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Charting the Course: Human Factors Research for Shipping Energy-Efficient Operations

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ABSTRACT

To achieve climate objectives, it is essential to close "energy efficiency gaps"—the discrepancies between potential and actual energy savings. While much research in the maritime sector has focused on policy and onshore influences, it is unclear to what extent research is overlooking the potential of onboard human factors to mitigate climate impact. This study addresses this gap through a systematic literature review of the results sections of 17 journal articles on maritime human factors. Using Thematic Analysis, we generate 12 themes, with the most prominent being *stakeholders*, *knowledge*, and *technical implementation*. These themes provide insights into onshore influences, seafarers' expertise, as well as examples of the usage and limitations of implemented systems. Conversely, underrepresented themes such as *learning*, *system properties*, and *safety* referring to how seafarers acquire knowledge, specific design guidelines for onboard technology, or how to overcome the goal conflict of energy efficiency and safety. Our findings underline that key areas in this field have been studied disparately, and that a complete picture is necessary to close the energy efficiency gap here and in other sectors.

Keywords: Energy efficiency, Human factors, Shipping, Maritime operations, Sustainable mobility

INTRODUCTION

In 2018, shipping was responsible for 3% of global carbon emissions, a figure that could grow by 50% by 2050 without industry-specific strategies (International Maritime Organization (IMO), 2021). The volatility of energy costs, which can account for up to 70% of a ship's operating costs (Rehmatulla and Smith, 2015), propels operators towards reducing fuel consumption, resulting in both economic and environmental advantages. The IMO introduced regulations, including the MARPOL Annex VI (IMO, 2011), to further environmental sustainability and meet climate objectives, implementing operational measures such as the Ship Energy Efficiency Carbon Intensity Indicator (CII) further evaluates large vessels' efficiency based on CO_2 emissions per cargo-carrying capacity and nautical mile (IMO, 2018). Yet, the anticipated reduction in shipping emissions is still unachieved, leading to "energy efficiency gaps", disparities between current or expected energy consumption and optimal energy usage (Acciaro et al., 2013; Jaffe and Stavins, 1994; Johnson and Andersson, 2016).

Although operational measures like slow steaming, weather routing, trim optimisation, hull and propeller maintenance, conserving auxiliary engines, and using energy-efficient appliances exist (Balcombe et al., 2019; Faber et al., 2011), they can conflict with interests of stakeholders onboard as well as onshore. For example, turning off onboard auxiliary engines, considered operationally unnecessary, might oppose a captain's safety concerns about backup generators (Ballou, 2013). This further demonstrates that barriers to energy efficiency, usually associated with economic and organizational elements within shipping companies (Poulsen et al., 2022; e.g., Rehmatulla and Smith, 2015), also include ships' crews having to make decisions in the complex and uncertain scenario of shipping operations (Zoubir et al., 2023).

One method to overcome this barrier is the development of technical systems, especially decision support systems. Previous work in this direction examines the implementation of new navigational tools from a sociotechnical perspective (Man et al., 2018; e.g., Viktorelius and Lundh, 2019). Yet, as the authors themselves suggest, there still remains potential in research with a focus on specific design implications and best practices, or in expanding on these findings from within e.g., a user-centered design process in the sense of ISO 9241–210 (ISO, 2019, p. 92) aiming for integrated, concrete (i.e., non-theoretical) solutions.

The objective of this paper is to present a systematic analysis of the current literature on maritime human factors concerning energy efficiency which involve ship crews, the analysis of the results of these papers and in the discussion derive key points for a research agenda.

METHOD

To conduct the systematic review, we included a structured and exhaustive literature search of previous papers in the research area via Google Scholar and ScienceDirect, as well as a forward-backward search. The search term for the systematic literature search followed the PICo scheme (Stern et al., 2014), which suggests terms for population, interest and context. *Population* was defined by the term "ship" as the most common term for the working environment and was a root word for further inflections (e.g. shipping). Our *Interest* was with the experience and behavior of seafarers, which is covered by the fields of "Human Factor OR Psychology". The *Context* was defined in the search by the term "Energy Efficiency AND IMO", as any applicable maritime research would cite IMO regulation (e.g., the Ship Energy Efficiency Management Plan). The search covered the period from 2011 to 2021. The beginning of the period in 2011 served to limit the search to publications only after the announcement of the MARPOL Annex VI (IMO, 2011) which extended energy efficiency regulations for new and existing ships. See *Figure 1* for an overview of the literature search and Table 1 for a full list of all papers included.

We applied Thematic Analysis (TA) to analyze the results from the perspective of energy efficiency. TA was chosen due to its flexibility and ability to explore heterogeneous data in detail (Braun and Clarke, 2006). A distinction was made between the data corpus (entire publications) and the data set for the analysis, which refers only to results. The data set was coded inductively, and on a semantic level of overt meaning, as we were interested in the explicit report of results. Coding was carried out with the aid of MAXQDA 2018 (Verbi, 2017) and consisted of the six phases as defined by Braun & Clarke (2006). Coding and theme creation was conducted iteratively with two of the authors (MZ and MG) who had previous experience, and with two student researchers. To ensure clarity, only text segments based on generated results of the researchers were coded (references to other research results were not coded to avoid double coding). Units of meaning (e.g. result, evidence or paraphrasing) were coded together to avoid redundancy.

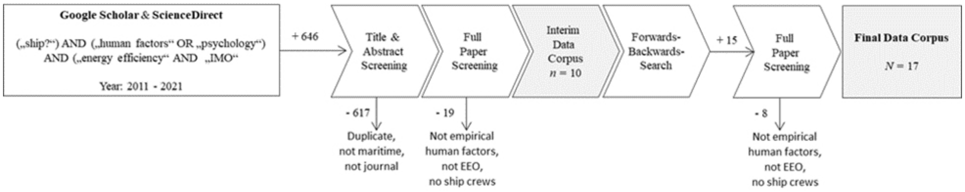

Figure 1: Procedure of the systematic literature search.

Table 1. Final list of papers included for analysis.

Reference	Paper Title
Banks et al. (2014)	Seafarers' current awareness, knowledge, motivation and ideas towards low carbon energy efficient operations
Beşikçi et al. (2021)	Determining the awareness and knowledge of officers towards ship energy efficiency measures
Dewan et al. (2018)	Barriers for adoption of energy efficiency operational measures in shipping industry
Hammander et al. (2015)	How do you measure Green Culture in shipping? The search for a tool through interviews with Swedish seafarers
Hansen et al. (2020)	Making shipping more carbon-friendly? Exploring ship energy efficiency management plans in legislation and practice
Jensen et al. (2018)	Energy-efficient operational training in a ship bridge simulator
Johnson et al. (2014)	Barriers to improving energy efficiency in short sea shipping: an action research case study
Johnson & Andersson (2016)	Barriers to energy efficiency in shipping
Lützen et al. (2017)	Energy efficiency of working vessels – A framework
Man et al. (2018)	Maritime energy efficiency in a sociotechnical system: A collaborative learning synergy via mediating technologies
Man et al. (2020)	From ethnographic research to big data analytics – A case of maritime energy-efficiency optimization
Poulson & Sampson (2019)	'Swinging on the anchor': The difficulties in achieving greenhouse gas abatement in shipping via virtual arrival
Rasmussen et al. (2018)	Energy efficiency at sea: Knowledge, communication, and situational awareness at offshore oil supply and wind turbine vessels
Viktorelius & Lundh (2019)	Energy efficiency at sea: An activity theoretical perspective on operational energy efficiency in maritime transport
Viktorelius (2020)	Adoption and use of energy-monitoring technology in ship officers' communities of practice
Viktorelius et al. (2021)	Automation and the imbrication of human and material agency: A sociomaterial perspective
Von Knorring (2019)	Energy audits in shipping companies

RESULTS

After analysing the results of 17 papers from the perspective of energy efficiency, 696 text segments were assigned to a total of 35 codes (with multiple assignments possible $N = 1102$), which in turn were assigned to twelve overarching themes. The following section describes each theme, its subthemes and gives examples, while Figure 2 gives an overview and displays proportion.

Most often, codes were assigned to the theme of *stakeholders* ($n = 201$), describing results applicable to onshore actors such as charterters, shipping companies, port authorities or other non-ship organizations. This theme included results pertaining to regulations (e.g., the SEEMP or EEOI), economic factors (e.g., principal agent problems between onshore parties, i.e. owners and charterers), or conflicts of interest between onshore and onboard motivation for EEO. In the latter, e.g. Hammmander et al. (2015) describes the conflict between a ship's motivation to replace a hydraulic hose, which was an environmental issue, but conflicted with onshore budgeting priorities.

Knowledge ($n = 153$) was explored in different forms, either as technical knowledge (e.g., understanding of onboard systems and their interactions), experience knowledge (i.e., information resulting from previous experiences while on the job), awareness (e.g., to what extent seafarers were conscious of the environmental impact of shipping or their role in EEO) or knowledge without specification. In contrast, *learning* was not often coded as a result ($n = 65$), and was either generalized learning or referred to formalized training, e.g. computer based training or as part of programs initiated by the shipping company. Of note is the overlap of codes on experience knowledge and learning, which underlines how seafarers' experience is shared with new crew members (e.g., Hansen et al., 2020). The *implementation* of *technology* ($n = 137$) or *operations* ($n = 130$) were often reported in the results, either as the objectives of the papers were the observation of such implementations, or seafarers reported on measures after the fact. Both themes included a subtheme on 1) benefits, such as seafarers realizing they can improve energy usage through better maneuvers without compromising punctuality (Viktorelius, 2020), 2) hindrances, such as mismatches between perceived complexity of a task and crews' willingness to invest time (Viktorelius and Lundh, 2019), or 3) consequences for future iterations such as the setting of clearly defined goals and the monitoring of these by a designated seafarer (Hansen et al., 2020).

The theme *communications* ($n = 108$) discussed two primary forms. Firstly, onboard information was communicated formally (e.g. during safety meetings) or informally (between officers e.g. in the mess). Secondly, between onboard and onshore stakeholders, which, in regard to EEO, ranged from close collaborations with e.g., via an environmental manager (Viktorelius, 2020) or to one-sided, with e.g., ships submitting requests but not receiving responses (Hammander et al., 2015). Another form of note is that of reporting (e.g. noon-reports), which was used e.g. to report fuel consumption "to prove that speed demands are met" (Hansen et al., 2020, p. 7).

Key *challenges* in regard to EEO included 1) task complexity, such as with analysis of large amounts of data (Viktorelius and Lundh, 2019), 2) balancing different goals, such as safety, economy, efficiency and environmental concerns (Hansen et al., 2020), 3) maintaining autonomy from employers, such as not wanting to be constantly monitored (Viktorelius, 2020), 4) uncertainty, e.g. regarding destinations, or 5) high levels of workload or fatigue, especially on smaller vessels (Poulsen and Sampson, 2019).

Results on seafarers' *attitude* ($n = 88$) often included descriptions of their stance on EEO, often as a concern for the environment, which was repeatedly coded as a motivator alongside a wish to have a good corporate relationship with external stakeholders. Stakeholders were also mentioned in the subtheme responsibility, which included segments reporting some seafarers rejecting personal responsibility, e.g. by blaming timetables set by external stakeholders (Viktorelius and Lundh, 2019).

Finally, we generated themes without subthemes. *Planning* ($n = 39$) referred to the process of how EEO were carried out or could be improved upon, e.g. by the bridge consulting with the engine department (Man et al., 2018). *System properties* ($n = 37$) described results specifically addressing elements of technical systems or interfaces, e.g. that the display of consumption rates and total fuel consumption were not useful for self-evaluation or navigational DSS (Man et al., 2018). *Safety* ($n = 26$) described this aspect beyond being a challenge, as was the case with the learning curve of officers who were previously fixated on safety but eventually found a balance between it and managing energy efficiency (Jensen et al., 2018). Lastly, the physical theme of *material* ($n = 11$) covered e.g. the spare parts used to maintain vessel machinery and their availability (Banks et al., 2014).

DISCUSSION

We conducted a systematic literature review of 17 papers of maritime human factors in energy efficient operations with a focus on ship crews. The generated results of these papers were analyzed with Thematic Analysis. Based on the number of codes assigned to the inductive themes, we found a large number of results on stakeholders, knowledge and implementation of technical systems and operations, while there is potentially a research gap regarding learning, system properties, and safety. Our findings underline that key areas in this field have been studied disparately, and that a complete picture - especially of complementary subjects - is necessary to close the energy efficiency gap here and other sectors. Insofar we propose two central research needs.

Increase Knowledge With Low-Workload On-The-Fly Training

Firstly, there is a discrepancy between research on seafarers' knowledge and how this knowledge is to be acquired. Previous research has shown that missing knowledge is a hinderance to crew implementing energy-efficient operations, and conversely, crew members with more technical training do not perceive knowledge as such a barrier (Zoubir et al., 2023). Similarly, e.g. Jensen et al. (2018), show that seafarers reflecting on their use of technical tools (thereby gaining experience knowledge) can reduce the fuel consumption of a vessel by 10%. At the same time, workload is a key challenge, with seafarers' calculating the likelihood of technical or operational implementation as a trade-off of fuel saving against how much time and effort would be required (Viktorelius, 2020). By integrating these findings, we propose that one key research need is to understand how seafarers can learn on the job without increasing workload.

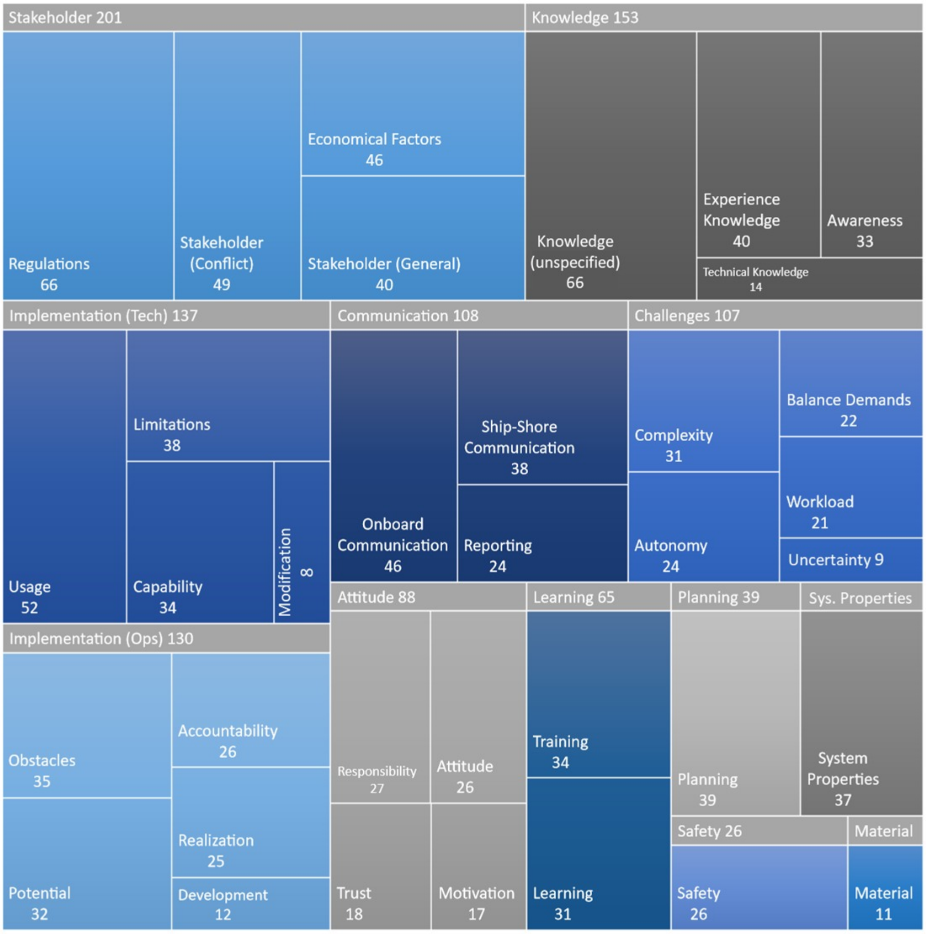

Figure 2: Overview of themes developed from the thematic analysis of the results of human factors research in EEO involving seafarers. Numbers indicate the count of segments with that code assigned.

One step towards this goal has been conducted by Man et al. (2018) which explores the possibilities of collaborative learning synergy with the use of mediating technologies. On the basis of qualitative research, this work identifies possible applications, such as the sharing of information and expertise between bridge and engine crews, or post-journey performance evaluations. As a next step, we postulate the need for quantitative user research which implements such features into a tool and assess usability and user experience metrics, especially workload, measured in a standardized way e.g. with tools such as the NASA-TLX (Hart and Staveland, 1988). This would allow for the comparison across applications and thereby the identification of features with the best trade-off between workload and achieved learning.

Support Seafarers' Balancing of Goal Conflicts With Transparency

Secondly, goal conflicts with stakeholders economic interests are well documented (e.g., Poulsen et al., 2022; Poulsen and Sampson, 2019), and it is still unclear how seafarer's can balance these. Furthermore, it is also unclear to what extent this balancing can similarly be applied to other prohibitive conflicts such as safety (or vice versa). Finally, as above, it is critical that any balancing does not require further workload, or even serves to reduce workload. We therefore propose that the second key research need is to understand how goal conflicts can be balanced or resolved onboard.

One part of this goal is the calibration of perceived conflicts. For example, Jensen et al. (2018) showed that in a ship simulator, although initially wary due to safety concerns, after experience and reflection workshops, seafarers found balance between safety and energy efficiency. This effect could be supported by visualizing goal conflicts. For example, restraints defined within charterer contracts (e.g., minimum speed requirements etc.) could be considered by routing tools. Another part of this goal could be to increase transparency to other stakeholders by keeping them in the loop, e.g., by having decision support systems generate exports to be included with the daily noon reports for ship stake holders. All-in-all the research above strongly suggests that without support seafarers will err to the side of caution when faced with subjective uncertainty and miss opportunities to save carbon emissions.

Limitations

While our study contributes insights into this field, we acknowledge limitations to our findings. Firstly, the quality of the studies included in the review varied in terms of methodology and rigor. Furthermore, less represented themes may be due to a bias in the existing literature rather than a true reflection of their importance in the field (e.g., "safety" being overwhelmingly important yet well-known and self-explanatory, in comparison to novel "stakeholder conflicts"). These aspects should be considered when interpreting the aggregated code counts. Secondly, the use of Thematic Analysis, while advantageous for summarizing diverse findings, could introduce interpretive bias. Themes are constructed categories by the authors and may not capture the complexity of the individual studies.

CONCLUSION

The results of our systematic review of human factors literature of energy efficiency in shipping revealed a wide breadth of research highlighting challenges in the maritime sector. On this strong basis, we identified potential research gaps, such as regarding learning, safety, system properties. Going forward, we suggest two approaches for the research agenda in this field: 1) understanding how seafarers can acquire knowledge on energy-efficient operations on-the-fly, to implement them autonomously and effective onboard, and

2) understanding how goal-conflicts can be balanced onboard, by increasing transparency and thereby reduce seafarers' uncertainty. Both approaches must take workload into account or risk being overlooked by seafarers already operating under high workload conditions. To achieve this, we suggest an increase of quantitative user research in this field, which utilizes concrete system features and evaluates these with standardized tools to allow for comparisons and allow for concrete design guidelines for future technical systems.

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AUTHOR CONTRIBUTIONS

Mourad Zoubir: Conceptualization, Methodology, Investigation, Formal Analysis, Writing (original draft, review and editing). **Marthe Gruner:** Methodology, Investigation and Formal Analysis. **Benjamin Schwarz:** Writing (review and editing). **Jan Heidinger:** Writing (review and editing) **Hans-Christian Jetter:** Writing (review and editing), Project Administration, Supervision. **Thomas Franke:** Funding acquisition, Project Administration, Writing (review and editing), Supervision.

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