SEVENTH FRAMEWORK PROGRAMME	**CASCADe** Model-based Cooperative and Adaptive Ship-based Context Aware Design	CASCADe

D2.13 – Report on new design methodology (incl. new techniques and tools) final version

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2 Abbreviations and Definitions

Abbreviation	Definition
DSA	Distributed Situation Awareness
ECDIS	Electronic Chart Display and Information Systems
GUI	Graphical User Interface
HCD	Human-Centred Design
HITL	Human In The Loop
HMI	Human-Machine Interface
IMO	International Maritime Organization
PSP	Physical Simulation Platform
UI	User Interfaces
VSP	Virtual Simulation Platform

3 General Info

This document is a report about the new CASCADe ship bridge design methodology based on the tools and techniques developed in the project. This new methodology has been applied during cycle 1 [month 01–19] of the project to design the CASCADe ship bridge, and then into making the demonstrators. We now derive the lessons learned during this process. D2.13 therefore capitalizes on the methodological developments during the project's first cycle, in an attempt to provide methodological improvements (in the form of techniques and tools) to the design methodologies currently used. In particular it attempts to satisfy the requirements for bridge design improvement from a human factors perspective. Furthermore, international guidelines are fostering to move forward human-centred design processes, e.g. e-nav HCD & SQA Guideline or ISO 9241.

The study of a bridge means to understand how the bridge is effectively realized at the actual level, i.e. as a real, concrete ship bridge. The actual level of a bridge is ideally a physical instantiation of all the functional structures and processes described in the functional bridge study. Thus, the bridge at the actual level should be a physical (including software) embodiment of the aspects described at the functional level (global tasks, agents, internal workflow, external workflow). The process of defining a new design methodology in the project started with an analysis of regulations and recommendations from IMO and DNV-GL concerning the actual level, i.e. bridge layout, consoles, user interfaces, lightning, acoustics, HVAC, and finishings. Information has been collected, described and analysed only on these dimensions of the actual level.

The regulations and recommendations named here were considered most relevant for these dimensions of the actual level:

For bridge layout:

IMO / NAV 55/4-Report of the Correspondance Group on IBS (Germany), ANNEX 1, Pages 9 & 10

IMO / NAV 45/6, ANNEX, Pages 4 to 11 (Report of the Correspondance Group on Ergonomic Criteria for Bridge Equipment and Layout – Germany)

DNV-GL / Rules for Ships, July 2006 - Pt.6 Ch.20 Sec.2 – Page 10 to 14/ Amended, see Pt.0 Ch.1 Sec.3 January 2010 (DNV-part6-chap 20-Nautical safety OSV)

For consoles:

IMO / NAV 45/6, ANNEX, Pages 3, Pages 11 to 14 (Report of the Correspondance Group on Ergonomic Criteria for Bridge Equipment and Layout – Germany)

IMO / NAV 55/4-Report of the Correspondance Group on IBS (Germany), ANNEX 1, Pages 4 to 8

IMO / NAV 45/6, ANNEX, Appendix 2, Pages 26 to 29 (Report of the Correspondance Group on Ergonomic Criteria for Bridge Equipment and Layout – Germany)

DNV-GL / Rules for Ships, July 2006 - Pt.6 Ch.20 Sec.2 – Page 16 to 19/ Amended, see Pt.0 Ch.1 Sec.3 January 2010 (DNV-part6-chap 20-Nautical safety OSV, section 3, workstation arrangement)

For user interfaces:

DNV-GL / Rules for Ships, January 2011- Pt.6 Ch.20 Sec.5 – Page 53

DNV-GL / Rules for Ships, January 2011 - Pt.6 Ch.20 Sec.3 – Page 29

DNV-GL / Rules for Ships, July 2006 - Pt.6 Ch.20 Sec.3 – Page 31 & 33

DNV-GL / Rules for Ships, July 2006 - Pt.6 Ch.20 Sec.3 – Page 33 – 35

For lighting:

IMO / NAV 45/6, ANNEX, Page 10 & 11

DNV-GL / D 700 Light arrangement on bridge and on deck

In parallel, a common generic design process for bridge systems and pilot equipment was defined by the partners of the consortium consisting of six successive phases (c.f. 0). Many improvements suggested by CASCADe include model-based techniques. In the project, we focus on modelling what information a seafarer needs to obtain in order to execute a certain task and how this information is usually obtained. Due to the massive amount of low-level intra- and inter-variability of behaviours of seafarers, we are aware that the techniques are not used to simulate whether a seafarer will put the knowledge obtained to good use, i.e. we do not aim to model the actual low-level sensor-motor-behaviour of seafarers.

4 Introduction

4.1 Objective of the report

This deliverable describes the proposed new human-centred design process and methodology for bridge systems and pilot equipment based on the lessons learnt in the project CASCADe.

This main content of the document is structured as follows:

- Section 5 will describe general ideas that underlie the proposed improvements to the design process and methodology.
- Section 6 will describe for each phase of the defined design process and methodology the improvements we suggest.

4.2 Summary of Requirements for Improvement

In earlier deliverables, we have provided a preliminary version of methodological improvement needs, as captured and understood during the first project cycle. These needs constitute an important input for driving the improvements described in this deliverable.

The following needs have been identified:

- To extend the design process with a user- and test-centred perspective
- Provide support for HMI resp. GUI design

Both needs are interdependent. The HMI (Human-Machine Interface) is the prime means for users to interact with the bridge systems, and improving the HMI is usually one of the main results of the application of a user-centred design methodology or perspective.

Furthermore, we updated the requirements for improvement during the progress of the project, as summarized below:

- The design process will need to focus on the functional requirements for the bridge system reflecting a use case view. The pure technical view of the international standards will need to be translated to the operator's perspective of what he wants to achieve when interacting with the bridge system.
- The technical design will need to support a flexible HMI design process which will enable us to quickly adapt to user's needs or new situational requirements.
- The development process will need to be adapted for early user or operator involvement (early integration, quick feedback cycles).

- The functional requirements will need to be mapped to typical situations or tasks which need to solved or handled by the operator with support of the bridge system. For each of the identified situation/task a specific display/HMI can be designed.

5 General Ideas behind Methodological Improvements

The methodological improvements we describe are based on a design process structure that is dissociated into 6 disjoint design phases. We will propose for each phase, specific improvements, based on the techniques and tools developed in the project.

Though these improvements are specific to the phases, they however rely on more general ideas for improving the design process, transverse to all phases.

- *taking the bridge and the wheelhouse as whole units*. **<u>They should be the object of design</u>**, not an equipment (e.g. ECDIS, Radar, conning display) seen in isolation. The bridge and the wheelhouse are seen as cooperative human-machine systems. It is CASCADe's ambition to show that embedded system design can be significantly improved by understanding - and designing - the human-machine system equipment.

- in particular, *modelling activities* should be extended beyond system modelling and *encompass the whole bridge and/or wheelhouse*, seen as (inherently cooperative) human-machine system. The modelling framework used for modelling these aspects should provide *executable models*, i.e. models of the bridge and/or wheelhouse that can be used on a Virtual Simulation Platform (VSP) to perform virtual simulations of how the bridge/wheelhouse behaves under specific circumstances. This will for example allow comparing between different design alternatives, or ensuring the requirements established for the bridge/wheelhouse are indeed satisfied by the design (models).

- introduce *improved consideration of Human Factors issues* in the design process, in particular at the bridge or wheelhouse level as described above: communication, situation awareness, cooperation between the crew/pilot, and within the systems. These aspects all resort from information (e.g., situation awareness) and information circulation (e.g., communication, user interfaces), and they must be designed too, as well as influence the design of the equipment involved (e.g., displays, overview displays). This should in particular concern the design of the (adaptive) user interfaces.

- consider producing *adaptable and adaptive products for the bridge and the wheelhouse*: adaptability means something that can be manually adapted by the user(s). Adaptiveness means automatic adjustments, by the systems themselves, to the peculiar user needs and context. Adaptability and adaptiveness should be provided both at the local, system level (e.g., user interface, workstation) and at the systemic, bridge or wheelhouse level (e.g., physical reconfiguration of the bridge for specific operations).

- provide and rely on *dynamic modelling of the bridge or the wheelhouse*, as a (cooperative) human-machine system. The expected dynamicity is the reason for which the models used for modelling the bridge or the wheelhouse should be executable (cf. above). This allows producing *dynamic and executable simulations of the bridge or wheelhouse* (on a *Virtual Simulation Platform, VSP*). These simulations can be used to verify if a given design satisfies some requirements (e.g., all users on the bridge during collision avoidance are fed with appropriate information, so that their situation awareness is optimal) or to compare between alternative designs (e.g., see if situation awareness of the circulation of information is better between two different bridge layouts). Such simulations can be used at an early stage of the design phase.

- provide and rely on *Human-In-The-Loop (HITL) full scale simulations* of the bridge and possibly the wheelhouse (*Physical Simulation Platform, or PSP*). They will be used during the test and evaluation phase, again either to ensure some requirements are indeed met or comparing between alternative designs, but also to uncover and fix potential integration problems at the bridge or wheelhouse level. The interest of the PSP is that it allows to see the bridge or the wheelhouse as a complete functional unit and see how it works in realistic (though simulated) situations. This allows tackling the "system of system" dimension inherent to the CASCADe approach. Equipment (e.g., ECDIS) should be tested and evaluated into the whole bridge or wheelhouse context.

6 CASCADe Improvements to the Design Process

In this section, we detail the methodological improvements proposed by CASCADe to a generic design process for bridge systems and pilot equipment. We give details for each phase in terms of which techniques and tools proposed and/or developed in CASCADe could be used to improve that process in terms of human factor issues. The common generic design process defined by the partners of the consortium consists of six successive phases:

- Project start-up
- Requirement analysis
- Design
- Implementation
- Test and evaluation
- Project closure

The whole analysis should consider the value of the proposed improvements in terms of cost vs. return, i.e. what is the cost of integrating the proposed improvement in the current design methodology (e.g. in terms of time, resources used) and what is the expected return (e.g. proceeding faster, more efficiently, yielding improved safety,...).

6.1 Project start-up phase – proposed methodological improvements

Make the stakeholders aware of the extension of the focus on the *design of the bridge and wheelhouse as an integrated system* of humans (human agents) and machines (machine agents). Humans and machines form a cooperative human-machine system (c.f. Figure 1) that has to implement the wheelhouse tasks at all times (i.e., all phases of the voyage) and under all circumstances (i.e., normal and abnormal traffic or environmental conditions).

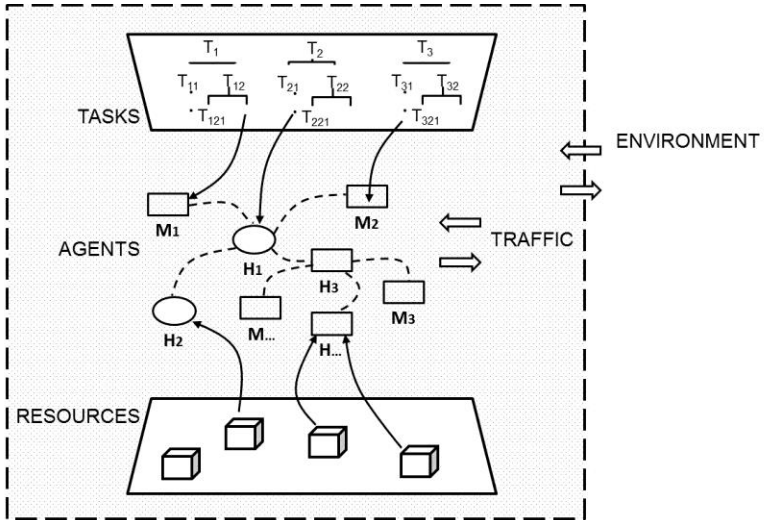

Figure 1: Cooperative Human-Machine System

This focus will have an impact on the phases that follow, and therefore on how the methodology will proceed (*Project planning and documentation*). This in turn will influence the nature of the activities to conduct, their focus (e.g., the wheelhouse, the bridge, the equipment), the personnel involved (*Human resource management*), their qualification or the timing of the activities. *Risk management* will also need to be adapted to integrate the new elements (e.g., wheelhouse or bridge level modelling). When these improvements are first applied, they will also impact the *improvement of the design process activity*. This impact will last until the design process has fully integrated the new proposed elements.

The inherently cooperative nature of some of the activities on the bridge, have clearly been confirmed during the experiments and evaluations we have conducted in WP4 in cycle 1. The seafarers have clearly expressed their interest for having cooperative activities on the bridge being better supported.

6.2 Requirement analysis phase – proposed methodological improvements

Again, change the focus and the object of design from equipment to the bridge and the wheelhouse as whole units. *Pay attention to the bridge as a whole* or even the wheelhouse as a whole. See the bridge/wheelhouse, as a cooperative human-machine system. This means new ways of looking at the bridge/wheelhouse and paying attention to other aspects, in particular:

a) communication between agents
b) circulation of information on the bridge
c) situation awareness, local & distributed
d) coordination & cooperation.

This will impact the collection of requirements and their modelling:

- the target design object addressed by the methodology must go beyond isolated systems. *Requirements must be collected at all appropriate levels: wheelhouse, bridge and systems*. In particular, the requirements at the wheelhouse and bridge levels must address them as whole functional units. The functions to be provided by the wheelhouse and/or bridge must be specified for all voyage phases, normal and abnormal.

- the *scope of the models* must also be enlarged to cover the target design object, at all appropriate levels: *wheelhouse, bridge and systems*. It is strongly recommended to rely on a modelling formalism that is *executable*. This will later on allow the implementation of a Virtual Simulation Platform to perform simulations at the design stage. These simulations allow comparing between two or more alternative designs (e.g., two different bridge layouts) or ensuring a given design indeed satisfy all design requirements, at all time (voyage phase) and circumstances (normal and abnormal).

- *task analysis* must be conducted for all bridge or wheelhouse users. Task analysis will aim at determining what the users must do, during the different voyage phases and in all circumstances (normal and abnormal). In cycle 1, it was confirmed during the experiments and evaluations that the seafarers really valued cooperation on the bridge. It is therefore particularly important to pay attention to the collaborative aspects of the tasks during the task analysis. The tasks will then be modeled and, if possible, the models verified with end users or bridge/wheelhouse experts, to ensure of their accuracy. Again, it is strongly recommended to resort to *executable task models*. This will allow using them on a virtual simulation platform at the design stage to simulate human behavior for all users and therefore provide complete wheelhouse or bridge-level virtual simulation, for virtual testing and evaluation purposes. In the framework of CASCADe, work processes of different seafarers as well as necessary information for work process execution can be described and modelled by using the Maritime Operation Planning Tool (MOPhisTO) of the CASCADe Modelling Tool Suite. MOPhisTO is a graphical editor for the modelling of normative maritime work processes, including the individual behaviour of different actors in relation to the environment and its dynamics. Derived from the main concepts of business process modelling languages, normative processes can be defined with a graphical notation as the basis for model-based safety analysis and optimisation. In an extended version of MOPhisTO it is possible also to model information flow including the information elements, which are exchanged between the agents. The task models can be executed via a cognitive architecture named CASCaS to mimic cognitive functions of human agents.

- *situation awareness needs*: the situation awareness needed by the different bridge users must be determined for all voyage phases and all circumstances (normal and abnormal). Situation awareness, local (to a given user) or distributed (between multiple users), is a key component of a safe and efficient wheelhouse/bridge. Situation awareness is needed for ***individual*** and ***joint***, bridge/wheelhouse level *perception of current and forthcoming situations*; *evaluation of current and forthcoming situations*; *decision-making*; *action planning* and *action implementation and monitoring*. Situation awareness needs can be determined in different, complementary ways. A first approach consists in exploiting the task analyses and task models produced previously and attempt to derive all information elements of the situation a user needs to be aware of, for each step in a given task. It is strongly recommended, as a complement to this preliminary approach, to validate these inferences with real seafarers (who may indeed to alternative strategies and/or heuristics). Observations on real wheelhouses/bridges may also be used to better determine situation awareness needs.

- *information presentation needs*: information presentation needs are derived from situation awareness needs. They represent a subset of the needed situation awareness. Many elements of situation awareness are indeed obtained by other means than direct presentation on user interfaces: direct observation (e.g., through the windows), circulation (via communication) of information between users, inferences and deductions (where a piece of information automatically implies another). During cycle 1, we have developed and applied a framework, based on information demand and supply to better assess these aspects. **The key objective is to ensure the bridge users will always have, at all time and under all circumstances, the situation awareness needed for performing their assigned tasks safely and efficiently**. In the framework of CASCADe, the evaluation on the VSP shall be performed in regards to the ability to provide all necessary information to seafarers (= *information presentation needs*) and support the seafarers to obtain task-specific "optimal" distributed situation awareness (DSA; = *situation awareness needs*). This ability will be measured according to the developed metric for the analysis tool, called DSA-Monitor.

- *adaptiveness for user interfaces*: CASCADe aims at shifting the focus towards designing and demonstrating adaptive user interfaces, i.e. interfaces that are adaptable (i.e., configured by the user) and adaptive (i.e., automatically reconfigured by the system, based on context). The information needs of above must then be processed in this respect, to derive requirements for adaptability and adaptiveness:
    - *adaptability*: which aspects (content and presentation) of the user interfaces must be adaptable by the user

- *adaptiveness*: the voyage, including normal and abnormal phases, must be dissociated into contexts and specific information needs must be determined for each of them.

- *collection and translation of requirements from standards:* typically the relevant standard (IMO, IEC, …) which apply to maritime bridge equipment formulate necessities to implement specific system functionalities with expected performance requirements. These requirements need to be translated early in the design process to functional requirements defining what the user needs to achieve with that system functionality. This will enable us to feed these use cases into the simulation framework mentioned above. Also this will lead to a more user focused interaction design.

6.3 Design phase – proposed methodological improvements

During the development of a preliminary design solution, as the main objective of the design phase, the following should be improved:

*See embedded system design as **part** of the whole bridge/wheelhouse design*. This is an important point. Embedded systems, including their user interfaces, such as the ECDIS, the Radar, the conning system, displays and controls, should not be seen as separate entities but as the components of a *larger functional system*: the bridge or wheelhouse. The bridge or the wheelhouse themselves must be seen as systemic and cooperative assemblies of human and machine agents, in charge of specific functions.

A consequence and second important point is that **the bridge or the wheelhouse both also have to be designed, as integrated and cooperative systems of human and machine agents.** Our approach reflects this perspective (at the functional and actual level), and we provide tools for supporting the process (such as the Virtual Simulation Platform and the Modelling Tool Suite). Embedded systems still have to be designed, but they have to be designed as components of larger functional systems and these systems must also be **explicitly designed**.

This also enforces the importance of paying attention to requirements (at the functional and actual levels) that apply to the whole bridge or wheelhouse. This entails seeing the bridge or the wheelhouse in particular as functional units that perform specific operations in specific contexts (normal navigation phases & abnormal situations). **The bridge or wheelhouse must be first designed at the functional level** and **then at the actual level**, seen as a physical (or actual) instantiation of the bridge or wheelhouse at the functional level. **Designing at the functional level is very seldom performed. This is a major source of error proneness on contemporary bridges**.

Rely on model-based design, for both embedded systems and the human-machine system. A model-based approach is already used in some case for designing embedded systems. This type of approach must be extended to the bridge and the wheelhouse, seen as wholly functional units. A model-based approach can be used for designing the bridge or the wheelhouse at both the functional and actual levels.

Do not hesitate to proceed in several steps for the bridge design process, from a general and conceptual perspective first, which can for example be demonstrated and evaluated on mock-ups, and then proceed to more detailed versions of the bridge, once the concepts have been evaluated and approved. The concepts can be model-based, but in a way that significantly simplify them, with the level of details just appropriate to express the differences between the conceptual bridge alternatives.

If a model-based approach is used for bridge or wheelhouse design, this also opens the door to dynamic simulation. In WP2, CASCADe has developed a Virtual Simulation Platform (VSP) that can be used to simulate the whole bridge or wheelhouse, including with dynamic models of human bridge users (e.g. the CASCaS cognitive architecture provided by the project).

This then allows performing virtual simulations, at both the functional and actual levels, for:

- ensuring a given design achieves specific requirements (e.g., a sufficient level of situation awareness for the human agents)
- comparing alternative designs with regard to peculiar performance indexes (e.g., comparing distributed situation awareness between two bridge layouts, comparing the amount of communications needed by the virtual human agents to perform their tasks on two alternative bridge layouts,...).
- better *map* functional and actual ship bridge designs in the future, i.e. by asking whether the actual design meets the functional requirements to fulfil and on-going task

That type of virtual analysis can be conducted on:

- individual equipment or a subset of them
- bridge, seen as a functional unit
- wheelhouse, seen as a functional unit

Within the framework of CASCADe, the virtual analysis can be done on the VSP that simulates the ship bridge as a cooperative system purely based on computational models. The architecture of the current implementation of the VSP is based on a co-simulation methodology that allows the simulation of individual elements by different simulation tools running simultaneously while exchanging information in a collaborative manner via interfaces based on the High Level Architecture Standard for integrated and distributed simulation (HLA RTI), defined under IEEE Standard 1516. The VSP integrates:

- models of human agents and machine agents, for modelling the behavior of all seafarers and the behavior of the workstations involved within selected scenarios of CASCADe,
- set of simulators that provide the physics and behavior of the crews' and potential surrounding ships,
- an environment simulator that provides a (graphical) simulation of the environment and scenarios e.g. navigational features based on Electronic Navigational Charts (ENC) data.

The VSP is a virtual and functionally equivalent replica of the Physical Simulation Platform (PSP). The VSP allows performing closed-loop simulation under various conditions in order to evaluate bridge designs at early design stages (when design changes are still feasible and affordable) and in many more scenarios than the PSP. Furthermore, it also allows the investigation of extreme scenarios that would be difficult to evaluate on the physical platform.

The design phase will clearly need to be changed to an iterative process. At each iteration feedback will be produced to optimize the current state of the design.
To gain early feedback in the design process while still working on simulators, mock-ups and User Interfaces (UI) prototypes one will need to start system integration early in the process. This agile approach leads to an overlap of design, implementation and integration/evaluation phases in the projects. By delivering increments of system functionality we avoid that we discover design errors or misconceptions merely at the end of the project during evaluation.

6.4 Implementation phase – proposed methodological improvements

Due to an agile approach to do early integration and evaluation of implementation of functional system components, the technical framework which serves as foundation of a next generation integrated bridge system needs elements which supports easy UI composition and can be deployed easily to a variety of different display formats.
Consequently this means that the framework will need to supply a flexible plug-in based mechanism with generic interfaces to feed data to functional user interface components. An HMI supporting a specific situation or task will then consist of a collection of UI plug-ins to provide access to system functions or display system state or data.

Also to be able to quickly react on user feedback after a system increment was delivered and integrated the framework needs to supply a tool which allows us to (re-)arrange quickly HMI plug-ins to a so-called perspective. A perspective will be defined to be a collection of HMI plug-ins for one situation or task.

6.5 Test and evaluation phase – proposed methodological improvements

Perform HITL (Human In The Loop) tests on a physical simulation platform. The two platforms used in CASCADe, the Virtual and Physical Simulation Platforms, are used to investigate the information flow in the cooperative system and the distributed situation awareness of seafarers during a subset of situations. Whereas the VSP can be used during the design phase for simulations with human models, the PSP can be used in evaluation experiments with human subjects during the implementation phase.

The objectives are the same than those recommended on the Virtual Simulation Platform at the design stage but now on a real, non-virtual simulation, and at a later stage of the design process.

These tests should aim in particular at verifying that:

- all requirements are implemented and satisfied
- the actual, i.e. physical implementation of the bridge and its systems indeed translates all the functional properties expressed at the functional level

The focus of the tests can be at three levels:

- individual equipment or a subset of them, including the user interface
  - usability
  - support to situation awareness through information presentation and access
- bridge, seen as a functional unit
  - physical comfort (e.g. with regard to anthropometrics)
  - usability
  - situation awareness
  - cooperation between users, on and off the bridge
- wheelhouse, seen as a functional unit
  - gait and distances (e.g., with regard to the wheelhouse layout)
  - internal communication,
  - internal vision (equipment, other users,...)
  - external vision
  - situation awareness
  - cooperation between users, on and off the wheelhouse

This entails new concepts that have to be mastered by the design team:

- usability
- situation awareness
- cooperation between users.

If bridge design proceeds in several stages, and in particular a conceptual stage, where simple bridge sketches are produced, the different alternative bridge solutions should also be evaluated. Evaluation can be made purely subjectively on 3D renderings that present several alternative conceptual solutions to the end users (seafarers). Simple physical full-scale mock-ups can also be made. The mock-ups, while simpler and less realistic than would be a fully working prototype, can be used for performing simple comparative experiments. When such experiments are difficult to perform, another possibility is to make short scripted movies that show how operations can be conducted on the different mock-up alternatives, so that the seafarers can better understand the conceptual options and subjectively value them.

The test and evaluation phase will also need to verify that the evolved human-centered bridge design fulfills all class and standards requirements. Thus a test report needs to be compiled which traces the requirements of the respective test and performance standards via the functional use case oriented design/implementation model back to the original required system functionalities. This is needed to close the loop starting with required functional components and ending with how they are verified.

6.6 Project closure phase – proposed methodological improvements

Provide or update documents on:

- the wheelhouse and/or bridge seen as a human-machine system.
- the results of the evaluations performed on a Virtual Simulation Platform (VSP)
- the results of the evaluations performed on a Physical Simulation Platform (PSP)