Human Interaction and Emerging Technologies (IHIET 2025), Vol. 197, 2025, 541–549
https://doi.org/10.54941/ahfe1006747

Mapping Human-Centred Design in Innovation-Driven Projects: An HRL Assessment of an Autonomous Ferry and Remote Operations Centre Concept

Hedvig Aminoff

Norwegian University of Technology and Science, Trondheim, Norway

ABSTRACT

As maritime systems integrate autonomous technologies and shift toward remote operations, human factors (HF) integration becomes increasingly critical yet more complex to manage effectively. This paper presents a case study on the application of the Human Readiness Level (HRL) framework to an autonomous urban passenger ferry and remote operations centre. While the ferry prototype was undergoing real-world trials (TRL 5-6), human readiness lagged due to fragmented Human-Centered Design (HCD) efforts. Using HRL as both a retrospective and planning tool, the study consolidated prior HF work, identified maturity gaps, and initiated activities aligned with HRL 3. Findings support HRL's role in making human-system integration visible and traceable across innovation-driven maritime projects.

Keywords: Human readiness levels, Human factors integration, Human centred design, Maritime autonomy, Remote operations, Systems engineering

INTRODUCTION

The maritime sector is rapidly transforming as increased automation, autonomous vessels, and remote operations infrastructures are reshaping sociotechnical systems. These changes challenge traditional design models and demand effective integration of human factors (HF) and Human Centred Design (HCD). In safety-critical domains like maritime transport, poor HF integration can lead to unclear supervisory roles, cognitive overload, and poor usability. Such issues can undermine operator performance and introduce latent safety risks, and ultimately risk eroding public and stakeholder trust in otherwise promising innovations.

These challenges are especially acute in innovation-driven environments (e.g., academia–industry collaborations, startup R&D), where shifting goals, distributed teams, and extended timelines can often lead to fragmented HCD efforts. Although HF integration (HFI) offers clear lifecycle benefits (improved safety, reduced rework), it can often get sidelined in engineering projects. HF metrics may be harder to quantify and more difficult to communicate within traditional engineering processes. Structured mechanisms are needed so that HF and HCD are managed systematically within project milestones and decision processes, like technical performance, cybersecurity, or regulatory compliance, which are typically integrated into formal risk and quality management frameworks.

To address these pervasive issues, the Human Readiness Level (HRL) framework was introduced through the ANSI/HFES Standard 400-2021(HFES/ANSI, 2021). HRLs complement Technology Readiness Levels (TRLs) by evaluating *human-use readiness*: can people use the system effectively and safely?

HRL is gaining policy traction, such as in the 2025 U.S. National Defense Authorization Act (NDAA), which mandates HRL reporting in major acquisition programs. There are indications it is being adopted or piloted by other major stakeholders such as the FAA, and Eurocontrol, reflecting a growing recognition of its value for risk management and lifecycle assurance in complex and innovative development settings. However, practical case studies still remain limited. Handley (2024), Savage-Knepshield et al. (2021) stress the need for real-world applications.

This article contributes to that effort by presenting a case study of HRL application in the development of an autonomous urban passenger ferry and its associated remote operations centre (ROC). Although the technical system had reached TRL 5–6, our assessment revealed that HF integration lagged behind. We used the HRL framework as both a retrospective checklist and a prospective planning tool to consolidate fragmented HCD work, identify latent risks, and establish a baseline for structured, traceable HF development. The results demonstrate HRL's value in complex, multidisciplinary development and spotlight its role as a forward-looking tool for HFI quality assurance.

Figure 1: The Milliampere2 autonomous passenger ferry prototype.

The HRL Framework

The HRL framework was conceptualized as a way to ensure that human capabilities are considered as part of technology maturity assessments (Kosnik and Acosta, 2010) and further developed through defence acquisition research at the Naval Postgraduate School. The final scale, published in 2021 was a result of multi-agency working groups that included experts from the DOD, FAA, NASA, and industry.

The nine-level scale spans the system lifecycle, from early concept formation to full operational use. Appendix C in the HRL standard HRL provides support for HRL assessment by describing evaluation activities (e.g., task analyses, scenario modelling); trigger questions that guide inquiry; types of supporting evidence and exit criteria to justify level advancement. Appendix D provides illustrative case studies offers concrete scenarios that can guide practitioners in tailoring HRL use to their specific project needs and contexts. Appendix E discusses how the HRL framework can be integrated into broader system development processes.

As noted by See (2022) HRL provides a "single number to communicate readiness for human use." This clarity helps HF issues be communicated and understood across engineering, program management, to support milestone decisions, risk reviews, and quality checks.

	HRL	**Description**
Production/ Deployment	9	System successfully used in operations with systematic monitoring of human-system performance.
	8	Human systems design fully tested, verified, and approved in mission operations.
	7	Human systems design fully tested and verified in an operational environment with system hardware and representative users.
Technology Demonstration	6	Human systems design matured and demonstrated in a high-fidelity simulated or operational environment.
	5	Human-centred evaluation of prototypes in mission-relevant part-task simulations.
	4	Modelling, part-task testing, and trade studies of human-system design concepts completed.
Research & Development	3	Human-centred requirements for performance and interaction established.
	2	Human-centred concepts, applications, and guidelines defined.
	1	Basic principles for human characteristics, performance, and behaviour observed and reported.

The Case Study: An Autonomous Ferry & ROC

This case study examines the human readiness levels of an urban autonomous ferry paired with a Remote Operations Centre. Developed through interdisciplinary efforts (academia, startups, industry), the ferry had reached TRL 4–5 and was undergoing real-world prototyping.

From the beginning, HCD had been high on the agenda: over the period 2019-2024, the project generated 12 academic publications and 9 student thesis projects specifically related to the MilliAmpere ferry. Previous work included observations, interviews, mock-ups, operator role studies, simulation trials, and participatory workshops. Contributions had been made by various actors over this extended period, including academic researchers, student teams, and industrial partners. However, HF efforts remained fragmented, as no central framework compiled or traced work, what gaps remained, or critical decisions around operator roles, cognitive workload, and safety.

Yet the system was rapidly maturing technically, and it became increasingly important to ensure that operator roles, cognitive demands, and safety-critical transitions were adequately understood and addressed. In this context the HRL framework appeared to be a relevant mechanism to structure and consolidate prior HCD efforts, diagnose gaps in HF work, and latent risks, and thereby create a baseline for future, traceable HF development. Rationale for HRL application The decision to apply the HRL framework was motivated by three converging challenges:

1. The difficulty of gaining a comprehensive overview of HF knowledge generated by multiple contributors over several years of development
2. Ensuring systematic application of HF insights rather than isolated studies
3. The need to find a way to demonstrate evidence of systematic human factors consideration for future regulatory compliance, particularly emerging human oversight mandates for autonomous maritime systems.

While the HRL framework is still emerging, with limited examples of practical applications, the MilliAmpere project provided an opportunity to both solve project challenges and contribute to understanding of this standard's practical value.

Method

The HRL evaluation was conducted by the author through review of both specific studies related to the autonomous ferry and broader autonomous ship literature. Sources included peer-reviewed publications (n=12), master's theses (n=3), ad studetn projects (n=6) and technical reports spanning 2019-2024. Key MilliAmpere-specific sources included work by Alsos et al., Veitch & Alsos, Petermann et al., and Park (2022). Broader autonomous ship research included studies by Ramos et al. (2019), the AUTOSAFE framework (Fjørtoft & Holte, 2021), and risk assessment methodologies (Hoem et al., 2022). Each identified source was analyzed for HF-relevant findings and systematically mapped against HFES/ANSI Standard 400-2021 evaluation questions and exit criteria.

Applying the Standard's Guidance

HRL 1

Foundational understanding Dispersed knowledge from project-specific research (Park, 2022; Alsos et al., 2022; Veitch and Alsos, 2023; Petermann et al., 2023) and broader autonomous shipping literature (AUTOSAFE reports, Hoem et al., 2022) was synthesised to establish baseline human factors understanding (table 1). This synthesis bridged fragmented insights, identified latent vulnerabilities, and highlighted areas requiring future study.

HRL 2

HRL 2 shifts from foundational understanding to applied analysis. In our case, key outputs included:

- Mapping of user roles (remote operator, shore technician, passenger) with associated skills, limitations, and training needs.
- Usage scenarios refined into structured "user journeys" and timelines that mapped user tasks and interactions across automation phases.
- Guidelines for interface design, trust-building, situation awareness, and accessibility—developed through thematic synthesis of relevant literature and usability feedback.
- Proposed candidate metrics for human performance (workload, task time, trust scores).

We also identified human performance issues from comparable systems (e.g. (Fjørtoft and Holte, 2021)), and began identifying potential sources of human error, particularly from scenarios. See Table 1 for more details about supporting evidence that was identified or generated.

Table 1: Summary of supporting evidence for HRL 1 and 2.

Evaluation question (HFES 400–2021 Appendix C)	Supporting evidence for exit criteria	Examples of findings
C.1.1.1 Have key human behaviours, capabilities, and limitations been identified?	Synthesized data from published studies, ferry observations, and stakeholder interviews to develop structured user characteristics across operator and passenger roles.	(Hoem, Veitch and Vasstein, 2022) found trust calibration essential; Alsos et al. (2022) noted interface legibility issues. Findings formed a consolidated reference point for key human factors insights, such as user characteristics, cognitive demands, interface challenges, and limitations.
C.1.1.2 Have preliminary usage scenarios for potential users been identified?	Created high-level user journeys describing boarding, monitoring, transitions, and emergency handling phases.	Mapped phases (manual–remote–autonomous) to specific user tasks and responsibilities.
C.1.1.3 Have potential key human performance issues and risks been identified?	Compiled performance risks (e.g., mode confusion, passive monitoring fatigue) from AUTOSAFE and project-specific scenarios.	Identified key risks in ROC operations and passenger interpretation of autonomy, e.g. (Petermann, Alsos and Papachristou, 2023).
C.1.1.4 Has basic human research relevant to the concept been conducted?	Synthesized findings from reviewed research articles, linking them to potential design implications.	User studies and interface evaluations by Park (2022), Alsos et al. (2022), and Veitch & Alsos (2023), provided insights into usability, workload, and passenger perceptions. Petermann et al. (2023) further contributed trust and acceptance data from early trials. Ramos, Utne, and Mosleh (2019) addressed cognitive demands and role definition for remote operators in more general maritime autonomy settings.

Continued

Table 1: Continued

Evaluation question (HFES 400–2021 Appendix C)	Supporting evidence for exit criteria	Examples of findings
C.2.1.1 Has knowledge of relevant human characteristics, capabilities, and limitations been refined?	Mapped operator and passenger roles and characteristics, including attentional needs and interaction demands.	Simulator observations and user feedback from (Veitch & Alsos 2022).
C.2.1.2 Have key human-centred design principles, standards, and guidance been established?	Derived domain-relevant HF guidelines from literature and design feedback (trust, cognitive load, redundancy).	(Alsos et al. 2022) identified challenges in visual hierarchy and emphasized the need for clear and consistent feedback mechanisms in ferry interfaces.
C.2.1.3 Have usage scenarios been updated to include basic task descriptions for user roles?	Developed task-centred scenarios for all roles, including ROC operator and emergency responder.	Clarification of timing, decision points, and overlapping roles across different autonomous phases.
C.2.1.4 Has human performance on legacy or comparable systems been analysed?	Compiled insights from maritime incident reports (e.g., Fjørtoft & Holte, 2021) and other previous research, such as empirical studies on passenger feedback regarding the information provided during the ferry journey (Claes, Liavaag and Simic, 2022).	Mode ambiguity and unclear supervisory roles flagged as critical concerns.
C.2.1.5 Have potential sources of human error and misuse been identified?	Synthesized human error risks from literature and conducted a targeted HAZOP for the autonomous ferry system to identify potential operator and system misuse scenarios across phases of operation.	Operator: over trust in automation; HAZOP revealed that unclear alarm prioritization and delayed takeover procedures pose significant risk during remote operation transitions.
C.2.1.6 Are appropriate metrics for successful human performance being identified?	Suggested early metrics tied to usage phases.	E.g., task duration, trust scores.

HRL 3

HRL 3 marks a transition from understanding user needs to formalizing human-centred requirements that inform design and development. It calls for structured analyses such as Cognitive Task Analysis (CTA) and function allocation and beginning to define traceable system requirements for human use. Our contributions included:

- Hierarchical Task Analysis and Cognitive Task Analysis (CTA) for ROC operator roles
- Timeline work/load assessments for remote takeover
- Alarm design aligned with IEC standards
- HAZOP analysis for control, propulsion, and communication failures
- Preliminary human–machine function allocations
- Preliminary guidelines addressing alarm presentation, automation mode transitions, and passenger experience, and situation awareness needs across teams and systems.
- Notes on environmental effects (e.g., glare, noise).

While we conducted substantial work toward meeting HRL 3, we determined that the level could not be considered fulfilled: no requirements were traced into system specifications, proof-of-concept validation was incomplete, and many aspects of HF integration across typical domains such as maintenance, training, staffing were not finalized. Table 2 reflects where criteria were met and where they were not.

Table 2: Summary of supporting evidence for HRL 3.

Evaluation question (HFES 400–2021 Appendix C)	Supporting evidence for HRL 3 exit criteria	Examples of findings
C.3.1.1 Have human systems experts been engaged?	HCD experts involved.	
C.3.1.2 Have usage scenarios been updated based on human needs?	Developed detailed user journeys with operational timelines.	Scenarios described remote supervision, emergency responses.
C.3.1.3 Have cognitive and task analyses been completed?	HTA and CTA conducted for remote operator tasks.	Identified critical tasks, decision points, and cognitive demands.
C.3.1.4 Have function allocations been evaluated?	Partially analysed.	Preliminary function allocations suggested for ROC–autonomy interaction Highlighted need for dynamic allocation during degraded modes.
C.3.1.5 Have information flow requirements been identified?	Partially analysed.	Partial analysis of information needs for remote control roles. Situation awareness gaps noted for team coordination under alarms.
C.3.1.6 Have initial safety analyses been completed?	HAZOP performed for propulsion, control, and communication systems. CRIOP scenario analysis conducted.	Identified failure modes, e.g., communication loss and response risks.
C.3.1.7 Have manpower, personnel, training analyses begun?	Partially analysed.	Role definitions and initial training needs outlined for ROC operators.
C.3.1.8 Have environmental factors been analysed?	Not systematically analysed.	Informal notes on ROC glare, noise, and visibility impacts. Interface readability under sunlight was flagged as an issue.
C.3.1.9 Have other HSI domains been addressed?		
C.3.1.10 Have maintenance interactions been considered?	Not yet addressed in systematic fashion. Partially addressed in preliminary CONOPS.	No documentation of human maintenance interaction needs.
C.3.1.11 Have user characteristics been specified?	Roles described in terms of cognitive and physical demands.	Operator and passenger profiles outlined; gaps in full specification.
C.3.1.12 Are human needs mapped to system demands?	Not achieved.	Partial mapping through CTA and workload analysis.
C.3.1.13 Have human performance data and metrics been evaluated?	Not achieved.	
C.3.1.14 Have design features to accommodate humans been recommended?	Alarm requirements and interface principles proposed.	Suggested redundancy in alarms; call for clearer mode indicators.
C.3.1.15 Have requirements been flowed into system requirements?	Not achieved.	Human-centred requirements not traced into system specs.

DISCUSSION

HRL 3 was not considered fulfilled, despite the substantial human factors work conducted. Key gaps remained as there was no clear evidence that human-centred requirements had been integrated into system specifications; no finalized proof of concept existed to validate human performance metrics; and critical cross-domain analyses such as training, staffing, and maintainability were still in early stages. These limitations reflect a common challenge in complex, innovation-driven projects: while significant HCD can be conducted and important HF insights may emerge, they often remain fragmented unless embedded into structured systems engineering processes.

This case reinforces the value of the HRL framework. By applying it as both a retrospective diagnostic and a forward-planning tool, we were able to consolidate disparate HCD activities, identify maturity gaps, and establish a traceable path forward. The HRL framework provided a shared language that made human readiness intelligible to diverse stakeholders.

As Austrian et al. (2024) note, most HRL applications to date are retrospective. While useful, such analyses are not enough. To fully realize HRL's potential as a proactive tool guiding design, risk management, and acquisition decisions more prospective applications are needed. We hope to apply HRLs earlier and more systematically in future settings, particularly within defence acquisition programs where lifecycle integration and traceability are critical.

ACKNOWLEDGMENT

This work was supported by the MAS project (Meaningful Human Control of digitalization in safety critical systems), a knowledge-building project for Industry under the PETROMAKS 2 program, managed by Stig Ole Johnsen at SINTEF Digital. The author would also like to acknowledge the Shore Control Lab at NTNU, including Ole Andreas Alsos, Jooyoung Park, Felix Petermann, and Eric Veitch, whose prior work formed an essential foundation for this study.

REFERENCES

Alsos, O. A. *et al.* (2022) 'NTNU Shore Control Lab: Designing shore control centres in the age of autonomous ships', *Journal of Physics: Conference Series (JPCS)* [Preprint]. Available at: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3058367 (Accessed: 29 February 2024).

Austrian, E. *et al.* (2024) 'Systematic Approach to Assessing the Readiness of a Technology for Safe and Effective Human Use', in. *SESAR Innovation Days*, Seville, Spain.

Claes, H. N., Liavaag, M. and Simic, V. (2022) *Design an autonomous passenger ferry for urban areas*. Master thesis. NTNU. Available at: https://ntnuopen.ntnu.no/ntnu-xmlui/handle/11250/3023103 (Accessed: 25 March 2024).

Fjørtoft, K. E. and Holte, E. A. (2021) 'AutoSafe-D1. 1–Rammeverk for vurdering av farer ved operasjon av autonome passasjerskip'. Available at: https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3116373 (Accessed: 16 April 2024).

Handley, H. A. H., See, J. E. and Savage-Knepshield, P. A. (2024) 'Human readiness levels and Human Views as tools for user-centered design', *Systems Engineering*, 27(6), pp. 1089–1102. Available at: https://doi.org/10.1002/sys.21773.

HFES/ANSI (2021) 'Human readiness level scale in the system development process'. HFES/ANSI. Available at: https://www.hfes.org/publications/ technical-standards.

Hoem, Å. S., Veitch, E. and Vasstein, K. (2022) 'Human-centred risk assessment for a land-based control interface for an autonomous vessel', *WMU Journal of Maritime Affairs*, 21(2), pp. 179–211. Available at: https://doi.org/10.1007/s13437-022-00278-y.

Kosnik, W. and Acosta, H. (2010) 'HSI as a Method for Embedding Human-Centered Design in Air Force Rapid Acquisition Programs', *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 54(25), pp. 2165–2168. Available at: https://doi.org/10.1177/154193121005402509.

Park, J. (2022) *Graphical User Interface Design for a Remote Operator to Monitor and Control Multiple Autonomous Ferries*. Master's Thesis. NTNU. Available at: https://ntnuopen.ntnu.no/ntnu-xmlui/bitstream/handle/11250/3012210/no.ntnu_inspera_97656036_47107342.pdf?sequence=5 (Accessed: 24 March 2024).

Petermann, F., Alsos, O. A. and Papachristou, E. (2023) 'Interaction between humans and autonomous systems: Human facing explanatory interface for an urban autonomous passenger ferry', in *Intelligent Human Systems Integration (IHSI 2023): Integrating People and Intelligent Systems. AHFE (2023) International Conference*, AHFE Open Access. Available at: https://doi.org/10.54941/ahfe1002821.

Ramos, M. A., Utne, I. B. and Mosleh, A. (2019) 'Collision avoidance on maritime autonomous surface ships: Operators' tasks and human failure events', *Safety science*, 116, pp. 33–44.

Savage-Knepshield, P. A., Hernandez, C. L. and Sines, S. O. (2021) 'Exploring the Synergy Between Human Systems Integration and Human Readiness Levels: A Retrospective Analysis', *Ergonomics in Design: The Quarterly of Human Factors Applications*, 29(4), pp. 16–24. Available at: https://doi.org/10.1177/10648046211009718.

See, J. E. (2021) 'Human Readiness Levels Explained', *Ergonomics in design*, 29(4), pp. 5–10. Available at: https://doi.org/10.1177/10648046211017410.

See, J. E. (2022) 'Applying the Human Readiness Level (HRL) Scale in the Systems Engineering Process'. *INCOSE Enchantment Chapter Meeting*. Available at: https://www.incose.org/docs/default-source/enchantment/applyinghrlscaleintheseprocessjudisee220511.pdf?sfvrsn=2a61c7_2.

Veitch, E. and Alsos, O. A. (2023) 'Gorillas on a boat: Inattentional blindness during supervisory control of autonomous vessels', *Journal of Physics: Conference Series*, 2618(1), p. 012010. Available at: https://doi.org/10.1088/1742-6596/2618/1/012010.