Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks

Deliverable Report – D7.4

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ABBREVIATIONS

DoA	Description of the Action
HR	Human Resources
HCI	Human-Computer Interaction
HRI	Human-Robot Interaction
UI	User Interface
VR	Virtual Reality

HISTORY OF CHANGES

Date	Written by	Description of change	Approver	Version No.

REFERENCED DOCUMENTS

- BUGWRIGHT2 Description of the Action (DoA)
- D1.5 Work Analysis of task, technology and social system
- D7.2 Virtual reality for Real-Time Mission Monitoring

- D7.3 User Interface for Inspection Mission Planning
- Ellwart, T., & Schauffel, N. (2023). Human-autonomy teaming in ship inspection: Psychological perspectives on the collaboration between humans and self-governing systems. In T. M. Johansson, D. Dalaklis, J. Echebarria Fernández, A. Pastra, and M. Lennan (Eds.), *Smart Ports and Robotic Systems. Navigating the Waves of Techno-Regulation and Governance. Studies in National Governance and Emerging Technologies* (pp. 343-362). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-25296-9_18
- Ellwart, T., Schauffel, N., Antoni, C. H., & Timm, I. J. (2022). I vs. robot: Sociodigital self-comparisons in hybrid teams from a theoretical, empirical, and practical perspective. Gruppe. Interaktion. Organisation. Zeitschrift für Angewandte Organisationspsychologie (GIO). 54, 273-284. https://doi.org/10.1007/s11612-022-00638-5
- Gründling, J. P., Schauffel, N., Oehrl, S., Pape, S., Kuhlen, T. W., Ellwart, T., & Weyers, B. (2023). Example Process for Designing a Hybrid User Interface for a Multi-Robot System. In *2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW),* Shanghai, China. https://doi.org/10.1109/VRW58643.2023.00124
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- Schauffel, N. (2023, September 25-26). *Implementing a multi-robot solution in ship inspection and maintenance. The role of human factors exemplified within the BUGWRIGHT2 project* [Paper presentation]. Summer School for Human Factors 2023, Chemnitz, Germany.
- Schauffel, N., & Ellwart, T. (2023, September 12-15). *Soziodigitale Selbstvergleiche in Mensch-Autonomie-Teams. Theoretische und empirische Perspektiven [Sociodigital self-comparisons in human-autonomy teams. Theoretical and empirical perspectives]* [Paper presentation]. 13st AOWI-Fachgruppentagung, Kassel, Germany.
- Schauffel, N., Gründling, J., Weyers, B., & Ellwart, T. (2023). *Implementing human-robot teams in the field. Insights on human resources methods and tools exemplified within the BUGWRIGHT2 project* [Unpublished manuscript]. Trier University.
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- Schroepfer, P., Schauffel, N., Gründling, J., Ellwart, T., Weyers, B., & Pradalier, C. (2023, August 31). *Trust and acceptance of multi-robot systems „in the wild". A roadmap exemplified within the EU-project BUGWRIGHT2* [Paper presentation]. SCRITA Workshop, Busan, South Korea.

Executive Summary

This deliverable report D7.4 documents the results of Task 7.4 “Human factors in Human-Robot-Teams/VR-interface design”. As specified in the Description of the Action (DoA), “the task supports the development of the VR interfaces with (1) an optimal fit between task, technical and user characteristics, (2) ensuring high user acceptance and (3) the development of user qualification requirements for an optimal transfer.” (DOA, p. 59).

The structure of the deliverable is threefold and deals with the following parts: (Part I) user interface (UI) design guidelines, (Part II) UI evaluation studies, and (Part III) human resources methods and tools for personnel development and field application. The main deliverables result from multiple off-site (e.g., literature review, laboratory studies) and on-site (e.g., field interviews and studies) research activities conducted within Task 7.4 (see Figure **1** for outcomes and deliverables).

This deliverable report includes three chapters. Chapter 1 summarizes the main deliverables. Chapter 2 spotlights the separate outcomes of Task 7.4 with a focus on the main results and value for BUGWRIGHT2. Reference is made to more extensive outcome documentation. Chapter 3 concludes with a summary.

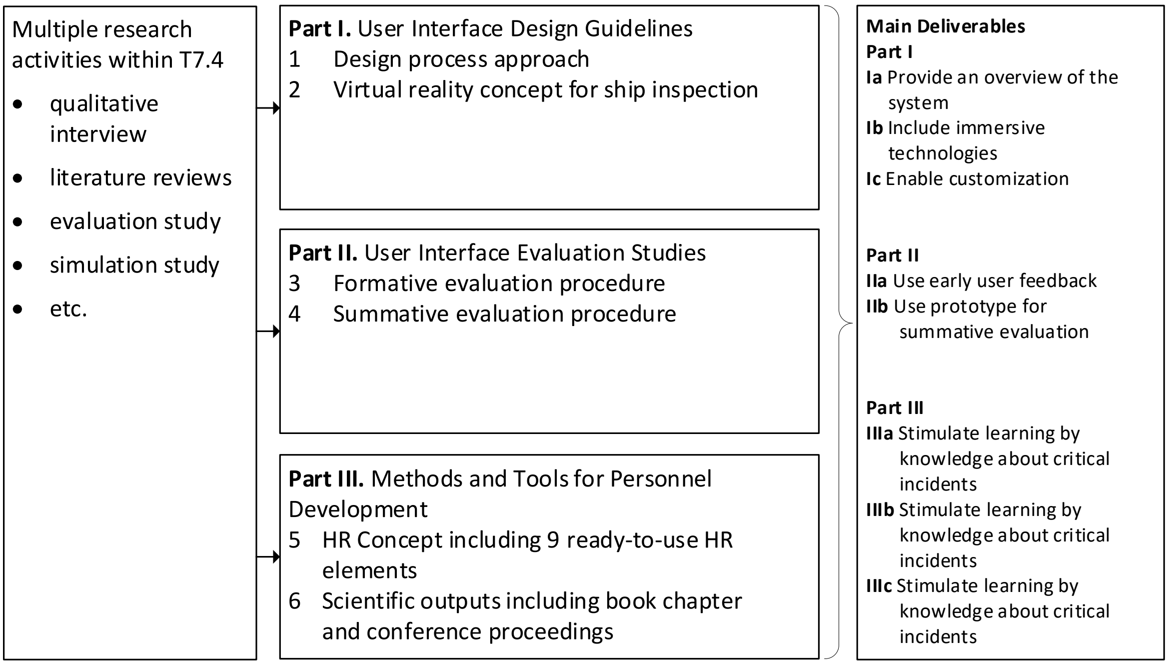

Figure 1: Overview of How the Main Deliverables of Task 7.4 Result from Different Research Activities

1. Introduction and Main Deliverables

The objectives and main deliverables of Task 7.4. follow a threefold structure (see Part I, II and III in Figure 2) and "support […] the development of the VR interfaces with (1) an optimal fit between task, technical and user characteristics, (2) ensuring high user acceptance and (3) the development of user qualification requirements for an optimal transfer." (DoA, p. 59). Thereby, research activities within Task 7.4 were not isolated but built on the findings and research activities of Task 1.5 which was the work analysis of task, technology, and social system.[1]

In detail, the separate outcomes of Task 7.4 are documented and referenced in Chapter 2. Briefly, the main deliverables of Task 7.4 are the following:

Part I. *UI Design Guidelines*

Task 7.4 aims to provide design guidelines for a user interface for the multi-robot system developed within BUGWRIGHT2. The research conducted during the project leads to three main deliverables:

(Ia) *Provide an overview of the system.* This includes a dashboard-like view that displays information such as available robots, a 3D model of the ship to inspect, a 2D plan of weld lines, a list of missions, suspect areas on the hull, and the option to add suspect areas. Additionally, a robot detail view should be included to provide detailed information on each robot's missions, position, sensor values, status log, and the option to control the robot.

(Ib) *Include immersive technologies*, such as virtual reality (VR), in the user interface. The use of VR can enhance the user experience and provide a more immersive and engaging interaction. A hybrid UI is proposed, combining a desktop application for system overview and a VR solution for detailed mission planning and monitoring. The VR component allows users to select robots, draw paths on the ship hull, and start missions.

(Ic) *Enable customizability* of the user interface. Users have different roles and workflows, and they want to shape the UI to suit their needs. Desktop applications should allow view adjustments, where users can choose the proportion of information displayed. The immersive part of the UI should also be available whenever possible, allowing users to seamlessly switch between desktop and VR environments.

Part II. *UI Evaluation*

BUGWRIGHT2 conducted several evaluations to find an appropriate evaluation procedure that could be adaptable to the design process iterations. Two main categories of UI evaluation procedures were identified: paper-based evaluation and prototype-based evaluation.

(IIa) *Use early user feedback:* Especially when developing for an emerging technology such as the system in BUGWRIGHT2, it is crucial to include end user feedback as early as possible. Therefore, creating mock-ups or paper prototypes of the UI design is a well usable method. The mock-ups serve as visual aids for discussions with end users and can be easily adapted based on their feedback. Cognitive walkthroughs are conducted with end users, where they are presented with the mock-ups and asked to describe how they would use the UI and provide comments and thoughts on each step and feature. This approach helps the development team gain insight into user thinking and reduces the risk of time-consuming implementations. The number of paper-based formative evaluations can vary depending on the changes indicated by each evaluation.

[1] Nextcloud: Deliverable report D1.5 of task 1.5

(IIb) *Use prototype for summative evaluation:* Once a version of the UI is ready to be implemented as a functional prototype, connect it to a real robotic system or simulator. Evaluation participants can then conduct their tasks in a close-to-reality setting. This allows for summative evaluations, including quantitative ratings like usability scores, to determine if the UI meets predefined Key Performance Indicators (KPIs). The evaluation includes a questionnaire tailored to the use case and based on the EN ISO 9241-110 standard. It also includes the System Usability Scale to measure overall usability. This approach provides structured feedback collection and helps ensure a high usability of the multi-robot UI.

Part III. *Personnel Development*

The implementation of automation in previously manual work fields leads to fundamental changes in human tasks, roles, and responsibilities. Individual circumstances make it impossible to use static solutions and predefined answers. Nevertheless, scientific outputs published (e.g., book chapter, conference proceedings) and multiple HR instruments developed (e.g., checklist, workshop skeleton) provide helpful basic principles to support the dynamic and uncertain phases of automation projects. Three main deliverables guide the action for personnel development:

(IIIa) *Stimulate learning by knowledge about critical incidents.* Avoid abstract discussion on failures, expectations, or requirements for successful human-autonomy interaction but focus on concrete tasks and experiences instead. The developed and applied HR instruments target critical incidents in routine and non-routine tasks. There, we combine critical incidents with both positive and negative outcomes and apply a retrospective and prospective perspective on reflection and evaluation to optimally stimulate organizational learning within BUGWRIGHT2.

(IIIb) *Ensure tangible mental models by process visualizations.* Process-based visualization of key processes, interdependencies, and challenges synchronizes the mental models of the stakeholders involved. The developed and applied HR instruments support efficient trust calibration and help to put expectations and fears into perspective.

(IIIc) *Consider skill shifts in technical and nontechnical skill areas.* Digitization and automation result in shifting skill requirements for employees. Importantly job-relevant skills go beyond technical skills (e.g., professional knowledge and qualifications) and include non-technical elements (i.e., interpersonal, and cognitive skills). The developed and applied HR instruments target the multifaceted nature of skill profiles, uncovered disruptive skill shifts, and specific training needs, especially in nontechnical skill areas.

2. Outcomes of Task 7.4 in Three Parts

Part I Guidelines: "applicable guidelines and design principles to integrate task characteristics and user expectations into task 7.2 and task 7.3." (DOA, p. 60)

(1) Design Process Approach
Presentation of the design process required for the BugWright2 UI
Outcome: Scientific Poster, presented at the IEEEVR23 conference; Journal Paper submitted
Method: Analysis, Design Process, examples, evaluation

(2) Virtual Reality concept for ship inspection
Early user feedback on a VR design draft for ship inspection

Outcome: Scientific Poster
Method: Analysis, Evaluation

Part II Evaluation: "evaluation designs, methods and results for the UI based on multivariate data from user experiences to mental workload indicators (e.g. survey data, prefrontal activation), or out-of-loop behavior during VR. Prototypes developed at RWTH will be tested iteratively." (DOA, p. 60)

(3) Formative evaluation procedure
Form to document decision that were drawn during the design process, based on formative evaluations

Outcome: Desgin decision template
Method: Mock-up based evaluation, documentation

(4) Summative evaluation procedure
Questionnaire and results from the summative evaluation of the BugWright2 UI.

Outcome: Design iterations and final UI concept, summative Questionnaire
Method: Structured interviews, questionnaire construction

Part III Personnel Development: "Data from the field evaluation (observations, surveys) for personnel development to ensure user attitudes and qualifications upon market introduction" (DOA, p. 60)

(5) Human Resources (HR) Concept on Psychological Change Management
HR concept supporting the implementation of a multi-robot system along the phases of psychological change management.
Outcome: Booklet that (1) summarizes relevant scientific input, (2) outlines the relevance for BUGWRIGHT2, and (3) provides HR elements to support the implementation of multi-robot systems in the field
Method: Literature research, best practice examples

(6) Scientific Research on Human-Autonomy Teaming in Relation to BUGWRIGHT2
Theoretical and empirical research on psychological variables and concepts of human-autonomy teaming.
Outcomes: e.g., book chapter, poster and research presentations at international scientific conferences, and summer school Human Factors
Method: Literature research, empirical research, practical recommendations

Figure 2: Overview of the Separate Outcomes that Contribute to Our Main Deliverables and Referred Documents

Part I. User Interface Design Guidelines

One core goal of task 7.4 is to provide design guidelines for a user interface for the multi robot system developed within BUGWRIGHT2. Therefore, it was carefully observed, which main principles contributed to a sophisticated user experience and how they connected to the work analysis in this case. Along the development process, three main findings can be formulated: (1) Provide an Overview, (2) Include immersive technologies, and (3) enable customizability.

(1) Design Process Approach

Theoretical background. Developing and implementing a user interface for a multi-robot system is a task that requires creativity, empathy, and thorough analysis. Especially when, as in this case, the multi-robot system is to be introduced into an existing work environment, it is crucial to achieve a good fit of the new technology with existing workflows. The Design Thinking approach (Meinel, 2011) appears as a useful methodology to characterize the current processes of work and to identify the needs and expectations of potential future users. Five Steps are associated with Design Thinking: **Empathize** with the users, **Define** the problem and solution space, **Ideate** about possible implementations of solutions, **Prototype** the ideas, **Test** the prototypes. These steps are run through iteratively, but not necessarily sequentially. To account for uncertainties in the beginning of the design process, it can be useful to start with smaller iterations of ideating and testing using drafts and mock-ups of the UI rather than moving on to implementing a prototype. This enables the development team to better understand how to address the user's need. The insights gained through this procedure contribute to producing a high user-friendliness of the prototype while reducing the risk of unnecessary costs of re-implementing the prototype.

Method. Design Thinking.

Main results. Two publications (Gründling et al., 2023; Gründling and Weyers 2024) provide information for guidelines to consider when designing a UI for a multi-robot system as developed in BUGWRIGHT2. Regarding our research, it turns out that including immersive technologies, such as VR, contributes significantly to the user experience of this multi-robot UI. We therefore propose a hybrid UI, combined of a desktop application for system overview and a VR solution for detailed mission planning and monitoring. The desktop application should be divided into three views, or pages, each dedicated to a specific task of the inspection process as described below.

Overview of the whole system. Users expect to start with information about what the system's current state is. We therefore propose providing a dashboard like view. The dashboard should include (1) robots available, (2) a 3D model of the specific ship to inspect, (3) a 2D plan of weld lines across the hull, (4) a list of missions currently running, (5) a list of suspect areas on the hull, (6) an option to add suspect areas.

Robot detail information. To enable the user to get detailed information on any robot at any time, a robot detail view should be included. We found out that it was necessary to provide (1) the missions the robot is participating in, (2) an option to add a new mission to this robot, (3) a visualization of the current robot's position, (4) visualization of sensor values, if applicable, (5) a status log of the robot, (6) the option to manually take over control of the robot or to stop/pause the mission.

Inspect suspect areas. The possibility to get detailed information on hull areas that might need to be repaired is an integral part of the UI. To successfully evaluate if a reparation is needed, the users require (1) visual material of the hull area, i.e., pictures, (2) location information, (3) information about affected metal plates (plate names), (4) option to propose an action, (5) text field to leave notes, (6) the option to start a new mission at this location.

Edit Missions. To plan, start and edit missions, the usage of VR proved useful, as it increased the situational understanding and provided an intuitive way to draw paths on the ship hull which represented the mission that a robot had to fulfill. In VR, the user should be able to select robots and afterwards draw a path onto the hull or place waypoints in the virtual space followed by confirming (starting) the mission.

Further details can be found in the referenced documents, while the design based on the here described process for this project is shown in the figures at the end of Part II.

Value. The value of these guidelines is at least twofold. First, it provides information on how 2D and 3D interfaces can be combined into one seamless UI. Second, it serves as an entry point for further research and development regarding the design of hybrid multi-robot interfaces.

Referenced documents.

Gründling, J. P., Schauffel, N., Oehrl, S., Pape, S., Kuhlen, T. W., Ellwart, T., & Weyers, B. (2023). Example Process for Designing a Hybrid User Interface for a Multi-Robot System. In *2023 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW),* Shanghai, China.

(2) Virtual Reality concept for Ship Inspection

Theoretical background. Immersive technology is a field that has been extensively researched in the past two decades. According to a study by Mohsen and Alangari, immersive technology research in education has been grounded on a robust theoretical framework such as constructivism, experiential learning, and cognitive load theory (Mohsen and Alangari, 2023).

Virtual reality (VR), augmented reality (AR), and mixed reality (MR) are the three main types of immersive technology. VR creates a simulated environment that is like the real world, while AR enhances the real world with virtual elements. MR combines elements of both VR and AR, allowing users to interact with virtual objects in the real world and vice versa (Mohsen and Alangari 2023; Lei et al., 2023).

Immersive technology has a wide range of applications, from entertainment to education and training. For example, VR can be used to create realistic simulations for training purposes, such as flight simulators for pilots or surgery simulators for medical professionals (Mohsen and Alangari, 2023).

A study by Majonica et al. explored immersive learning in the field of Human-Robot Interaction (HRI) and identified several areas of risk, including miscommunication, privacy concerns, and injuries. The study also explored common human learning outcomes based on the interaction categories (Majonica et al., 2024).

Additionally, literature indicates that virtual reality can improve the quality of human-robot interaction by providing a more immersive and engaging experience (Duguleana et al., 2011).

Method. Literature research, design sessions, prototype, and test.

Main results. The publication by Gründling and Weyers (2023) presents that the usability of a VR interface draft is acceptably high. The interaction concepts used for that investigation were utilized in the further course of development within the BUGWRIGHT2 Project. As described in Part II, they led to an increase in usability and were appreciated by the end users included in the evaluations. In general, there were three main findings: (1) provide as many environment details as possible, (2) continuous movement can be appropriate, (3) use consistent interaction.

Details. During the experiments conducted for this project, it became apparent that the participants did not only appreciate interacting with the 3D representation of the ship, but also specifically demanded environmental details to be included in the virtual environment. Of course, the core goal here must be to avoid a distractive environment. Therefore, the developers are challenged to find a balance between the number of details included and the level of distraction induced by them.

Navigation. Common navigation techniques in VR include, e.g., teleporting or real walking. However, for this specific case it seemed that another, rather unpopular option might be best: Continuous Movement. Continuous movement, also referred to as steering or fly-around navigation utilizes the controller's pointing direction to determine the user's movement direction and the control stick to control the speed. In a scenario where the user needs to move around a ship at different heights and distances, this method appeared to be preferable to other types of navigation.

Consistency. In the first prototypes that where evaluated, it became apparent, that even if there are different types of robots to create and monitor missions for, the users wished to have the same interaction type to do this for all robot types.

Validation. The validation of these principles was done through the evaluations described in Part II.

Value. The value of these findings lays in that there is now a better understanding about what details to include, how to design navigation techniques and interaction in a VR environment as part of a hybrid multi-robot user interface. Future research can build upon this knowledge to further improve the design of hybrid user interfaces for multi-robot systems. The implementation of the VR user interface was conducted by RWTH and is further described in D7.2 and D7.3.

Referenced documents.
Gründling, J. P., & Weyers, B. (2023). Early User Feedback on a VR Interface Draft for Interaction with a Multi-Robot System in Ship Hull Inspection (in press). In *29th ACM Symposium on Virtual Reality Software and Technology.* ACM. https://doi.org/10.1145/3611659.3617228

Part II. User Interface Evaluation

During the project BUGWRIGHT2, several evaluations were conducted. In the search for an appropriate evaluation procedure, it was found, that the best evaluation is flexibly adaptable to the iterations of the design process. This way, it was possible to obtain user feedback as soon as possible and include it in the ongoing UI development process. Two main categories of UI evaluation procedures need to be highlighted: (3) Paper-based evaluation, and (4) Prototype based evaluation.

(3) Formative evaluation procedure.

Theoretical background. Ideation is at the beginning of first visual outputs of the design process. Ideation refers to the process of brainstorming and finding ways to address the task characteristics and user needs in the ship inspection task. This results in first drafts, also called mock-up or paper prototype. While these mock-ups do not provide actual functionality, they are a great visual aid to deliver the intended UI appearance. Hence, they function as a useful tool for discussions with end users. As mock-ups come at low cost of time and are easily adaptable following feedback from end users, they should be used extensively during process phases in which the uncertainty about the final UI is rather high. The actual evaluations of mock-ups are done by conducting cognitive walkthrough with end users, meaning that in workshops, the users are presented with the mock-up and are asked to describe how they would conduct their tasks using the UI represented by the mock-up and provide comments and thoughts on each step and feature seen in the mock-up. By doing so, the development team gains further insight into how end users think about using the multi-robot technology UI while reducing the risk of time-consuming implementations for a functional prototype. The number of formative paper-based evaluations can be variable, depending on the changes indicated by each evaluation compared to the previous evaluation. At the point in time where the increments of change required by end users become small enough to be made in a functional prototype without too high costs, the development switches to implementing and evaluating the actual prototype.

Method. Sketching, cognitive walkthrough, think-aloud.

Main results. The file “Design decision template” provides a structured form to protocol feedback on certain features of the UI. By using this structured form, it is possible to keep track of the comments and feedback provided by end users that shaped the design process. Agile methods like digital whiteboard sketching to visualize each iteration of the UI have proven as a valuable approach. During the evaluations of the UI design iterations, it became clear that a user interface of the kind needed in BUGWRIGHT2 leverages its full potential, when it is adaptable to different use cases. Whether it is one user role or another, ship inspection or storage tanks, service supplier or classification society, etc. Almost every user wants to shape the UI appearance in a way that suits their workflow and needs. Therefore, we recommend for desktop applications, to enable view adjustments, where the proportion of information displayed can be chosen freely by the user. Furthermore, the immersive part of the UI should be available whenever possible, such that the users can switch seamlessly between desktop and VR whenever they see fit to do a task in the respective environment.

The iterative testing of mock-ups developed in collaboration with RWTH Aachen has led to the UI design drafts displayed in Figure 3 (Dashboard), Figure 4 (Robot detail), Figure 5 (Inspect suspect areas), and Figure 6 (Mission editing).

Value. The template provided helps structuring the feedback and description of implementation decisions.

Referenced documents.
Design decision template.[2]

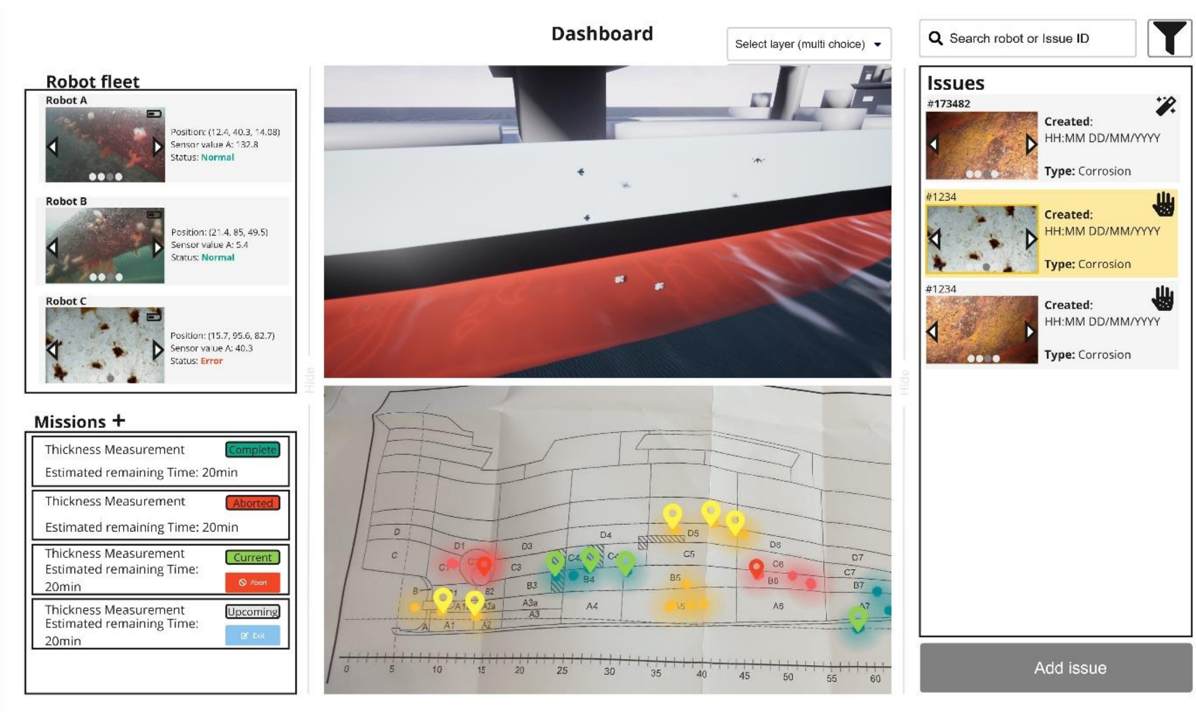

Figure 3: Mock-up of the Dashboard providing an overview over the system

[2] Nextcloud: “Design Decision Template.docx”

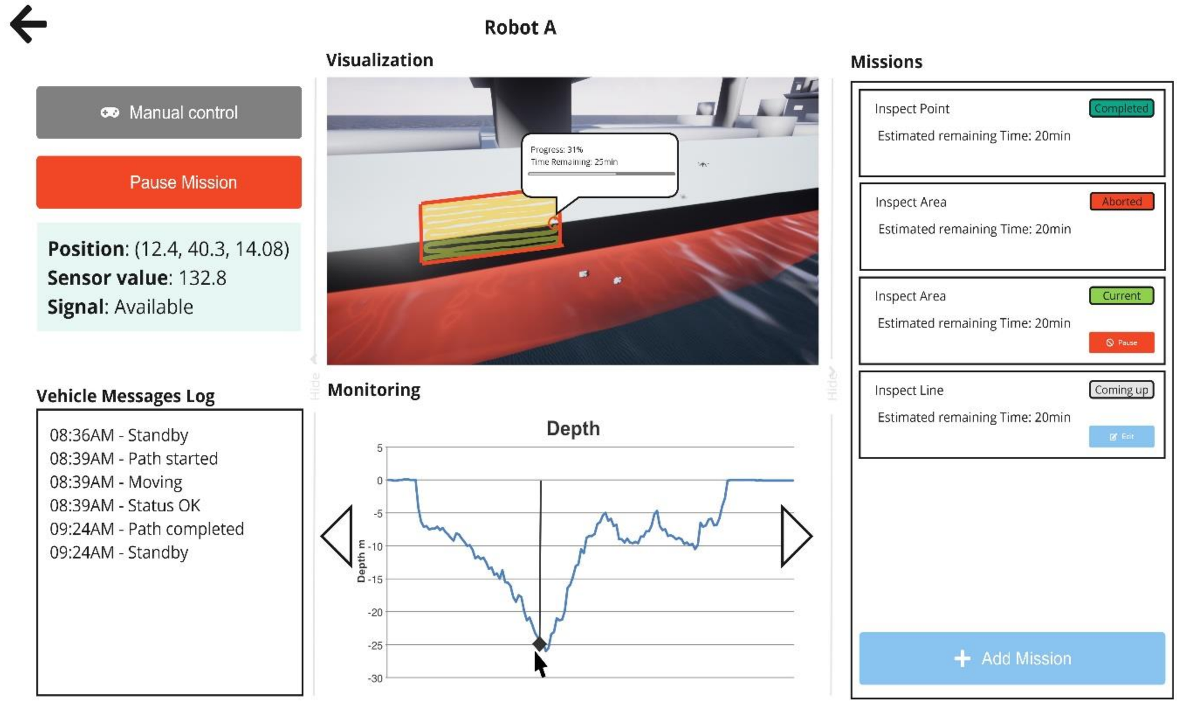

Figure 4: Mock-up of 2D interface for robot detail information

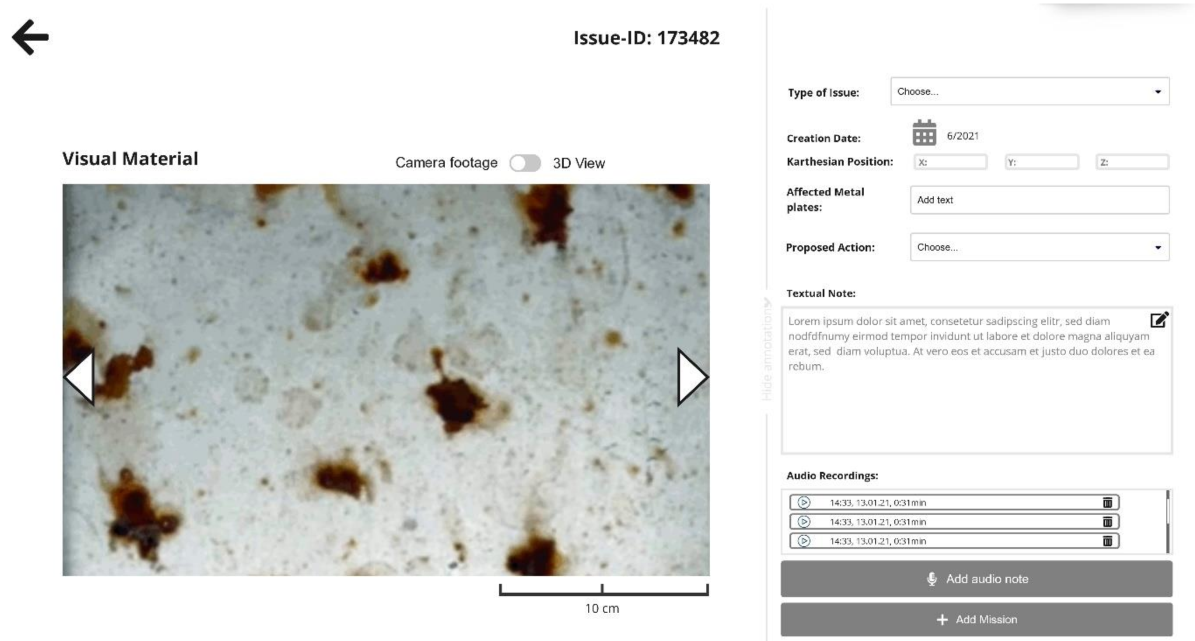

Figure 5: Mock-up of 2D interface for suspect area inspection

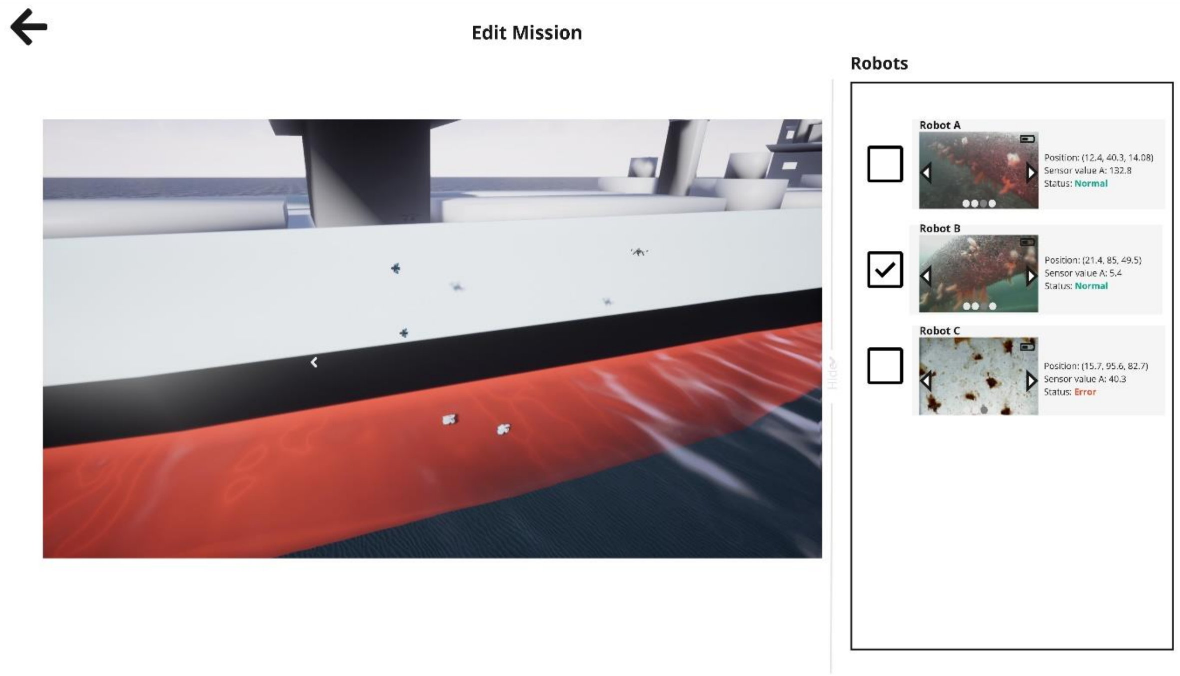

Figure 6: Mock-up of 2D interface for mission editing

(4) Summative evaluation procedure.

Theoretical background. Once the development team decided on a version of the UI that is ready to be implemented as a functional prototype, this prototype can be used for the evaluation procedure. By connecting the UI prototype to a real robotic system or a simulator, the evaluation participants can conduct their tasks in a close-to-reality setting. This opens the possibility to conduct evaluations in a summative nature, including quantitative ratings like usability scores. Therefore, it enables to evaluate whether the UI meets the predefined KPIs and if not, what actions are needed to fulfill the requirements.

Method. Implementation, testing.

Main results. As an example of how a summative evaluation can be conducted adhering to the EN ISO 9241-110, we provide the questionnaire that was used in the final evaluation of the BUGWRIGHT2 UI. The questionnaire was tailored to the use case and carefully considered the most relevant parts of the ISO norm. Additionally, it includes the System Usability Scale (SUS), which is an indicator of how well the UI is usable by the participants of the evaluation. The questionnaire considers each part of the UI on its own plus an overall rating at the end.

Value. The provided questionnaire unfolds its value in providing a structured feedback collection mechanism that focuses on the most relevant details needed to ensure a high usability of the multi-robot UI. As it accounts for the role of the specific participant answering it, the questionnaire can reflect which role specific requirements need to be considered during the design process. UT conducted quantitative and qualitative evaluation studies during the summative evaluation. End-users tried out the UI prototype using the desktop and VR versions of the UI implemented by RWTH Aachen and rated the different UI views based on previously described procedure. The insights were analyzed, clustered, and discussed together with the team of RWTH. The results of this evaluation with N=5 participants yield a score on the System Usability Scale of 79.5. Further information on and a thorough demonstration of the finally implemented UI can be found in Deliverables D7.2 and D7.3.

Referenced documents.

Gründling, J. P., & Weyers, B. (2023). Early User Feedback on a VR Interface Draft for Interaction with a Multi-Robot System in Ship Hull Inspection (in press). In *29th ACM Symposium on Virtual Reality Software and Technology.* ACM. https://doi.org/10.1145/3611659.3617228

Summative Questionnaire[3]

Part III. Personnel Development

Multiple research activities aimed at gathering "data from the field evaluation (observations, surveys) for personnel development to ensure user attitudes and qualifications upon market introduction" (DoA, p. 60). Two separable groups of outcomes can be highlighted: (6) HR concept on psychological change management and (7) scientific research on human-autonomy teaming.

(5) HR Concept on Psychological Change Management

Theoretical background. Implementing a multi-robot solution in ship inspection and maintenance resembles a multiphase change process. We differentiate four overall phases of change management in the automation project BUGWRIGHT2 (i.e., planning phase, implementation phase, stabilization phase, evaluation and learning phase). Each phase is characterized by specific tasks and challenges for practitioners and stakeholders involved (Schlicher et al., 2018). Topics of use case specification and work analysis are fundamental in the planning phase (e.g., Kauffeld & Martens, 2014). Change communication and task-specific reflection regarding human-robot interaction might help to reduce resistance to change during the implementation phase (e.g., Elving, 2005). Especially for the long-term success and acceptance of new robotic technologies, role-specific skill management, the identification of skill demands, and knowledge of concrete training needs are elementary (e.g., Rieth & Hagemann, 2021; Sharma & Kim, 2022). Topics on how to support and stimulate organizational learning are essential to draw lessons learned, improve technology development in iterative loops, and identify transfer potentials (e.g., Argote, 2011).

Method. Literature research, field studies, tool development, and validation were conducted.

Main results. The booklet (Schauffel et al., 2023) provides an overarching HR concept including scientific input on psychological change management and deep dives into selected topics of change management within the project BUGWRIGHT2. The deep dives tackle the topics of process-based work analysis (HR-E2), technical and nontechnical skill shifts (e.g., HR-E3, HR-E4), and creating, retaining, and transferring knowledge as organizational learning (e.g., HR-E8, HR-E9). Each deep dive is introduced scientifically, followed by an exemplary illustration and realization within BUGWRIGHT2. Highlights of the HR concept are 9 ready-to-use HR elements. Such HR elements include checklists, interview guidelines, and workshop skeletons to reassess and examine key topics of change management in the future. See Table 1 for an overview of the developed HR elements, including a short description and exemplary scientific basis.

Value. The HR concept with a triad of theory, field application, and HR instruments is valuable within and beyond the BUGWRIGHT2 project for at least three reasons:

(1) *Technological enhancement.* Continuous development of technological bricks of the multi-robot system leads to the fact that the composition, functions, and user interface demands of the multi-robot system

[3] Nextcloud: "Summative Questionnaire.pdf"

continue to change. Readjustment of work processes and skill profiles become relevant, which requires continuous change management.

(2) *Specific circumstances.* Single stakeholders are characterized by framework conditions (e.g., perform sub-processes only, outsourced work steps, company size), which require additional analysis of their specific circumstances.

(3) *New application cases.* The technological bricks can also be used in additional use cases and field applications (e.g., in-water drug detection).

The HR elements provide a blueprint for practitioners on how to proceed in such cases in the future, and to justify their action based on state-of-the-art scientific knowledge.

Reference to HR Concept developed within Task 7.4.

Schauffel, N., Gründling, J., Weyers, B., & Ellwart, T. (2023). *Implementing human-robot teams in the field. Insights on human resources methods and tools exemplified within the BUGWRIGHT2 project* [Unpublished manuscript]. Trier University.[4]

Table 1. Overview of Developed HR Elements Compiled to Support the Change Process within Automation Projects

HR Element	Short Description	Scientific Basis
HR-E1. HR Checklist	Checklist to support the phases of change management in automation projects	e.g., Lewin (1947); Paruzel et al. (2020); Schlicher et al. (2018)
HR-E2. HR Work Analysis Guide	Guideline to conduct a process-based work analysis in two steps. Key elements are the visualization of process sequence and interdependencies and the identification of central work characteristics and automation potentials	e.g., Grote et al. (2000); White & Miers (2008)
HR-E3. HR Skill Set	Worksheet summarizing the three-level HR Skill Set including technical and non-technical skills in four overarching skill areas (basis knowledge, system knowledge, cognitive skills, (inter-)personal skills)	e.g., Mishra et al., (2009); Sharma & Kim (2022)
HR-E4. HR Skill Survey	Worksheet to elaborate present and future skill needs in human-robot teams with a focus on non-technical skill areas	e.g., Mishra et al., (2009); Sharma & Kim (2022)
HR-E5. HR Knowledge Guide	Worksheets to structure reflection on knowledge needs in technical skill areas in human-robot teams	e.g., Mishra et al., (2009); Sharma & Kim (2022)
HR-E6. HR Recruiting Guide	Guideline and exemplarily realization of a multimodal job interview	e.g., Schuler (1992, 2018)
HR-E7. HR DIN 9241 Guide	Workshop skeleton to derive support needs and user interface design recommendations	e.g., DIN EN ISO 9241-110

[4] Nextcloud: "BW2 - HR Concept.pdf"

HR-E8. HR Mission Tracking	Template how to document and reflect critical incidents following missions	e.g., Flanagan (1954); Mehlich (2012)
HR-E9. HR Learning Guide	Interview guidelines to monitor organizational change and stimulate organizational learning combining a retrospective ("looking back") and prospective ("looking ahead") perspective on change	Ellwart et al. (2023)

(6) Scientific Research on Human-Autonomy Teaming in Relation to BUGWRIGHT2

Theoretical background. Reviewing existing research on human-autonomy teaming a solid basis of models (e.g., input-mediator-output-input model of teaming, Kozlowski & Bell, 2013; McNeese et al., 2018; O'Neill et al., 2022; You & Robert, 2017) and central concepts (e.g., trust, Hancock et al., 2011; Hoff & Bashir, 2015) exist. However, multi-robot teams in real-world scenarios expand the complexity of human-autonomy teaming by multiple human and non-human actors and stakeholders involved (e.g., Pastra et al., 2022). Field visits within BUGWRIGHT2 and outcomes of Task 1.5 revealed blind spots in existing HRI research that touched – among others – topics of a complex ecosystem of trust and acceptance, knowledge needs in collaboration between humans and self-governing systems, and comparison processes between human and non-human actors in a work setting.

Method. Using literature reviews, qualitative interview data, quantitative data from simulated human-autonomy teams in the laboratory, and vignette studies, we conducted multiple research projects to address the blind spots identified. The results were disseminated by publications and communicated at international and interdisciplinary scientific conferences in the fields of human factors, work psychology, and engineering.

Main results. On a meta-level, the results show that existing psychological concepts and methods can be transferred to the context of human-autonomy teaming (e.g., calibration of mental models, trust dynamics, and comparison processes). The results cannot be summarized without further ado on a detailed level because the research questions and methods are highly diverse between the publications.

Value. The results are valuable from at least three points of view.

(1) Visibility BUGWRIGHT2. Submissions to international conferences and open-access publications increase the visibility of the BUGWRIGHT2 project with its research topics in the research community (e.g., HRI, HCI, work psychology, engineering psychology) and within related automation projects in the maritime sectors (e.g., MariData).

(2) Stimulate Research. The results expand knowledge and outline specific action fields for further research (e.g., antecedents, consequences, and temporal dynamics of socio-digital self-comparisons in human-autonomy teams, Ellwart et al., 2022; Schauffel & Ellwart, 2023).

(3) Guide practitioners. The results summarize concepts (e.g., mental models) and methods (e.g., elaboration and visualization), to be considered in the field implementation of automation projects in the future (e.g., Schroepfer et al., 2023).

Reference to research outcomes of Task 7.4.

Ellwart, T., & Schauffel, N. (2023). Human-autonomy teaming in ship inspection: Psychological perspectives on the collaboration between humans and self-governing systems. In T. M. Johansson, D. Dalaklis, J. Echebarria Fernández, A. Pastra, and M. Lennan (Eds.), *Smart Ports and Robotic Systems. Navigating the Waves of Techno-Regulation and Governance. Studies in National Governance and Emerging Technologies* (pp. 343-362). Palgrave Macmillan. https://doi.org/10.1007/978-3-031-25296-9_18

Schauffel, N. (2023, September 25-26). *Implementing a multi-robot solution in ship inspection and maintenance. The role of human factors exemplified within the BUGWRIGHT2 project* [Paper presentation]. Summer School for Human Factors 2023, Chemnitz, Germany.

Schauffel, N., Weber C.-H., & Ellwart, T. (2023, May 24-27). *Self-comparisons in human and human robot teams: Effects on threat experience and job insecurity* [Paper presentation]. 21st EAWOP Congress, Katowice, Poland.

Schauffel, N., & Ellwart, T. (2023, September 12-15). *Soziodigitale Selbstvergleiche in Mensch-Autonomie-Teams. Theoretische und empirische Perspektiven [Sociodigital self-comparisons in human-autonomy teams. Theoretical and empirical perspectives]* [Paper presentation]. 13st AOWI-Fachgruppentagung, Kassel, Germany.

Schroepfer, P., Schauffel, N., Gründling, J., Ellwart, T., Weyers, B., & Pradalier, C. (2023, August 31). *Trust and acceptance of multi-robot systems „in the wild". A roadmap exemplified within the EU-project BUGWRIGHT2* [Paper presentation]. SCRITA Workshop, Busan, South Korea.

(2) Scientific Research on Human-Autonomy Teaming in Relation to BUGWRIGHT2
Theoretical and empirical research on psychological variables and concepts of human-autonomy teaming.
Outcomes: e.g., book chapter, poster, and research presentations at international scientific conferences and summer school Human Factors
Method: Literature research, empirical research, practical recommendations

Human-autonomy teaming. Book chapter reflecting psychological perspectives on collaboration between humans and self-governing systems in ship inspection **doi:** https://doi.org/10.1007/978-3-031-25296-9_18	**Sociodigital self-comparisons and threat perception.** Empirical research presented at EAWOP congress on the consequences of self-comparisons in human-robot teams on realistic threat and job insecurity **EAWOP Congress:** 24-27 May 2023 Katowice, Poland	**Trust and acceptance BUGWRIGHT2 „in the wild".** Position paper that outlines the roadmap of effectively leverages shared mental models in multi-robot, multi-stakeholder scenarios to foster calibrated trust and technology acceptance **IEIE RO-MAN Conference:** 21 August 2023 Busan, Korea
Human-like vs. machine-like AI. Empirical research on the relations between framing an artificial intelligence as either human-like or machine-like and system trust in a hybrid team setting **Internal report:** Bachelor's thesis (work in progress)	**Sociodigital self-comparisons in human-robot teams.** Theoretical and empirical perspectives on human-robot self-comparisons presented at AOW congress. **AOWI Congress:** 13-15 Sept, 2023, Kassel, Germany	**The role of human factors in BUGWRIGHT2.** Poster presenting the roles, roadmap, and lessons learned regarding human factors within BUGWRIGHT2 at the German Summer School for Human Factors **HF Summer School:** 25-26 Sept, 2023, Chemnitz, Germany

Figure 7: Overview of Research Outputs Resulted from Research Activities within Task 7.4c

3. Summary and Conclusion

Task 7.4 focuses on the design of an interface for a multi-robot system developed within BUGWRIGHT2 as well as the HR tools needed to introduce such a system into existing workflows. The research activities were built on the findings and research activities of Task 1.5, which was the work analysis of task, technology, and social system. The main deliverables of Task 7.4 include:

UI Design Guidelines:

(Ia) This task provides design guidelines for a user interface for the multi-robot system. The research includes providing an overview of the system, including robot details, 3D models, and a robot detail view.

(Ib) Include immersive technologies like virtual reality (VR) in the user interface to enhance user experience and engagement. A hybrid UI is proposed, combining a desktop application for system overview and a VR solution for detailed mission planning and monitoring.

(Ic) Enable customizability of the user interface to suit users' different roles and workflows. Desktop applications should allow view adjustments and the immersive part of the UI should be available whenever possible.

UI evaluation:

(IIa) Paper-based evaluation for collecting early user feedback involves creating mock-ups or paper prototypes of the UI design.

(IIb) Prototype-based evaluation connects the prototype to a real robotic system or simulator for summative evaluations.

Personnel development:

(IIIa) Stimulate learning by knowledge about critical incidents: Focus on concrete tasks and experiences instead of abstract discussions.

(IIIb) Ensure tangible mental models by process visualizations: Synchronize stakeholders' mental models through process-based visualization of key processes, interdependencies, and challenges.

(IIIc) Consider skill shifts in technical and nontechnical skill areas: Digitization and automation result in shifting skill requirements for employees. HR instruments target the multifaceted nature of skill profiles, uncovered disruptive skill shifts, and specific training needs, especially in nontechnical skill areas.

In conclusion, task 7.4 of the deliverables presented in this document offers comprehensive guidance on the development and implementation of a UI for multi-robot systems in an industrial maritime setting.

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