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Investigating Challenges in Decision Support Systems for Energy-Efficient Ship Operation: A Transdisciplinary Design Research Approach

Schwarz, Zoubir, Heidinger, Gruner, Jetter & Franke

ErgoShip Conference
Esbjerg - 2nd Nov. 2023

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

MARDATA

What are key results of **design research** concerning **onboard DSS** regarding **EEO and CO_2e emission reduction**?

Results

4 Challenges

1 Prototypical implementation

6 Design considerations

Results Challenges

1 Addressing key human factors

- onboard DSS should **accompany goal conflicts** (cf. [5])
- DSS need to **keep workload and uncertainty at a minimum** (cf. [6])
- could be supported by automation, but this may conflict with already constrained feelings of autonomy [7] → **consult basic psychological needs** (BPN)

2 Context-sensitive integration of navigational and operational data

- necessity and crucial factors for the **integrative display of energy-efficient metrics** [7]
- key challenge for the design of Energy-Efficiency-DSS
- **hierarchical task analysis** [8] and **cognitive work analysis** [9] should accompany the design phase.

Results Challenges

3 Transparency in data quality and processing steps

we emphasize call for **explainability and algorithmic transparency** in decision support systems (cf. XAI [10], HCAI [11]).

we identify **explainable and transparent information presentation** as key challenges for onboard DSS to strengthen crew's autonomy [12] and mitigate biases [13]

4 Mitigation of biases

in concert with increasing transparency to strengthen **crew's perceived autonomy in EE decision-making** [12], we identify the **mitigation of e.g., automation bias** [14] as a key challenge for any onboard nautical DSS

manifestation in design is manifold; **transdisciplinary development of design proposals** with domain experts from engineering psychology, nautical and ship operations, software development and design proved beneficial

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Results Design Considerations

1 Design as opportunity-seeking [4]: Eco Score

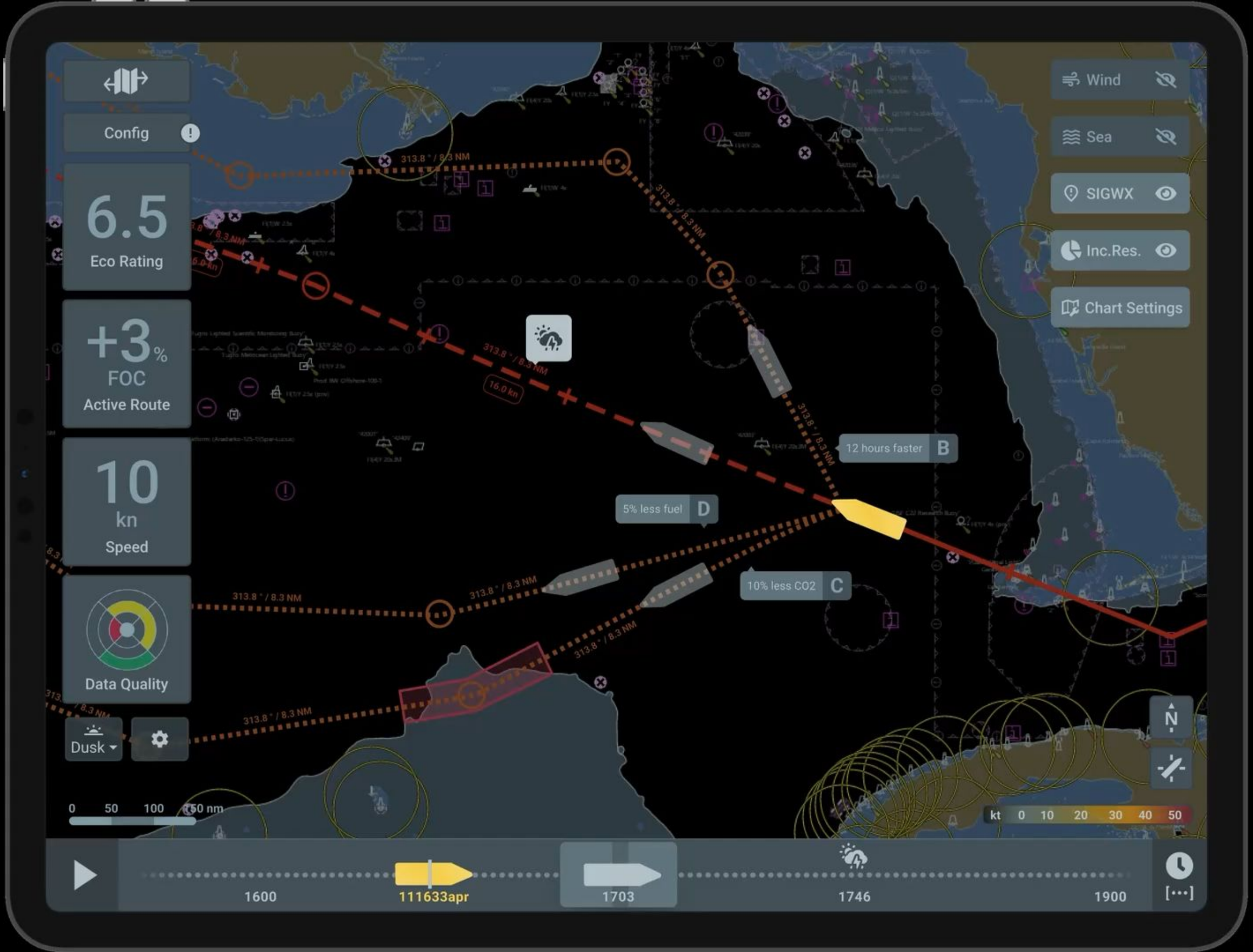
2 Integrated Navigational and Operational View

3 Decision Support instead of Decision Automation

4 Goal-oriented Decision Support

5 Ecology-aware Autonomous System

6 Transdisciplinary Work and Participatory Design



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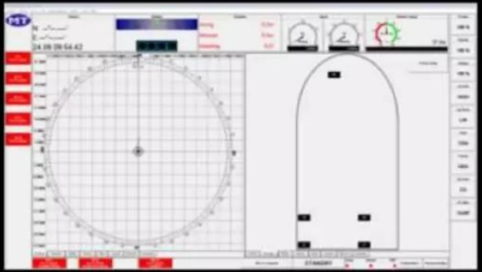
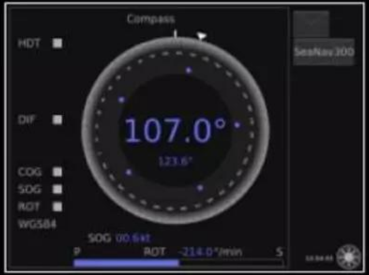
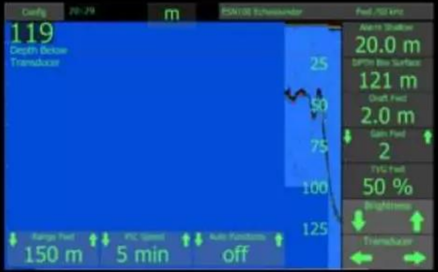
~53–63k ships comprising
3% CO_2e emissions

- Faber, S., Hanayama, S., Zhang, S., Pereda, P., Comer, B., Hauerhof, E., & Kosaka, H. (2020). *Fourth IMO GHG Study 2020*. International Maritime Organization: London, UK.
- Figure: Accessed 18.09.2023 from Shipmap.org





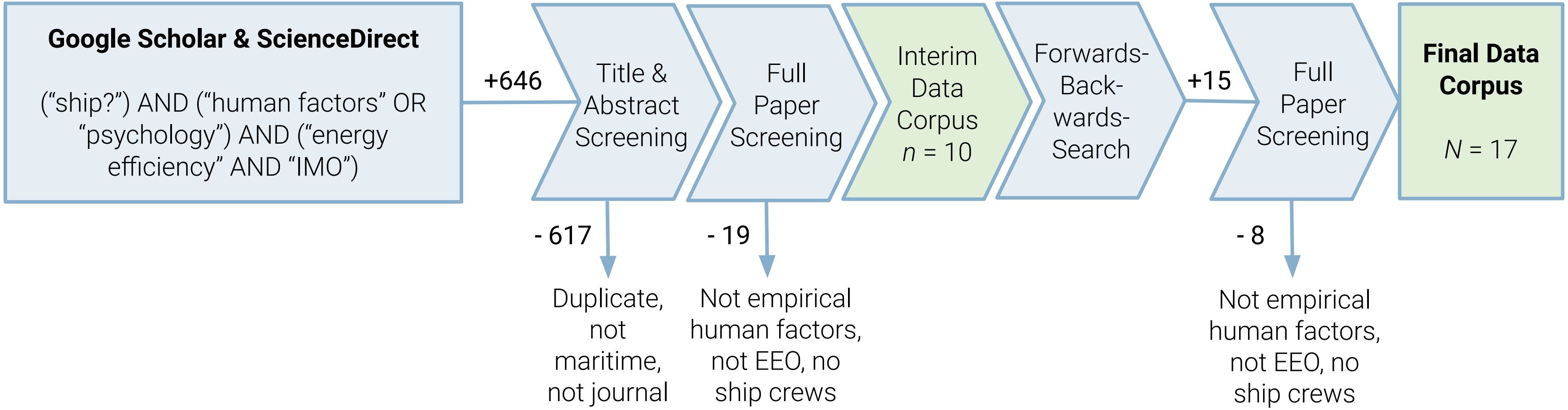


Arkitektur- og designhøgskolen i Oslo
The Oslo School of Architecture and Design

What are key **results** of human factors **research** with **ship crews** on **energy efficiency**?

Method Systematic Literature Search

Data used:
result sections
of the articles



Results Thematic Analysis

17 papers

identified

696 text segments

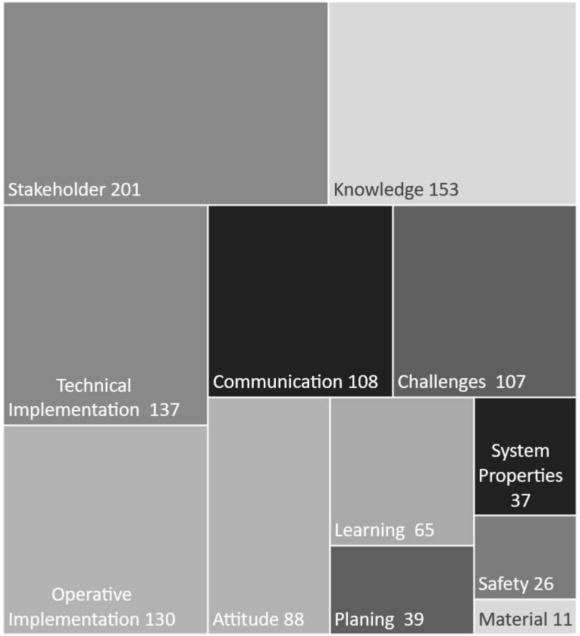
assigned (multiple times)

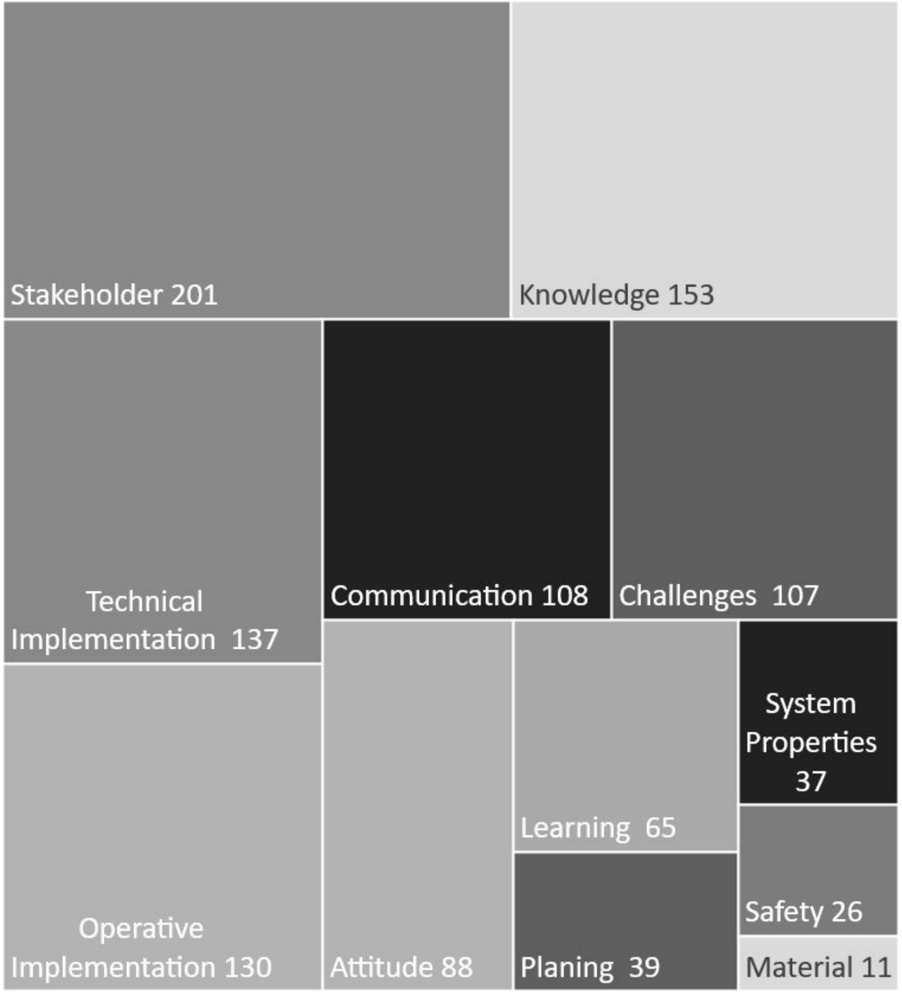
35 codes

synthesised

12 themes

Overview of Codes to Themes (*N* = 1102)





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Research Spotlight: Interviews

Participants (N = 22): all had spent months at sea (M = 24.1, Mdn = 18, SD = 27.7), and had previously planned a number of routes, either in the classroom (M = 16.5, Mdn = 10, SD = 17.5) or on duty (M = 54.5, Mdn = 3, SD = 212.3)

Part of a larger study where P. were asked to plan thee routes in various conditions in a professional ship bridge simulator, involving our prototype

Interviewed following semi- structured guideline;
After recounting their decision-making in the third condition, we asked P. sets of questions eliciting positive and negative feedback
Interviewers were instructed to repeat the question until participants no longer had anything to add; Results were summarized narratively

Results Interview Discussion

Results **highlight the value of a verification process** post-route planning, e.g., via subsequent validation via ECDIS and/or guided system handover/review. Furthermore, users may benefit from **well-calibrated expectations of the system's capabilities**.

To manage user expectations of the DSS's capabilities, **transparency in data retrieval and processing**, as well as the **system's confidence in its suggestions**, could be enhanced. Achieving this transparency, aligning with trust calibration principles [18], could involve calculating a confidence score and providing explanations [19].

The potential of automation to aid seafarers should be further researched to understand how it might impact their sense of autonomy: Not all seafarers feel that they have influence on energy-efficient operations onboard, despite being motivated to contribute [12]. Relating this to **basic psychological needs** (e.g., [17]) should inform future design decisions.

Background Energy Efficiency Onboard (EEO)

MARPOL Annex VI implemented policies to lower 70% of emissions by 2050.[1]

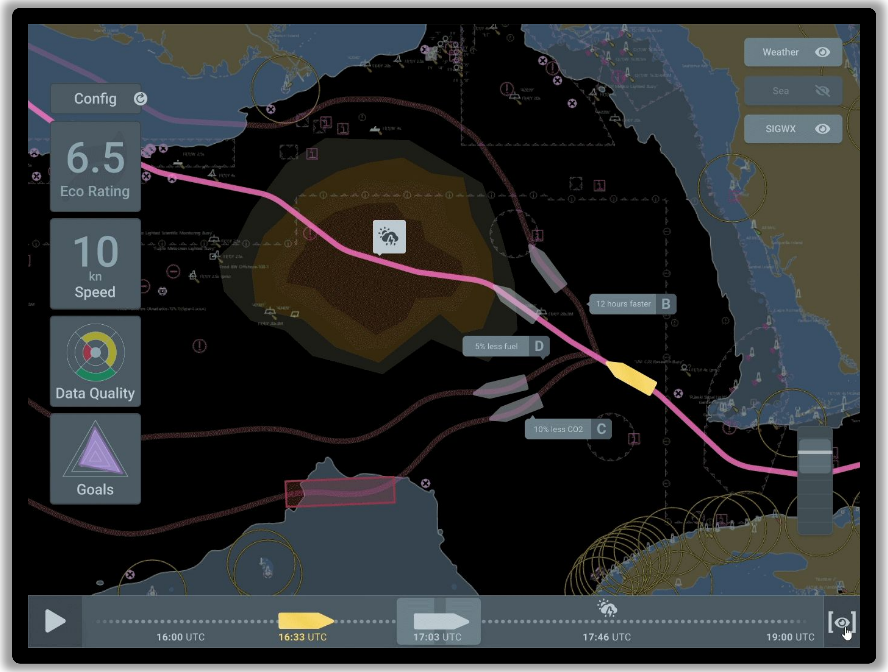
However, inconsistency between **optimal** and **actual implementation**, so-called „Energy Efficiency Gaps“, exists.[2]

IMO

SEEMP **CII** **EEOI**

Energy Efficiency = Technical Potential X **Human Behaviour**

Background MariData



Decision Support System
for energy management onboard

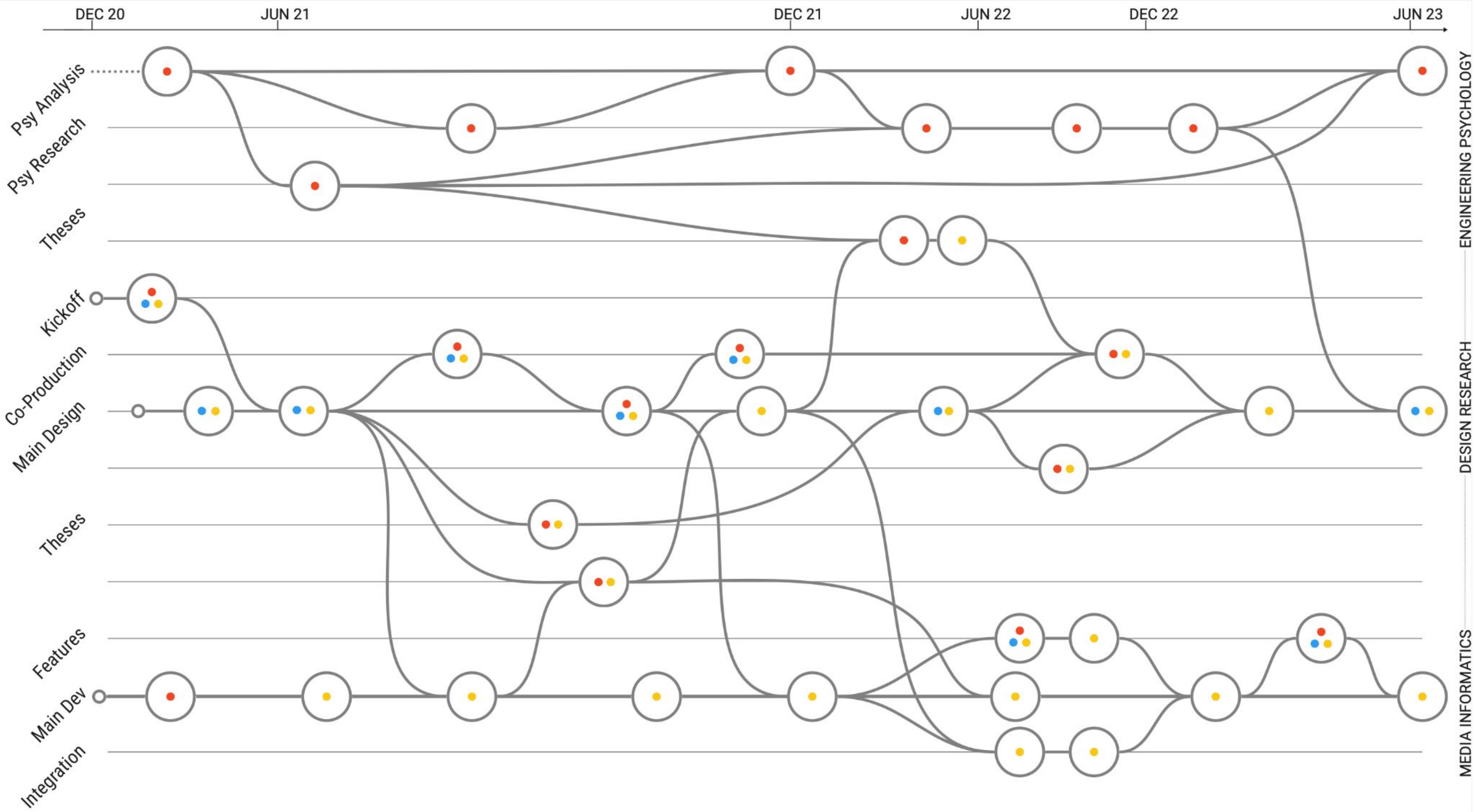
Focus on route planning using digital twins

Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

Research Activities through a MAPS[3] lens



Research Roles

Engineering-psychological research conducted can be described as contributing to research and **analysis** phases.
included **literature reviews** with quantitative and qualitative analysis methods, **cognitive work analysis**, **hierarchical task analysis**, as well as **empirical evaluations** of these with experts and the user group

Media informatics was involved akin to design in all phases, but with a strong emphasis on the **realization** phase. Focus: Study prototype, which could be used for evaluative feedback as well as a demonstrator in the wider project context; sparring partner for design.

Design discipline acted as **moderator and mediator** throughout whole process. Diverse body of methods and theory applied in **design research**, including **co-production methods**, evaluation of **theory-guided design guidelines**, **qualitative and evaluative research** methods, guided by psychological and design research theory, and UX prototyping.

Joint effort: Formative evaluation in a professional ship training simulator

Outlook

Upcoming/current design research activities include

1) design-driven development of KPIs and their integration into a DSS,
2) Dedicated route and engine monitoring views allowing for en-route comparison of prognosed versus actual metrics and
3) a data quality module enhancing system transparency and explainability of the algorithms’ routing proposals.

human factors revealed at least three topics of interest for further review of the design proposals and new directions for design inquiry:

1) Seafarers’ motivation for EEO
2) Challenges in relation to automation and agency
3) Energy-efficiency-related collaborative learning

Thank you for your attention!

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https://maridata.app

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Summary

We conducted **transdisciplinary research** involving, i.a., **EngPsy, Informatics and Design.**

Key results so far are **4 challenges, 1 demonstrator and 6 design considerations**.

External Stakeholders and **Domain Experts** were involved throughout the course of 3yrs through a **wide range of research methods**.

We see implications for future research, including **consideration of operators' BPN**.

References

1. IMO. 2018. *Initial IMO Strategy on Reduction of GHG Emissions from Ships*.
2. Johnson, Hannes, and Karin Andersson. 2016. "Barriers to Energy Efficiency in Shipping." *WMU Journal of Maritime Affairs* 15 (1): 79–96. doi:10.1007/s13437-014-0071-z.
3. Jonas, Wolfgang, Rosan Chow, Katharina Bredies, and Kathrin Vent. 2010. "Far beyond Dualisms in Methodology-an Integrative Design Research Medium 'MAPS.'" In *Design & Complexity - Proceedings of the Design Research Society Conference, 2010*, 684–698. Montreal: Design Research Society.
4. Chow, Rosan. 2009. "Projection before Analysis." *Design Principles and Practices: An International Journal—Annual Review* 3 (1): 341. doi:10.18848/1833-1874/CGP/v03i01/37603.
5. Hansen, Elin Kragesand, Hanna Barbara Rasmussen, and Marie Lützen. 2020. "Making Shipping More Carbon-Friendly? Exploring Ship Energy Efficiency Management Plans in Legislation and Practice." *Energy Research & Social Science* 65: 101459. doi:10.1016/j.erss.2020.101459.
6. Poulsen, René Taudal, and Helen Sampson. 2019. "'Swinging on the Anchor': The Difficulties in Achieving Greenhouse Gas Abatement in Shipping via Virtual Arrival." *Transportation Research Part D: Transport and Environment* 73: 230–244. doi:10.1016/j.trd.2019.07.007.
7. Viktorelius, Martin. 2020. "Adoption and Use of Energy-Monitoring Technology in Ship Officers' Communities of Practice." *Cognition, Technology & Work* 22 (3): 459–471. doi:10.1007/s10111-019-00578-z.
8. Stanton, Neville A. 2006. "Hierarchical Task Analysis: Developments, Applications, and Extensions." *Applied Ergonomics*, Special Issue: Fundamental Reviews, 37 (1): 55–79. doi:10.1016/j.apergo.2005.06.003.
9. Stanton, Neville A., Paul M. Salmon, Guy H. Walker, and Daniel P. Jenkins. 2017. *Cognitive Work Analysis: Applications, Extensions and Future Directions*. CRC Press.
10. Gunning, David, Mark Stefik, Jaesik Choi, Timothy Miller, Simone Stumpf, and Guang-Zhong Yang. 2019. "XAI—Explainable Artificial Intelligence." *Science Robotics* 4 (37): eaay7120. doi:10.1126/scirobotics.aay7120.
11. Shneiderman, Ben. 2020. "Human-Centered Artificial Intelligence: Reliable, Safe & Trustworthy." *International Journal of Human–Computer Interaction* 36 (6). Taylor & Francis: 495–504. doi:10.1080/10447318.2020.1741118.
12. Zoubir, Mourad, Marthe Gruner, and Thomas Franke. 2023. "'We Go Fast - It's Their Fuel': Understanding Energy Efficiency Operations on Ships and Marine Vessels." *Energy Research & Social Science* 97 (March): 102992. doi:10.1016/j.erss.2023.102992.
13. Parasuraman, Raja, and Dietrich H. Manzey. 2010. "Complacency and Bias in Human Use of Automation: An Attentional Integration." *Human Factors* 52 (3). SAGE Publications Inc: 381–410. doi:10.1177/0018720810376055.
14. Chan, Jevon P., Rose Norman, Kayvan Pazouki, and David Golightly. 2022. "Autonomous Maritime Operations and the Influence of Situational Awareness within Maritime Navigation." *WMU Journal of Maritime Affairs* 21 (2): 121–140. doi:10.1007/s13437-022-00264-4.
15. Wang, Shuaian, Harilaos N. Psaraftis, and Jingwen Qi. 2021. "Paradox of International Maritime Organization's Carbon Intensity Indicator." *Communications in Transportation Research* 1 (December): 100005. doi:10.1016/j.commtr.2021.100005.
16. Parasuraman, R., T.B. Sheridan, and C.D. Wickens. 2000. "A Model for Types and Levels of Human Interaction with Automation." *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans* 30 (3): 286–297. doi:10.1109/3468.844354.
17. Moradbakhti, Laura, Benedikt Leichtmann, and Martina Mara. 2022. "Development and Validation of a Basic Psychological Needs Scale for Technology Use." Preprint. Open Science Framework. doi:10.31219/osf.io/4eabq
18. Hoff, Kevin Anthony, and Masooda Bashir. 2015. "Trust in Automation: Integrating Empirical Evidence on Factors That Influence Trust." *Human Factors* 57 (3). Sage Publications Sage CA: Los Angeles, CA: 407–434. doi:10.1177/0018720814547570.
19. Zhang, Yunfeng, Q. Vera Liao, and Rachel K. E. Bellamy. 2020. "Effect of Confidence and Explanation on Accuracy and Trust Calibration in AI-Assisted Decision Making." In *Proceedings of the 2020 Conference on Fairness, Accountability, and Transparency*, 295–305. FAT* '20. New York, NY, USA: Association for Computing Machinery. doi:10.1145/3351095.3372852.