Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks

Deliverable Report – D1.5

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ABBREVIATION

DoA	Description of Action
HRT	Human-Robot Team
VR	Virtual Reality
AR	Augmented Reality
UI	User Interface
SDSC	Socio-Digital Self-Comparisons
HRI	Human-Robot Interaction
HAT	Human-Autonomy Teaming
HR	Human Resources

HISTORY OF CHANGES

Date	Written by	Description of change	Approver	Version No.
--/04/2022	UT	Writing	CNRS	V1
11/04/2022	CNRS	Proofreading	CNRS	V1

REFERENCED DOCUMENTS

- BUGWRIGHT2 Description of the Action (DoA)
- Interim Report Stakeholder Overview: Detailed documentation of the results of the interview series "Stakeholder Overview" *[file NextCloud: "210318 Interim Report SO for D1.5_part1_UT.pdf"]*
- Report Field Visit at AASA: Detailed documentation of the results of the field visit at AASA in December 2021 *[file NextCloud: "T1.5_field visit report_UT.pdf"]*
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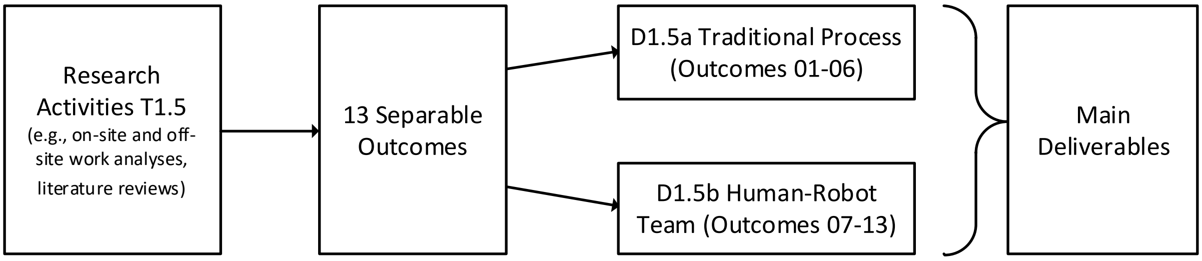
Executive Summary

This deliverable report D1.5 documents the results of Task 1.5 “Work analysis of task, technology and social system”.

As specified in the Description of the Action (DoA), the results of the work analysis refer to both “the analysis of the current task and person-related characteristics for the Human-Robot Team (HRT)” and the “analysis describing the future automated working environment and identifying the affective, cognitive, and behavioral demands and support needs for inspectors of HRT” (DOA, p. 48).

The main deliverables that deal with the traditional process (D1.5a) and the HRT (D1.5b) result from 13 separate outcomes. These separate outcomes, in turn, result from multiple off-site (e.g., literature review, interview series) and on-site (e.g., field visit at partner Arsenal Do Alfeite (AASA) in Portugal) research activities conducted within Task 1.5 (see Figure 1).

Figure 1: Overview of How the Main Deliverables of Task 1.5 Result from the 13 Separate Outcomes



This deliverable report includes four main chapters. Chapter 1 introduces the context, overall aim, and methods applied within the scope of Task 1.5. Conducting a holistic multi-phase multi-method work analysis, the deliverables of Task 1.5 consider the task, human, technology, and organisational perspectives. Chapter 2 summarises the main deliverables of Task 1.5 structured by these four perspectives with precise application perspectives for the ongoing BUGWRIGHT2 project. Chapter 3 spotlights 13 separate outcomes of Task 1.5 that lay the foundation for the main deliverables of Task 1.5, with a focus on the main results and value for BUGWRIGHT2. Reference is made to more extensive outcome documentation. Chapter 4 concludes with a summary and outlook on how the gathered knowledge is used within the further course of the BUGWRIGHT2 project.

1. Introduction

The EU project BUGWRIGHT2 (Horizon 2020) *"Autonomous Robotic Inspection and Maintenance on Ship Hulls and Storage Tanks"* is an EU project combining different interdisciplinary perspectives in research and innovation. The aim of the project focuses on the development of an adaptable autonomous robotic solution for the inspection and maintenance of ship hulls and storage tanks. The inspection of ship hulls and storage tanks is intended to be done by a combination of heterogeneous robotic technologies (in air, underwater, above water). In addition, virtual reality (VR) and augmented reality (AR) are tested as environments to control the drone to contribute to revolutionizing ship inspections and maintenance.

The implementation of an autonomous multi-robot system into existing work processes causes substantial changes in the underlying work processes, from a work-psychological point of view. These changes may lead to challenges and risks but also provide psychological opportunities. To ensure successful Human-Robot Interaction (HRI), there is a need to balance the human, technical and organisational subsystems that are involved in a specific target task (e.g., ship hull thickness measurement). "Adopting [such] a socio-technical approach to system development leads to systems that are more acceptable to end-users and deliver better values to professional practices" (DoA, p. 47).

Therefore, Task 1.5 *Work analysis of task, technology, and social system* is part of work package 1 (WP1) within the BUGWRIGHT2 project which is conducted from M1 (month one) until M28. In general, WP1 "deals with the use-case analysis and specifications, the definition of the hardware modification requirements, the legal insight, and the analysis of the work process from the end-user's point of view" (DOA, p. 47). In Task 1.5 specifically, we used a multi-method socio-technical approach to analyse the work process for designing the Human-Robot work system to provide input for the VR interface design in WP7.

The methods and approaches used to fulfill Task 1.5 are based on well-established theories and models of human-centered and motivational work design (e.g., Hackman & Oldham, 1976; Karltun et al., 2017; Klonek & Parker, 2021; Wäfler et al., 2003), technology acceptance (e.g., Bröhl et al., 2019; Venkatesh et al., 2003; Venkatesh et al., 2016) and team research from all-human (e.g., Kozlowski & Bell, 2003; Mathieu et al., 2008) to HRT (e.g., Robert, 2018; You & Robert, 2017, 2019).

Due to the global COVID-19 pandemic crises and the related travel restrictions, the time scope and action sequence of our initial action plan[1] had to be readjusted. Contrary to initial plans, early on-site analyses were not feasible. Therefore, we started with an extensive online, video-supported interview series. Furthermore, we conducted multiple off-site research activities including literature reviews, online expert interviews, and virtual workshops. We kept in regular and close contact with RWTH Aachen University, as the results of Task 1.5 are supposed to be further processed by Task 7.4, such that they increase user acceptance of the user interface (UI) developed in Tasks 7.2 and 7.3.

Whenever possible, we presented our interim results to the consortium during the virtual integration weeks, stakeholder meetings, or made the results available for the consortium members on NextCloud. In

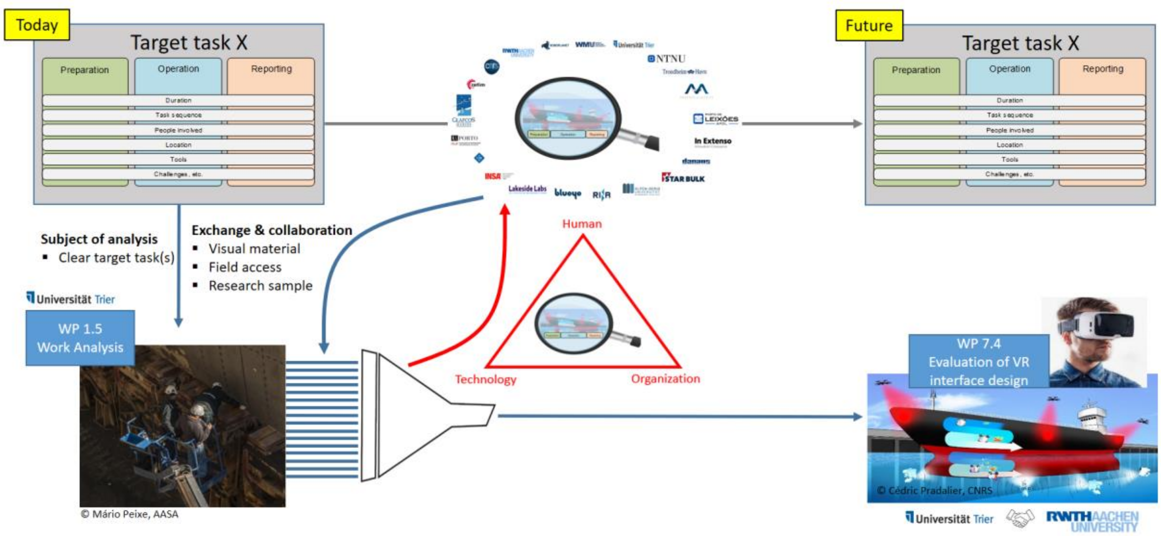
[1] See file *"210318 Interim Report SO for D1.5_part1_UT.pdf"* on NextCloud for detailed insight into the action plan of Task 1.5.

December 2021, an on-site work analysis at AASA was finally feasible. The activities conducted within Task 1.5 are interdependent. Upstream findings influence downstream actions within Task 1.5.

Figure 2 visualises the underlying work model of WP1 Task 1.5. The basis of the analysis is the current manual hull inspection process (Figure 2, left). In on-site (e.g., field visits at AASA) and off-site (e.g., interview series) work analyses we extensively elaborated the process of a ship hull inspection, including its task sequence, main characteristics, and challenges as well as the potential for future automation. We identified critical factors for the acceptance of BUGWRIGHT2 and used this insight to narrow down our research focus (Figure 2, funnel). Within various research activities, we spotlighted selected psychological factors (e.g., trust, self-efficacy, and cybersickness) from theoretical, empirical, and practical perspectives. The insights gained were constantly relayed back to the consortium (Figure 2, red line) to optimally support a balance between the “triangle” of the human, technological, and organisational subsystem within the design process of BUGWRIGHT2. The implementation of a multi-robot system in the process of ship hull inspection is understood as a transformation phase that impacts a given work task with its subtasks, roles, responsibilities, and tools used, among others (Figure 2, right).

After having introduced our work model of WP 1 Task 1.5, we present the main deliverables of Task 1.5 in Chapter 2. These main deliverables are based on 13 separate outcomes, which are aggregated for the deliverable report. Chapter 3, then, gives more detailed insights into our separate outcomes that contribute to our main deliverables. In Chapter 4, we give an outlook on our next steps and conclude with recommendations for the VR interface design (WP 7, Task 7.4).

Figure 2: The Underlying Work Model of Action Plan WP1 Task 1.5



2. Main Deliverables

Heterogeneous factors that are rooted within the task, human, robot technology, and organisational perspectives impact the user acceptance of the future robotic BUGWRIGHT2 system (see Outcome 03), in line with leading design principles of human factors and approaches for the humane design of socio-digital systems (e.g., Karltun et al., 2017; Wäfler et al., 2003). At a glance, the main deliverables of Task 1.5 are the following:

Task perspective.

Similar, yet different. The traditional ship hull inspection process is similar and standardised between potential application cases on an abstract level but very unique in detail. In this vein, the ship inspection process is a multi-phase and highly interdependent process (see Outcomes 01 and 02). Behind a comparable generalisable hull Inspection process, individual applicants (e.g., different harbors and shipyards) have very specific processes as well as environmental and market conditions that cannot be generalised (see Outcomes 06 and 07).

Task-specific Benefits, Hindrances, and Limitations. For the future robotic system, the need for robotic support became very clear across use cases (see Outcomes 06-08), even if the application scenarios differ in particular cases. The task-related anticipation of autonomous robots yields high potentials (e.g., effectiveness, safety, and economic benefits) – at the same time, it shows user-specific demands and support needs as well as task-related hindrances and limitations that make a user-flexible design and appropriate implementation of the BUGWRIGHT2 system necessary (see Outcomes 03, 07, and 08).

Applying this task perspective and knowledge to the VR interface design (WP7), the main deliverables speak for a task-specific evaluation design. Next to overarching evaluation characteristics (e.g., performance expectancy and reliability), application-specific elements (e.g., specific interface elements) need to be considered.

Human perspective.

The vital element is trust. In the traditional process, we see that trust is a vital and complex factor (see Outcome 02). High interpersonal trust must exist between the key players (see Outcome 02, 05, and 12) involved in the inspection process. An appropriate level of trust in the reliability and robustness of the existing procedure is elementary (no overtrust or mistrust) and makes a calibration processes nessesary. In the future, HRT trust becomes even more complex and remains essential, as both interpersonal (human-human) and system trust (human-robot, human-interface) and even trust between multiple robots (robot-robot) might interact. Trust within the BUGWRIGHT2 system thus is multifaceted, technology- and task-specific, and dynamic (see Outcome 12).

Technology acceptance needs an appropriate introduction. Even though there are many analog methods used in the traditional method of the inspection process (see Outcomes 02 and 06), from the Operators' point of view, clear application needs can be formulated for autonomous robotic solutions, which must be integrable into the overall process (see Outcomes 08). However, perceived functionality combined with low efforts in the specific Operator task environment is the key requirement for individual acceptance.

Applying this human perspective to BUGWRIGHT2, the results show that trust and acceptance towards a system are critical and co-dependent factors offering multiple methods for adjustment both from a technological and Human Resources (HR) perspective. For the development of future HR instruments, in a first step, we propose to identify knowledge areas that support well-calibrated trust and technology acceptance (see Outcome 08). This information might help technological experts to communicate specific functions and technological advantages but also weaknesses to potential users. In addition, for the design and evaluation of VR interfaces, the main deliverables speak in favor of a modular design (e.g., provide optional elements for specific needs of end-users), with a focus on highly functional (e.g., 2D shell expansion plan) over "fashion" elements. VR interface evaluation should consider compatibility with the existing work process.

Technology perspective.

Analog presence – robotic potential. Even if the current (traditional) inspection process is highly analog, it is also highly robust as well as adaptable to changing circumstances (see Outcomes 02 and 06). Nevertheless, from the Operators' point of view, clear demands and technological support needs (i.e., automation potential) can be identified for automated robotics, which must, however, be able to be integrated into the overall process (see Outcomes 07 and 08).

Reliable and valid systems with low efforts and sustainability in the long run. The technical systems on site are subjected to a highly complex calibration before each deployment and must work reliably under extreme conditions (e.g., heat, rain, or wind, see Outcome 06). The performance benefits of robotics-based inspection technologies are recognized by on-site experts but they must be accompanied by acceptable efforts in the implementation and execution, including long-term maintenance. Thereby aspects of (interface) design, system operation, and maintenance should be considered when evaluating the usability of robotic inspection technologies (see Outcome 04).

Applying this technology perspective to BUGWRIGHT2, these main deliverables result in the recommendation that the standards of the current inspection must be matched and even surpassed with newly introduced methods to ensure high user acceptance. Current processes are both reliable and robust under different working conditions. For the developers of the new systems, this means that sustainability, as well as long-term usage, need to be ensured for high user trust and acceptance. End-user participation has proven to be an effective way to improve technological systems using diverse HR tools (e.g., workshops, reflection, or guidelines) to collect and integrate ideas and feedback from end-users.

organisational perspective.

Multiple roles cause multiple requirements. On-site field observations show that in traditional hull inspections multiple roles (see Outcomes 02 and 05) are involved in the planning, operation, and evaluation of hull thickness measurement and that hull inspection has time- and space-related interdependencies with other processes on ship inspections (see Outcomes 02 and 06).

One surface for different roles. To avoid coordination losses and conflicts, BUGWRIGHT2 needs to address the different demands of key players involved (e.g., Technical Manager, and Surveyor, see Outcome 05). Data and information from robot measurements should be compatible with the present mapping model to allow communication and process coordination.

Applying this organisational perspective, different stakeholders involved in the development of BUGWRIGHT2 should be conscious of these multiple interdependencies between tasks and roles. Dependencies and system operation in routine vs. non-routine tasks should receive great attention as an evaluation parameter. Also, individuals' satisfaction with the interface should be evaluated concerning role-specific requirements.

Notably, the main deliverables that concern the task, human, technology, and organisational perspective are interdependent. Applying a holistic perspective on technology acceptance and system trust, these subsystems intertwine (see Outcomes 03, 09-13). Furthermore, the evaluation of trust and acceptance is subjective and might be subject to cultural differences. Nevertheless, reflecting on the main deliverables along the different subsystems ensures that the different perspectives are equally taken into account to establish a balance.

Figure 3 specifies the separable outcomes of Task 1.5 that are referenced within the main deliverables above. More specifically, Figure 3 displays the *outcome label* (e.g., 01 Schematic Hull Inspection Process), followed by a *short outcome description.* In addition, the main *method* applied is specified. The upper part of Figure 3 refers to the outcomes that mainly relate to the analysis of the current traditional hull inspection process (D1.5a), whereas the lower part of Figure 3 summarises the outcomes that mainly relate to the future automated working environment (i.e., HRT, D1.5b).[2] Highlighted Outcomes 09 to 13 indicate outcomes that refer to presented BUGWRIGHT2-related research outcomes, like conferences, journal papers, or published e-books.

In Chapter 3, we report the 13 separate outcomes, each in form of a structured abstract, summarising the theoretical background, the method applied, and the main results. If applicable, we also include information about the validation process and refer to related reports or open-access articles for more extensive information. We elaborate on the value of each outcome for the BUGWRIGHT2 project.

[2] Please note that the individual outcomes cannot always be clearly assigned to a specific time focus (i.e., current vs. future), as single analyses have included both current and future work processes. However, to keep the structure of D1.5 reader-friendly, we have adopted this structure from the DoA (DoA, p. 48).

Figure 3: Overview of the Separate Outcomes that Contribute to Our Main Deliverables and Referred Documents

D1.5a Traditional Process: “Analysis of current task and person-related characteristics for the Human-Robot Team (HRT)” (DOA, p. 48)

01 Schematic Hull Inspection Process
Scheme of a prototypical hull inspection process based on interview data

Method: Interview series „Stakeholder Overview“

02 Task Characteristics and Current Challenges
Central task characteristics and challenges mapped to different tasks within the prototypical hull inspection process

Method: Interview series „Stakeholder Overview“

03 Critical Factors for BugWright2 Acceptance
Identification of 23 critical factors for user acceptance within the task, human, technology, organization, visualization, and hybrid teaming

Method: Interview series „Stakeholder Overview“

04 Evaluation State-of-the-Art Technology (Spring 2020)
Technology-specific strengths and weaknesses with focus on user acceptance

Method: Interview series „Stakeholder Overview“

05 Personas of Key Players within a Hull Inspection
Personas describing the prototypical operator, technical manager, and surveyor, including person-related characteristics, needs, and desires

Method: Interview series „Personas“

06 Work Analysis at AASA
Use case-specific analysis of the process of steel plate thickness measurement with focus on the tasks, current challenges and requirements, and automation potentials

Method: On-site field visit at AASA

D1.5b Human-Robot Team: “Future automated working environment” and identified “affective, cognitive, and behavioral demands and support needs for inspectors of HRT” (DOA, p. 48)

07 Characteristics of the Future Automated Work Environment
Interface design requirements for the future automated work environment from the perspective of GLAFCOS

Method: Remote field screening GLAFCOS

08 Demands and Support Needs for Inspectors in HRT
Identification of knowledge requirements and relevant interface design elements for ship inspectors from the perspective of AASA

Method: On-site workshop at AASA

09 Psychological Factors in Human-Robot Teams
E-book reviewing the theoretical background, empirical relations, and practical perspective of 14 psychological factors for BugWright2
doi: https://doi.org/10.23668/psycharchives.5584
Method: Literature research

10 Hybrid teams – Effects on Work, Safety, and Health
Theoretical reflection on the effects of humans and robots working in hybrid teams on work, safety, and health

doi: https://doi.org/10.23668/psycharchives.5310
Method: Literature work, conference paper

11 Human-Robot Self-Comparisons
Empirical study on the role of socio-digital self-comparisons (SDSC) in human-robot-teams

Status: in press
Method: Empirical study (*N* = 166)

12 Human-Robot Trust
Reflection on human-robot trust from a work psychology perspective as a joint Research project in cooperation with the World Maritime University, Sweden.
Status: accepted for publication
Method: Empirical and theoretical study

13 Human-Autonomy Teaming
Book chapter reflecting psychological perspectives on collaboration between humans and self-governing systems in ship inspection.
Status: in preparation
Method: Empirical and theoretical study

Note. grey = BUGWRIGHT2 case-specific outcomes; orange = research outcomes related to BUGWRIGHT2.

3. Separate Outcomes

3.1. Outcomes 01-06: Analysis of the traditional hull inspection process

The multi-method “Analysis of current task and person-related characteristics for the Human-Robot Team (HRT)” (DoA, p. 48) resulted in six outcomes.

01 The Schematic Hull Inspection Process

Theoretical background. Transforming a currently mainly manual ship inspection process into a future robotic-supported process leads to fundamental changes of the underlying work process, roles, and responsibilities. To anticipate the consequences of such changes on human acceptance, behavior, and well-being, it is necessary to first get a detailed understanding of the actual manual process. Well-established methods of psychological work analyses (e.g., Wäfler et al., 2003) and business process modelling are complemented. A schematic process of the current hull inspection process acts as an externalisation of the mental models of the given target task, which becomes increasingly important for team processes (Fiore & Wiltshire, 2016).

Method. The schematic hull inspection process was investigated using a semi-structured interview series called “Stakeholder Overview” with members of the consortium in Spring 2020. We conducted 17 interviews in total. Each interview lasted about one hour. The collected information was analysed qualitatively, using the visualisation software MS Visio. Detailed descriptions of the interviews are documented in the interim report (see referenced documents).

Main results. The prototypical process of a hull inspection (e.g., coating thickness measurement, plate thickness measurement) can be schematically systematised as a multi-phase process, consisting of a preparation phase, an optional cleaning phase, an operation phase, and a reporting phase. Figure 4 shows the derived schematic task sequence of a prototypical hull inspection process. The task process is not linear but circular. Upstream process phases influence downstream processes and each phase consists of multiple subtasks. Thereby, the tasks are highly interdependent. The “mission planning” is a critical pivoting point in the hull inspection process. After initial “mission planning” in the preparation phase of the inspection, constant calibration of the inspection plan takes place, depending on the given results of the cleaning, operation, and reporting tasks.

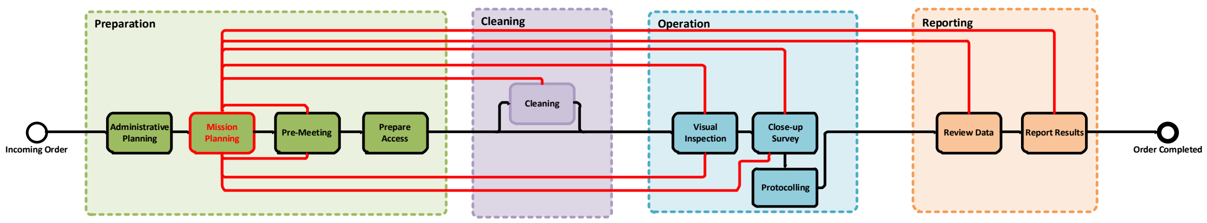
Validation. The task sequence has been validated by maritime experts within the BUGWRIGHT2 consortium and was considered suitable for a typical class survey. Also, during the on-site work analysis at AASA, the main task sequence was evaluated as appropriate for AASA (see Outcome 06). The intuitive task visualisation acts as common ground when reflecting on the current and future work environment (e.g., on-site work analysis). The chosen level of granularity of consecutive task blocks is cognitively manageable and does not exceed the cognitive capacity of human short-term memory (7+/-2 chunks, Miller, 1956).

Value. The schematic hull inspection process forms a valuable basis for subsequent on-site and off-site analyses within WP1 Task 1.5. The process view makes up- and downstream processes of a specific inspection (e.g., thickness measurement of steel plate thickness) visible. Task characteristics and existing challenges can be discussed against the background of clear work tasks. Technological development and functions are set in relation to a specific work task. HRI can be discussed, anticipated, and evaluated on basis of an intuitive process scheme.

Referenced documents.

- **Interim Report Stakeholder Overview:** Detailed documentation of the results of the interview series "Stakeholder Overview" *[file NextCloud: "210318 Interim Report SO for D1.5_part1_UT.pdf"]*
- **Report Field Visit at AASA:** Detailed documentation of the results of the field visit at AASA in December 2021 *[file NextCloud: "T1.5_field visit report_UT.pdf"]*

Figure 4: Schematic Hull Inspection Process based on Interview Data (*N* = 17)



02 Task Characteristics and Current Challenges

Theoretical background. Based on a joint understanding of the hull inspection process, on a more detailed level, it is crucial to determine the goal of each process step and identify central task characteristics. In this case, psychological methods of work analyses specify main task characteristics to sufficiently describe a work task including its aim, roles, temporal aspects, technological tools used, and given challenges (e.g., Wäfler et al., 2003).

Method. The task characteristics and current challenges of a hull inspection process were investigated within the interview series "Stakeholder Overview" (see referenced documents).

Main results. Based on the task visualisation, focal task characteristics and current challenges can be assigned to different tasks within the process phases of a prototypical hull inspection process (see Figure 5). Table 1 gives further (explanatory) information about selected task characteristics and challenges. It becomes evident that the preparation phase overall is quite time-consuming and multi-staged. The reporting phase is as time-consuming as the actual inspection itself (time). The location switches between office tasks and on-site tasks at the ship. Vital roles involved in the ship inspection process are the Surveyor, Technical Managers, and Operators. Also, communication with ship owners, port authorities, and sub-companies can be located within the process (roles). Regarding the tools used and the Level of Automation (LoA), the entire process is manual, mainly paper-pencil-based. Several challenges occur in the current hull inspection process. Time is a critical factor throughout the entire inspection process, such as the availability of qualified HR. Due to the high coordination demands during a ship inspection, interpersonal trust is crucial in the operation itself. Safety risks and environmental aspects such as extreme weather conditions mainly burden the on-site operation at the ship. The low LoA and technical support especially burden the preparation and reporting phase (old-fashioned tools).

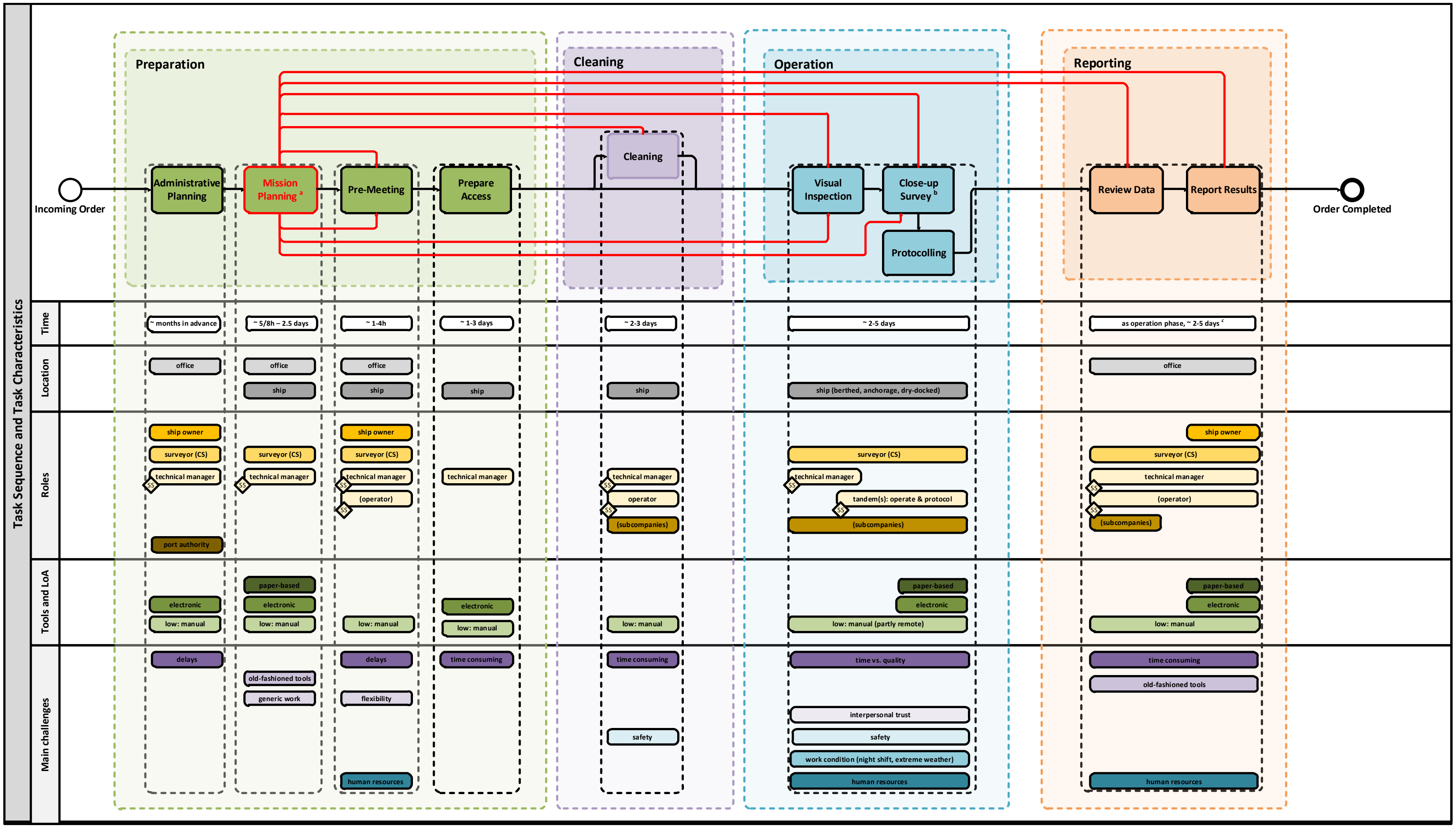
Value. The visualisation of task-specific characteristics and challenges provides valuable insights into the current manual ship inspection process. Even though many differences exist between different ship yards, even within a company depending on the unique ship that is being inspected, it is important to note that the schematic hull inspection process proves to be a valuable basis for on-site and off-site analysis within WP1 Task 1.5. In the field, a process scheme is an easy-to-use tool to help analyse the process in a given use case. The identified challenges act as starting points for HR instruments (Task 7.4). For the BUGWRIGHT2 consortium, a detailed description of the task characteristics makes the process of ship inspection more tangible.

Validation. The task characteristics and current challenges have been confirmed and specified within the two-day field visit at AASA in December 2021 (see referenced documents) and Outcome 06.

Referenced documents.

- **Interim Report Stakeholder Overview:** Detailed documentation of the results of the interview series "Stakeholder Overview" *[file NextCloud: "210318 Interim Report SO for D1.5_part1_UT.pdf"]*
- **Report Field Visit at AASA:** Detailed documentation of the results of the field visit at AASA in December 2021 *[file NextCloud: "T1.5_field visit report_UT.pdf"]*

Figure 5: Schematic Task Sequence and Selected Task Characteristics of Prototypical Hull Inspection Process based on Interview Data (*N* = 4)



Note. CS = Classification Society; SS = Service supplier; LoA = Level of Automation. The visualisation was based on interview data (*N* = 4) and was validated by experts within the BUGWRIGHT2 consortium. The prototypical hull inspection process was considered suitable for a class survey.

[a] Includes first visual inspection. [b] Includes e.g., thickness measurement of plate thickness or painting. [c] Reporting phase can be longer for an extensive survey.

Table 1: Selected Task Characteristics of the Hull Inspection Process in Addition to Figure 4 based on Interview Data (N = 4) and the Validation Process

Phase	Task	Characteristics
	Incoming order	**Order:** Owner or classification society **Period of notice:** Varies between 4-5 months (preventive inspections, e.g., class inspection) up to 1 year (e.g., dry-dock) to ad hoc inspection (e.g., incidents); short term windows for inspection are rare **Frequency order:** Varying (daily routine - 3-4 times a year) **Frequency inspection:** Depending on the inspection type (ad hoc / annual / every 2.5 years / every 5 years)
Preparation phase	**Overall**	**Duration:** Min 5/8 h - max 2.5 days **Goal:** Sufficient inspection planning **Comparability:** Execution: low; procedure: high
Preparation phase	**Administrative planning**	**Roles and tasks:** *Ship Owner:* Flexible and transparent communication (ship arrival, delays, meeting) *Classification Society:* Guidelines and requirements *Service Supplier:* Schedule inspection (time and place(s) e.g., multi-stop class survey, adjust timeline due to delay of the ship) and pre-meeting; legal questions (responsibility, insurance), financial aspects (e.g., payment port) *Port Authority:* Cooperation needed, payment for doing the inspection
Preparation phase	**Mission planning**	**Roles and tasks:** *Service Supplier:* Preparation of service, allocation of resources *Classification Society:* Deliver survey scope **Procedure:** Standardized procedure with highly diverse content including to collect, analyse, and integrate information (e.g., design of the ship, reporting history, stating system, condition), to contact the owner, agree on a meeting, and wait for the ship; preparation phase includes a first visual inspection (e.g., decide if cleaning is necessary). **Tools:** Previous reports (paper-based, electronic), drawings (paper-based) **Challenges:** Efficiency (the more you can prepare the better); cognitive and human resources (highly skilled experts, generic information integration, collection of critical information)
Preparation phase	**Pre-meeting**	**Goal:** Gather information and agreement on the inspection scope; prepare maintenance program **Challenges:** Flexibility (time), trust between involved parties
Preparation phase	**Prepare Access**	**Procedure:** After final agreement on the inspection process, making ship accessible (e.g., scaffolding) and reliable inspection possible (e.g., sufficient illumination)
	Cleaning	**Main goal of cleaning:** Optimisation of fuel consumption and sustainability **Optional phase:** If cleaning is integrated into a class survey = precondition for reliable inspection
Operation phase	**Overall**	**Goal:** Reliable basis for decision-making, efficient realisation **Comparability:** Execution: low; procedure: high
Operation phase	**Visual inspection**	**Task sequence:** Visual inspection of a surveyor, coordination with a technical manager (service supplier, a person in charge) **Roles and tasks:** *Surveyor:* Visual inspection of the ship, coordination with the technical manager **Tools:** Mainly manual process (~ 99%); first attempts towards remote inspection

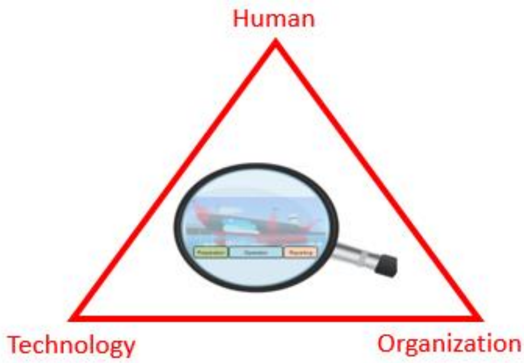
	Task	Characteristics
	Close-up survey	**Expansion of inspection plan**: Specific measurement points fixed in the mission/survey plan. Additional points are detected and examined independently by the service supplier. Classification Society might guide to additional points of interest, as well. The inspection plan and measurements are expanded in case of substantial corrosion. **Roles and tasks:** *Ideal:* All three parties (surveyor, operator, owner) work together at any time *Reality:* Surveyor is inspecting alone (at first). A tandem (or a group of tandems) of an operator and a person recording the minutes are inspecting on their own. Surveyor and service supplier are present at any time. **Challenges:** Trust between involved parties (classification society, service supplier); safety of the ships (situation awareness, presence of the surveyor) vs. safety of the surveyor (avoid dangerous situations); time vs. quality; operational conditions (e.g., high temperature, night shift, weather condition); minimise dry-dock times
	Protocolling	**Task sequence:** Protocolling in a tandem parallel to the measurement itself
Reporting phase	Overall	**Duration:** Comparable time effort to the operation phase **Goal:** Decision-making about maintenance and health-status of the ship
	Review data	**Goal:** Disseminate information as a basis for decision-making; difficult part **Roles and tasks:** Standardised procedure *service supplier* prepares the information and the report, *classification society* validates the report
	Report results	**Roles and tasks:** Same people are involved as in the pre-meeting. The final report is handed over to the owner, port authority, and/or insurance company. The maintenance history of the ship is updated as a basis for future inspection.

Note. The task characteristics are derived based on interview data (N = 4) and the iterative validation process of the schematic hull inspection process.

03 Critical Factors of User Acceptance within BUGWRIGHT2

Theoretical background. Multiple models of *technology acceptance* exist (see Venkatesh et al., 2003; Venkatesh et al., 2016 for a synthesis of widely used models of technology acceptance) which have been successfully applied to the context of Human-Robot acceptance (e.g., Bröhl et al., 2019). Their underlying concept is that individual reactions towards a system determine a behavioral intention, which leads to actual behavior towards a system (Venkatesh et al., 2003). To ensure high user acceptance (e.g., behavior intention), the future system must be perceived as useful, add value to the end-users' work performance (performance expectancy), and must be easy to use (effort expectancy, Venkatesh et al., 2003). Besides, from research on *human motivation* and *well-being*, it is well-known that the robotic system must be subjectively experienced (by the single user) as an opportunity, not an offense regarding basic human needs (for an overview on the self-determination theory see for example Deci & Ryan, 2008; Ryan & Deci, 2019). Whether key factors of technology acceptance (e.g., performance expectancy, effort expectancy) and basic human needs (e.g., need for competence) are satisfied or frustrated might depend on various factors. According to models of *socio-technical system development*, high user acceptance results from a good fit of demands of the *task* and available resources on side of the *human* (individual and team), the *technology*, the *organisational context,* and their interaction (Karltun et al., 2017). Consequently, factors that influence user acceptance should refer to aspects within the task, human, technology, organisation, or their interplay (see Figure 6).

Figure 6: Multiple Perspectives on User Acceptance within BUGWRIGHT2



Method. The critical factors for user acceptance within BUGWRIGHT2 were investigated within the interview series "Stakeholder Overview" (see referenced documents).

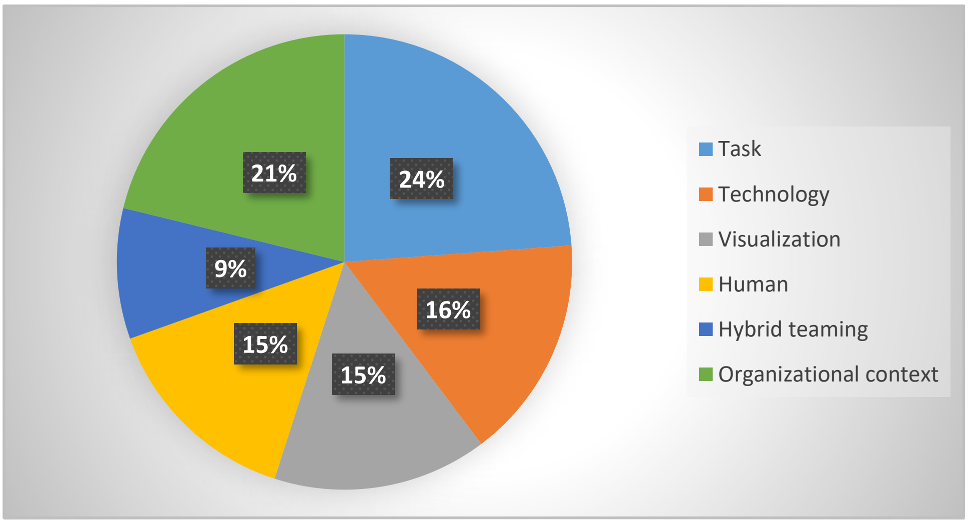
Results. In a qualitative analysis (151 interview statements), we identified six categories and 23 critical factors for user acceptance within BUGWRIGHT2. As theoretically expected, the critical factors referred to factors within the *task*, *human*, *technology*, and *organisational context* (see theoretical background). Furthermore, the categories *visualisation* and *hybrid teaming* were introduced as additional categories. Figure 7 displays the frequency distribution of statements referring to critical factors (i.e., needs, risks) by categories. The most frequently named critical factors referred to aspects of the task (24%) and the organisational context (21%). Critical factors within the technology, the human, and the visualisation were named approximately comparably frequent (15-16%). Factors of hybrid teaming are also relevant for user acceptance within BUGWRIGHT2. 9% of the interview statements referred to this category.

Value. The wide range of critical factors highlights the usefulness of applying a socio-technical approach in the context of HRT. The qualitative analysis of single interview statements makes the perceptions, fears, and wishes of multiple stakeholders involved in the BUGWRIGHT2 project visible. Furthermore, they include specific design elements relevant for WP7 Task 7.4. The quantitative analysis displays a trend with critical factors that could be particularly important for the acceptance of BUGWRIGHT2. The results allowed for an empirically founded decision on future narrowed down research foci of Trier University (e.g., human-related critical factors such as trust or cognitive load) and analyses with a higher level of resolution (e.g., task-specific evaluation) within WP1 Task 1.5, as well as within WP7 Task 7.4.

Referenced documents.

- **Outcome 09:** E-book spotlighting selected psychological factors form a theoretical and practical perspective on HRT
- **Outcome 13:** Book chapter that deals with the critical factors identified within BUGWRIGHT2
- **Interim Report Stakeholder Overview:** Detailed documentation of the results of the interview series "Stakeholder Overview" *[file NextCloud: "210318 Interim Report SO for D1.5_part1_UT.pdf"]*

Figure 7: Critical Factors of User Acceptance within BUGWRIGHT2 based on the SO (*N* = 17, 151 Interview Statements)



04 Evaluation of State-of-the-Art Technology (2020)

Theoretical background. Following a socio-technical system perspective on HRI and acceptance within BUGWRIGHT2 (see Figure 6), robot characteristics strongly impact user acceptance (Bröhl et al., 2019). In the context of BUGWRIGHT2, the concept of technology acceptance is complex as the future robotic solution will combine qualitatively different remote inspection technologies (RITs) (i.e., micro aerial vehicles [MAV], small Autonomous Underwater Vehicles [AUV] with teams of magnetic-wheeled crawlers operating on the surface of the structure). Technological strengths and weaknesses, therefore, need to be discussed tool-specific. Furthermore, the evaluation of robot strengths and weaknesses needs to go beyond technological features since user acceptance also includes the perceived ease of use, and perceived usefulness in a given context (Venkatesh et al., 2016).

Method. Within the interview series "Stakeholder Overview" (see referenced interim report), we discussed the strengths and weaknesses of the state-of-the-art. The focus was on robot technology in spring 2020. Subsequent technological developments and enhancements were not included in the analysis. Strengths and weaknesses are clustered along with the three topics a) (technological) features, b) (interface) design, and c) system operation and maintenance.

Results. Table 2 summarises the key aspects of our analysis. It becomes evident that technology must significantly support Operator performance (i.e., machines are better than men) while not causing additional effort and disruption. The question of low-maintenance systems that can be used in the long term also becomes clear, which directs attention both to operational use but also to service life and sustainability.

Value. The mentioned aspects offer first insights into the support needs of inspectors in HRT (e.g., training). Concerning VR visualisation and interface design, Table 2 includes design recommendations (e.g., same gaze) and critical aspects (e.g., sun reflection, heavy rain) that have been discussed in subsequent iterative workshop rounds with the related BUGWRIGHT2 partners (i.e., RWTH Aachen University). Further, (technological) features evoked that this might influence the user's acceptance of the future BUGWRIGHT2 system (e.g., tether, battery capacity).

Referenced documents.

- **Interim Report Stakeholder Overview:** Detailed documentation of the results of the interview series "Stakeholder Overview" *[file NextCloud: "210318 Interim Report SO for D1.5_part1_UT.pdf"]*

Table 2: Evaluation of the State-of-the-Art Technology with Focus on User Acceptance

Magnetic Crawler

	Strengths	**Weaknesses**
(Technological) Features	• Camera: GoPro integrated (competitors have no camera) • Level of resolution: 3 measures/m^2 are typical, a crawler can perform 100x more accurate than a human operator, higher probability of error detection	• Tether: a wireless tool is realistic for above water applications but underwater a tether will be needed (not necessarily a disadvantage)
(Interface) Design	• Robustness: highly resistant crawler and equipment	• Weight: heavy equipment with the potential for improvements, goal: the size of a backpack • Gaze: different visual points joystick (driving the robot) and monitor equipment (visualisation of measurement)
System Operation & Maintenance	• Low level of maintenance on the field; approx. yearly check-up (tracking number)	• Manpower: a tandem of two people needed (driving, monitoring) • Maneuverability: uncertainty if joysticks are smooth enough for the application areas • Reporting: time-consuming marking of crawler's route in ship drawings afterward • Measurement station: every 20 m measurement station has to be moved to another stop

Additional notes

Current operational areas	**(Support) Services**	**Competitors**
• Thickness measurement on ships, e.g., storage tanks • Maritime industry mostly the French navy • Petrochemical industry (e.g., pipes) • International market: most used crawler in France, also used in Belgium, the UK, Netherlands, and Spain	• Three days of face-to-face implementation and training in a group setting (1x trainer, max. 5 trainees) • Day 1/2: field practice and information on post-processing and reporting; day 3: focus on maintenance, troubleshooting, and robot cleaning • Calibration certificate possible, but not always needed by end-user	• Competitors TesTex (e.g., Viper crawler system, US) and Eddyfi (e.g., Scorpion 2, Canada) • None of the competitors crawlers are present in the maritime industry: low focus on robotic supported hull thickness measurement in the navy maritime industry until now, here, mainly manual thickness

Underwater Drone

	Strengths	**Weaknesses**
(Technological) Features	• Fleet size: approx. 700 vehicles available	• Price: 9000 and 11000 dollars each (affordable to a private buyer?) • Battery capacity: limited operational time ("sometimes just reaching the surface and moving back"); back-up battery needed; extra payload reduces battery capacity additionally; for shallow inspection 2h realistic; lower battery capacity in deeper inspections • Camera: only full HD camera but no 4k camera for best visual inspection • Real-time data: video streaming in real-time only with tether possible, cable-free inspection only possible if data are exported afterward
(Interface) Design	• Robustness: high robustness, very few customer complaints • Shape: good stability underwater due to unique drone shape when no waves • Weight Interface: light interface equipment • Gaze: driving and monitoring on the same gaze • Flexibility: high flexibility as smartphone, tablet, or streaming to a flat-screen is possible	• Transportation: heavier than other drones • Sun reflection: sun reflection on the interface is a problem for some users • Heavy rain: joystick unusable when it rains, not waterproof, and hard to handle when raining • Ergonomy: lowered head position when using the joystick • Holder: no holder for the tablet (bigger screen), only for smartphone • VR glasses (first try-out): danger of trip over and cybersickness

System Operation & Maintenance	• VR glasses (first try-out): lesser disturbances by surroundings, no problems with sun reflections, positive feedback • Deployment: ready to go in 2 min • Day-to-day maintenance: freshwater, charging • Self-service: camera, battery, motor, or cable can be replaced by the end-users	• Lateral motion: challenges in reaching hidden areas (e.g., propellers), human divers are more flexible • Drone stability: lower drone stability in areas close to the surface • Joystick: navigation via joystick is not intuitive for everybody • No certification yet
Additional notes		
Current operational areas • Inspection for pipelines and tanks • Inspection of aquaculture • Visual ship inspections (i.e., painting, corrosion, ⌀ 1-2h; propeller: 1-1,5h) • Robot operation close to the robot	**(Support) Services** Full-service of implementation, support service, and training: • Face-to-face training: i.e., monthly training (1 day) course at BYE office for local users and interested (10-15 people max.) • Remote training (i.e., webinars, youtube videos) • Customized demonstration: visit client, prototype drone, train inspection process, accompany one inspection • Written information: manuals in many different languages • Policy: tolerant policy in case of early drone problems • Support contact at BYE (< 2 days till help to costumer)	
Aerial Drone		
	Strengths	**Weaknesses**
(Technological) Features		• Battery: low battery capacity
(Interface) Design	• Point clouds: generate good and consistent point clouds from different sensor modalities (e.g., laser, imagery)	• Level of Control: trade-off between human demands (“f the thing is in the air, you do not want to have anything to do with it”) and technical features (remote-controlled, “an should always be able to take back the control”) • LoA: automation of aerial drones is more critical than for crawlers (is more feasible)
System Operation & Maintenance	• Deployment: easy deployment, “walking carpet” with markings where to place which kind of drone • 5-10 min preparation phase, positive feedback	• Manpower: in general, a tandem of two people is needed (flying the drone, controlling the camera, zooming, etc.); the operation process can be done partly automated but at least one person should be involved in the process
Additional notes	• visual hull inspection: collecting data for detecting defects and effects of corrosion and defining areas for a close-up survey (post-processing) • Outer hull inspection is less critical for aerial platforms (4-6 meters from the hull)	

Note. The analysis is solely based on interview data (Stakeholder Overview, $N = 17$). LoA = Level of Automation.

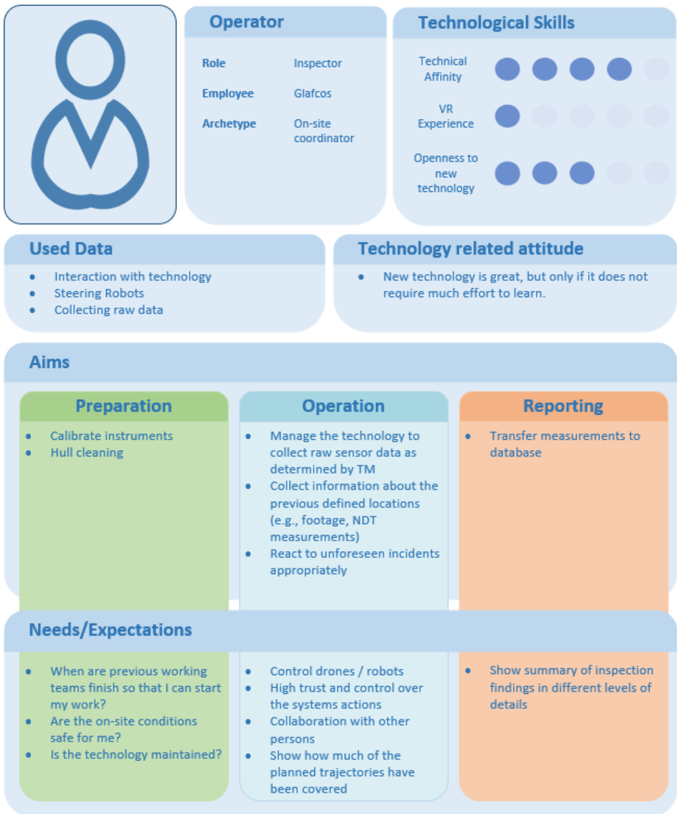
05 Personas of Key Players within a Hull Inspection

Theoretical background. The stakeholder interviews and inspection process analysis revealed that the Surveyor, Technical Manager, and Operator are three key players of a prototypical hull inspection process, especially in the operation phase (see Figure 8). This suggests that a UI, both for mission monitoring and for data analysis, should be tailored to these three actors. Thus, we focused on these key players when analyzing how they would use such an interface and what they expect from it. Personas describe prototypical users and include narrative person-related descriptions of these prototypical users (Jansen et al., 2021). Personas are a useful tool for user-interface design and support the process of mock-up generation and evaluation as well as help identifying and modeling the target group (Chang et al., 2008). This makes it easier for the developers to understand how the target user thinks, what aims they have when using the software, and what utilities they need to successfully fulfill their tasks.

Method. We generated three personas based on a two-step process consisting of an online survey and expert interviews. The Online survey was designed based on knowledge gathered from the previous work analysis steps. Especially the task characteristics and identified roles along the inspection process were important for this. The online questionnaire was used to present different ideas of how inspection-relevant information could be displayed and which actions the user could possibly perform during or after inspection. Users were asked to rate the options presented in terms of their importance and appropriateness for the tasks involved in an inspection. In addition, users were asked about their function in the inspection process, their attitude towards (new) technology, their experience with VR, and which general functions in the UI they consider important.

Results. The results of the interviews were used to create one persona sheet per role. As an example, the Operator sheet is displayed in Figure 8. For the three roles of Operator, Technical Manager, and Surveyor, the findings were surprisingly homogeneous. All three claimed they had little experience with VR. Furthermore, a medium level of affinity for technology and a medium level of openness for new technology were revealed. While Surveyors and Technical Managers reported spending about 50% of their work time processing numerical data and about 25% on visual data, Operators reported interacting mainly with technology and collecting raw data. In terms of visual information, Surveyor and Technical Manager indicated a need for primarily structural information about the hull, rather than textures or the like. The aims and needs of the three roles differ slightly. While it is the main objective of the Operator (see Figure 8) to collect data and control technical equipment, the Technical Manager (see Figure 9) wants to coordinate and summarise the data collection, and therefore needs collaboration and reporting tools. The Surveyor (see Figure 10), in turn, wants to review the summarised information and, therefore, needs it displayed in a way that allows to decide if the structural integrity of the ship is given.

Figure 8: Example of a Persona (Operator)



Value. The personas serve as a foundation for the development of an evaluation approach for (VR) interface design, which is useful for Task 7.4. The vivid user descriptions aid in the consideration of person-related features during design and the ability to empathise with the end-user. They were presented to the consortium as part of the virtual integration week, which took place in May 2021. During several workshops, for example with RWTH Aachen University and Glafcos Marine (GLM), the personas are critical in molding mock-ups and organising the process of VR interface design. It should be noted that Task 1.5 and WP7 are inextricably linked, and the outcomes of Task 1.5 seamlessly flow into Task 7.4. As a result, the deliverable report D7.4 contains additional results on derived VR interface design and evaluation methodologies, showing how personas are used.

Referenced document.

- **Personas:** Detailed documentation of the personas of the three key players Operator, Technical Manager, and Surveyor *[file NextCloud: "T1.5_Personas.pdf"]*

Figure 9: Aims, Needs, and Expectations of a Technical Manager Role

Figure 10: Aims, Needs and Expectations of a Surveyor Role

06 Work Analysis at AASA

Theoretical background. The procedure of psychological work analysis examines individual activities, entire workplaces, and working conditions to identify focal characteristics (strengths and weaknesses) of work design (Mlekus et al., 2017). The identified challenges and weaknesses might be reduced and identified strengths emphasised by SMART (Hay et al., 2020; Klonek & Parker, 2021) work design and the implementation of new workplace technology. Multiple methods of psychological work analysis exist, however, for supporting the implementation of workplace technology, complementary approaches that integrate the analysis of existing work systems with prospective analysis are superior (Wäfler et al., 2003).

Method. In a two-day field visit at AASA in December 2021 (see Agenda in Figure 11), we conducted a multi-method work analysis including field observations, workshops, and document analyses based on well-established methods of (complementary) work analysis (e.g., Wäfler et al., 2003). We focused on the process of steel place thickness measurement. The collected data (i.e., photos, videos, interview statements, process schemes) were integrated, qualitatively analysed, and documented in an extensive interim report for the BUGWRIGHT2 consortium (see referenced document).

Main results. At a glance, the work analysis specified which subtasks are included in a thickness measurement task (e.g., equipment calibration) and how they are conducted. The work analysis revealed which role interdependencies are most critical for the inspection progress (e.g., Expert Teams, Technical Manager, Project Manager), and which work design challenges (e.g., time, physical effort, HR) offer concrete potentials for future automation (e.g., aerial drones that can detect the welding lines, or shell expansion plans integrated into the UI).

Value. The work analysis added value to the BUGWRIGHT2 project in at least three ways. First, direct end-user participation and feedback guaranteed a clear user-centered design of the BUGWRIGHT2 project. Second, the collected data (e.g., photos and videos) provide a realistic insight into the on-site work for all BUGWRIGHT2 partners. The pictures of welding lines or hull corrosion provide realistic test dimensions for obstacles and corrosion detection of the newly developed robotic system and reporting materials should be integrated into the UI design. Third, the information gathered offers starting points for HR instruments needed in WP 7 (e.g., competence profile, training needs).

Referenced document.

- **Report Field Visit at AASA:** Detailed documentation of the results of the field visit at AASA in December 2021 *[file NextCloud: "T1.5_field visit report_UT.pdf"]*

Figure 11: Agenda Two-Day Field Visit at AASA, Lisbon (9.12.2021 - 10.12.2021)

Day	Time	Element	Goal *(Contact AASA)*	Details
Thursdy, 9. December 2021	08:30-09:30 (1 h)	Check-in and Briefing	Synchronize Agenda *(Dina & Cristina)*	**Content**: Discuss the agenda of the field visit, if necessary adaptation to the current business plan **Location:** Conference room with internet, beamer, and HDMI
	09:30-12:00 (2,5 h)	Field Observation	Tangible experience of the thickness measurement process *(1-x ship inspectors + translator)*	**Content**: Based on the former agenda (March 2020): 1. Visit the shipyard (places where thickness measurement is carried out) 2. The procedure of the methodology used to measure the thickness on the hull 3. Thickness measurement equipment (e.g., ultrasound equipment) 4. Simulation of measurement test on the hull of a ship 5. Insight in: Planning phase, data processing, and final reporting **Method**: Walk-through, field visit **Location:** On-site at the ship & workshop
	12:00-13:00 (1 h)	Lunch/Break		
	13:00-15:00 (2 h)	Interview/Workshop	Identify automation needs within the current inspection process *(1-x ship inspectors + Dina and Cristina)*	**Content**: Current inspection challenges (e.g., stress, support needs) and task characteristics (e.g., meaningfulness) **Method:** Guided interview and rating **Location:** Conference room with internet, beamer, and HDMI
	15:00-16:00 (1 h)	Discussion and Debrief	Identify future demands and support needs *(Dina & Cristina)*	**Content:** Staffing requirements, personnel challenges, competence shift, current challenges **Method:** Loose interview **Location:** Office of Dina/Cristina
Friday, 10. December 2021	08:30-09:00 (30 min)	Check-In and Briefing	Synchronize Agendas *(Dina & Cristina)*	
	09:00-12:00 (3 h)	End-user Workshop	Presentation of User Interface design draft *(1-x ship inspectors + translator)*	**Content**: Presentation of User Interface design draft and Feedback from End-Users **Method**: Workshop supplemented by videos and a short questionnaire (in Portuguese) **Location:** Conference room with internet, beamer, and HDMI
	12:00-13:00 (1 h)	Lunch/Break		
	13:00-14:00 (1 h)	Debrief & Close-up	Summarize Field Visit *(Dina & Cristina)*	**Content**: Resume and reflect on experiences on-site, specify possible follow-up steps **Method**: Discussion **Location:** Conference room with internet, beamer, and HDMI

3.2. Outcomes 07-13: Analysis Human-Robot Team

The analysis of the "future automated working environment" and identified "affective, cognitive, and behavioral demands and support needs for inspectors of HRT" resulted in 7 outcomes.

07 Characteristics of the Future Automated Work Environment

The findings from Task 1.5 can be used to draw a picture of how the work environment in the future could look like. The characteristics of such a future environment are described in the following, using the example of a UI to interact with novel technologies.

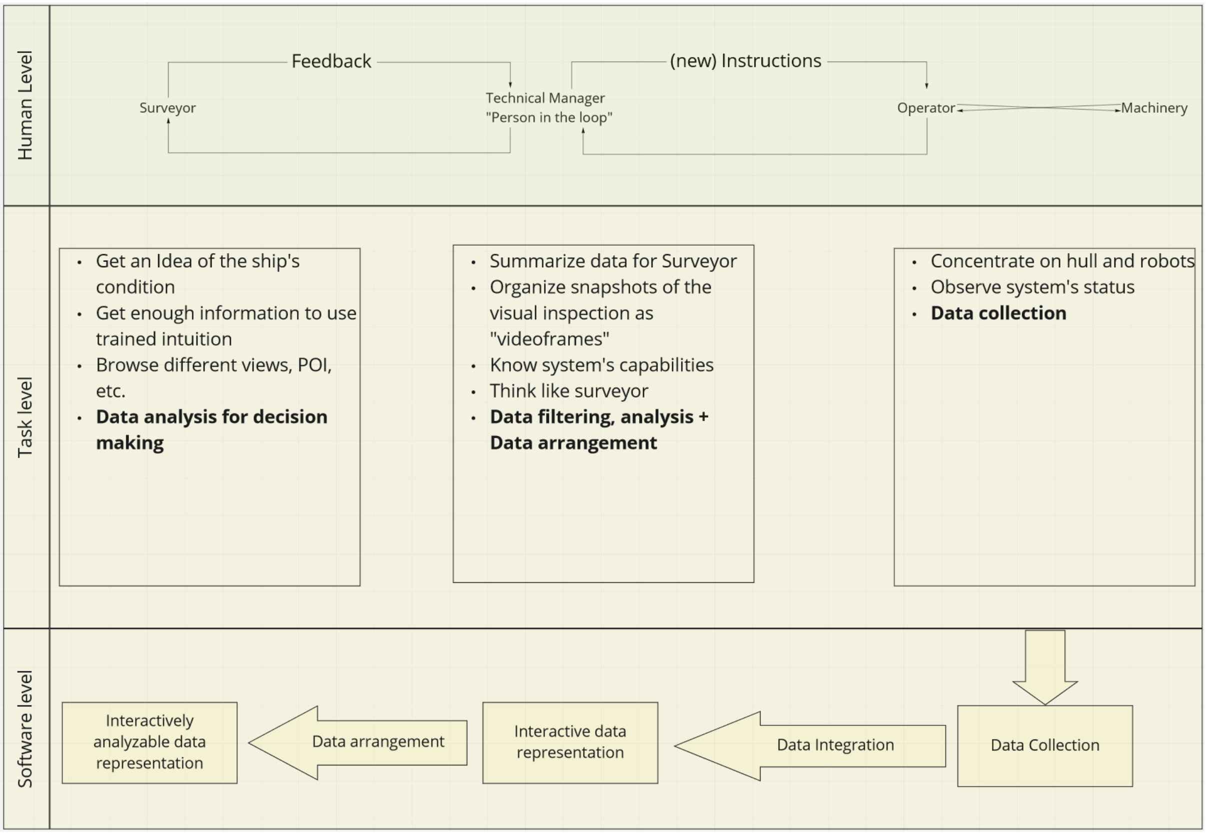
Theoretical background. A disruptive change in existing ways of working, such as the automation of manual processes in organisations, is a type of change that needs to be well prepared and must not be rushed. Therefore, meticulous planning is required to introduce these changes as quickly as possible, but as slowly as necessary (Lauer, 2021). In order to successfully set up a plan, it is helpful to gain an impression of what changes can be expected under the given conditions. Moreover, this knowledge is essential when it comes to design a UI for the workers to use with the newly introduced technology. To this end, the following sections are intended to provide a preliminary assessment of how the technologies developed in BUGWRIGHT2 might affect the working environment around hull maintenance and what a UI should bring to make the best use of the technology.

Method. To be able to assess what a future working environment around hull inspection could look like, two different knowledge bases were essentially used. First, information about current work processes was used to formulate the starting point for possible developments. Second, the goals of the technical developments in the BUGWRIGHT2 project were considered to estimate what advances in technology could be expected. With this information at hand, a workshop was conducted with GLM to draw a vision of how the BUGWRIGHT2 technologies might integrate into a future automated work environment. Lastly, this information was mapped onto task and software levels, to identify characteristics necessary in a UI.

Main results. As described in the previous sections of this document, the current process of metal plate thickness measurement is mainly manual. During the workshop with GLM and also in discussions with various people involved in the inspection, it became very clear that the technology developed within BUGWRIGHT2 will not be implementable overnight. Rather, there will be a step-by-step process that supports the way Operators, Technical Managers, and Surveyors work by increasingly incorporating robotic technology. This process may eventually lead to full automation of the measurement of metal plate thickness on the hull. However, it is not clear today when exactly this point in time will be reached. In discussions, GLM employees estimated a time horizon of 10 years. In the workshop, it became clear that at least until the metal plate thickness measurement is fully automated, a person must be present during the measurement. This person, described by GLM as "human-in-the-loop", would take over activities that regulate the preparation and arrangement of the data as well as the coordination of additional data acquisition between the mere data acquisition (currently carried out by the Operator) and the data evaluation (by the Surveyor). According to our previous understanding, these tasks fall within the area of competence of the Technical Manager. An overview of how these activities are distributed at the task level, as well as the generally formulated requirements for the UI, can be seen in Figure 12.

Value. Understanding how a Service Supplier and potential end-user of the technologies developed in BUGWRIGHT2 sees the integration of these into the work processes is essential for creating a feasible and helpful way to introduce new technology. Moreover, this makes a valuable extension to the previously described personas by showing how these are interrelated to each other and at which points they are in exchange. It is shown that data collection, data integration, interactive data representation, data arrangement, and interactively analysable data representation are core elements that a future UI should provide for humans to interact with technologies like those of BUGWRIGHT2.

Figure 12: Mappings of Roles, Tasks, and UI Aspects



08 Demands and Support Needs for Inspectors in Human-Robot Teams

Theoretical background. Information regarding the ship inspection process was collected according to pre-arranged questions which spotlighted process characteristics, humane work design (Handke et al., 2020; Hay et al., 2020; Klonek & Parker, 2021), and team characteristics (You & Robert, 2017) as well as safety issues (You et al., 2018). Rieth and Hagemann (2021) identified several categories of user knowledge, which were discussed in the workshop.

Method. During a two-day field visit, we observed the shipyard of AASA, attended a simulated thickness measurement, and conducted several different workshops with workers (e.g., Operators, Technical Managers, Project Manager) from AASA. The general rationale of BUGWRIGHT2 was introduced and feedback was obtained. The focus of attention was on the validation of the inspection process potential (see Outcome 06) as well as automation potentials, knowledge-based and interface demands, and support needs for inspectors working in HRT (see Outcome 08).

Main results. At a glance, several automation potentials, knowledge-based and interface demands, and support needs could be identified. For an extensive description of the findings see the referenced document.

First, *automation potentials* were identified in multiple phases of the inspection process. For example, the Operators pointed out that automation of the thickness measurement could be of help, especially in crawl spaces and hard-to-reach spots. No automation should be implemented in areas in which a need for human safety exists (walk-through inspection of the ship before ship inspection process) or where a human is liable.

Second, *knowledge categories* concern areas of interest for Operators on-site as well as Technical Managers. Nine areas of knowledge needs were identified (see Figure 13). Especially the knowledge regarding the validation process was emphasised by both Technical Managers and Operators, highlighting the end-users need to know details about how the robot or system is validated before thickness measurements.

Third, *interface design elements* were collected and first impressions and feedback on existing drafts were gathered for the iterative design process. Overall, the feedback by potential users was positive (>60%). An interesting insight was the idea to include the hull expansion plan in the interface to enable a smooth transition from the current process to a future one. Figure 14 illustrates the UI draft material used in the workshop. Further details on the creation of the UI design drafts are described in deliverable report 7.4.

Value. The field visit at AASA proved to be helpful for our work within BUGWRIGHT2. The field visit concretised automation potentials and provided specific starting points for the interface design and evaluation in WP7. Critical interface elements (e.g., shell expansion plan) could be identified. The uncovered knowledge demands will be considered in the HR instruments developed within WP7.

Referenced documents.

- **Outcome 06:** Results of the on-site work analysis at AASA with a focus on the inspection process and automation potentials.
- **Report Field Visit at AASA:** Detailed documentation of the results of the field visit at AASA in December 2021 *[file NextCloud: “T1.5_field visit report_UT.pdf”]*

Figure 13: Knowledge Categories

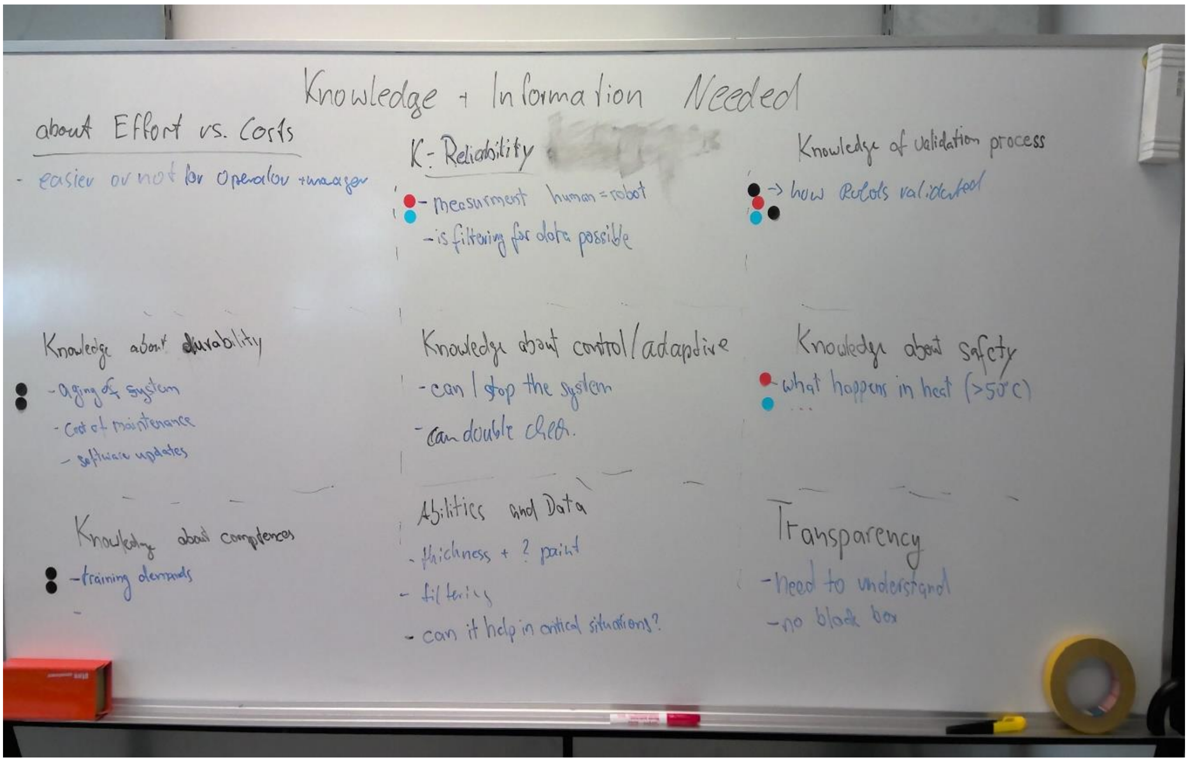
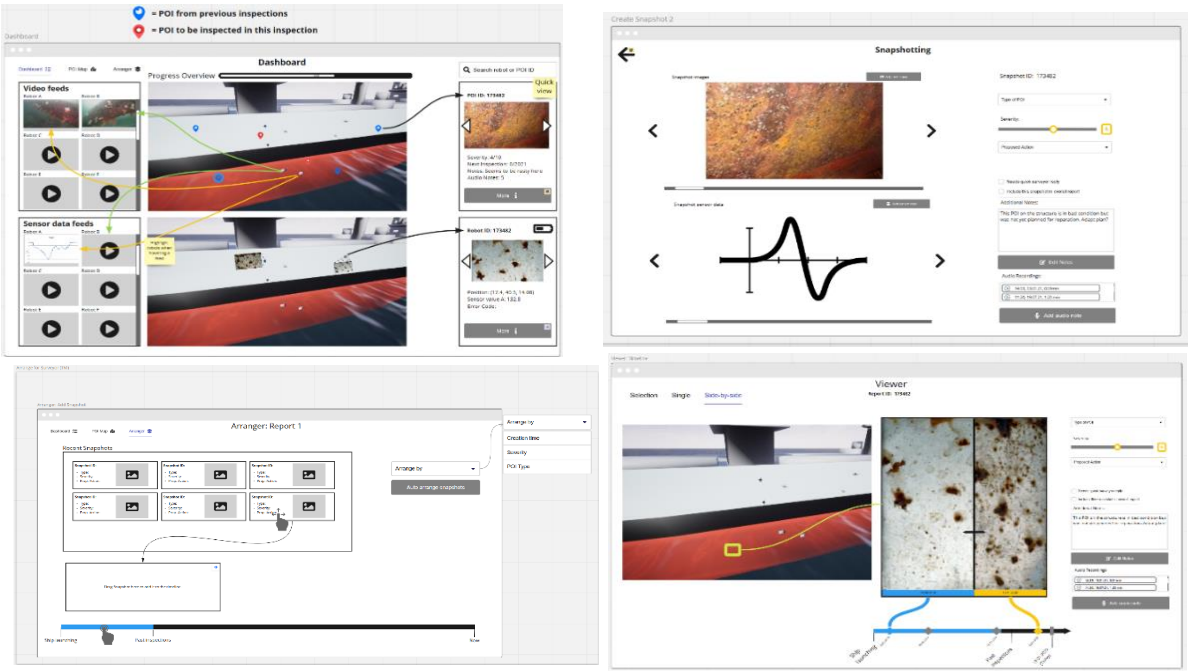


Figure 14: UI Drafts



09 Psychological Factors in Human-Robot Teams

Theoretical background. Our analysis revealed multiple critical factors for user acceptance within BUGWRIGHT2 rooted in the *task*, *human*, *technology*, and *organisational context* as well as in aspects of the interface design, *visualisation,* and *hybrid teaming* (see Figure 7). Many of these critical factors refer to well-established concepts of human factors and work psychology such as trust (Hancock et al., 2011), cognitive load (Sweller, 2011), self-efficacy (Rosenthal-von der Pütten & Bock, 2018), or basic human need satisfaction (Smids et al., 2019).

Method. We reviewed the scientific state-of-the-art of selected critical factors for the acceptance of BugWrigth2 with a focus on a psychological perspective.

Main results. The e-book "Human-Robot Teams. Spotlight on Psychological Acceptance Factors exemplified within the BGUWRIGHT2 Project" spotlights 14 psychological topics identified as essential for the acceptance of an autonomous robotic solution developed within the BUGWRIGHT2 project. Each psychological topic is presented in a factsheet that summarises the scientific input, provides appropriate literature recommendations, and concludes with recommendations for the BUGWRIGHT2 project. At a glance, this e-book presents how *agent transparency* and *explainable artificial intelligence (XAI)* contribute to high robot trust and acceptance. In addition, we focus on concepts closely related to human attention such as *situational awareness* that reflect the perception about the current circumstances, or *cognitive load*, a concept rooted in learning science that can also be applied to problem-solving within HRT tasks. Two factsheets deal with phenomena in the context of virtual environments namely *cybersickness* and *immersion and presence*. Different methods to measure *task performance* and key concepts of *technology acceptance* are also reviewed. Regarding cognitive-motivational factors, two factsheets deal with the topic of *trust* in HRT. The impact of competence self-perceptions in HRT is reviewed in the factsheet on *self-efficacy*, which describes one's self-perceived confidence to succeed in a situation or task. The relevance of human *attitudes* in HRT and possible methods of attitude change are presented. Regarding humane work design, we present the concept of *smart work design* which is a valuable framework to analyse and evaluate Human-Robot work settings. Furthermore, we outline the critical role of *basic human need satisfaction* in HRT. The factsheets are presented in alphabetical order.

Value. This open-access e-book is valuable beyond the BUGWRIGHT2 project. For the BUGWRIGHT2 consortium, this e-book provides an easy-to-read introduction to a psychological perspective on Human-Robot collaboration. Beyond BUGWRIGHT2, the e-book is valuable for any researcher or practitioner interested or involved in the implementation of robotic solutions in a work environment.

Original publication (E-book).

Schauffel, N., Gründling, J. Ewerz, B., Weyers, B., & Ellwart, T. (2022). Human-Robot Teams. Spotlight on Psychological Acceptance Factors exemplified within the BUGWRIGHT2 Project. *PsychArchives*. http://dx.doi.org/10.23668/psycharchives.5584

10 Hybrid Teams – Effects on Work, Safety, and Health

Theoretical background. Researchers estimate that the capabilities of future "digital teammates" such as robots and software agents in the field of machine learning will exceed our human capabilities in the next decades (Grace et al., 2018). New forms of cooperation are studied extensively under multiple different terminologies, for example, human-agent teams (Chen et al., 2011), Human-Robot Teaming (Endsley, 2017), Human-Robot collaboration (Chen et al., 2020), hybrid teams (Straube & Schwartz, 2016), socio-digital teams (Ellwart & Kluge, 2019). Illustrated on the concrete case of ship hull inspection, this paper deals with the question: What are the concrete characteristics of cooperation in a hybrid team, and with which consequences?

Method. Along with interdisciplinary fields of research on human factors, organisational and differential psychology, and artificial intelligence, this article outlines focal concepts for the description and evaluation of hybrid teamwork and its effects on work processes, safety, and health.

Main results. This article identifies five cross-disciplinary characteristics of successful HRT design: the primacy of the task, holism, transparency, dynamics, differentiation, and interdisciplinarity.

Value. It becomes clear that concepts and criteria of a functional man-machine function division known from traditional work psychology (e.g., Hacker, 1995; Strohm & Ulich, 1997) can be extended by further perspectives from different psychological disciplines, engineering, and computer science. The interdisciplinary perspective, therefore is a useful strategy for planning, introducing, and supporting hybrid teams.

Original publication.

Ellwart, T. (2020). Mensch, Softwareagenten und Roboter in hybriden Teams. Auswirkungen auf Arbeit, Sicherheit und Gesundheit. [Humans, software agents and robots in hybrid teams. Impact on work, safety and health] In R. Trimpop, A. Fischbach, I. Seliger, A. Lynnyk, N. Kleineidam & A. Große-Jäger (Hrsg.), *21. Workshop Psychologie der Arbeitssicherheit und Gesundheit - Gewalt in der Arbeit verhüten und die Zukunft gesundheitsförderlich gestalten!* (pp. 25-40). Asanger.

Open-access English translation.

Ellwart, T., & Schauffel, N. (2021). Humans, software agents, and robots in hybrid teams. Effects on work, safety, and health. *PsychArchives*. http://dx.doi.org/10.23668/psycharchives.5310

11 Human-Robot Self-Comparisons

Theoretical background. Rooted in psychological research on social comparison in all-human teams this article introduces socio-digital self-comparisons (SDSC) as individual evaluations of one's own abilities in comparison to the knowledge and skills of a cooperating digital actor in a group. SDSC provides a complementary perspective for the acceptance and evaluation of HRI. As autonomous robots enter the workplace, in addition to human-human comparisons, digital actors also become objects of comparison (i.e., I vs. robot). To date, SDSC have not been systematically reflected in HRI.

Method. The article is threefold. First, the article conceptualises SDSC based on psychological theory and research on social comparison. Second, we illustrate the value of SDSC for HRI using empirical data from 80 hybrid teams (two human actors and one autonomous agent) who worked together in an interdependent computer-simulated team task. Third, the (practical) potential of SDSC for HRI is discussed.

Main results. SDSC in favor of the autonomous agent corresponded to functional (e.g., robot trust, team efficacy) and dysfunctional (e.g., job threat) team-relevant variables.

Value. A comparative perspective on HRI adds to research and practice. SDSC as an underlying mechanism might explain complex functional and dysfunctional consequences of autonomous robots in work teams.

The concept of SDSC illustrates why HRT might be a double-edged sword. The discussion of concrete practical potentials of SDSC can be integrated by personnel developers and robot design to minimise the "dark sides" of SDSC in favor of a robot and HRT.

Original publication.

Ellwart, T., Schauffel, N., Antoni, C. H., & Timm, I. J. (in press). I vs. robot: Sociodigital self-comparisons in hybrid teams from a theoretical, empirical, and practical perspective. *Gruppe. Interaktion. Organisation. Zeitschrift für Angewandte Organisationspsychologie (GIO)*

12 Ecosystem of Trust in Remote Inspection Technologies

Theoretical background. Rooted in psychological research on interpersonal relations (e.g., McAllister, 1995; Zand, 2016), trust in robotic technologies is viewed as a complex and multi-layered research topic. During a remote inspection process, the expectation is that the Operator (of the robotic technology) and the semi-autonomous system will actively cooperate to examine the vessel. As such, this interdependency evokes the need for a well-calibrated level of trust and avoidance of mistrust and overtrust in RITs. Thereby, different forms of RITs, such as micro aerial vehicles (MAVs) or drones, magnetic-wheeled crawlers (crawlers), and remotely operated vehicles (ROVs) coexist, which multiplies the complexity of trust in the context of RITs. A broader perspective on trust, as an ecosystem of trust in RITs, is needed.

Method. The interdisciplinary research article explores trust from a psychological perspective, reflecting on its characteristics and predictors, followed by a discussion on the AI-trust ecosystem as envisioned by the European Commission. Structured interviews with 33 subject matter experts guide the main analysis, specifying certain elements of a trustworthy ecosystem for RITs.

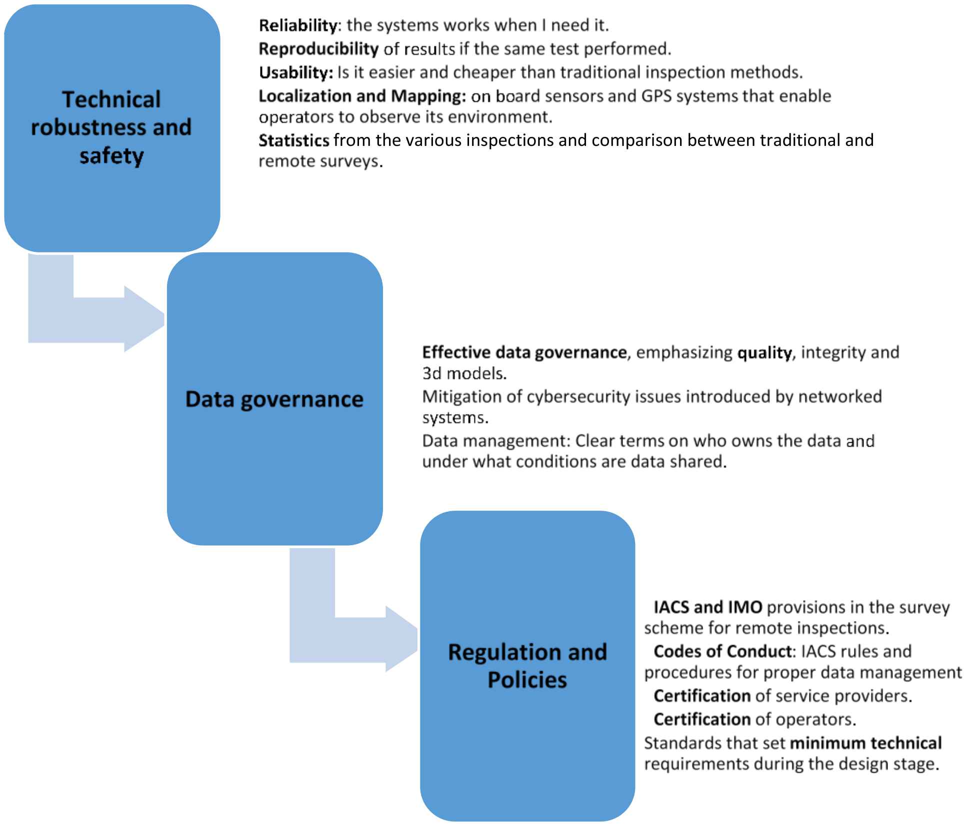
Main results. The article elaborates on five psychological insights when reflecting on trust in RITs. The structured interviews with 33 subject matter experts revealed that trust is an essential precondition for integrating RITs into the current manual-driven inspection system. The most important aspects of trustworthy RITs are a) technical robustness and safety, b) data governance, and c) regulation and policies (see Figure 15). On side of the human element, the skills and training of the Surveyors are most critical. Furthermore, the vessel lifecycle and environmental conditions turned out to critically impact trust in RITs.

Value. The article contributes to the discussion concerning the role of trust in robotic and autonomous systems (RAS), with a sharp focus on RITs for vessel inspection and maintenance. To this end, the article provides a first-hand insight into one of the major findings from BUGWRIGHT2 that are transferable to other autonomous robotic solutions in and beyond the maritime sector. A synoptic overview of the vital trust elements is provided and carves out the ways forward for developing a trustworthy environment governed by HRI.

Original publication.

Pastra, A., Schauffel, N., Ellwart, T., & Johansson, T. (accepted, 2022). Building a trust ecosystem for remote inspection technologies in ship hull inspections. *Law, Innovation and Technology.*

Figure 15: Most Important Aspects of Trustworthy RITs for Hull Inspection



13 Human-Autonomy Teaming

Theoretical background. For many decades, work psychologists studied the automation of work processes (e.g., Corbett, 1985; Fitts, 1951; Kaber & Endsley, 1997). However, autonomy in maritime and other sectors is qualitatively different from automation of work processes by implementing software, systems, or tools to support (or supplement) the human worker. Autonomous systems are characterised by a high degree of self-governance concerning adaptation, communication, and even decision-making. From a psychological perspective, maritime autonomy means that autonomous agents and humans work interdependently as a human-autonomy team (You & Robert, 2017).

Method. As part of the book "Smart Ports & Robotic Systems: Navigating the Waves of Techno-regulation & Governance", we theoretically reflect on the psychological perspective on HRT in the maritime sector. These considerations are enriched with qualitative data from use cases of ship hull inspections, focused on within the BUGWRIGHT2 project.

Main results. In this book chapter, we first introduce the concept of human-autonomy teaming (HAT) in the context of maritime work settings. We highlight its essential characteristics and the importance of coordination processes, well-calibrated trust, and knowledge structures for efficient HAT functioning. Second, we reflect on HAT regarding the next generation of autonomous agents in ship hull inspection and maintenance. Qualitative interview results from 17 maritime and technological experts give insights into the complex pattern of possible opportunities and hindrances when facing agent autonomy in maritime application fields. Finally, we outline future trends in HAT increasingly needed due to continuous technical improvement. Autonomy is no static goal, but an adaptive team characteristic impacted by human and situational demands with potential for collaborative learning, challenges for leadership, and open questions regarding the role of responsibility.

Value. The benefits of a holistic psychological perspective on HRT in the maritime sector become visible. Future trends of adaptability and adaptable systems can be taken up in future BUGWRIGHT2 project phases.

Referenced document.

Ellwart, T. & Schauffel, N. (2022, in preparation). Human-autonomy teaming in ship inspection. Psychological perspectives on the collaboration between humans and self-governing systems. In *Smart ports & robotic systems: Navigating the waves of techno-regulation & governance* (vol. 2). Palgrave Macmillan.

4. Next Steps and Interface Design Recommendations

To summarise this deliverable report, 13 separate outcomes were evaluated in Task 1.5 that are both process-related and related to HR-interface. These outcomes describe the roles as well as needs and expectations of individuals involved in the inspection process (e.g., Operator, Technical Manager, Surveyor). In addition, knowledge categories, which play an important role in trust and acceptance of remote ship inspection technologies, were identified and discussed as well as rated with Operators. The outcomes described in the previous chapters are an essential part of the development of training materials and HR tools for introducing the needed changes to organisations that intend to deploy the technologies developed in BUGWRIGHT2. In addition, they are essential for the further design of UI development and evaluation. Based on the findings described in this deliverable report, this section lists recommendations for HR tools and UI aspects that should lead to increased user adoption and thus support the success of BUGWRIGHT2 technology.

Regarding HR tools, first, HR tools need to guide the process of technology introduction and implementation to ensure user acceptance and willingness to implement new processes in work routines. Second, successful change needs ongoing diagnosis of task-specific resistance, knowledge needs, or change-related adjustments. HR tools have to provide measures that are applicable to monitor task-specific needs and attitudes to guide technology implementation. Third, specific HR methods for supporting technology implementation at different stages of the implementation process are needed that address the key variables described in this report and lead to a successful application.

Regarding UI aspects, it is necessary to design an interface that is tailored to the three core components of data processing in the future work process. These are data acquisition, data organisation, and data analysis. These core components require different interaction capabilities, so a future interface should provide appropriate concepts for each of the three components. Furthermore, it should be noted that within the scope of data acquisition, a possibility to control the robots in case of emergency should be available. Throughout the process, a well-calibrated level of trust, as well as acceptance, must be achieved through the information provided. Ultimately, a future UI will enable the responsible parties to be well supported in drawing their decisions.

These recommendations to UI design will be transferred as direct input into Task 7.4 and used to implement the following work there.

First, precise design proposals based on the aforementioned recommendations will be developed. These are based on modern principles of the UI design process. Second, concepts will be developed to evaluate the prototypes based on the design proposals concerning their appropriateness in terms of trust calibration, usability, user experience, and assistance with data acquisition, processing, and analysis. These evaluation concepts will be applied iteratively to continuously support the development of the UI for BUGWRIGHT2. The results will be disseminated among the consortium. Finally, it is our goal to provide HR recommendations to enable a smooth transition from current ship inspection processes to new technologies used in companies.

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