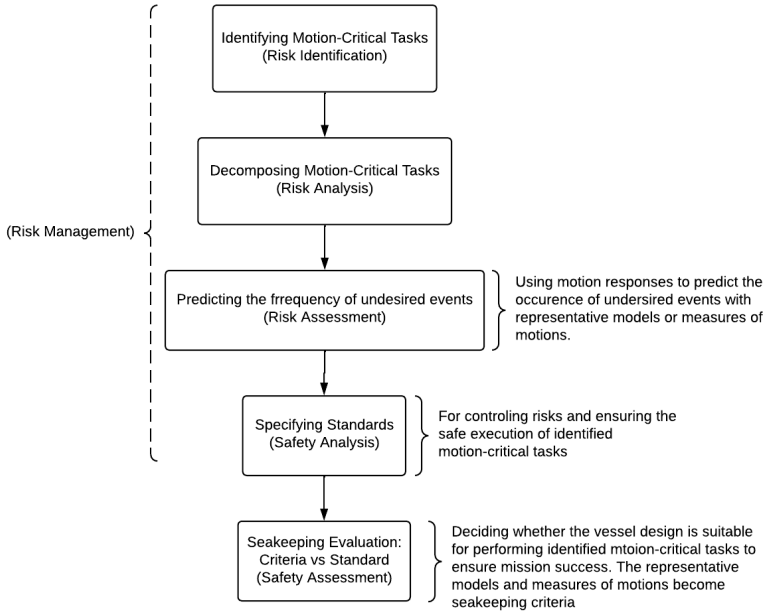


Figure 4.1. Risk management-informed logic underlying the proposed task-based seakeeping evaluation framework

The proposed framework is illustrated in Figure 4.2. The consequences of vessel motions may arise through different parts of the vessel system: the crew, onboard equipment, machinery, and hull (including stability-related responses). The framework was therefore conceived to address seakeeping evaluation across the vessel system rather than only through one isolated aspect of performance. The route from functional requirements to final evaluation is consequently structured as a progression: from identifying and analysing motion-critical tasks, through selecting and documenting the relevant evaluation criteria and standards, to predicting the vessel's motion responses and checking that they satisfy those criteria and standards, and finally to deciding whether the vessel, as designed, is suitable for its intended purpose.

A key point, however, is that although the framework has been conceived broadly to cover the entire vessel system, the studies appended to this thesis develop its crew-related branch. This emphasis is deliberate. The preliminary interviews, the focus-group discussions, and the critical review in Paper A all showed that the consequences of vessel motion for crew task performance and safety were an underdeveloped aspect of seakeeping evaluation. Existing approaches are generally better equipped to describe vessel response and some equipment-related effects than to represent how motions interfere with the successful execution of crew-related tasks. The thesis, therefore, develops the framework most fully in relation to the crew, while still retaining the broader systems perspective within which crew, equipment and hull-related effects can all be considered.

This more focused systems-oriented formulation motivates the role of task analysis in identifying and decomposing motion-critical tasks, providing the missing link between vessel function, what the crew must perform, how they interact with the machinery and equipment, and the effects of platform motions on task execution. The focus on motion-critical tasks is also deliberate. The aim is not to represent all onboard tasks, but to identify those tasks whose successful execution is significantly influenced by vessel motion and is important for mission success or safety. Such tasks are the most relevant for seakeeping evaluation because they define the moments at which vessel motions begin to constrain operational capability. The adoption of task analysis in this context reflects the view of the vessel system as a socio-technical system; thus, any examination or evaluation must reflect this nature. Paper C presents and demonstrates the role of task analysis and its

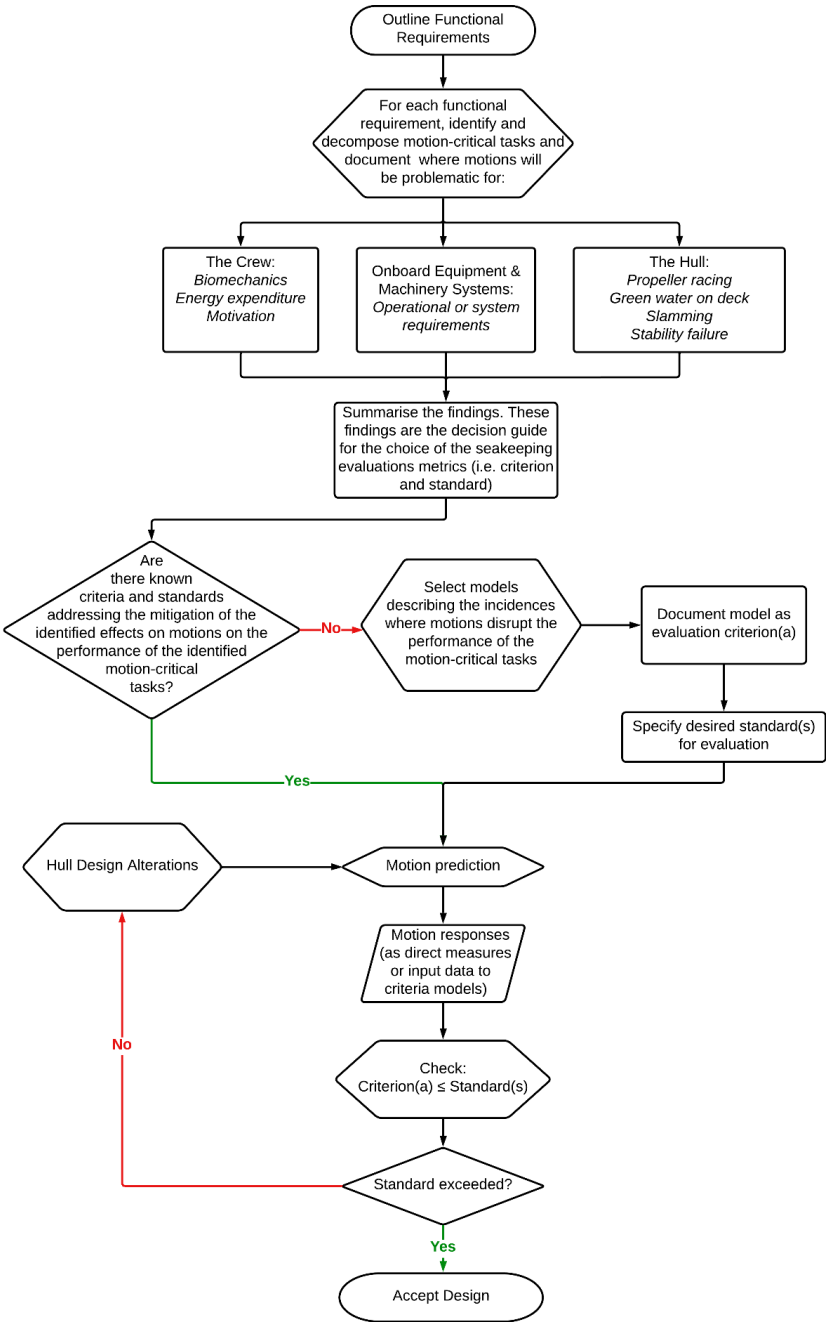


Figure 4.2. A systems-oriented seakeeping evaluation framework (adapted from Paper C)

methodological application for identifying motion-critical tasks for the crew. The identification and decomposition of motion-critical tasks, which is the first stage of the framework (see Figure 4.2), is a structured procedure. Figure 4.3 sets out this procedure in detail, showing how motion-critical tasks are identified and how the influence of motions on the crew, equipment, and hull can compromise task execution.

Papers B and C support the proposed framework in complementary ways. Paper B established that generic seakeeping criteria are insufficient for vessels with mission or vessel-specific task demands and argues that criteria should be tailored to the vessel's mission, operational contexts, and tasks to be performed on board. Paper C then developed this into a more explicit and structured framework grounded in task analysis and demonstrated its application. Together, these papers support the framework as a structured and empirically grounded response to the shortcomings identified in current seakeeping evaluation practice.

The usefulness of the framework lies in how it makes the selection of seakeeping criteria easier to communicate and more defensible. It does so by tracing the choice of seakeeping criteria back to the vessel's intended purpose, the tasks required for mission success, and the motion-related limitations that threaten their successful execution. In this regard, the framework is presented as a coherent method for structuring vessel-specific and task-based seakeeping evaluation. It offers a practical approach to bringing together functional requirements, onboard work, and motion responses into a more relevant basis for seakeeping assessments. The practical application of this framework, including how motion-critical tasks were identified and decomposed in the case studies, is presented in the following section.

4.4 Demonstrating the framework through case-based applications

The practical value of the proposed framework lies in its applicability to real vessel contexts. This section, therefore, demonstrates the framework through the case studies used in this research. The purpose is not only to illustrate the framework procedurally, but also to show how it supports an operationally relevant seakeeping evaluation. The framework is demonstrated through its application to two Swedish case-study vessels: the Swedish Coast Guard vessel KBV 202 and the Swedish Maritime Administration's fairway maintenance vessel Fyrbjörn. In Paper C, these vessels were application cases used to

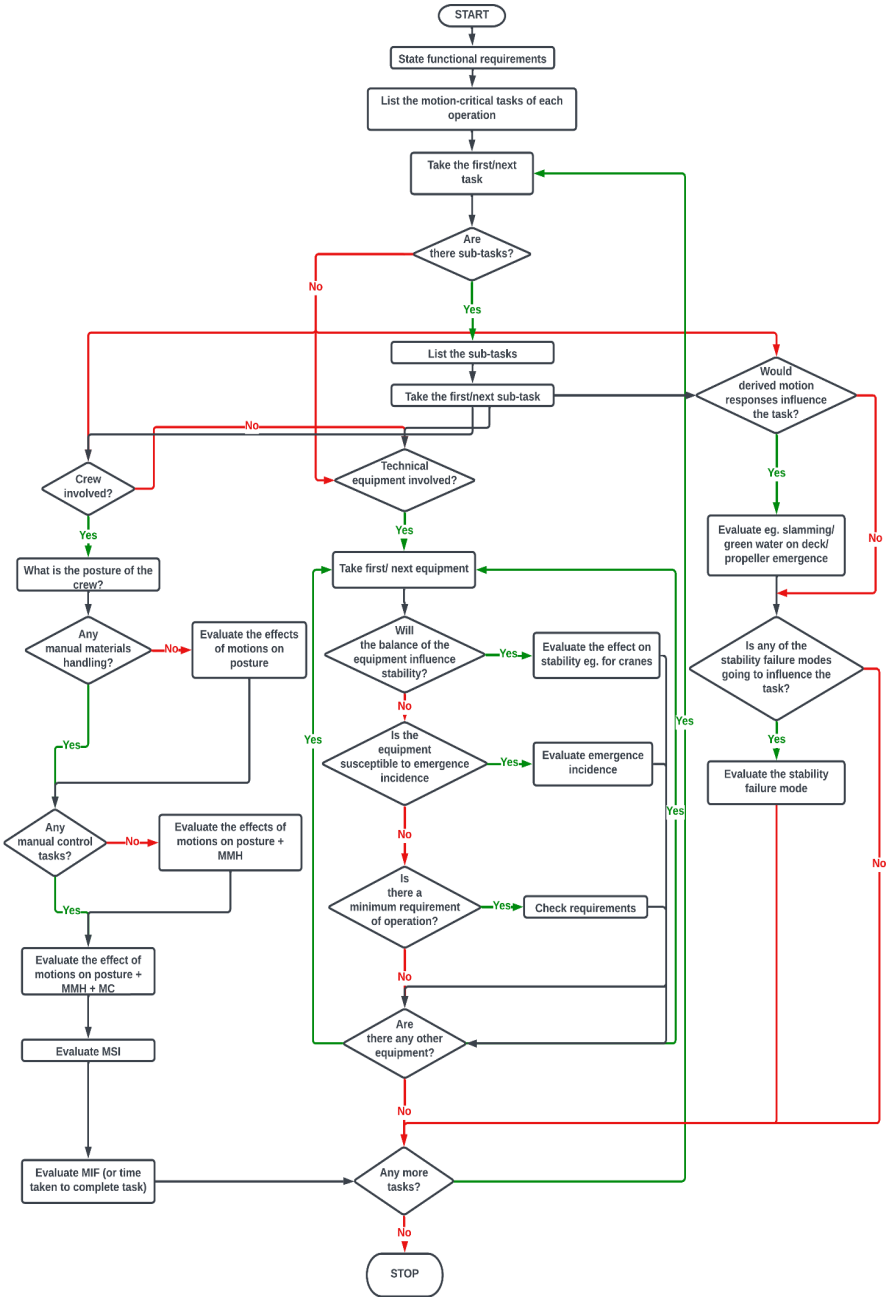


Figure 4.3. A systems-oriented procedure for identifying motion-critical tasks and the influence of motions on their execution. (MMH: manual materials handling; MC: manual control)

demonstrate how motion-critical tasks could be identified, decomposed, and translated into seakeeping evaluation criteria and standards, using the proposed framework.

The starting point in both cases was the vessels' functional requirements, understood as the operations needed to achieve the vessels' primary purpose. For KBV 202, the case-study application focused on the oil-recovery operation, which was treated as a key functional requirement of the vessel. For Fyrbjörn, the application was centred on a lighthouse replacement operation, representing a different vessel function and work context. In both cases, another objective was to show that the relevant seakeeping metrics differ with the vessel's purpose, the operations required to achieve that purpose, and the tasks the crew must carry out on board. The case studies, therefore, provided a concrete demonstration of the central claim developed in this thesis: that seakeeping evaluation metrics should not be applied generically to all vessels, but be specified in relation to vessel function, onboard tasks, and operational demands.

The implementation of the framework in these cases followed the task-analysis approach presented in Paper C, as summarised in Figure 4.4. Motion-critical tasks were identified and decomposed using Hierarchical Task Analysis (HTA) and Task Decomposition (TD), supported by interviews that examined the tasks the crew performed in their daily roles, how motions affected those tasks, and which tasks were critical for successful operations. Observations were then used to complement the interview data and support the decomposition of the identified motion-critical tasks.

The HTA showed the progression of how motion-critical tasks were performed, and the TD process focused on features that could connect onboard work to motion-induced performance limitations, namely, posture, manual materials handling, and manual control. These features were analysed in light of scientific literature to infer likely motion-induced effects, particularly Motion-Induced Interruptions (MII), Motion-Induced Fatigue (MIF) and Motion Sickness Incidence (MSI) (Wertheim, 1998). This way, the framework facilitates the move from a generic description of vessel motions towards a more explicit understanding of how motions can affect the successful execution of onboard tasks.

The two cases demonstrated this clearly. In the Fyrbjörn case, the lighthouse replacement motion-critical tasks were identified as crane operations and

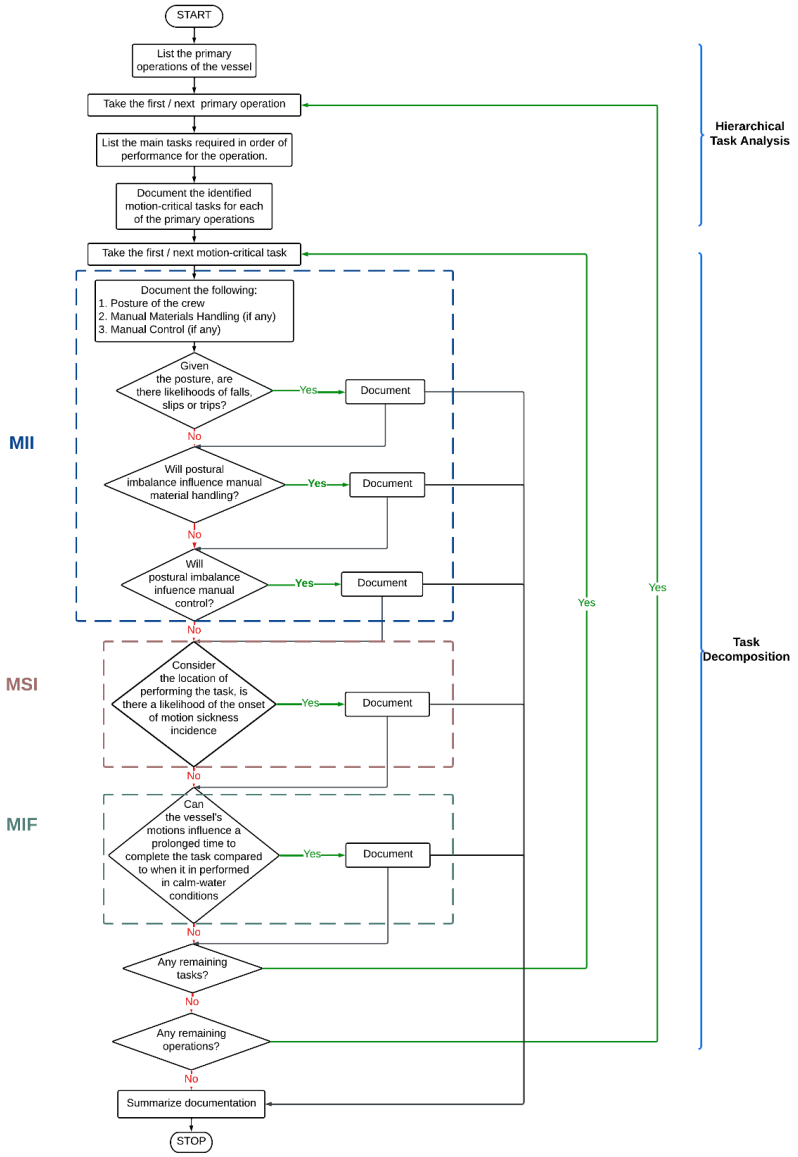


Figure 4.4. Flow chart for the data collection and task-analysis process used to identify and decompose motion-critical tasks in the case studies (from Paper C)

manual handling of loads between the vessel and the lighthouse. In the case of the KBV 202, the motion-critical tasks identified for the oil-recovery operation included fitting oil recovery cassettes through guide rails and crane operations to extend the spreader booms. In both cases, the task-oriented approach revealed that relevant seakeeping evaluation criteria could not be selected meaningfully without first understanding how the crew actually performed their tasks and where vessel motions would likely interfere with them.

The case studies also demonstrated the added value of the framework compared with more conventional seakeeping evaluation practices. The original seakeeping evaluation of the KBV 202 used general motion criteria such as roll angle, vertical and lateral accelerations, with threshold values selected from broad comfort-oriented standards. The original evaluation did not explicitly account for how motions affected specific crew tasks, nor were the criteria directly tied to the oil-recovery operation. By contrast, the criteria and standards obtained through the proposed framework were used to reassess operability. The task-based oil-recovery evaluation yielded substantially lower operability than the original general assessment, because it was evaluated against criteria specific to the demands of the oil-recovery operation rather than against generic comfort-oriented thresholds. While this does not establish whether either operability figure more accurately reflects the vessel's true operability, it shows that the task-based evaluation gives an assessment more closely tied to what the crew must actually do. Establishing which figure is more accurate would require validation against operational experience. In this way, the framework increases operational specificity by linking criteria selection directly to functional requirements.

In summary, the case studies showed that the framework can translate functional requirements into more traceable, operationally relevant seakeeping evaluation criteria. They also show that task analysis was not merely an auxiliary method but the means by which vessel function is linked to motion-critical tasks and, in turn, to the selection of criteria. A particularly important outcome of the case-study demonstrations was that task decomposition made the relevant motion-induced effects more explicit. Among these, motion-induced interruptions (MIIs) were especially important because they denoted events in which vessel motions disrupted postural stability and ongoing physical task execution. For this reason, the next section focuses more closely on motion-induced interruptions as a task-based seakeeping evaluation metric.

4.5 Motion-induced interruption as a task-based seakeeping evaluation metric

The case studies showed that vessel motions may affect crew performance through several motion-induced effects, particularly motion-induced interruptions (MII), motion-induced fatigue (MIF), and motion sickness incidence (MSI). Among these, MII warrants greater focus because it provides the most direct link between vessel motion and the immediate disturbance to ongoing work. Unlike MSI and MIF, which develop more cumulatively with exposure, MII appears as a discrete event in which motion interferes with postural stability and interrupts task continuity. Therefore, MII is examined in greater detail in this thesis. At present, the use of MII in engineering applications, such as seakeeping evaluation, is complicated because the concept has not been treated consistently in the scientific literature. Paper D addresses this problem by systematically reviewing how MII has been defined, represented, and quantified across different research studies.

Across the reviewed studies, MII is defined, operationalised and measured in different ways: sometimes as postural instability, sometimes as loss of balance, sometimes as task disruption, and sometimes through secondary indicators linked to those effects. The systematic review, therefore, showed that although MII is recognised as a meaningful performance constraint, its conceptual and methodological treatment remains heterogeneous. This makes further clarification necessary before it can be used consistently in seakeeping evaluations.

Among the clarifications in Paper D was the definition of MIIs, which the paper proposed as:

> all kinds of duty interruptions caused by the physical motion of the place where the duty is done. Whenever this motion is making an individual stop, adjusting posture, or changing pace in what they are doing, even for a short amount of time, it is an MII.

This definition retains the core idea found across the literature while broadening the concept to include general interruption of task continuity. Paper D also clarifies that using MII in seakeeping evaluations requires more than simply labelling interruptions as motion effects. Rather, for each application context, an indicator of MII must be defined, a method for estimating the MII rate must be chosen, and, finally, an acceptable standard for that rate must be set, depending on the task. This therefore places the task-

dependent evaluation of MIIs at two levels: first, selecting the threshold for interruption onset, and second, selecting the acceptable interruption rate for the task under consideration. While the first has received some attention in the literature, the second remains weakly addressed, and Paper D highlights this gap.

Paper D also shows why MII deserves particular attention in seakeeping evaluation. A further conclusion of the review is that MII can act as a bridge between operability and human performance because it directly links motion exposure to task interruption in a form usable for seakeeping evaluation. The review also shows that MII has evolved from an observed indicator of disturbed task performance to a criterion for evaluating vessel capability and task feasibility in motion-rich environments, such as on a marine vessel. In this regard, MII emerges not only as a human-response phenomenon but also as an evaluative metric for operability and task-based seakeeping evaluation.

A further practical concern is how MII rate is estimated once a context-based indicator has been defined. Existing MII estimation methods already offer several approaches to this problem. As reviewed in Paper E, these include Graham's rigid-block formulations, the inverted-pendulum models, multilink models and the generic footprint-based approaches (Graham, 1990; Graham et al., 1992; Langlois et al., 2013). Although these models differ in complexity, they are built on the same underlying biomechanical principle: balance is maintained as the effective gravity projection remains within the base of support, and interruption occurs when this balance condition is no longer sustained. Among these approaches, Graham's models have remained especially important in seakeeping evaluations because they are straightforward to implement and have supported many practical applications in design and operability assessments.

Additionally, Paper E highlights an important limitation in the current MII prediction landscape. While existing models can be useful, their practical application is limited by their reliance on anthropometric representations and prescribed stance orientations. Paper E therefore developed an estimator that predicts MIIs from the ratio of in-deck-plane resultant accelerations to the vertical acceleration at the task location, replacing prescribed body geometry with an empirically derived, task-specific threshold. The practical motivation for this is clear: in routine seakeeping analysis, the quantities most readily available are predicted vessel motions rather than anthropometric descriptors of end users. The estimator was derived as a systematic reduction of Graham's

resultant tipping and sliding conditions, and was compared against Graham's formulation to evaluate the consequences of the two reduction steps. The comparison showed that removing the rotational inertia terms changed the predicted rate only marginally for the vessel studied; their contribution diminishes for vessels with longer natural roll periods, though it may be more significant for stiffer-rolling vessels. Replacing the geometric threshold with the task-specific MII coefficient, by contrast, substantially affected the predicted rate, demonstrating that the threshold, and therefore the task being performed, is the dominant factor governing predicted MIIs. These findings reinforce the need to relate both the onset of interruptions and the acceptable interruption rate to the task being performed.

The outcomes of the research presented in this chapter show that seakeeping evaluation must move beyond the application of generic motion criteria to a vessel-specific, task-based approach. The interviews revealed the task-dependent nature of motion-induced effects, and the critical review showed the inadequacy of current seakeeping criteria and practices. In response, a task-based seakeeping evaluation framework was developed, and its usefulness was demonstrated through the case studies. The chapter further highlights both the current limitations and the potential of MII as a task-based metric, thereby strengthening the basis for crew-centred seakeeping evaluation.

5 Discussion

5.1 Implications for practice, design and procurement decision-making

A major implication of this thesis is that seakeeping evaluation practice should shift from the routine application of generic motion criteria towards vessel-specific and task-based evaluation, especially when the real concern is the safe and effective execution of onboard tasks. The findings of this research suggest that current seakeeping evaluation practices focus heavily on describing vessel responses rather than on judging whether the predicted responses will permit work on board under realistic sea conditions. The need for this shift is practically relevant because predicted motions do not communicate any meaning on their own. Rather, the significance of these predicted motions depends on how they are expressed, the threshold or acceptance basis used, and the task or functional requirement specified. To improve the benefits of seakeeping evaluation, the procedure should focus on the vessel's purpose, the tasks the crew must perform, and how motion begins to constrain these. The benefit of shifting from only describing motion responses to task-based judgements requires more than just adding to existing evaluation metrics; it requires an improvement in the approach or methodology used to select and interpret these metrics.

The findings presented in this thesis also emphasise a more useful role for seakeeping in vessel design. When seakeeping evaluation is linked to functional requirements, seakeeping assessments in vessel design become more than a late-stage verification step confirming compliance with familiar criteria. Instead, it can inform design decisions earlier in the design process by identifying where motions would compromise the vessel's operation and which

aspects of the vessel's design would require particular attention. These include workstation design, equipment location and arrangement, and crew demands at specific onboard positions.

The broader implication of this research is that seakeeping can be brought into design trade-offs in a more meaningful way. This is because the proposed framework was developed with a broader systems logic that, in principle, can support other aspects of seakeeping evaluation. These include habitability, workability, and survivability, since each can be related to motion-induced effects and consequences. The design value of the framework, therefore, includes its support for crew-centred operability assessments, as well as its ability to make trade-offs more explicit in design and decision-making. This broader evaluative logic is reflected in the proposed framework, which is grounded in the Safety-II perspective, where operability and safety are treated as integrated and not mutually exclusive.

A further implication is that vessel design processes would no longer rely on the assumption that satisfactory global motion responses reflect satisfactory operational performance. A vessel's predicted motion responses may appear acceptable when judged against generic or familiar seakeeping criteria. However, these motions may not be acceptable for the actual conditions under which the crew must live, work, and sustain the vessel's intended mission. By making the relationships between vessel motions, task requirements, and evaluation metrics more explicit, the proposed framework helps reveal such potentially misleading conclusions earlier in the design process, where they can be easily addressed, rather than after the vessel has been built and delivered.

The findings would also benefit procurement and requirement setting. Procurement documents should specify requirements that explicitly state the vessel's intended operations, the expected operating conditions, and the key onboard tasks to be supported, rather than relying mainly on general references to standards or commonly used motion criteria. A more task-oriented procurement requirements specification would also improve transparency and comparability. This way, seakeeping evaluation outputs would be easier to interpret if they made visible not only the numerical results but also the selection logic for the applied criteria and standards, and the decisions made from interpreting their outputs. This approach would help ensure a fairer appraisal of comparative hull designs, as assessment results would be directly linked to operational needs.

5.2 Methodological limitations and challenges

The findings in this thesis are shaped by the methodology used to carry out the research. The mixed-methods design of the research was a reasonable choice given the nature of the research problem. However, the practical conditions surrounding data collection place limitations on the scope and type of evidence that could be collected to support the research. Access to the vessels, stakeholders, and the observed operational scenarios was selective and based on availability. Parts of the research findings were therefore based on interpreted accounts, focused observations and available material rather than on direct observation of every relevant detail. This, however, does not invalidate the study; rather, it means that the evidence base should be understood as purposive and developmental rather than exhaustive.

A further limitation concerns the scope of stakeholder evidence from the crew and naval architects. Most of the empirical work in this thesis was conducted with crew and operators aboard vessels whose missions are highly dependent on human task performance under motion-rich conditions. This does not constitute a comprehensive representation of all vessel types or operating contexts. However, the underlying issue, that vessel motions affect the safe execution of work on board, is not unique to any particular vessel category, though its manifestation will differ across types.

There are also limitations associated with experience-based and discussion-based evidence in the interviews and focus groups. The accounts of participants reflect their own operational experiences. Recall, context dependence, and differences in roles and responsibilities or in exposure therefore influence the empirical data collected. Nevertheless, the interpretation of the empirical data collected is strengthened by triangulation. The interviews, focus groups, literature studies, observations, and case studies were used together to create a coherent interpretation of the shortcomings of current seakeeping evaluation practices. Overall, this triangulation of methods strengthens the credibility of the interpretation.

5.3 Broader considerations: sustainability and diversity

Maritime shipping and other maritime operations are deeply embedded in the global economy and everyday life, providing essential services ranging from international cargo transport and energy supply to coastal safety,

environmental protection, and the maintenance of critical marine infrastructure. At the same time, these operations have significant sustainability implications across all three dimensions: environmental, social, and economic. On the environmental side, shipping is a major contributor to greenhouse gas emissions, air and noise pollution, and the risk of oil spills and other forms of marine contamination, with direct consequences for climate stability (SDG 13), ocean health (SDG 14), and marine and coastal ecosystems (SDG 15). Socially, maritime operations create employment and support livelihoods in coastal communities, but also expose workers to demanding and sometimes hazardous conditions that place pressure on health, safety, and wellbeing (SDG 3, SDG 8). Economically, the efficiency and reliability of maritime services have broad consequences for supply chains, national infrastructure, and public services. These implications are not without tension. Critical scholarship has questioned whether growth-oriented "blue economy" framings genuinely serve sustainability, or whether their environmental and social benefits and costs are distributed unevenly, particularly across the Global South (Bond, 2019; Childs & Hicks, 2019; Ertör & Hadjimichael, 2020). This is a reminder that broad framings can obscure what they are meant to serve: just as generic seakeeping criteria can overlook the particular vessel, task, and crew they are meant to serve, a growth-oriented sustainability agenda can overlook the particular communities it affects.

Given this background, the most direct sustainability contribution of this research lies in the social dimension, specifically in the relationship between vessel design, crew working conditions, and well-being. A vessel whose seakeeping limits the safe performance of onboard tasks, generates excessive fatigue, or renders certain operations unsafe, fails not only as a technical system but as a working platform. The consequences are not only acute: persistent exposure to motion-rich environments has cumulative effects on crew health, contributing to musculoskeletal strain, chronic fatigue, and an increased risk of injury over time. Beyond individual health, these conditions affect workforce sustainability; experienced crew who routinely operate in poorly designed motion environments are more likely to leave their roles, taking with them operational knowledge that is difficult to replace. These concerns are directly relevant to SDG 3 (good health and well-being) and SDG 8 (decent work and economic growth, specifically Target 8.8 on safe and secure working environments). By placing crew task performance and motion-induced effects at the centre of the evaluation framework, this thesis advocates for vessel designs that treat the working conditions of crews as a primary

engineering concern rather than a secondary consideration. This approach recognises the vessel as a motion-rich workplace where continuity of work, crew well-being, performance, and productivity must be preserved against the inherent challenges of the sea environment, and where the sustainability of the workforce itself depends on getting the design right.

Social sustainability in the maritime domain also encompasses questions of inclusion and diversity, and these are not separable from the seakeeping evaluation problem. The physiological and anthropometric models that govern conventional motion-effects criteria, including MII and MSI models and whole-body vibration standards, were developed predominantly from studies of military personnel, historically a narrowly defined population in terms of gender, age, and physical profile. As a result, the assumptions embedded in these models do not adequately represent the range of individuals who work at sea, particularly as the maritime industry works towards a more gender-diverse workforce (SDG 5, SDG 10). The task-informed MII estimator developed in Paper E partially addresses this by deriving interruption predictions from local accelerations rather than prescribed body geometry, reducing but not eliminating the dependence on historically constrained anthropometric defaults. More broadly, a task-based seakeeping evaluation framework is structurally better placed to accommodate diversity than generic criteria, because it grounds the evaluation in what specific crews must actually do rather than in population averages. If the crew of a given vessel includes workers with varying physical profiles, ages, or capabilities, the task analysis can in principle be conducted with those workers and their specific demands integrated into the evaluation basis. This does not mean the framework, as demonstrated here, fully resolves questions of diversity in vessel design. The case study crew were not characterised by gender or physical diversity, and acceptable MII rates for specific tasks across diverse populations remain an open research question. Rather, the framework creates the structural conditions through which these questions can be addressed more systematically in future work, contributing over time to more inclusive evaluation standards (SDG 16).

A related dimension of diversity concerns the research community itself. Seakeeping research has historically been produced in a small number of industrialised regions, with little representation from large parts of the world, including much of Africa. This concentration shapes which vessels, operations, and crew are treated as the implicit reference case. A task-based evaluation

framework, grounded in the specific demands of a given vessel and its crew rather than in generic assumptions, is inherently less bound to any single regional default. Expanding the geographic base of seakeeping research would further strengthen the field's capacity to serve the full range of contexts in which vessels are designed and operated.

The research also has implications for environmental and economic sustainability, most directly demonstrated through the two case-study vessels. The Fyrbjörn is engaged in fairway maintenance, including lighthouse replacement operations, work that is essential for safe marine navigation, which in turn supports the efficient and low-risk movement of vessels through Swedish coastal waters. Delays, accidents, or failures in this work have environmental consequences, as navigational failures at sea can lead to groundings, collisions, and associated pollution, all of which threaten the marine environment (SDG 14). They also impose economic costs through infrastructure downtime, emergency response, and lost operational capacity. By enabling a more realistic evaluation of whether Fyrbjörn can safely support these operations under expected sea conditions, the proposed framework contributes to more durable and effective procurement decisions and, in turn, to the long-term sustainability of the maritime infrastructure these operations serve. Similarly, KBV 202 is engaged in oil spill recovery, a mission whose primary purpose is the protection of the marine environment (SDG 14, SDG 15). The effectiveness of this mission depends directly on the crew's ability to execute specific, physically demanding tasks under realistic sea conditions. A seakeeping evaluation that does not adequately reflect these task demands risks producing a vessel that is assessed as compliant but operationally limited precisely when its environmental mission is most urgent. The task-based framework, by contrast, ties the evaluation to the conditions required for the oil-recovery operation to succeed, making it a more environmentally meaningful basis for design.

Taken together, these considerations suggest that seakeeping evaluation is not a narrowly technical matter. The way vessel performance in waves is assessed and what counts as acceptable has consequences for who can work safely at sea, how reliably critical maritime services can be delivered, and how well vessels can fulfil environmentally significant missions. A more systematic, crew-centred, and task-based evaluation approach can, therefore, support safer, more inclusive, and more effective maritime operations in ways that align with the broader aims of sustainable development.

5.4 Implementation pathway and recommendations

If the proposed seakeeping evaluation framework is to be implemented in practice, it must be usable. The practical workflow begins with defining the vessel's mission and the operating context in which its seakeeping performance must be judged. From there, the functional requirements pertaining to that operation must be outlined, and the motion-critical tasks identified from the specified functional requirements. These motion-critical tasks must be examined closely to determine when motions become problematic for successful execution. With this information, the evaluation metrics and acceptance levels can be defined. Only after these metrics are defined should motion responses be predicted and quantified at the relevant onboard positions to feed into the evaluation logic. The value of the workflow is that it keeps seakeeping analysis and seakeeping evaluation distinct yet linked.

A meaningful seakeeping evaluation should document more than numerical output alone. The goal of a seakeeping evaluation is to support design or procurement decisions; explicit documentation of the mission profile, the tasks that define the evaluation basis, the chosen evaluation metrics, the modelling assumptions used, and the operational interpretation of the evaluation results is therefore necessary. If these elements are absent, even technically correct results would be difficult to interpret, communicate, and defend to concerned stakeholders, particularly vessel owners.

This recommendation follows directly from one of the strongest motivations for developing the proposed framework: improving the traceability and defensibility of the metrics used to evaluate a vessel's seakeeping, especially in design comparisons or procurement decisions. Given that a seakeeping evaluation is intended to reflect functional requirements and end-user needs, the logic behind the procedure must be transparent. A vessel-specific seakeeping evaluation therefore needs to communicate not only what was predicted or calculated, but also why those results were relevant for the evaluation and how the resulting judgement should be interpreted for decision-making.

6 Conclusions

The aim of this thesis was to develop a systematic approach to seakeeping evaluation. This aim was achieved by creating and demonstrating a vessel-specific and task-based seakeeping evaluation methodology. The methodology provides a structured means of translating specified functional requirements and end-user needs into relevant criteria and standards for evaluating the suitability of vessel designs for their intended functions and supporting procurement decisions.

This thesis was guided by the following research questions:

i. What limitations arise in current seakeeping evaluation practices?
ii. How can seakeeping evaluations be structured as a systematic, vessel-specific process that maps functional requirements and end-user needs to a communicable and defensible set of evaluation metrics (including task-performance indicators)?
iii. How can the identified evaluation metrics be predicted efficiently for a seakeeping evaluation?

Regarding the first research question, this thesis shows that current seakeeping evaluation practices are limited by their reliance on generic seakeeping criteria and response descriptions that do not adequately reflect the onboard task demands and operational profiles.

Regarding the second research question, this thesis shows that seakeeping evaluations can be structured as a systematic, vessel-specific, and task-based process through a framework grounded in socio-technical systems thinking, task analysis, and Safety-II principles. These foundations provide the basis for relating functional requirements and end-user needs to relevant seakeeping

criteria and task-performance indicators. The practical value of the framework was demonstrated through two case studies involving vessels with motion-critical operations. By applying the framework, structured documentation detailing the procedural logic used to derive the seakeeping criteria and standards for the evaluation was produced. The framework output was then interpreted to determine whether the vessel's specified functional requirements could be met. Overall, the framework provides a transparent and defensible basis for communicating the evaluation logic to relevant stakeholders, particularly vessel owners, to support design and procurement decisions. The framework is also centred on identifying motion-critical tasks from the functional requirements, thereby narrowing the scope of tasks to investigate and making it easier to identify motion-induced effects.

Regarding the third research question, this thesis shows that these motion-induced effects can be predicted using models that describe how motions affect task performance, with response inputs obtained from seakeeping analyses. Such models may be selected from the existing scientific literature or developed by mechanically representing the physical phenomenon. Within the proposed framework, model selection is guided by decomposing motion-critical tasks to identify motion-induced limitations affecting task execution.

In addressing these research questions, this thesis makes the following key contributions to knowledge and practice. It provides a structured account of seakeeping criteria and standards from well-established sources, cataloguing them into a single reference document. It identifies limitations in current seakeeping evaluation practices and proposes a more vessel-specific, task-based approach to enhance their value in vessel design. It also introduces a structured framework for conducting seakeeping evaluations and an estimator that predicts MII from local accelerations against task-defined empirical thresholds, without prescribed stance geometry or orientation.

Nevertheless, this thesis does not provide an exhaustive treatment of the topic. Although it has demonstrated the value of a systems- and task-oriented approach to seakeeping evaluation, several aspects remain for further research and development. The applicability of the proposed framework was only demonstrated on two vessel types. Future work should therefore include testing the framework on a wider range of vessel types and operational contexts, including recreational, merchant, and naval vessels, in order to examine its broader applicability. It would also be valuable to apply the framework to multiple functional requirements in parallel, to better reflect the

multi-functional nature of many vessels and to identify where trade-offs may arise between competing or overlapping demands. This would support more informed design and procurement decisions by clarifying which requirements can be satisfied simultaneously and which should be prioritised. Further research is also needed to support the development of standards in the form of acceptable values or event rates for generic onboard tasks, potentially through risk-based approaches. Another valuable direction would be to develop a database of threshold values for the onset of motion-induced interruptions in generic onboard tasks, particularly manual materials-handling tasks. This would support a more systematic specification of acceptable event rates for future task-based seakeeping evaluation standards. Finally, the practical value of the framework would be strengthened by applying it in a real early-stage vessel design project or in the evaluation of already-built vessels for alternative purposes, so that its usefulness for design iteration and procurement could be examined under realistic constraints.

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Appendix

Appendix A – Participant informed consent

The following is the participant informed consent script read at the start of each interview.

Introduction to the PhD topic and the project

Thank you for scheduling this meeting with me today.

- My PhD studies are being done within a national project named ASK-arbetsbåtarssjöegenskapskriterier, funded by Trafikverket, as you are well informed about now.
- This project is a collaboration between Swedish maritime consultancy SSPA Sweden AB and the technical university KTH.
- To date, there is no well-defined universal set of seakeeping criteria or seakeeping performance requirements when designing a new workboat or assessing whether it has good performance relative to other vessels of the same type. This is what the ASK Project seeks to address.
- The current step in the project is to interview operators of smaller work boats and map working conditions on board, i.e. to identify the different tasks, operations and machinery systems/equipment that are influenced by the seakeeping performance, with particular interest in the Pilot Boat, Fairway Maintenance and Icebreaker fleet of Sjöfartsverket.
- I wish I could do all the interviews in person and visit the boats, but it's not possible at the moment, so instead, you can try to explain things to me as best as you can, and if you want to share your screen with me to show me pictures or such, that's possible, and it's appreciated!

Consent to record

Firstly, do you mind I record this interview? The purpose is for me to be able to go back to the recordings of all my interviews later and analyse the answers and the best way forward in my studies.

(recording begins)

Now I would like to inform you that:

- This recording will only be used by me and possibly my supervisors in the context of the project, and it will not be published.
- The collected data will be stored, consulted, analysed, and utilised for publications, presentations, and educational events for the purposes of the ASK project and for research and education at SSPA and KTH.
- The data will be anonymised, and no publications or presentations will identify you by name. Perhaps I would like to refer to your company and role in the company. Would this be possible, and how would you prefer to be referred to?

- If during today's interview you want to withdraw from participating, you are free to do that. And we will delete your data.
- Later in the study, I can show you my papers and excerpts with your transcripts for your input.

Do you have any questions? Do you consent to the usage of data under these terms?

(yes or no; consent confirmed)

Now, can you give me some basic information about yourself before I start the main questions?

Closing

Thank you so much for your time!

Can I keep your contact and contact you again if I have any additional questions later?

If you share any pictures, company documents or other materials with me, are you okay with me utilising these pictures/videos in my publications and presentations?

If you yourself have any questions or comments concerning this study, you may contact me.

Appendix B - Interview questions for mapping working conditions

The following question guide was used in the interviews. "(vessel type here)" was replaced with the vessel relevant to each participant.

Intro questions:

1. Summarise the main purpose of (vessel type here)? (any other uses?)
2. Which station are you based?
3. Do you use different (vessel type here) models for different occasions? Elaborate.

Main questions:

4. What are the different tasks you perform on a daily operational basis on a (vessel type here), by you and your colleagues?
5. Are any of the identified tasks limited by ship motions? Could you elaborate by matching the identified tasks and the machinery/equipment involved to the motions, limiting them?
6. Do these limiting motions compromise safety in your working environment? Elaborate.
7. How often are these limiting motions encountered?
8. Is it related to the seaway of travel or resulting from bad weather?
9. Do you still perform those tasks anyway?
10. How does one decide to continue or to discontinue these tasks?
11. Are there any existing criteria/rules developed by Sjöfartsverket/SSRS based on these limiting motions, e.g. halting deck operations when roll angles are greater than 25°? Elaborate.

Seakeeping & Criteria:

12. Can you categorise the seakeeping performance of the (vessel type here) you work on?
13. Based on what criteria/properties have you made this categorisation?
14. Are you of the view that operator skills influence the seakeeping performance of the (vessel type here)?
15. Are you / have you been involved in the procurement process and/or influenced the choice of new (vessel type here)? If so, elaborate.
16. Elaborate on the seakeeping properties of the (vessel type here) that matter most for efficient performance in rough weather.

17. Would you have any specific design recommendations for a new (vessel type here) to optimise it for the most important seakeeping property you have identified?
18. Any other recommendations or ideas?

Appendix C - Focus group discussions with naval architects

The following question guide structured the focus group discussions with naval architects.

1. How do you understand seakeeping?
2. When a customer comes to you to ask for a new design, how much of it is dedicated to the seakeeping characteristics of the design?
3. How do you, as naval architects, wish to receive the requirements/specifications from the customers?
4. How is seakeeping addressed today during
    a. procurement,
    b. tender formulation,
    c. contract specification
    d. and ship design?
1. Do you have insight into how the tasks are performed onboard and the views of the crew?
    a. How is this investigated?
2. How do you transform such requirements into a concrete, tangible and measurable design that can be assessed and compared against the seakeeping of other similar vessel designs?
3. How do you incorporate Nordforsk or other established seakeeping criteria in the design?
    a. Nordforsk or which criteria do you use?
    b. And how do you combine that with the customers' requirements?
4. How is seakeeping followed up in relation to other design aspects?
5. To what extent are requirements actually evaluated?
    a. what impact do doubtful evaluation results have when a vessel is finally delivered?
6. What criteria are missing?
    a. For what sort of vessel?
7. How would you like them to be developed and presented for your future use?
8. How do you make sure that you meet these?

Appendix D - Identifying motion-critical tasks for seakeeping evaluation

The following questions structured the interviews used to identify and decompose motion-critical tasks. Participants were given the background and definition of a motion-critical task before the task-specific questions.

1. [Tailored to the participant's employment status to establish the vessel types they have worked on or currently work on.] For example, what type of vessel are you working on? / Which types of vessels have you worked on? What are/were the primary operations of this vessel?
2. What is/was your role onboard?
3. What tasks do/did you perform in your role that contribute(d) to the primary operations of this vessel?
4. Can you identify which of these tasks you must perform in your role that are/were motion-critical, per the given definition of a motion-critical task? (here, it is assumed that the participant has been given the background and definition of a motion-critical task)
5. For each of the primary operations of the vessel you mentioned, is/ was there a specific order in which the tasks required for the operation were performed?

a. Can you walk through this order to the best of your recollection?

b. Can you identify which of these tasks in the order you have mentioned is/was/are/were motion-critical?

c. Elaborate on how motions limit(ed) the performance of these motion-critical tasks.

d. Do/did any of these tasks require the duties of your role? If yes, elaborate.

e. Preamble: For each of the motion-critical tasks identified, the participant is to answer the following:

   i. What is/was the main posture when performing this task? Are you standing, sitting, crouching, or kneeling?

   ii. Does/did the task require large movements of the arms, e.g. lifting, lowering, pushing, pulling? If yes, mention which arm movements.

iii. Does/did the task require using fine movements of the fingers, e.g. tracking, tracing or typing/button punching? If yes, mention which.

6. Has there been any point where the decision to discontinue these tasks has been made? If yes, what was the underlying cause/factor for this decision?
7. Specify true/false for the following statements regarding the motion-critical tasks.
    i. It is complex to perform with vessel motions and may lead to injuries or accidents.
    ii. It has to be performed within a specified time frame.
    iii. It requires precision.
    iv. It requires coordination.

Appendix E - Demographics Form

Subject ID: _____

1. Gender

☐ Female

☐ Male

2. Nationality:

   _____
   _____

3. Year of Birth:

   _____
   _____

4. Academic Background:

   _____

5. Current Position at Sjöfartsverket

☐Navigator (master/watch officer)

☐ Pilot

☐ VTS operator

☐ Simulation training instructor/navigation lecturer

☐ Hydrographic Surveyor

☐ Student/cadet

☐ Other (please specify):

_____

6. Number of years working in position:

   _____

7. Other Maritime related positions ever held:

   _____

At Sjöfartsverket or other:

_____

For how long:

_____

8. Besides the current position you have at Sjöfartsverket, do you have any other positions anywhere else at the same time? (e.g., part of any management team or advisory board, or part of any ongoing projects etc):

   _____

9. Highest rank obtained

☐ Student/cadet

☐ Third mate

☐ Second mate

☐ Chief mate

☐ Master

☐ Other (please specify):

_____

10. Total years spent working at sea:

    _____

11. Total years of onboard navigation experience:

    _____

12. Types of vessels worked on:

☐ Pilot boat / craft

☐ Fairway Maintenance Vessels

☐ Icebreakers

☐ Rescue Boats

☐ Hydrographic Survey

☐ Military Coastguard Vessels

☐ Tug boat

☐ Multipurpose vessel

☐ RoRo

☐ LoLo

☐ Passenger/cruise ship

☐ Dry bulk

☐ General cargo ship

☐ Liquid bulk ship/tanker

☐Container ship

☐ Offshore ship (supply, anchor handling, salvage, etc.)

☐ Other (please specify):

_____

NOTES:

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Appended Papers