	CASCADe Model-based Cooperative and Adaptive Ship-based Context Aware Design	

PROJECT FINAL REPORT

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Executive summary

Reporting Period:	01.01.2013 to 31.12.2015	**Contract No:**	314352
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Project context and main objectives

The development of ship bridge systems, workstations and displays on the one hand and bridge procedures of the crew on the other, is characterized by being non-harmonious and far from optimal from the perspective of end users. Existing regulations for system and procedure design are disconnected and defined on a level which is not informative for bridge design. Research has shown that accidents and incidents most of the time involve human errors e.g. due to the non-optimal design of human-machine interactions leading to degraded situation awareness across the bridge team. Yet, the ability of ship's personnel to co-ordinate activities and communicate effectively with each other is vital during emergency situations. Also during routine sea passages or port approaches the bridge personnel must work as an effective team. Thus, bridge design should consider the capabilities of humans and the nature of the tasks at hand as information overload and decreased situation awareness can lead to "human-out-of-the-loop" situations.

CASCADe addresses the study and design of bridges as an integrated whole to improve overall safety and resilience on ship bridges. The main objective of the project is to develop, demonstrate and evaluate a new methodology enabling the design of a highly Adaptive Bridge System (ABS) from a cooperative system perspective. This methodology integrates techniques and tools for harmonization of system development, procedure development and human factors fostering a holistic and affordable human-centred approach to ship bridge design. The results of the project contribute to the improvement of safety of maritime transport through:

(1) a new Adaptive Bridge System that will recognise, prevent and recover from human errors by increasing cooperation between all crew and machines on the bridge

(2) a new human-centred design methodology supporting analysis of agent interaction at early development stages

CASCADe delivers four strongly connected key innovations. Figure 1 shows how these innovations together contribute to the ultimate goal of the ABS. The top of Figure 1 shows the difficulty of maintaining situation awareness on a ship bridge. This is paramount because a navigator will routinely find themselves in stressful situations. Not during calm and clear weather, when traffic density is low, but when the weather is poor, in reduced visibility due to fog or rain, in increased traffic density or in confined or shallow waters. In this context, the navigator needs to maintain a very clear situational awareness by relying on cooperation between colleagues and equipment data.

The cooperative system perspective is essential for our techniques, tools and design developments in CASCADe (Figure 1). CASCADe uses this cooperative system design methodology to develop an Adaptive Bridge System that permanently or semi-permanently adapts the information content, distribution and presentation on the user interfaces to the current situation, relevant procedures and the needs of the individual seafarer. It allows to detect and solve potential conflicts incl. human errors, inconsistencies and redundancies already during design time of ship bridges.

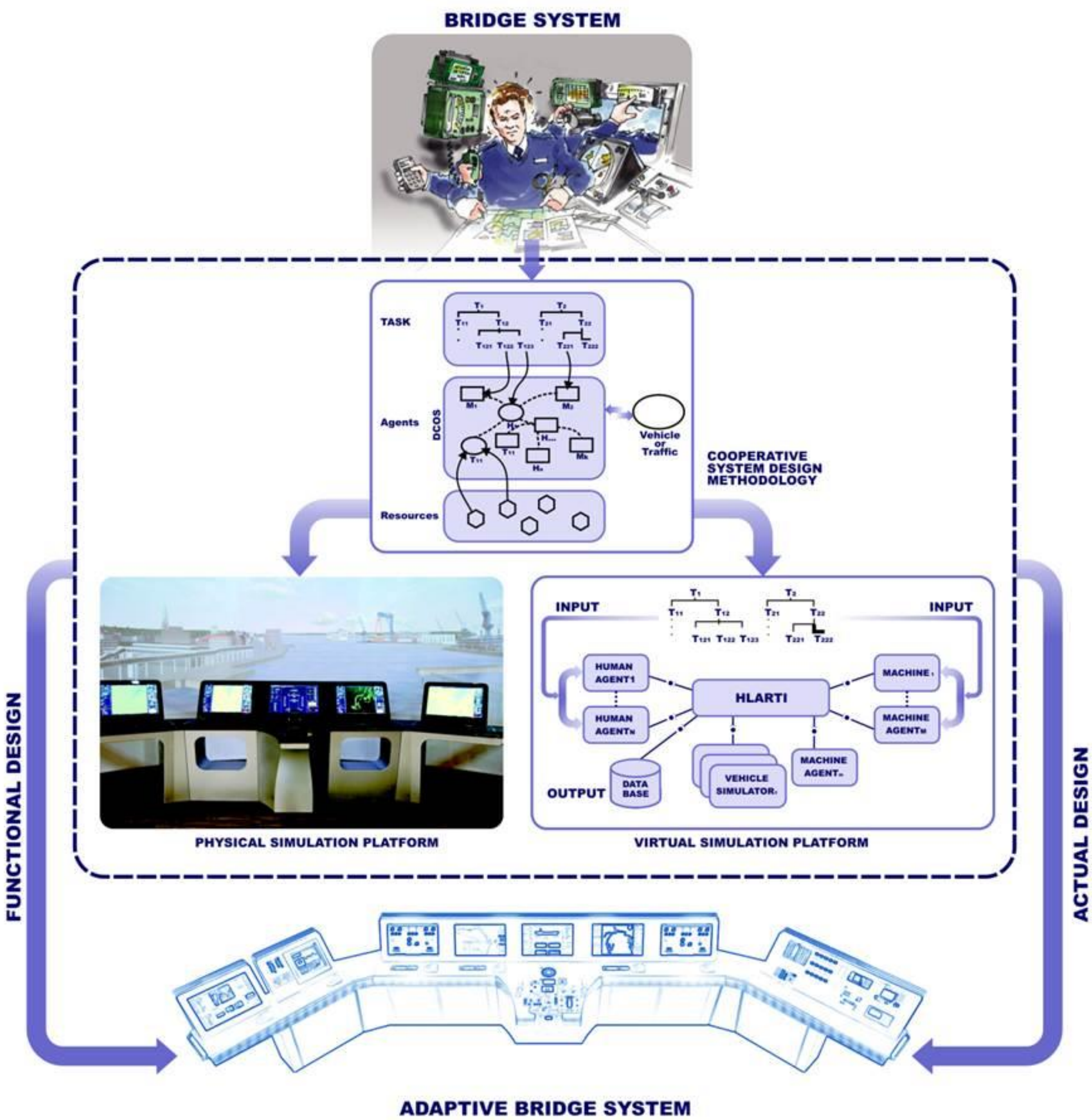


Figure 1: Key innovations of CASCADe

Based on the system perspective, the ship bridge is seen as a cooperative socio-technical system. This system consists of the ship bridge as a technical system and control centre of the ship, where cooperative decision making between crew members, automated systems, human-machine interaction as well as communication with other ships or the shipping company is involved. We consider all involved agents, e.g. human agents like Captain, Navigation Officer, Pilot and machine agents like

Radar, ECDIS or AIS to study as well as redesign the way in which they share the performance of tasks according to procedures. The bridge as a whole is analysed as an information processing system that has to assess objectives and situations, such as berthing, make decisions on how to behave and react as a whole, distribute associated tasks to currently available agents who will perform them based on currently available resources. The methodology is human-centred because it puts an emphasis on optimizing the interaction between all human and machine agents.

The design methodology is applied on two simulation platforms (Figure 1): a Physical Simulation Platform (PSP) and a Virtual Simulation Platform (VSP). The PSP is based on a full-scale bridge simulator, whereas the VSP is a virtual and functionally equivalent replica of the physical platform, purely based on computational models. The two platforms enable to compare and evaluate different functional and actual ship bridge design solutions of the ABS. The functional level is an abstract level about how the bridge functions and processes information, to assess goals and situations, make decisions and implement them into actions. For example by tracing how information circulates from different sources, is exchanged between agents, is used by them and for which goals. The actual level is a concrete level about how this abstract process is embodied by the physical world of the bridge, e.g. which user interface is the source of information on traffic and how can it be used, on which consoles are the user interfaces available, and how are the consoles laid out on the bridge. When the actual level does not perfectly embody and support the functional level, and it is impossible or hard for the cooperative system to work as intended. This of course implies that bridges must be studied and designed at both levels, taking into account how the two of them interact.

The Physical Simulation Platform, based on the full-scale bridge simulator, is extended with a prototype of the ABS. The Virtual Simulation Platform integrates models of the human agents, i.e. seafarers, and of the machine agents, e.g. models of the user interfaces to perform closed-loop simulation under various conditions. For modelling behaviour of seafarers we develop cognitive models based on empirical data, psychological theories and a pre-existing cognitive architecture. The two platforms are used to investigate bridge behaviour and information processing during a subset of routine, hazardous and emergency scenarios with human seafarer subjects and human models.

Both platforms are used as tool support for the cooperative system design methodology. We investigate the information flow in the cooperative system and the distributed situation awareness of seafarers during normal and critical situations, in experiments with human subjects using the PSP and simulations with human models using the VSP. We ask questions such as: has information presentation matched information needs of the agents at all time during the scenario? This allows us to better map functional and actual ship bridge designs, i.e. by asking whether the actual design meets the functional requirements to fulfil an on-going task? In addition to experiments with real seafarers on the PSP, the VSP facilitates closed-loop simulations in many more scenarios and the investigation of extreme scenarios than on a Physical Simulation Platform. Furthermore, it also allows the investigation of bridge designs at early design stages, i.e. when design changes are still feasible and affordable.

Together the two platforms allow a very careful investigation and evaluation of an Adaptive Bridge System (Figure 1) to research solutions for adaptation which provide benefits that outweigh their costs. The project seeks to address the issues of efficient communication and a clear and unambiguous display of data through a variety of approaches, procedures and adaptive displays, to reduce human errors on ship bridges.

Main S&T results/foregrounds

Safety relevant scenarios and project baseline

CASCADe provides a new methodology that allows designing a ship bridge as a cooperative system with associated integrated techniques and tools. The cooperative system perspective highlights the interconnection between systems, people and procedures. To start from such perspective and to enhance the safety and resilience of today´s ship bridges, the project established a baseline and captured current design methodologies in the beginning. Thus, the project team defined safety relevant scenarios, including routine, hazardous and emergency ones, on which the study, design, development and evaluation can be based. The selection, definition and description of safety relevant scenarios covered routine, hazardous and emergency situations from a human factors perspective. Furthermore, the project baseline and evaluation parameters were defined as a starting point to measure the improvements in terms of safety and resilience. Significant results were formal UML models of these scenarios that act as part of the requirements for adaptive bridge systems, e.g. new bridge tools and displays.

To conceptualise seafaring from a cooperative system perspective, safety relevant scenarios need to be modelled as situations triggered by events with different human and machine agents. The consortium defines scenarios as being non-trivial sequences of events and tasks carried out by multiple human *and* machine agents involving the ship bridge. In all cases, there is some element of safety management, largely human-centred activities, which the scenario seeks to address. In the first cycle of the project, the contributory factors to shipping incidents and accidents as well as different operating modes of the bridge were considered. In the second cycle, we focused on scenarios that were extended by using new tools developed in CASCADe.

The consortium also collected criteria that scenarios should fulfil to drive developments in CASCADe and to enable ship bridge design from a cooperative system perspective.

In essence, scenarios must be:

- Model friendly: capable of being modelled by existing formalisms
- Improvable: there must be room for optimisation
- Sufficiently detailed: especially with regard to cognitive activity
- Multi-agent: i.e. involve cooperation at a level greater than one person working alone on a single activity
- Suitable for experimentation
- Repeatable
- Implementable in ship bridge simulators
- Support examination of in/dependent variables on simulators
- Of interest to partners: reflecting the industrial aims and research interests

Furthermore, the known limitations of bridge usage from a human factors perspective and the known limitations of ship bridges (physical) were defined to set the project´s baseline in the first cycle. Regarding the technical system to be considered, the Integrated Navigation Systems (INS) Performance Standard in combination with the INS Test Standard (IEC61924-2 Ed.1) gives the framework in which CASCADe is developed. Regarding the human factors perspective, we identified more conventional and common concepts pertaining to maritime team behaviour as potential baselines for the project. These are:

- Levels and types of communication
- Issues related to decision-making and
- Attitudes towards risk-taking

Throughout the project these concepts were refined and CASCADe focussed on the following parameters:

- Communication
    - dialog/request (human-human, human-machine)
    - information demand
    - information supply
- Situation awareness
    - perception (observations from e.g. displays)
- Task completion
    - set of tasks executed vs. set of tasks not executed
    - deviations from required normative tasks

- Physical effort
    - walk
    - turn body
    - turn head (eye)

It is our belief in CASCADe that better design solutions will reduce the physical effort; improve situation awareness due to less cognitive effort, reduce the need and amount of communication and improve the completion of the tasks.

From eleven identified major accident types involving the bridge, ranging from bridge control system failure to fire with data from the UK's Marine Accident Investigation Board, the French Marine Accident Investigation Office, Transportation Safety Board of Canada and marinecasualty.com, the consortium selected a (1) COLLISION, (2) GROUNDING and (3) FULL PASSAGE scenario in the first cycle. The full passage scenario allows studying normative behaviour and task execution on the bridge.

In the second cycle of the project, the scenarios were extended based on the three new console designs, which were produced in the first cycle of CASCADe and presented as wooden mock-ups. Central to each design was a new "Shared Display", based on the Perspective Editor developed in CASCADe. The Perspective Editor allows users to customise the information that is shown on the Shared Display. Each of the three console designs was used to act out a scenario in which a master and a pilot use the Shared Display to plan a vessel's passage out of Kiel harbour. These included three use cases for the Shared Display, namely a (1) MASTER-PILOT EXCHANGE, (2) WATCH HANDOVER and (3) EMERGENCY HANDOVER scenario.

Before the selected scenarios were described in UML models, they were thoroughly analysed in passage plans, broken down into activities of the crew, and the detailed bridge settings were studied. The models highlight agents, tasks, resources, and the sequential interactions between them. Importantly, they also denote the broad classes of activity that the bridge may be in. We refer to these as situations. At the level of the whole passage they might include route preparation, leaving port, collect pilot, deposit pilot, plain sailing, manoeuvre, approach port, berthing etc. One example of an UML model is shown in the figure below (Figure 2). CASCADe relied on a technique that segments the scenarios into disjoint sub-steps for further analysis of agents, tasks, resources and communication.

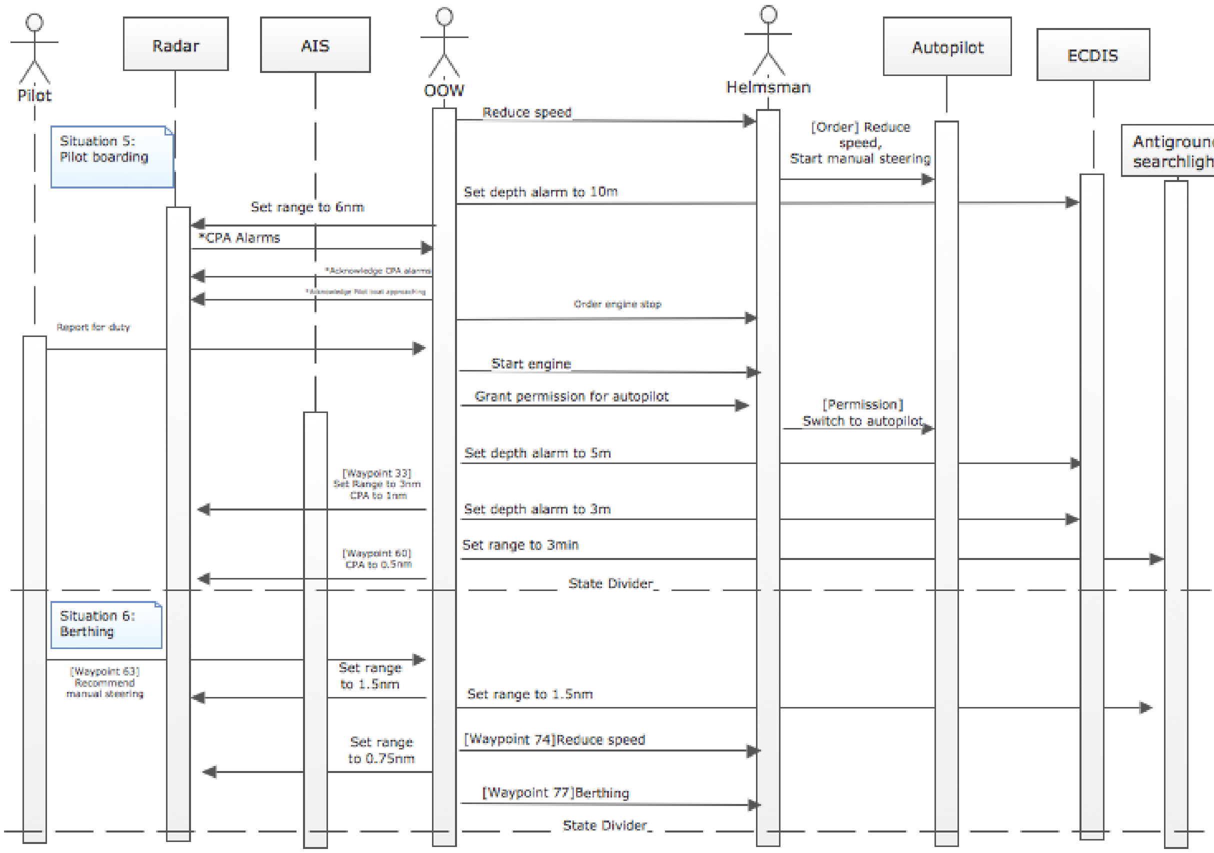


Figure 2: Example of an UML model showing the "port approach situation" of the full passage scenario

Methodology for bridge study and design

An important activity was establishing a link between generic scenarios to the new human-centred methodology and the study and design of ship bridges. The bridge procedures of the scenarios were analysed with the tools and techniques developed in the model-based methodology, including both Virtual and Physical Simulation Platform. The techniques and tools of the methodology allow modelling, simulation and analysis of the functional and actual design level. In the end, the Virtual and Physical Simulation Platform enable to improve the current design methodology for ship bridges in terms of the human element.

The capture of current design methodologies involved an in-depth study and investigation of the scope and the steps of the design processes. As a result a generic design process model was extrapolated and needs for methodological improvements from a human factors perspective were elaborated. These included:

- 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 Human-Machine-Interaction (HMI) design process which will enable us to quickly adapt to user's needs or new situational requirements (leads to an editor for flexible HMI perspectives)
- 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

For each design phase further methodological improvements were defined. Furthermore, generic methodological improvements were defined that are summarised in the following:

- Taking the bridge and the wheelhouse as whole units: they should be the object of design, not an equipment (e.g. ECDIS, Radar, conning display) seen in isolation
- Modelling activities should be extended beyond system modelling and encompass the whole bridge and/or wheelhouse, seen as (inherently cooperative) human-machine system: executable models, i.e. models of the bridge and/or wheelhouse 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: communication, situation awareness, cooperation between the crew/pilot, and within the systems
- 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
- Provide and rely on dynamic modelling of the bridge or the wheelhouse, as a (cooperative) human-machine system: 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: equipment should be tested and evaluated into the whole bridge or wheelhouse context

Besides the methodological improvements, the modelling, simulation and analysis tools for the Virtual Simulation Platform were provided. The Virtual Simulation Platform is a virtual and functionally equivalent replica of the Physical Simulation Platform, purely based on computational models. The VSP integrates models of human agents and of machine agents exchanging information in a collaborative manner via interfaces based on the High Level Architecture Standard to perform closed-loop simulations under various conditions (Figure 3). The platform has been used to investigate the distributed situation awareness of seafarers. The architecture 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 via interfaces.

Besides models of human and machine agents for modelling the behaviour of all seafarers and the behaviour of the bridge workstations involved within selected scenarios, the VSP integrates a set of Vehicle Simulators that provide the physics and behaviour of the crews' and potential surrounding ships, and an Environment Simulator that provides a (graphical) simulation of the environment and scenarios e.g. navigational features based on Electronic Navigational Charts (ENC) data.

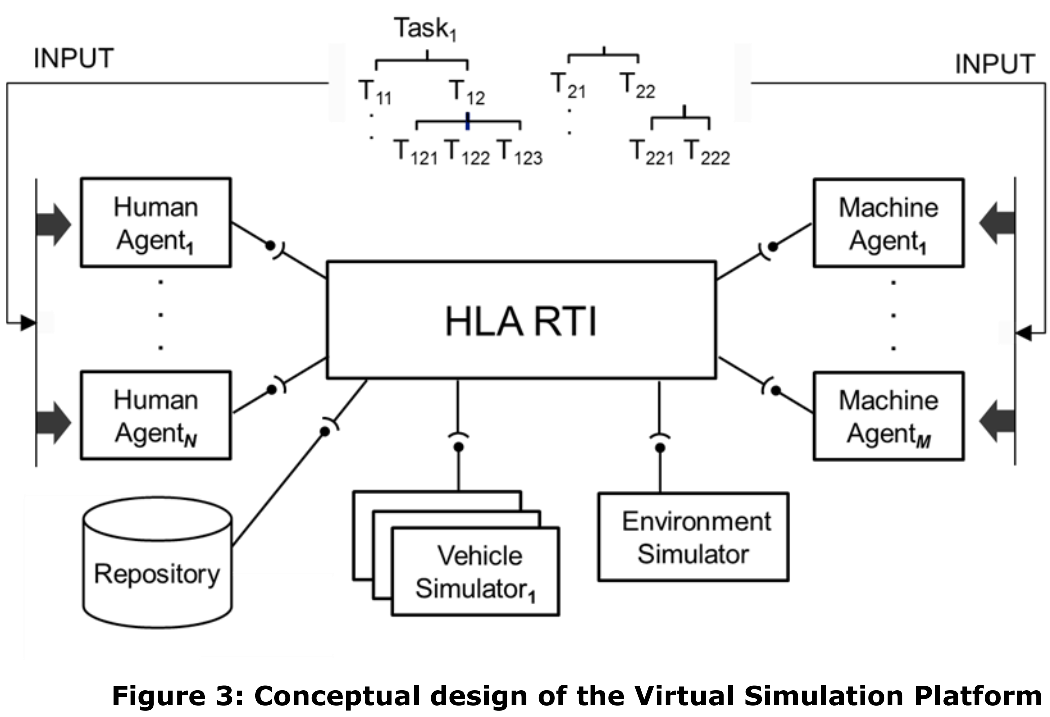


Figure 3: Conceptual design of the Virtual Simulation Platform

The Virtual Simulation Platform allows evaluating bridge designs at early design stages, when design changes are still feasible and affordable and in many more scenarios than the Physical Simulation Platform, because it is easier to perform model-based simulations, once the models are available, compared to real seafarers participating in simulator experiments. The VSP is used to evaluate and compare different functional and actual ship bridge design solutions with regard to their ability to provide all necessary information to seafarers and support the seafarers to maintain task-specific "optimal" Situation Awareness (SA, c.f. Endsley 1995 & Salmon et al. 2000). This allows us to 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 an on-going task? Due to the massive amount of low-level intra- and inter-variability of behaviours of seafarers, the VSP is 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. Instead 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.

On CASCADe's VSP we generally separate the actual from the functional level bridge analysis. On the functional level a mathematically formal analysis is performed to analyse e.g. the amount of successful information exchanges, missing information and the effort for information access. In CASCADe, we see the overall ship bridge as well as its agents as information processors. During execution of tasks, information is used, e.g. to take decisions, and also given to other agents, e.g. as commands. The atomic entity of information is called an information element. Therefore it is necessary to model information flow including the information elements, which are exchanged between the agents, both machine and human. The functional level modelling combines three different models dealing with the work procedures (cooperative process models), the (new) ship bridge design/layout (bridge model) and the information model which includes positioning of information elements in the space of the bridge as well as information supply or information demand.

The actual level considers the cognitive aspects of human behaviour by Cognitive Seafarer Models (CSMs) and the DSA-Monitor (Distributed Situation Awareness) for analysis. The actual (level) behaviour of a seafarer is modelled as seafarer´s tasks and executed by the cognitive architecture CASCaS (Cognitive Architecture for Safety Critical Task Simulation). Perception- and motor-components can be used to make decisions and produce actions by Cognitive Seafarer Models. The DSA-Monitor is a software tool that can be used for the analysis of distributed situation awareness constructed during a simulation run of the Virtual Simulation Platform. Within the scope of CASCADe this tool facilitates a human-centred approach to ship bridge design by supporting analysis of agent awareness and interaction at early development stages. The DSA-Monitor provides methods to analyse the simulation runs of the VSP with key performance indicators.

The two platforms, Virtual and Physical Simulation Platform, are used to investigate the information flow in the cooperative system and the distributed situation awareness of seafarers. On the PSP this is tested during a subset of situations in experiments with human subjects. During experiments seafarers and pilots were asked for their preferences using new adaptive/adaptable tools and functionalities of the project, bridge design options and monitor placement or types of information shown in different bridge modes. The experiments performed on the Physical Simulation Platform were based on analytical questions that were of interest for both, the Virtual and the Physical Demonstrator development, of the Adaptive Bridge System. We derived hypotheses concerning how the bridge, as a cooperative system, processes information for setting up the scenarios at the Virtual Simulation Platform.

Based on focus groups, simulator experiments and questionnaires, two versions of the Physical Simulation Platform were developed over the project duration to decide which layout is the most appropriate for the further development of the bridge - and its instantiation into a final CASCADe ABS prototype.

The development of the Physical Simulation Platform prototype comprises:

- the CASCADe physical console mock up

including new features and displays:

- Shared display with Perspective Editor (adaptable console application)
- Portable Pilot Unit (adaptive & adaptable pilot application)
- Adjustable height and modularity of the mock up

Study and design of Adaptive Bridge System

It is the aim of CASCADe to study and design a new Adaptive Bridge System that automatically or manually adapts the content, presentation and distribution of information to current situations, roles or preferences of persons to foster the safety and resilience of the bridge. Functional design requirements as well as new design ideas for the bridge on the actual level were developed for the scenario situations in CASCADe. We devote a lot of effort and attention also to the functional level, through its characterization and its dynamic simulation on the VSP. Behind the physical bridge, there is a hidden reality of the bridge at the functional level, seen as an information processing system, and this is what CASCADe wants to capture and then improve in design.

For each scenario situation we studied the bridge's functions and tasks, how interaction between the bridge and its environment is achieved, which human and machine agents are involved, and what are their roles, functions, tasks and procedures, and finally how is information circulated between them? The dimensions included in the functional level study of the bridge are:

a. Global tasks: tasks the bridge as a whole has to achieve (e.g. navigate according to passage plan, assess collision alert)

b. Human agents (e.g. human operators/crew members): their roles, tasks and task allocation, resources and resource consumption

c. Machine agents (e.g. autopilot, radar): with functions, tasks and task allocation, resources and resource consumption

d. Interactions and communication: including internal and external (e.g. human-human interactions, human-machine interactions, external communication)

The results of the functional analysis were modelled and a series of requirements for improving the bridge at the functional level were derived. The requirements aim at improving how the bridge behaves from a functional point of view and in particular in terms of its ability to work as a coherent system of human and machine agents acting in a cooperative way to achieve the overall tasks (global tasks) assigned to the bridge as a whole. By satisfying the functional requirements, it aims at having the bridge functioning as a better, improved information processing system.

Functional requirements were "translated" into a series of potential functional improvements. These focussed on the bridge as a whole cooperative system, adaptiveness, information distribution and situation awareness. As a last step, we defined general potential functional improvements (GPFIs) at a higher level, including for example:

GPFI 1: Better support to the preparation of navigation phases

GPFI 2: Better support to the execution of navigation phases

GPFI 3: Increase support to time-varying situation awareness on the bridge

GPFI 4: Improve distribution of situation awareness on the bridge

GPFI 5: Improve initial acquisition of situation awareness when situations change or are handed over

GPFI 6: Better support to conflict detection

GPFI 7: Better support to conflict resolution on the bridge, seen as a cooperative process

The general requirements and potential improvements from the functional level were the main input for performing actual level bridge study and design. The approach on the actual level produced new design ideas of bridges on the actual level and the final CASCADe design. Different phases were needed to find the final actual design of the console. It was then implemented and tested on the final demonstrator.

The bridge at the actual level should be seen as an instantiation - a physical instantiation - of the functional structures and processes described in the functional bridge study. Actual level bridge study pays attention to the bridge from an actual point of view, i.e. in terms of what the bridge physically is. Whereas in functional analysis the view on the bridge is rather abstract and interested in the global functions or tasks assigned to the bridge, to its human and machine agents, their roles, functions, tasks and workflows.

Regulations and recommendations from IMO and DNV-GL concerning the following dimensions on the actual were analysed: bridge layout and console, user interfaces and software applications, lighting, acoustics, HVAC (Heating, Ventilation and Air Conditioning) and finishings. Based on this analysis, the lessons learned and the results of CASCADe´s first cycle, we derived a series of actual bridge requirements that drive the final design of new bridge system. The requirements touched the design of tools to better support information and cooperation on the bridge such as Master-Pilot-interactions, to better distribute situation awareness or to provide adaptability and physical reconfiguration capabilities. We went through various design phases and Figure 4 represents the main output of the first project cycle 1 regarding console design, a conceptual solution that was developed into an actual solution in cycle 2.

Figure 4: CASCADe´s conceptual console after cycle 1

To further specify the design ideas, we addressed the topic of users' postures when using the console. Three postures were analysed: seated, seated high, standing up. 3D models of a virtual manikin (percentile 50, European populations) postured in front of the main console parts, i.e. displays & working surface have been used to determine optimal values for the height of the working surface, height of the top of the displays, and heights for the two seated postures. Figure 5 below illustrates part of this analysis. It shows the distance to the closest visible point on the horizontal plane (~wheelhouse floor). It was decided to further design the console for the "seated high" and "standing up" postures.

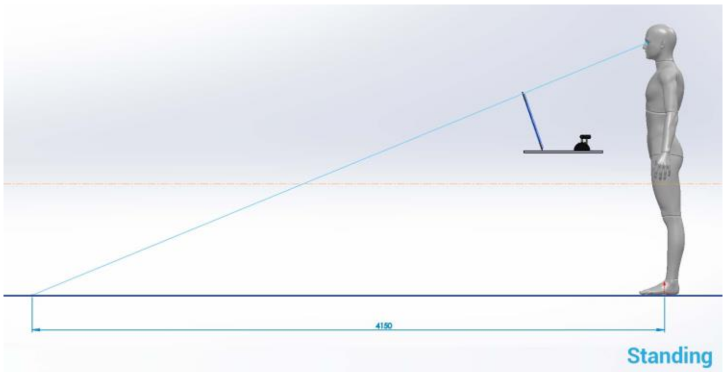


Figure 5: Standing up posture analysis

Further analyses were conducted to determine the best orientation and position for the Shared Display. The Shared Display is a large touch display that is placed in the middle section of the console, between the users on both sides of the console. This is a consequence of the evaluations in cycle 1 (Figure 4). Given the Shared Display is a touch display, it needs to be easily accessible to the users on both sides: each touch zone must be easily reachable. Accessibility was studied with the virtual 3D manikin (percentile 50, European populations) through four different reach zones and three options for the orientation and position of the shared display. The corresponding reachability zones for the sitting high postures are shown in Figure 6. The analysis for different postures led to the conclusion that the landscape "bottom" position and orientation was the best one.

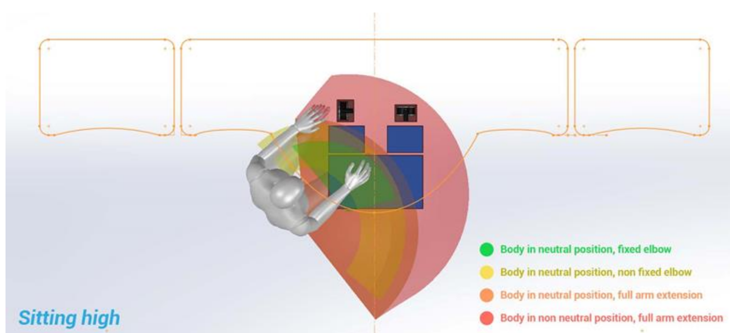


Figure 6: Landscape “bottom” position and orientation for shared display

The elaborated improved console designs, based on the visibility and reachability analyses, followed a collection of accurate information on the final list of equipment. Together with the equipment dimensions, modelled in 2D and mapped on a 2D model of the console, the 3D model for the CASCADe console was elaborated with a few iterations (Figure 7).

Figure 7: Final CASCADe console design

The final CASCADe console design satisfies the functional and actual requirements of the project, by:

- large traditional displays (32") that facilitate information taking, including from a distance, to contribute to better situation awareness;
- a detailed anthropometric analysis conducted (3D models and virtual manikin) ensuring that the displays do not prevent vision ahead of the console and therefore gaining situation awareness through the front windows;
- a new kind of Shared Display, which can be used by users on both sides of the console to share *and* distribute situation awareness, work cooperatively on specific issues (e.g. voyage preparation, problem solving like in collision avoidance or shallow water), making digital annotations on some of the contents (e.g. navigation charts) by both users for better cooperation;
- the Perspective Editor sport on the Shared Display provides adaptation to the bridge, that can also be assigned to any of the other more traditional displays (i.e. "non shared") on the console;
- the adjustable height of the console that is adjustable separately for the three parts of the console, i.e. left, middle and right to contribute to the adaptability of the bridge;
- the Portable Pilot Unit (PPU) that can be coupled with the console, through the PPU mirroring facilities (i.e. the content of the PPU can be sent the console

displays) and its SafePilot software that provides both adaptability and adaptiveness;

- two small 12" multi-function touch displays incorporated to be used for multiple usages (e.g. presenting alarms, checklists or for commanding specific ship equipment);
- additional secondary equipment, beside the displays and their operating devices (keyboards, trackballs,...), such as the VHF stations and handsets or the AIS device;
- spare space for e.g. a logbook or storage spaces for small equipment such as binoculars;
- a foot rest on both sides of the console, this to increase the users' comfort when working in the seated (high) posture;
- a cap placed on the console front on top of the displays to prevent visual reflexions that may be induced by the wheelhouse lighting system and
- by two hand rails, one attached to the cap (on top of the displays) and the other one on the console back edge, just in front of the seafarers to be grasped in case of rough sea conditions.

Bridge experiments and analysis

In the beginning of the project, the purpose of bridge experiments was to produce hypotheses on how the bridge, as a cooperative system, processes information. By conducting surveys, focus groups and simulator observations of seafarers, we built up a conceptualisation of the bridge from the end-users perspective, with a particular focus on identifying those areas where there are currently problems and therefore there is scope for improvement.

The theoretical framework for bridge experiments is the 'Combined Effects approach', as used in the Cardiff Seafarers' Fatigue study (Smith, Allen and Wadsworth 2006). This approach posits that dangerous situations are built up from multiple factors. Whilst the addition of one or more dangerous factors (e.g. fatigue, bad weather) can have an enormous impact on the likelihood of a serious outcome (e.g. collision or grounding), the reverse of this equation is that by addressing one or two problems, significant benefits can be felt. The bridge experiments helped identifying areas where such improvements might be focused.

An early survey in the project with mostly 'open' questions as a means of gathering some initial impressions concerning the areas that are of most concern to seafarers included the following key issues:

- Many seafarers are concerned about the over-reliance on technology by new seafarers. Respondents frequently mentioned the problem of new seafarers looking at displays rather than out of the window.
- Poor communication is a common theme. In addition to problems of basic communication skills, cultural and language problems were often highlighted.
- When under pilotage, many respondents identify the danger of crew members becoming complacent and becoming over-reliant on the pilot. The seafarers name also other situations where a pilot only communicates with the captain, with information not shared amongst the rest of the bridge team.
- Course trainers also highlight that general training in communication and leadership is currently lacking, with an almost exclusive focus on technical rather than 'soft skills' on simulator based courses.

Picture 1: CASCADe team onboard visit

Technological solutions that would be of practical help in the real work environment were also suggested in parallel to the modelling work in the project. Early design ideas helped to stimulate discussion with end users. Four broad design ideas were therefore developed as a starting point from which a drawing tool was the most positively received by the respondents, i.e. a tool that allows seafarers to annotate over the top of key pieces of equipment e.g. ECDIS. Seafarers liked the idea of adding extra notes and annotations, but only if these could easily be removed, or were only shown an auxiliary rather than primary display. As an example, adding notes and annotations during a watch were named that could then be used as a means of conveying key information at hand-over.

A picture emerged concerning where it might be most beneficial for CASCADe to focus. This can be seen as a 'seafarers-eye-view' of the bridge; an identification of areas for improvement based on the direct experience of seafarers. In a broad sense, the most promising area for potential innovation appeared to be around communication. The idea of some form of communication tool for the bridge emerged, one which could be used to both log information, aid in hand-over, and aid in sharing information and situational awareness around the bridge team. This tool could also aid in bringing a pilot 'into the loop', as he/she could use the tool as a means of communicating intentions amongst the bridge team. The seafarers approached were receptive to the idea of using touch as the means of interaction, and having space to both annotate over bridge screens (such as ECDIS) and write down notes and messages on some form of 'scribble pad'.

To collect early feedback on further design ideas being developed in the project we trialled these in experiments in a rudimentary form. Keeping this direct connection with seafarer experience is essential in terms of ensuring the end product(s) of the project are of real value to seafarers. Engaging with seafarers was meant to learn from their experience and to collect information on seafarers' experiences with our experimental scenarios. The Physical Simulation Platform, a ship simulator with five multi-purpose console screens was prepared for CASCADe´s experiments. Two previously defined scenarios were performed by seafarers and pilots during the experiments, a Master-Pilot exchange and a collision avoidance scenario while taking the vessel out of the harbour. Simulator data and traces were recorded and the participants' behaviour was observed to provide data for modelling of seafarers' actions and (baseline) behaviour for the Virtual Simulation Platform as well as to judge the possible impact of new design concepts developed in the project. The focus of the experiments was on depth, looking in detail at the reasoning behind decisions, and how the participants related these decisions to real life.

In terms of the new design ideas presented, the participants were all generally very receptive. All seafarers gave the new concepts consistent strong ratings for Safety, Efficiency, Communication and Exchange speed. Matching up the challenges described by the participants with the new designs presented, it appears that the CASCADe concepts are focused on areas of key concern of seafarers. Specifically, where communication is frequently identified as one of the biggest dangers on the bridge, aids such as the annotation tool, introduced to help avoid misunderstandings, were extremely well received by the participants. The concept of the ship's ECDIS to have waypoints that could be moved simply by touching and dragging them on screen was the best received of the design ideas presented. Participants were encouraged to write on transparent overlays on the screens to help with communication, a new design idea that was very well received, tested in a basic form.

Procedures interviews gave us answers to the analytical questions and thus knowledge on the actual execution of seafarers' work. The generated procedures models are used on the Virtual Simulation Platform (VSP) together with the logged simulator data for other vessels, environmental conditions, machine data and display configuration. The experimental set-up of the experiments were re-build in the Virtual Simulation Platform. Based on procedures interviews and logged simulator data, further process models on the functional level and cognitive seafarer models on the actual level were created.

In CASCADe the seafarers' tasks are used to analyse and assess the human-machine interaction on the socio-technical ship bridge system. Furthermore, new adaptive designs will have influences on the procedures that can be studied by models in very early development stages. For the assessment a challenge is to create comparability between different orchestrations of human, machine and their work organization. Therefore we identify abstract procedures and compare different concrete instances of them.

During the cycles of experiments and evaluations, we determined the best position for the newly developed Shared Display on the ship bridge. With the function and position of the Shared Display established, we examined the content that might be shown on the Shared Display in different modes of operation. Two focus groups of experienced navigating officers thus designed screens that would be most useful during ten key modes of operation/scenarios. In brief, we achieved the following results and further conclusions as follows:

- Customized/adaptable versions of the shared display for 10 different modes of operations/scenarios designed by two focus groups
- The ability to annotate electronic charts was seen as the most valuable element of the Shared Display
- The notepad feature was also regarded as extremely valuable, giving crew members the ability to record and share information
- Unforeseen to the research team in advance, the value of incorporating checklists in the Shared Display was highlighted as extremely valuable
- Participants highlighted the potential value of keeping information shared between multiple screens in the same location on the Shared Display to help with visual search
- Duplication of existing bridge screens on the Shared Display was seen as of little or no value, unless additional features could be added e.g. annotation
- The Shared Display was seen as valuable in terms of planning and discussion, but of considerably less value in terms of navigation where standard bridge displays will always be used

Demonstrator development and evaluation

The development of a new Physical Demonstrator for an Adaptive Bridge System involved the implementation of a new bridge console system with adaptive/adaptable design features in different physical layouts, a new console application as well as a new pilot application with adaptation/adaptability concepts for information content, distribution and presentation. From the various bridge layouts developed over the project duration, one best evaluated layout has been elaborated into a real bridge to produce a fully integrated, realistic and functioning bridge prototype. The central console design of the final CASCADe bridge is shown in Picture 2.

In cycle 1 of the project, a simple version of the physical bridge has been produced, to demonstrate and evaluate the basic ideas behind the design choices. In cycle 2, these design choices were further evolved and a new, more realistic version of the demonstrator has been produced. The features selected for investigation on the physical bridge demonstrator are:

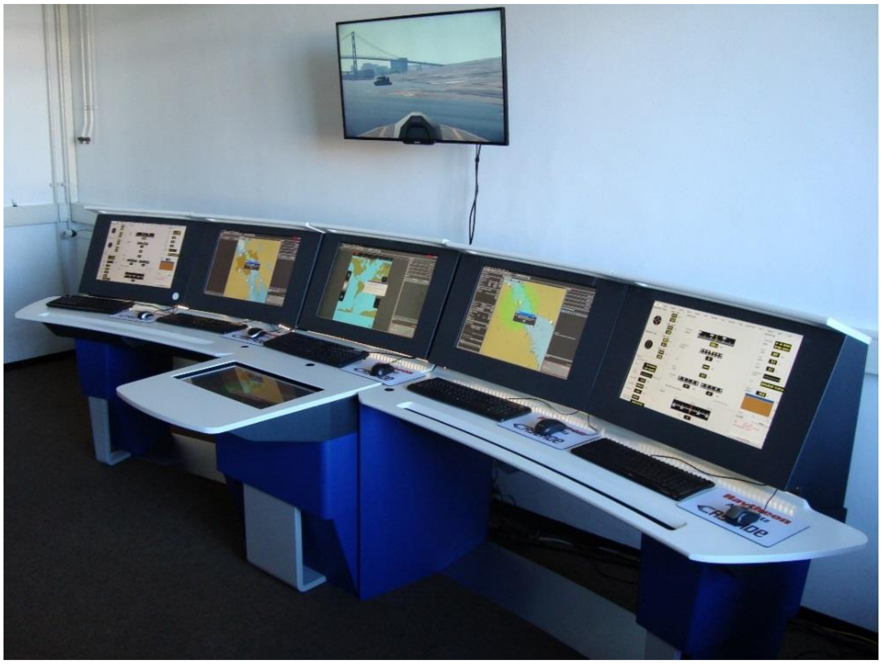
- light structure, with most computer equipment off the bridge console;
- displays on the console;
- Shared Display in central position, i.e. middle section of the console;
- Shared Display with landscape orientation - most appropriate to work with the Perspective Editor;
- height adjustment capabilities, separately for all three bridge sections (left, middle, right);
- cap/visor above the displays to allow controlling light reflexions on the displays, especially from the ceiling;
- vertically tiltable display to improve control of angle of vision and of light reflexions, coming from wheelhouse lighting or sources external to the wheelhouse;
- handrails to allow the bridge users to grab the handrails and ensure stability, especially in rough seas and
- storage space for secondary operational material, such as binoculars.

The demonstrator sports some of the features we believe are innovative and meet the requirements for ship bridges that were collected in study and design phases.

Console Application

The Perspective Editor is a highly flexible and reconfigurable console application tool. The Perspective Editor is intended as the touch display to be used on the Shared Display on the CASCADe console, though it can be used on any other console displays. The Perspective Editor allows designing perspectives, which are a special arrangement of windows, with specific content and functionalities. The perspectives can then be displayed on the console, and it is possible to swap between perspectives on a given display.

The application enables the manual configuration of the actual perspective with regard to the occurring situation, i.e. it supports adaptability and additional customizable features in the Perspective Editor (radar overlay, checklist, and notepad).



Picture 2: CASCADe´s final Physical Demonstrator

Pilot Application

The Pilot application is called SafePilot and is designed for iPad (iOS). The task was to design a tool to better support Master-Pilot-interactions in CASCADe. The portable tablet with SafePilot software is used by the Pilot and brought on board to support presentation and further discussion with the Captain. The software supports intelligent chart handling allowing multiple layers, providing all relevant navigational data in proper resolution, previously piloted vessels and day/night screens, a navigation and a planning mode. To facilitate Master-Pilot-cooperation, the tablet´s information can be integrated into the ship bridge system. The Pilot unit can be mirrored on the ship bridge displays and the routes can be shared between PPU and the ships ECDIS. The SafePilot PPU software is both adaptable and adaptive.

Virtual Demonstrator

The Virtual Demonstrator is a replicate of the Physical Demonstrator and combines models of bridge systems, user interfaces, vessels, environment and all human and non-human agents. All components of the Physical Demonstrator are represented in the Virtual Demonstrator by computational models. The Virtual Demonstrator allows to evaluate bridge designs at early development stages by using computational models of these components. For example, virtual seafarers mimic task execution, situational awareness, human-human as well as human-machine cooperation of real seafarers. Besides the simulation of new bridge design ideas for evaluation, the Virtual Demonstrator enables to show new design ideas corresponding to the console application and pilot application. Usage of new applications can be modelled using Virtual User Interfaces (VUI) and Cognitive Seafarer Models.

The Virtual Demonstrator thus aims to simulate a ship bridge as a cooperative system purely based on computational models. The Virtual Demonstrator facilitates the VSP's 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 Virtual Demonstrator provides a modelling tool suite to assess the new bridge design on the functional level, i.e. a mathematically formal analysis in the time-space continuum. On the functional level, we link multiple cooperative process models of the selected bridge scenarios with one global information model of the bridge and different design variants of bridge models. The information model contains all information elements which are supplied by the monitors, displays, or equipment parts used on the spatial bridge model. The cooperative process models provide the work procedures of the crew members. Analysis on the functional level allows to trace how information circulates from different sources of the specific bridge design, is exchanged between agents and used by them, for which goals and work procedures.

On the functional level, the analysis is executed with the Distributed Situation Awareness Tool Suite ShiATSu. ShiATSu couples the bridge model and the cooperative process models and thus creates the bridge resource management that allows an analysis of the following metrics regarding the selected scenarios and bridge designs:

- Information exchange between agents
- Influence of missing information for the system´s Distributed Situation Awareness (DSA)
- Conflicts in execution
- Emergence of additional communication
- Effort for information accesses

- Information fitness

Furthermore, the output of the simulation runs of the Virtual Demonstrator can be analysed on the actual level (Figure 8). This allows a more detailed analysis, in addition to the functional level, by including cognitive aspects through Cognitive Seafarer Models, Virtual User Interfaces and time of completion.

The Distributed Situation Awareness Monitor (DSA-Monitor) is a software tool that can be used for the analysis of the distributed situation awareness of CSMs constructed during a simulation run. The models from the modelling tools suite are used on the actual level together with the logged simulator data for other vessels, environmental conditions, machine data and display configuration (Figure 3). The CSMs are able to interact with Virtual User Interfaces due to the cognitive architecture CASCaS that allows visual perception, sensor-motor behaviour, task execution or communication of human agents. VUIs are used in the Virtual Demonstrator to model new console application design ideas. VUI are capable of presenting information of nautical equipment to cognitive seafarers in the VSP's virtual space.

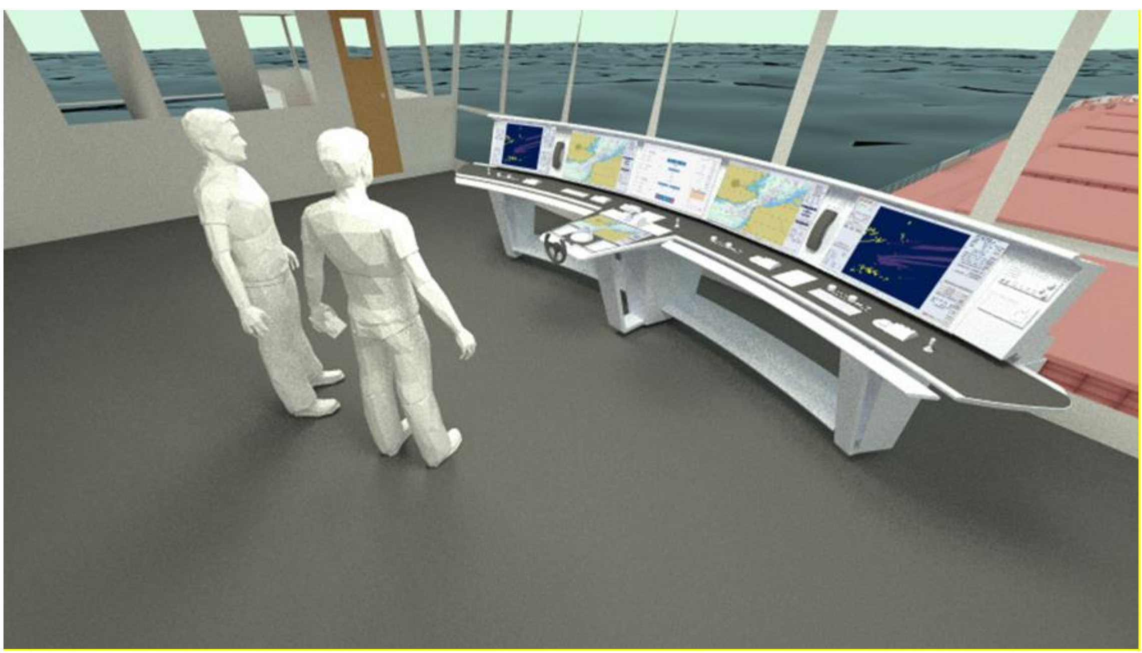


Figure 8: 3D view of a scenario on the Virtual Demonstrator

They provide a visualisation of information and information change during a simulation run to the ship bridge engineer/designer and allow careful evaluation of information flow and usage during the executed simulation. To use a VUI, the CSM reads certain displays that are interconnected via the simulation platform architecture.

On the actual level, the following key performance indicators (KPI) were identified. The DSA-Monitor constructs these KPI's values out of the simulation runs.

- Physical effort of the seafarers
    - Head rotation angle (looking from one screen/waypoint to other)
    - Head rotation count
- Communication count of each of the seafarers
- Task/goal completion
    - time of completion

Based on the final Physical Demonstrator experimental evaluations by walk through were performed with seafarers and pilots. The Physical Demonstrator is a fully realistic and functioning bridge prototype that integrates the Perspective Editor on the Shared Display and the PPU. The results analysis revealed that participants saw positive impacts of all CASCADe tools when taken on a walk-through scenario demonstrating how they would be used. When rated on a scale, the highest rated tools were the tiltable display, height adjustment, PPU mirroring and chart annotation. The PPU tools demonstrated were also very well received, with pilots indicating that the PPU design was an overall improvement over PPU designs commonly available now.

With regard to adaptiveness and adaptation, earlier evaluations showed that often seafarers discarded the notion of adaptiveness, preferring to be in total control of display adaptations, and therefore only favouring adaptability and additional customizable features. Investigations by the project partners of how adaptation should be implemented led to the following:

- Switching between modes of operation should be under full control of the user: it should never be automatic, i.e. for mode adaptation, the users want adaptability, but not adaptiveness
- Within a mode, adaptation of the view can be automatic: users appreciate both adaptability and adaptiveness

Evaluation of the Virtual Demonstrator is based on the selected scenarios, key performance indicators, design and display configurations. All components of the Physical Demonstrator are modelled as computational models to simulate a ship bridge as a cooperative system. By means of the Virtual Demonstrator we tested the assessment of different bridge layouts and displays and compared the results to the evaluation results on the Physical Demonstrator. The analysis revealed that the Virtual Demonstrator is capable of generating useful simulation data while being functionally equivalent to the Physical Demonstrator. The generation of the performance metrics showed that the scenario results are significant to get further insight into the individual bridge work procedures (by different agents) and the performance of the cooperative system as a whole, by e.g. following the overall time for task completion. By measuring specific key performance indicators, the demonstrator provides predictive capability in very early design phases. Requirements for improvements were derived to feed back into the methodology and the bridge development.

Potential impact, main dissemination activities and exploitation of results

CASCADe's final results are twofold: we develop, demonstrate and evaluate

(1) a new methodology enabling the design of and

(2) an Adaptive Bridge System (ABS) from a cooperative system perspective.

The methodology integrates techniques and tools for harmonization of system development, procedure development and human factors regarding today´s ship bridges. By our study and design approach, we gain a deep understanding of bridges in functional terms to then produce ideas that could help improving how bridges behave, in safer and more efficient ways. Safety relevant scenarios are analysed with regard to the bridge´s functions, components, operators and tasks at the functional level. We obtain functional design requirements for the bridge by studying the bridge's functions and tasks, how interaction between the bridge and its environment is achieved, which human and machine agents are involved, what are their roles, functions, tasks and procedures, and finally how information is circulated between them. Improving situation awareness on the bridge, be it individual or distributed, is the type of functional improvement by CASCADe.

Fulfilment of the requirements improves how the bridge behaves from a functional point of view and in particular in terms of its ability to work as a coherent system of human and machine agents acting in a cooperative way to achieve the overall tasks (global tasks) assigned to the bridge as a whole. By satisfying the functional requirements, the bridge functions as a better information processing system, i.e. how the agents on the bridge perform the tasks assigned to them, how these agents interact and cooperate on the bridge (internal workflow) and with agents or other vessels (external workflow). Based on the requirements, generic potential improvements are developed to enhance how the bridge works in functional terms. Behind the physical bridge, there is a hidden reality of the bridge at the functional level, seen as an information processing system, and this is what CASCADe captures and then improves in design.

The study and design approach is also conducted on the actual level, producing new design ideas of bridges on the actual level and the final design. Again, the general requirements and potential improvements are necessary to translate these into the actual level bridge study and design. Actual level bridge study pays attention to the bridge from an actual point of view, i.e. in terms of what the bridge physically is. In

CASCADe, the impact is on the following dimensions of actual design: bridge layout and console, user interfaces and software applications, lighting, acoustics, HVAC and finishings.

Instead of designers jumping immediately to the actual level, with insufficient and incomplete consideration of the processes it has to support, CASCADe´s study and design approach can prevent many human errors caused by poor or inappropriate design at the functional level. Due to the innovative methods put in place in CASCADe, notably through the dissociation between functional and actual design, the approach has been further elaborated and tested. The application of the approach in CASCADe, in particular through combining investigations and evaluations on simulators, really helped proving the added value of the approach and confirms the consortium's belief that it has a high commercial value.

The CASCADe methodology determines an adequate “translation” of the functional level in the actual one. When the actual level does not perfectly embody and support the functional level, it is impossible or hard for the cooperative system to work as intended. This of course implies that bridges must be studied and designed at both levels, taking into account how the two of them interact in CASCADe.

The design on functional and actual levels in CASCADe is supported by two simulation platforms: a physical and a virtual one. Together the two platforms allow a very careful investigation and evaluation of an Adaptive Bridge System to research solutions for adaptation which provide benefits, e.g. by increasing situation awareness, that outweigh their costs, e.g. by cognitive disruption. We devote a lot of effort and attention to the functional and actual level, through its characterization and its dynamic simulation on the Virtual Simulation Platform. The VSP integrates models of human agents and of machine agents exchanging information in a collaborative manner via interfaces to perform closed-loop simulations. Under various conditions and scenarios, we can hereby analyse the distributed situation awareness of seafarers and further key performance indicators. The VSP thus allows evaluating bridge designs at early design stages, when design changes are still feasible and affordable. Because it is easier to perform model-based simulations, once the models are available, compared to real seafarers participating in simulator experiments. We can evaluate many more scenarios than in the Physical Simulation Platform.

In our simulations we are able to focus on *what* information a seafarer needs to obtain in order to execute a certain task and *how* this information can be easily obtained. The VSP can be used to evaluate and compare different functional and actual ship bridge design solutions with regard to their ability to provide all necessary information to seafarers and support the seafarers to maintain task-specific “optimal” situation awareness. Hereby, we better map functional and actual ship bridge designs, i.e. by asking whether the actual design meets the functional requirements to fulfil an on-going task? The Virtual Demonstrator thus allows the careful investigation of key performance indicators such as the effort for information access, conflicts in the execution of cooperative work procedures or the influence of missing information for the system´s distributed situation awareness. These and further factors analysed such as the task completion and the time of completion are extremely relevant for the safety on board in terms of bridge management. In CASCADe, we hereby foster a holistic and affordable human-centred approach to ship bridge design improving safety in maritime transport.

CASCADe addresses the issues of efficient communication and a clear and unambiguous display of data through a variety of approaches, procedures and adaptive displays, to reduce human errors on ship bridges. We use the design methodology to develop techniques to permanently or semi-permanently adapt the whole cooperative system to the current situation, relevant procedures or the needs of the individual seafarer. As an example, we adapt information made available on a bridge, in terms of its content, presentation and distribution. Lessons learnt from the evaluations in the project, revealed that often seafarers discarded the notion of adaptiveness, preferring to be in total control of display adaptations, and therefore only favouring adaptability and additional customizable features. Further investigations showed that for mode adaptation, the user wants adaptability, but not adaptiveness. Once within a mode, adaptation of the view can be automatic. This automatic or manual adaptation developed in CASCADe has been tested with seafarers and pilots over the project duration. Also the central console design has been tested and designed according to the results from seafarer opinions and the analysis on the Virtual Demonstrator.

Further impact of CASCADe´s methodology for bridge design is the definition of methodological improvements, in the form of techniques and tools, to the design methodologies currently used by the manufacturers. We proposed a new design process and methodology for integrated bridge systems (IBS) and pilot equipment. Accordingly, we related the methodological improvements proposed by CASCADe to the current generic industrial bridge design process, that we divided into different phases. The techniques and tools proposed and developed in CASCADe can be used to improve that process in terms of human factor issues. Potential impact of the tools and techniques during a very early phase of bridge development can be achieved by e.g. the integrated systems approach that stakeholders need to be made aware of, the collection of requirements at all appropriate levels beyond isolated systems, the usage of models and task analysis and/or the presentation of information according to the situation awareness needs. The nature of activities during the implementation phase of bridge development can also be enhanced by e.g. agile approaches to early integration of functional system components, flexible plug-in based mechanism or tools that allow quickly rearranging HMI plug-ins. The impact of this human-centred approach is that bridges are not just showing sensor-based information but that they are adaptive in terms of providing the most important information, in the most effective way at the most useful time, based on context awareness. Our approach thus can deliberately push the boundaries of what is allowable in current IBS standards.

The results and progression of the project has been disseminated by:

- CASCADe website: http://www.cascadeproject.eu/
- Press releases by different partners and links on other web sites
- Articles in the maritime press
- Peer-reviewed academic papers/book articles
- Several scientific papers to technical/academic conference
- Talks at workshops and conferences
- Videos and the final CASCADe film:
  https://www.youtube.com/watch?v=Y6ZdLz6FLUw

Articles in the maritime press, e.g.

- Beyond ergonomics: technology with a human heart

CASCADe was featured in an article in the February 2014 issue of "IHS Maritime Technology" magazine, entitled "Beyond ergonomics: technology with a human heart", which explores how bridge designs are becoming more human centred so the watchkeepers can make better and safer decisions.

- Bridge Technology leaves seafarers in its wake

CASCADe was mentioned in an article in Marine Engineering & Offshore Technology - Issue 21/ 4 trimester 2013, on how the advent of electronic charts for navigation purposes has brought the issue of human interaction with modern-day technology into focus.

- Keeping ship designers in the loop

The issue September 2014 of the human element bulletin Alert! investigated what makes it easy – or difficult – to operate and manoeuvre ships and encourages designers and operators of vessels to work together.

Peer-reviewed academic papers/book articles

Book article in Human Factors in Transportation: Social and Technological Evolution across Maritime, Road, Rail and Aviation Domains

Title: Assessing the Fitness of Information Supply and Demand during User Interface Design

ISBN 9781498726177

URL: https://www.crcpress.com/Human-Factors-in-Transportation-Social-and-Technological-Evolution-Across/Bucchianico-Vallicelli-Stanton-Landry/9781498726177

Book article in Knowledge Engineering and Knowledge Management

Paper: Assessing the Spatio-Temporal Fitness of Information Supply and Demand on an Adaptive Ship Bridge

URL: http://dx.doi.org/10.1007/978-3-319-17966-7_27

Book chapter in Navigation Accidents and Their Causes

Title: Crew, manning, fatigue

ISBN 9781906915322

URL: http://www.nautinst.org/en/shop/checkout/shop-product-details.cfm/navigation-accidents-and-their-causes

6th International Conference on Applied Human Factors and Ergonomics, Las Vegas, USA, 26-30 July 2015

Paper/Presentation: Model-based Adaptive Bridge Design in the Maritime Domain. The CASCADe Project

URL: Elsevier Science Direct Author Access/AHFE 2015 Proceedings Vol.3: http://www.sciencedirect.com/science/journal/23519789/3

International Conference on Ergonomics & Human Factors 2015, Daventry, Northamptonshire, UK, 13-16 April 2015

Paper/Presentation: Communication on the bridge of a ship

ISBN 9781138028036

URL: https://www.crcpress.com/Contemporary-Ergonomics-and-Human-Factors-2015-Proceedings-of-the-International/Sharples-Shorrock-Waterson/9781138028036

Scientific papers to technical/academic conference, e.g.

- 11th Berliner Werkstatt Mensch-Maschine Systeme, Berlin, Germany, 7-9 October 2015

- International Conference on Human Factors in Ship Design & Operation- London
- Ateliers de la Recherche en Design (ARD) 9 – Liège, Belgium

Talks at workshops and conferences, e.g.

- Evaluation Workshop with Seafarers and Pilots, 30 Sept. 2015, Kiel
- 3rd FAROS workshop 15-16 Sept. 2015, London
- Focus Group Exercises with Seafarers, Warsash Maritime Academy
- 2nd FAROS workshop 30 Sept. 2014, Helsinki

Videos and the final CASCADe film:

The final CASCADe film can be seen at the link below:

https://www.youtube.com/watch?v=Y6ZdLz6FLUw

Project overview:

http://www.youtube.com/watch?v=2SBJ5Vs9SE4

These videos, filmed with actors in front of green-screen consoles, were used to evaluate the cycle 1 mock-up console:

1. Dual sync display: https://www.youtube.com/watch?v=RSAYfL7Swmk
2. Central console: https://www.youtube.com/watch?v=w9Y3U4DdEb4
3. Chart table: https://www.youtube.com/watch?v=CU3alOtkfxQ

Through the work of the CASCADe consortium, the shipping industry will have access to a new control room and console design methodology. It is the consortium's belief that human errors and safety hazards occur in joint cooperative human-machine systems when they have not been first designed at the functional level. It is currently very common in bridge design to immediately "jump" into the actual level (i.e. the physical level of equipment, furniture, room layout etc.) without paying enough attention to how the underlying overall human-machine cooperative system will process information, make decisions and implement them. Through CASCADe, new design methods have been put to the test and improved and this will mean an increased ability to satisfy users' needs, in particular in terms of understanding, modelling and then covering them adequately.

The use of a human-centred approach in conjunction with virtual simulation will provide an advanced tool for functional optimisation of ship bridges at design stage. Through the endorsement of a shipping company, this approach will be tested and used in practice.

The CASCADe work clearly identified the need of an innovative modern communication tool, implemented in the form of a Shared Display. The Shared Display will add great value for navigators. It will allow proper communication between the pilot, master and officer and thus avoid misunderstandings. The Shared Display will help the seafarers to quickly explain to the master the current complexity of the traffic situation in case of an emergency (like an impending collision). The seafarers can on demand retrieve the information they need to perform their duties. During their watch they can record findings like current weather data, sea and tide stage, traffic situations etc. This valuable information is now in an organized way readily available to the incoming officer after the watch handover. The Shared Display incorporates the wheelhouse checklist as well and is expected to become a central part of the navigators' future work place.

The CASCADe consortium believes that shipyards selling vessels with integrated bridge systems will base their future designs on the CASCADe work. Complex vessels, which greatly depend on correct human operation will need in the future navigation bridges where the operation consoles are designed to avoid human mistakes and fatigue. Consortia charged to develop such vessels will appreciate and build upon the CASCADe work. Ship mangers charged with major conversion projects will also benefit from CASCADe´s work, when they have to renew navigation bridges. In addition, equipment manufacturers will benefit the most from CASCADe´s work. They will be able to offer products which are more user-friendly. As such they will be more "liked" and preferred by the persons responsible for the purchases.

The CASCADe work can in the future be further developed into tools which allow the shipping industry to convert human movements, human detection and actions into data. This data would allow to evaluate and eventually to validate more scenarios by simulation, if not even all possible ones. Such CASCADe´s data acquisition tools can also be used for accident investigation team, by just reversing the known events. A much more educated accident investigation would be possible in this way.

2 Use and Dissemination of Foreground

Section A (Public)

LIST OF ALL SCIENTIFIC (PEER REVIEWED) PUBLICATIONS										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[1] (if available)	Is open access[2] provided?
PAPER										
	Assessing the Fitness of Information Supply and Demand during User Interface Design	Denker, C.; Fortmann, F.; Ostendorp, M.C., Hahn A. & A. Lüdtke	Human Factors in Transportation: Social and Technological Evolution across Maritime, Road, Rail and Aviation Domains.	forthcoming: August 30, 2016	CRC Press/Taylor & Francis Group		2016	tbd	ISBN 9781498726177	No

[1] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[2] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

	Assessing the Spatio-Temporal Fitness of Information Supply and Demand on an Adaptive Ship Bridge	Denker, C.	EKAW 2014 Satellite Events: VISUAL, EKM1, and ARCOE-Logic	24.-28.11. 2014	Springer	Berlin, Germany	2015	pp. 185-192	DOI 10.1007/978-3-319-17966-7_27	No
	Model-based Adaptive Bridge Design in the Maritime Domain. The CASCADe Project	Javaux, D.	6th International Conference on Applied Human Factors and Ergonomics	26.-30.07.2015	Elsevier, available via Sciencedirect.com		2015	pp. 4557–4564	http://www.sciencedirect.com/science/article/pii/S2351978915004734	Yes
	Communication on the bridge of a ship	Allen, P. & Smith, A. P.	International Conference on Ergonomics & Human Factors 2015, Daventry, Northamptonshire, UK	13.-16.04.2015	CRC Press		2015	pp.433 – 440	ISBN 9781138028036	No

LIST OF ALL DISSEMINATION ACTIVITIES								
No.	Type of activities[3]	Main leader	Title / Description	Date	Place	Type of audience[4]	Size of audience	Countries addressed**
	Video dissemination	CU	Final CASCADe Film: https://www.youtube.com/watch?v=Y6ZdLz6FLUw	11-2015	-	all	>200	International
	Video dissemination	MAR	Pilot application: http://vimeo.com/safepilot/videos	10-2014	-	Industry	-	International
	Web dissemination	MAR	Pilot application: http://www.marimatech.com/products/piloting	10-2014	-	Industry	-	International
	Video dissemination	CU	Dual sync display: https://www.youtube.com/watch?v=RSAYfL7Swmk Central console: https://www.youtube.com/watch?v=w9Y3U4DdEb4 Chart table: https://www.youtube.com/watch?v=CU3alOtkfxQ	06-2013	-	Public, Industry, Civil Society Medias		International
	Video dissemination	CU	Project overview http://www.youtube.com/watch?v=2SBJ5Vs9SE4	04-2013	-	Public, Industry, Civil Society Medias		International

[3] Dissemination activity are publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.
[4] Type of audience is : Public, Scientific Community (higher education, Research), Industry, Civil Society, Policy makers or Medias ('multiple choices' is possible.

LIST OF ALL DISSEMINATION ACTIVITIES

No.	Type of activities[3]	Main leader	Title / Description	Date	Place	Type of audience[4]	Size of audience	Countries addressed**
	Article in Datawork 61	OFF	Finaler Workshop dreier EU-Forschungsprojekte zu Sicherheit von Seefahrern	12-2015	Oldenburg, Germany	Public, Scientific Community, Industry, Policy makers	>200	National
	3rd FAROS Workshop (together with CASCADe and CyClaDes)	OFF	Human-centred methodology to adaptive ship bridge design / The role of seafarers	15.-16.09.2015	London, UK	Scientific Community, Industry, Policy makers	>150	International
	Evaluation Workshop with Seafarers	CU	Evaluation of the final physical demonstrator of an Adaptive Ship Bridge	30.09.2015	Kiel, Germany	Industry	-	International
	11th Berliner Werkstatt Mensch-Maschine Systeme	OFF	Das CASCADe Projekt: Modellierung und Simulation von kooperativen Prozessen auf Schiffsbrücken	07-09.10.2015	Berlin, Germany	Scientific Community, Industry,	>200	International
	Go-3D Konferenz	OFF	Nutzung der virtuellen Realität zur Erhebung von nautischen Prozessen	03.09.2015	Rostock, Germany	Scientific Community, Industry,	>100	National
	Interdisciplinary Research Center Critical Systems Engineering for Socio-Technical Systems	OFF	Modelling human-machine cooper-ation for human-centred ship bridge design	07.-08.01.2015	Bad Zwischenahn, Germany	Scientific Community, Industry, Policy Makers	>80	International

LIST OF ALL DISSEMINATION ACTIVITIES								
No.	**Type of activities[3]**	**Main leader**	**Title / Description**	**Date**	**Place**	**Type of audience[4]**	**Size of audience**	**Countries addressed****
	Ateliers de la Recherche en Design (ARD) 9	SYM	De la recherche au monde reel	-	Liege, Belgium	Industry	-	National
	19th International Conference on Knowledge Engineering and Knowledge Management (EKAW)	OFF	Assessing the spatio-temporal fitness of information supply and demand on an adaptive ship bridge	24.-28.11.2014	Linköping, Sweden	Scientific Community, Industry	>100	International
	CASCADe Evaluation Survey on Nautilus International & Maritime Cluster Northern Germany Website	CU/OFF	Survey videos for evaluation	10-2014	-	Public, Industry	-	International
	Article in Human Element Bulletin Alert!	BMT	Keeping ship designers in the loop	09-2014	-	Public, Industry	-	International
	2nd FAROS Workshop	OFF	Modelling information flow on ship bridges as cooperative socio-technical systems	30.09.2014	Helsinki, Finland	Scientific Community, Industry	>100	International
	International Conference on Applied Human Factors and Ergonomics	OFF	Assessing the Fitness of Information Supply and Demand during User Interface Design	19.-23.07.2014	Krakow, Poland	Scientific Community, Industry	>500	International

LIST OF ALL DISSEMINATION ACTIVITIES								
No.	**Type of activities[3]**	**Main leader**	**Title / Description**	**Date**	**Place**	**Type of audience[4]**	**Size of audience**	**Countries addressed****
	CASCADe Advisory Board Meeting	OFF	Towards cooperative and adaptive ship bridge design	04.07.2014	Oldenburg, Germany	Scientific Community	-	International
	CyClaDes Talk at OFFIS and interchange	OFF	Creworientiertes Design von Schiffssystemen	03.07.2014	Oldenburg, Germany	Scientific Community, Industry, Policy makers	>150	National
	Transport Research Arena (TRA)	OFF	Outreach Marketplace Poster: Modelling human-machine cooperation for human-centred ship bridge design	14.-17.04.2014	Paris, France	Scientific Community, Industry, Policy makers	>300	International
	Article in Datawork 58	OFF	Sicheres Zusammenspiel auf der Schiffsbrücke	05-2014	Oldenburg, Germany	Public, Scientific Community, Industry, Policy makers	>200	National
	Article in IHS Maritime Technology (Feature: Bridge Systems)	OFF	Beyond ergonomics: technology with a human heart	02-2014	-	Industry, Policy makers	-	INternational
	International Conference on Human Factors in Ship Design & Operation	OFF	Paper/Presentation: Simulation of socio-technical systems for human-centred ship bridge design	26-27.02.2014	London, UK	Scientific Community, Industry, Policy makers	>100	International

LIST OF ALL DISSEMINATION ACTIVITIES

No.	Type of activities[3]	Main leader	Title / Description	Date	Place	Type of audience[4]	Size of audience	Countries addressed**
	Article in Marine Engineering & Offshore Technology (Issue 21)	BMT	Bridge technology leaves seafarers in its wake	4trimester 2013	-	Public, Industry, Policy makers	-	International
	Workshop between UK Hydrographic Office with BMT	BMT	Future commercial amendments to products in light of research results from CASCADe	11-2013	London, UK	-	-	National
	Presentation at FAROS Workshop	BMT/CU	Preliminary studies in situation awareness and adaptive bridge design/CASCADe	17.-18.09.2013	London, UK	Scientific Community, Industry, Policy makers	>80	International
	Article in Fairplay Solutions	BMT	European research to review safety on board vessels	07-2013	-	Industry, Policy makers, Medias	>300	International
	Press release in IMO bulletin	BMT	European research to review safety on board vessels	07-2013	-	Industry, Policy makers, Medias	-	International
	Article in MITE Magazine	BMT	CASCADe sets out to tackle interconnectedness	06/07-2013	-	Industry, Policy makers, Medias	-	International

LIST OF ALL DISSEMINATION ACTIVITIES								
No.	**Type of activities[3]**	**Main leader**	**Title / Description**	**Date**	**Place**	**Type of audience[4]**	**Size of audience**	**Countries addressed****
	Article in World Maritime News	BMT	BMT participates in EU funded project on enhancing maritime safety	22.05.2013	-	Industry, Policy makers, Medias	>300	International
	Article in IHS Safety at Sea (Cover Story)	BMT	Bionic bridges	05-2013	-	Industry, Policy makers, Medias	>300	International
	Press release at project start	BMT	New R&D Project to Help Enhance Maritime Safety	22.05.2013	London, UK	Industry, Policy makers, Medias	>100	International
	Press release at project start (German and English)	OFF	Short description of the project in German: Schiffsbrücken-Design: mensch-zentriert und adaptiv	05-2013	Oldenburg, Germany	Scientific Community, Industry, Policy makers, Medias	>100	National
	Article in Schiff und Hafen (German)	OFF	Start des EU-Projektes CASCADe	03-2013	-	Industry, Policy makers, Medias	>200	National
	Project Logo	BMT	CASCADe	03-2013	-	-	-	International

	Project Website	BMT	http://www.cascadeproject.eu/	03-2013	-	Public, Scientific Community, Industry, Policy makers, Medias	-	International
	Presentation at Digital Ship 2013 Hamburg	OFF	Towards cooperative and adaptive ship bridge design – FP7 project CASCADe	02-2013	Hamburg, Germany	Industry, Medias	>200	International
	Press release at project start (German)	OFF	Maritime Cluster Northern Germany announces project start: Gemeinsam für mehr maritime Sicherheit	02-2013	Kiel, Germany	Industry, Policy makers, Medias	>200	National
	Project description at OFFIS Website	OFF	Short description of the project objectives and partners	01-2013	Oldenburg, Germany	Public, Scientific Community, Industry, Policy makers, Medias	-	International
	Article in Fairplay Solutions	BMT	Crew factor tops Asia meeting (about start of the project)	11-2012	-	Industry, Policy makers, Medias	>300	International

3 Report on Societal Implications

A General Information

JU Grant Agreement Number:	314352
Title of Project:	CASCADe - Model-based Cooperative and Adaptive Ship-based
Name and Title of Coordinator:	Dr. Andreas Lüdtke

B Ethics

1. Did you have ethicists or others with specific experience of ethical issues involved in the project?	**x** ○	**Yes** **No**

2. Please indicate whether your project involved any of the following issues (tick box) :	***YES***
INFORMED CONSENT	
• Did the project involve children?	No
• Did the project involve patients or persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	Yes
• Did the project involve Human Genetic Material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No
• Did the project involve Human Embryonic Stem Cells?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (e.g. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)	No
• Did the project involve tracking the location or observation of people?	Yes
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloning farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Use of local resources (genetic, animal, plant etc)	No

• Benefit to local community (capacity building i.e. access to healthcare, education etc)	No
DUAL USE	
• Research having potential military / terrorist application	No

C Workforce Statistics

3 Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	1
Work package leader	2	4
Experienced researcher (i.e. PhD holders)	2	1
PhD Students	0	2
Other	0	3

4 How many additional researchers (in companies and universities) were recruited specifically for this project?	
Of which, indicate the number of men:	0
Of which, indicate the number of women:	0

D Gender Aspects

5	**Did you carry out specific Gender Equality Actions under the project?**	○ X	Yes No

6 Which of the following actions did you carry out and how effective were they?

		Not at all effective → Very effective
❑	Design and implement an equal opportunity policy	○ ○ ○ ○ ○
❑	Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○
❑	Organise conferences and workshops on gender	○ ○ ○ ○ ○
❑	Actions to improve work-life balance	○ ○ ○ ○ ○
○	Other:	

7 Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

X No

E Synergies with Science Education

8 Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

X No

9 Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

X No

F Interdisciplinarity

10 Which disciplines (see list below) are involved in your project?

○ Main discipline[5]: 1.1

○ Associated discipline[5]: 2.2 ○ Associated discipline[5]: 5.1

G Engaging with Civil society and policy makers

11a	**Did your project engage with societal actors beyond the research community?** *(if 'No', go to Question 14)*	X ○	Yes No

11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)? X No ○ Yes- in determining what research should be performed ○ Yes - in implementing the research ○ Yes, in communicating /disseminating / using the results of the project		
11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ X	Yes No
12 Did you engage with government / public bodies or policy makers (including international organisations)		
○ No X Yes- in framing the research agenda ○ Yes - in implementing the research agenda X Yes, in communicating /disseminating / using the results of the project		
13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers? ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible) X Yes – as a **secondary** objective (please indicate areas below - multiple answer possible) ○ No		

13b If Yes, in which fields?

Agriculture Audiovisual and Media Budget Competition Consumers Culture Customs Development Economic and Monetary Affairs Education, Training, Youth Employment and Social Affairs		Energy Enlargement Enterprise Environment External Relations External Trade **Fisheries and Maritime Affairs** Food Safety Foreign and Security Policy Fraud Humanitarian aid		Human rights Information Society Institutional affairs Internal Market Justice, freedom and security Public Health Regional Policy **Research and Innovation** Space Taxation **Transport**	

[5] Insert number from list below (Frascati Manual)

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- X European level
- X International level

H	**Use and dissemination**	
14	**How many Articles were published/accepted for publication in peer-reviewed journals?**	**4**
To how many of these is open access[6] provided?		**1**
	How many of these are published in open access journals?	**1**
	How many of these are published in open repositories?	**0**
To how many of these is open access not provided?		**3**
	Please check all applicable reasons for not providing open access:	
	X publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available X no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other: ……………	
15	**How many new patent applications ('priority filings') have been made?** *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*	**0**

16	**Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).**	Trademark	**0**
		Registered design	**0**
		Other	**0**

17	**How many spin-off companies were created / are planned as a direct result of the project?**	**0**
	Indicate the approximate number of additional jobs in these companies:	

18 Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

❑	Increase in employment, or	❑	In small & medium-sized enterprises
❑	Safeguard employment, or	❑	In large companies
❑	Decrease in employment,	❑	None of the above / not relevant to the project
X	Difficult to estimate / not possible to quantify	❑	

[6] Open Access is defined as free of charge access for anyone via the internet.

19 For each project partner, please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs:	*Indicate figure:*
Difficult to estimate / not possible to quantify	X

I Media and Communication to the general public

20 As part of the project, were any of the beneficiaries professionals in communication or media relations?

X Yes ○ No

21 As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?

○ Yes X No

22 Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?

X	Press Release	X	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	X	Coverage in international press
X	Brochures /posters / flyers	X	Website for the general public / internet
X	DVD /Film /Multimedia	X	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

x	Language of the coordinator	X	English
X	Other language(s): French		

Question F-10: Classification of Scientific Disciplines according to the Frascati Manual 2002 (Proposed Standard Practice for Surveys on Research and Experimental Development, OECD 2002):

FIELDS OF SCIENCE AND TECHNOLOGY

1. NATURAL SCIENCES
1.1 Mathematics and computer sciences [mathematics and other allied fields: computer sciences and other allied subjects (software development only; hardware development should be classified in the engineering fields)]
1.2 Physical sciences (astronomy and space sciences, physics and other allied subjects)
1.3 Chemical sciences (chemistry, other allied subjects)

1.4 Earth and related environmental sciences (geology, geophysics, mineralogy, physical geography and other geosciences, meteorology and other atmospheric sciences including climatic research, oceanography, vulcanology, palaeoecology, other allied sciences)
1.5 Biological sciences (biology, botany, bacteriology, microbiology, zoology, entomology, genetics, biochemistry, biophysics, other allied sciences, excluding clinical and veterinary sciences)

2 ENGINEERING AND TECHNOLOGY
2.1 Civil engineering (architecture engineering, building science and engineering, construction engineering, municipal and structural engineering and other allied subjects)
2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]
2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

3. MEDICAL SCIENCES
3.1 Basic medicine (anatomy, cytology, physiology, genetics, pharmacy, pharmacology, toxicology, immunology and immunohaematology, clinical chemistry, clinical microbiology, pathology)
3.2 Clinical medicine (anaesthesiology, paediatrics, obstetrics and gynaecology, internal medicine, surgery, dentistry, neurology, psychiatry, radiology, therapeutics, otorhinolaryngology, ophthalmology)
3.3 Health sciences (public health services, social medicine, hygiene, nursing, epidemiology)

4. AGRICULTURAL SCIENCES
4.1 Agriculture, forestry, fisheries and allied sciences (agronomy, animal husbandry, fisheries, forestry, horticulture, other allied subjects)
4.2 Veterinary medicine

5. SOCIAL SCIENCES
5.1 Psychology
5.2 Economics
5.3 Educational sciences (education and training and other allied subjects)
5.4 Other social sciences [anthropology (social and cultural) and ethnology, demography, geography (human, economic and social), town and country planning, management, law, linguistics, political sciences, sociology, organisation and methods, miscellaneous social sciences and interdisciplinary , methodological and historical S1T activities relating to subjects in this group. Physical anthropology, physical geography and psychophysiology should normally be classified with the natural sciences].

6. HUMANITIES
6.1 History (history, prehistory and history, together with auxiliary historical disciplines such as archaeology, numismatics, palaeography, genealogy, etc.)
6.2 Languages and literature (ancient and modern)
6.3 Other humanities [philosophy (including the history of science and technology) arts, history of art, art criticism, painting, sculpture, musicology, dramatic art excluding artistic "research" of any kind, religion, theology, other fields and subjects pertaining to the humanities, methodological, historical and other S1T activities relating to the subjects in this group]

4 List of Beneficiaries and Contact Details

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I have read and I agree to the following statement:*

The electronic submission of the report using this application (SESAM) stands for formal submission of the report and its attachments to the European Commission, in the context of the aforementioned research project. The European Commission will file and register the report and its attachments as formally received communication from you and proceed with its treatment. Consequently, submission of the same information via other channels (e.g. in paper format or by e-mail) is not necessary. Only the version submitted via SESAM is considered as the valid one; versions sent in parallel via other channels will be ignored.

5 Abbreviations

Abbreviation	Meaning
ABS	Adaptive Bridge System
AIS	Automatic Identification System
CASCaS	Cognitive Architecture for Safety Critical Task Simulation
CSMs	Cognitive Seafarer Models
DNV-GL	Det Norske Veritas - Germanischer Lloyd
DSA	Distributed Situation Awareness
ECDIS	Electronic Chart Display and Information System
ENC	Electronic Navigational Charts
GPFI	General Potential Functional Improvements
HLA-RTI	High Level Architecture Run Time Infrastructure
HMI	Human-Machine-Interaction
IBS	Integrated Bridge System
IMO	International Maritime Organisation
INS	Integrated Navigation System
KPI	Key Performance Indicator
OOW	Officer of the Watch
PPU	Portable Pilot Unit
PSP	Physical Simulation Platform
SA	Situation Awareness
VSP	Virtual Simulation Platform
VUI	Virtual User Interfaces

6 References

Endsley, M. R. (1995) Toward a theory of situation awareness in dynamic systems. Human Factors 37, pp. 32–64.

Salmon, P. M.; Stanton, N. A.; Walker, G. H. and Jenkins, D. P. (2000) Distributed Situation Awareness - Theory, Measurement and Application to Teamwork, pp. 35-56, 183-204.

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