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Use of ANSI/HFES Human Readiness Level to Ensure Safety in Automation

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ABSTRACT

This paper describes the value of the Human Readiness Level (HRL) framework in assessing technology's readiness for safe and effective human use in development of high automation and remote operations. We have explored issues from the oil and gas industry and Maritime Autonomous Surface Ships (MASS) to identify challenges with automation and remote operations, and the need for alignment with the EU's AI Act. Literature reviews, case studies and interviews with industry experts reveal shortcomings in human factors (HF) integration, particularly in human-centered design, early user involvement, and cognitive ergonomics. We have observed that consequences of missing HF design are poor safety, efficiency, and usability. Poor HF design has been a root cause in 50% to 80% of accidents. Our goal is to describe how HRL can improve safety, efficiency, and usability in engineering as described by ISO 11064, supported by the verification and validation method CRIOP.

Keywords: Automation, AI, High-risk AI, Human factors, Human readiness level, Safety

INTRODUCTION

This paper documents experiences from the oil and gas industry and maritime industry as they implement automation, AI, and remote operations. Challenges and emerging regulation of AI highlight the need for comprehensive and systematic Human factors activities. We explore how systematic HF efforts can be supported by the practical application of the ANSI-HFES Human Readiness Level (HRL) framework, aligning its application with ISO 11064, and CRIOP method (Johnsen et al., 2011), both commonly used in the oil and gas industry. We apply a systems perspective-MTO (Man, Technology, Organization) or "sociotechnical systems" - as we are exploring interactions among people and technology in complex workplaces.

Background and Challenges

New technology such as automation and remote operations can reduce costs, improve safety and efficiency, and decrease environmental impact, but also presents significant human factors (HF) challenges. Automation can spare humans from dirty, dangerous, difficult, tiresome, and dull work but there are also typical automation challenges known as "ironies," "paradoxes," and "myths" (Bainbridge, 1983; Hancock, 2021; Bradshaw, 2013).

These include maintaining Situational Awareness (SA), retaining operator skills, balancing authority, and responsibility, mitigating complacency and workload issues, and avoiding automation-induced surprises. For instance, highly automated drilling systems might lead to operator complacency, delaying critical interventions. The Boeing Max accident demonstrated the disastrous consequences of poorly implemented automation. Rapid technology innovation often outpaces HF considerations, regulations, and guidelines, creating a need to balance technological developments with systematic and comprehensive HF principles throughout the system lifecycle.

When introducing remote operations, operators accustomed to physical cues like vibrations, sounds, smells, and other contextual knowledge, must rely on digital systems and automation, potentially hindering SA, and decision-making. In remote operation of ships, losing kinesthetic feel and visual perception can reduce SA during navigation. Similar issues affect Unmanned Aerial Vehicle (UAV) operations, where poor human-machine interfaces impede performance and increase accidents (Waraich et al., 2013). Future remote operation crews may lack offshore experience, further increasing the risk of operational disconnection, and highlighting the need for HF based design, training, and operation.

Increased automation and remote operations can exacerbate existing HF challenges by making work systems more complex, which makes it important to adopt sociotechnical systems view to avoid overlooking critical human-machine-organization interactions. For instance, weak change management during integration of multiple subsystems from different vendors can lead to mixed design principles in applications, and fragmented information, making it difficult for operators to understand and control the situation (Johnsen et al., 2018). Poor management of interactions among collaborators, such as operators, service companies, and suppliers can impede communication, learning and effective intervention during system failures. Industry experts express concern over a bias towards primarily addressing physical ergonomics, which is seen as more easily quantifiable than cognitive ergonomics.

The maritime industry faces unique issues, alongside these common automation and remote operations challenges. Autonomous ferries offer benefits, but raise safety and human factors concerns, such as operator SA in remote operations centers and the need for robust human and organizational capabilities to mitigate risks from reduced crew presence (Johnsen et al., 2022). Designing autonomous ships and shore control facilities requires a holistic approach to reduce systemic failures across Man, Technology or Organization (MTO), which are exemplified in the Helge Ingstad accident (Johnsen, 2021).

Valuable lessons can be learned from the oil and gas industry's experience with automation and remote operations, where research indicates poor design compromising SA as a root cause of 50–80 % accidents (Johnsen et al., 2023; Vatn et al., 2023). Research and industry experience show that successful automation and remote operations hinge on prioritizing HF from the outset, to ensure well-planned and resourced HF design and evaluation activities. This includes a balanced exploration of cognitive, physical, and organizational issues through HF methods such as task analysis, cognitive workload analysis, and ecological interface design. Additionally, early, and continuous, collaboration between technology developers and end-users is crucial (Johnsen et al., 2023).

Impact of Regulatory Action

The EU Artificial Intelligence Act (AIA, 2024) mandates human centric development and human oversight over high-risk AI systems. In the oil and gas industry, AI-integrated components in process control, drilling, and safety instrumented systems (SIS) might be designated as high-risk AI. Maritime Autonomous Surface Ships (MASS), such as autonomous ferries, have a role in transportation infrastructure and rely on AI for safe operation, and may qualify as high-risk AI. Key questions about responsibility, competence, resources, and authority in human oversight need to be resolved (Enqvist, 2023), but it is evident that the AIA has significant human factors design implications for the development and deployment of advanced technologies in offshore and maritime industries.

MITIGATING HF CHALLENGES IN HIGH AUTOMATION AND REMOTE OPERATIONS THROUGH STRUCTURED HF METHODS

To mitigate the HF challenges inherent in automation and remote operations we propose leveraging the ANSI/HFES Human Readiness Levels (HRL) scale. This systematic framework can ensure that technological advancements align with human capabilities and meet regulatory demands for human oversight. We will demonstrate the practical application of HRL in the maritime domain through a case study with an autonomous ferry. Additionally, we explore integrating HRL with established industry standards and best practices for control centers in the oil and gas industry, such as ISO 11064 and the CRIOP, to tailor the framework to the specific requirements of this domain.

The Technology Readiness Levels (TRL) scale, developed by NASA in 1970 for ensuring quality of technology development in space missions (Yasseri, Bahai 2018), assesses technology maturity and guides its development from concept to operational use. The Human Readiness Level (HRL) framework, an ANSI-HFES standard since 2021, complements TRL by focusing on the technology's developing readiness for human use. Our systems of interest are dependent on collaboration between humans in distributed organizations, which necessitates a balance between technological and human readiness to ensure safety.

The ANSI Human Readiness Level standard (ANSI/HFES 2021) offers a structured human-systems integration (HSI) approach. The framework comprises nine levels, guiding human factors activities from early concept exploration to operational use. Each level includes trigger questions on safety, human systems integration, and usability, which aids in the planning and execution of HF activities. The assessments help identify human-centered risks, define mitigation strategies, and track their effectiveness throughout development phases. Human systems experts and subject matter experts collaborate to ensure that each level's exit criteria are met, providing justification for the assessment.

Project risk is reduced by progressing through the HRLs, with iterative demonstration and testing. The HRL framework supports early integration of human factors without prescribing specific methods, but by providing evaluation guidance to help ensure that critical topics are addressed at relevant stages in the development process. Given that the HRL standard details a generic process that needs to be tailored for a specific context by HF expertise, and the domain-specific nature of human factors issues and development requirements, the oil and gas and maritime industries will need to develop and implement domain-specific strategies and practices for HRL assessments. This will help ensure that domain-relevant knowledge and experience is utilized, accumulated, and applied in consistent and meaningful HRL evaluations.

The following sections describe a case where we apply the HRL framework to an autonomous ferry and its shore control room, as a practical exploration of the HRL standard's utility in a real-world case involving high automation, AI and remote operations. After that we investigate how HRL aligns with existing standards and guidelines commonly used for control centers in Norwegian oil and gas industry: ISO 11064 and CRIOP.

This exploration aims to contribute to the development of domain specific HRL strategies, with the long-term goal of enhancing human factors integration in both the maritime and oil and gas industries. This is particularly timely given the increasing regulatory pressure from the EU AI Act. (AIA, 2024).

A HRL ASSESSMENT OF AN AUTONOMOUS FERRY CASE

We conducted a retrospective Human Readiness Level (HRL) assessment of an autonomous ferry project. This was done to evaluate its alignment with human-centered design (HCD) and human factors (HF) principles, and to guide future development efforts. The assessment revealed that while the project had engaged in extensive HCD and HF activities, these efforts were not systematically documented or aligned with the HRL framework. This resulted in only partial fulfillment of HRL levels 1 and 2, despite the ferry already being in the technology demonstration phase (TRL 4–5), indicating potential project risks due to incomplete human systems integration.

To address this, existing material was complemented, using the evaluation guidance to fulfill the exit criteria for HRLs 1 and 2. For instance, HRL 1 involved identifying key human characteristics and behaviors related to remote monitoring of the ferry, such as the transformation in operator roles, challenges in supervisory control, and collaborative issues in human-AI interaction. This provided a basis for HRL 2, which included developing high-level guidelines for remote operator information requirements, alarms and human-AI interaction in the remote operations center, and design principles for the passenger experience. Additionally, potential sources of human error or misuse were documented, covering risks related to autonomous maritime operations and human failure events. Initial metrics for successful human performance were defined, including usability metrics, operational metrics, and supervisory control metrics based on the taxonomy for human supervisory control (Cummings et al., 2008). These metrics covered aspects such as situation awareness, workload, accuracy of mental models, and reliance and perceived usability of the automation.

Ahead, meeting HRL 3 requirements will include applying CRIOP to systematically identify hazards and evaluating design concepts against the metrics defined in HRL 2.

Learnings from the HRL Assessment

The case demonstrated that the HRL framework provides valuable guidance and structure for incorporating HF best practices and state-of-the-art research into projects, especially those with limited existing human factors expertise or lacking a robust Human Systems Integration (HSI) process, as can be the case in entrepreneurial or academic settings with a strong technology focus. As the HRL emphasizes total system analysis, it ensures that wider HSE perspectives are considered at an early stage, for instance considering training requirements and maintenance personnel needs early, rather than as an afterthought in the face of implementation.

The case also illustrated how the HRL process can elevate overall HF competence within a project team, by mandating human factors (HF) planning and activities, thereby equipping UX designers with a better understanding of safety and HF methodologies. For instance, HRL 1 and 2 activities helped establish clear criteria for addressing human factors design issues related to high automation and AI. This is expected to contribute to improved design and evaluation of complex human-system interactions.

The case study demonstrated that the HRL standard is a useful framework for HF activities in an innovative, multi-stakeholder development project for remote and autonomous systems with an extended timeline. This approach can help demonstrate the safety and operational readiness of these systems, as it contributes to their perceived trustworthiness and that they adhere to emerging regulatory standards for AI, which will be crucial for their acceptance and integration into society.

ALIGNING HRL WITH DOMAIN-SPECIFIC METHODS

In the following we suggest how the phases and activities of the TRL and HRL can be aligned with established HSI methodologies used in industry (such as oil and gas) for control center design, i.e., ISO 11064 (2013), and a method for verification and validation, called CRIOP, (Johnsen et al., 2011).

ISO 11064 is a mature human factors method commonly applied in engineering control centers in the industry. It provides detailed guidance on control room layout, workstation design, display and control design, environmental factors, and operational and management systems. The ISO 11064 standard describes a generic best practice development process, that is iterative and consists of the phases: A) Clarification; B) Analysis; C) Conceptual Design; D) Detailed Design and Building/Construction; E) Operation and Operational Feedback/ Maintenance. As the work progresses from phase A) to E) experiences show that the cost of change increases exponentially, (Johnsen et al., 2011).

Thus, it is important to ensure that the project initiation (phase A) Clarification and B) Analysis) is high quality and as complete as possible, to ensure that key challenges are identified and mitigated (as an example: human centric design, not piecemeal design, ergonomical user interface). The HRL levels 1 to 3 that define the trajectory and scope of the development are of special importance. ISO 11064 describes what is needed to be done (i.e., tasks) and requires often more specification of documentation, and this guidance is offered by HRL.

CRIOP is a human factors guideline for verifying and validating best practice, developed by the oil and gas industry in Norway, (Johnsen et al., 2011), that supports evaluation as defined by ISO 11064 part 7. CRIOP is a mature and accepted methodology that is frequently used across the planning, design, and operational phases of offshore control room development. The method uses best-practice checklists and scenarios to verify and validate operational safety and usability in control centers. This includes control room layouts, safety measures, and processes, focusing on the ability to manage both normal and abnormal conditions.

CRIOP's HF best practice checklists correspond to the concept of "Work as imagined." "Work as done", (Hollnagel et al., 2013), is explored in a team setting by examining safety-critical scenarios selected by relevant users and experts. Identified weaknesses then lay the ground for recommendations and action plans for improvements. The CRIOP work is based on an action research approach (Greenwood & Levin 2006). Action research is a collaborative model often used in the automotive industry, in between industry, regulators, and workforce to prioritize learning from "work as done" vs "work as imagined" based on learning through implementation and reflection.

There are three main phases of the human readiness levels:

- Human Readiness Levels 1, 2, and 3 focus on conceptual development, defining human-centered requirements for performance and interaction. This corresponds to ISO 11064 clarification and analysis i.e., state of the art/research, concept clarification, HAZOP analysis (hazard and operability study) and design activities.
- Levels 4, 5, and 6 involve prototyping with increasing fidelity, and correspond to ISO 11064 analysis, conceptual and detailed design activities with tasks analysis, functional requirements, HMI, procedures, and integration testing from prototyping (high-fidelity simulation) to more realistic and complex demonstrations with representative users documenting test reports.
- Level 7, 8 and 9 focus on operational validation and system deployment correspond to the 11064 finalizing design, building operational production system, and performing full integration testing, user acceptance and implementation with supporting successful operation and maintenance.

In the following table 1, we have listed the key development phases of HRL, TRL and matched the HRL level to the ISO 11064 phases. We suggest key activities and results in the development process, to ensure safety, efficiency, and usability.

Table 1. Phases of HRL, TRL and ISO 11064.

HRL	TRL	ISO 11064 Phase & Key CRIOP Issues
1-Basic principles for human characteristics, performance, and behaviour observed and reported	Basic principles observed and reported	A) Clarification(1): Scope, Architecture vs adaption to "Fitts List" challenges, HF experts involvement
2-Human-centered concepts, applications, and guidelines defined	Technology concept and/or application formulated	A) Clarification(2): Human-Centered design principles & standards; Key safety tasks; Current successes, problems, and errors used to develop and describe Scenarios
3-Human-centered requirements to support human performance and human-technology interactions established	Analytical and experimental critical function and/or characteristic proof of concept	A) Clarification (3): Functional description; Safety critical tasks; Cognitive task analysis; Human Machine allocation; Situational awareness flow
4-Modeling, part-task testing, and trade studies of human systems design concepts and applications completed	Component and/or breadboard validation in laboratory environment	B) Analysis: Updated Task analysis and human machine function allocation; Rapid Prototyping; Test plan
5-Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design	Component and/or breadboard validation in relevant environment	C) Conceptual Design: Functional prototype, updated task analyses vs design, updated HMI, key observations for procedures, user test report
6-Human systems design fully matured and demonstrated in a relevant high-fidelity, simulated environment or actual environment	System/subsystem model or prototype demonstration in a relevant environment	D) Detailed Design and Building/Construction: Document functional req., with task analysis, HMI, user procedures/ manuals, full user test report
7-Human systems design fully tested and verified in operational environment with system hardware and software and representative users	System prototype demonstration in an operational environment	D) Detailed Design and Building/Construction: Document human interaction and effectiveness of systems, document integration test
8-Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users	Actual system completed and qualified through test and demonstration	D) Detailed Design and Building/Construction: Document full system test and acceptance
9-System successfully used in operations across the operational envelope with systematic monitoring of human-system performance	Actual system proven through successful mission operations	E) Operation and Operational Feedback/ Maintenance: The system is now in operations and key results is the Periodic evaluations, and control of changes from a HF perspective

Key Results in ISO 11064 That Should be Verified and Validated

Based on the results mentioned in the introduction, we have suggested that the following key results should be verified and validated as the HRL steps are progressing.

- HRL1 and A) Clarification: Document Scope, Architecture vs Human/Machine challenges as highlighted in (Roth et al., 2019) - since there is a need to match human capabilities and oversight with technology maturity, due to a strong technology optimism. AI must be analyzed in a sociotechnical/MTO context. HF experts must be involved from the start. Concepts supporting human performance should be identified.
- HRL2 and A) Clarification: Human-centered design principles& standards; Key tasks or safety critical tasks to get a holistic view; Current successes, problems, and errors, (documented in Scenarios that are powerful tools) since HF challenges and best practices often is missing. The exploration of experiences improves understanding of successful approaches. Key metrics are related to safety, efficiency, and usability – i.e. risk assessment, and specifics such as situation awareness, workload (physical and mental), accuracy of mental models between actors involved in oversight.
- HRL3 and A) Clarification: Functional description; Documentation of Safety critical tasks; Cognitive task analysis; Human Machine allocation; Situational awareness flow – since a fundamental understanding of functions and tasks is needed to support cognitive tasks analysis, and human/machine allocation. Missing SA flow has been a significant root cause in accidents and need to be addressed early.
- HRL4 and B) Analysis: Updated Task analysis and human machine function allocation; Rapid Prototyping performed; Test plan established – since there is a need to involve the users and update the design based on testing and prototyping as early as possible.
- HRL5 and C) Conceptual Design: Functional prototype, updated task analyses vs design, updated HMI, key observations for procedures (TOC), user test report – since the functional prototypes will support user centred design, and help update task analysis, HMI, and structure procedures.
- HRL6 and D) Detailed Design: Document functional req., with task analysis, HMI, user procedures/ manuals, full user test report – since the functional requirement and user testing will document user needs and finalize task analyses and HMI.
- HRL7 and D) Detailed Design: Document human interaction and effectiveness of systems, document integration test – since the integration test will document the quality of the whole system and quality of human interaction.
- HRL8 and D) Detailed Design: Document full system test and acceptance – since the full system test will expose the users to all aspects of the system and ensures that the acceptance of the system is based on actual whole system test with users, documentation and the whole organization involved.

- HRL9 and E) Operation: Maintenance - Periodic evaluations – since the periodic evaluations are important to ensure acceptable management of change and that the "see-to-it duty" has been clearly placed and not fragmented.

CLOSING REFLECTIONS

ISO 11064 serves as a reference for relevant ergonomic principles and provides guidance for human-system interaction. HRL offers a broader, structured approach to human-systems integration, emphasizing HCD and integrating research to ensure designs remain adaptable and responsive to new findings, which is especially valuable in rapidly developing fields, where conventional standards may lag. Combining HRL with the control center-specific guidance of ISO 11064 can be highly beneficial. CRIOP complements HRL by providing domain-specific guidance and a structured approach to identifying hazards.

Both HRL and ISO 11064 emphasize risk assessment, but with different focuses. HRL addresses a wide range of HSI risks and overall project risk, for instance misalignment between HRL and TRL. ISO 11064 guides risk assessments considering the probability and severity of hazards, emphasizing user involvement. CRIOP specifies the need for HAZOP analysis and key documentation of mitigation of critical scenarios. HRL facilitates comprehensive human factors documentation, mitigating the problem of tracking and aggregating low-level analyses.

CONCLUSIONS AND FURTHER WORK

The HRL standard, with its MTO systems perspective and focus on human centric design can play an important role in mitigating common issues in automation and remote operations, such as poor human readiness for new unproven technology, piecemeal changes which risk making safety brittle, and prioritization of physical ergonomics rather than cognitive ergonomics. It also holds potential for ensuring compliance with AIA (2024) by supporting systematic and comprehensive HSI work and documentation, providing evidence and an easily understandable metric for human readiness. In conclusion, to ensure safety, efficiency, and usability in rapidly increasing levels of automation and remote operations, we see the need to base the design on a risk-based approach considering the whole MTO system. The HRL framework with HSI methodologies like ISO 11064 and CRIOP can prove a powerful toolkit to achieve this goal.

The HRL framework is a powerful and cost-efficient management tool for prioritizing Human Factors in the early conceptual stage, identifying key HF activities at the right time, and ensuring that key documents are produced before progressing to the next step. Thus, HRL supports project management through checking activities, exit criteria and resulting documentation as supporting evidence. The CRIOP method supports this, by a more detailed quality assurance of both work as imagined (i.e., description by documents) and work as done (i.e., workshops with detailed scenario analysis of critical tasks).

While human-AI interaction research has long emphasized the need for human intervention when risks or errors are detected, (Enqvist, 2023) argues that human oversight is essential throughout the AI system's lifecycle, i.e. from early conceptual development to deployment and operation. Application of ANSI-HFES HRL2021/ ISO-11064 and CRIOP will support this. The suggested methods should also help during operations and maintenance, as the initial tasks in HRL 1–3 proactively identify challenges, thus supporting change management.

Future research should look deeper into the concept of effective human oversight in AI systems in the domain: design principles and evaluation metrics, as well as the practical implementation and distribution of responsibilities among providers and users of high-risk AI. This paper is funded by the MAS project, RCN 326676.

Reliability, Credibility, and Transferability

Reliability is supported through consistent issues being identified by other researchers in the referenced literature. Credibility was established through checks with stakeholders, and prolonged engagement with the research. Transferability is demonstrated by identification of similar issues across multiple industries, through workshops, interviews, and case studies,

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