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Model-based adaptive bridge design in the maritime domain. The CASCADe Project

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Abstract

CASCADe is a European project aiming at designing advanced adaptive ship bridges, using model-based approaches and simulations. The models are used for capturing and simulating the seafarers' tasks and their information and situation awareness needs, through the use of cognitive seafarers' models; for studying and designing their physical interaction with console equipment, including controls and displays, through sophisticated anthropometric 3D models; and finally for designing and manufacturing the physical bridge itself (console, workstation, furniture).

Keywords: Maritime; Ship bridge; Model-based design; Situation awareness; Human-machine cooperation

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1. The CASCADe project

The main objective of the CASCADe (Model-based Cooperative and Adaptive Ship-based Context Aware Design) European project is to develop and apply new design methodologies that better integrate human factors in the bridge design process; by providing adaptiveness and context-awareness to the bridge, enhancing situation awareness, and better supporting communication and collaboration between seafarers. This will improve the overall adaptiveness and resilience of the bridge to contingencies and therefore lead to increased safety.

Beside cognitive ergonomics, CASCADe also pays deep attention to physical ergonomics and anthropometrics and to the interplay between physical postures, physical moves and cognitive behavior and communications on the bridge. They are all investigated through a series of inter-connected static and dynamic models of the bridge and of its human operators and interactive systems (through physical and cognitive simulations).

CASCADe is a European project in the Seventh Framework Program (FP7). The project started in January 2013 and will end in December 2015. CASCADe is led by OFFIS (DE), a German research institute in computer science, and integrates industrial and research partners from several other European countries: Raytheon Anschutz (DE), BMT (UK), the University of Cardiff (UK), Marimatech (DK), Mastermind (CY) and Symbio (BE). The consortium has expertise in modelling, simulation, model-based design, hardware and software engineering, industrial design, human factors, ergonomics, and of course the maritime domain.

2. Underlying hypotheses

To achieve its objectives, CASCADe relies on three fundamental ideas:

- the *cooperative human-machine system perspective*: CASCADe sees the ship bridge as a cooperative human-machine system. Human operators (human agents) and systems and automation (machine agents) cooperate to achieve the overall functions of the bridge, for all navigation phases and in all circumstances. For example, a possible collision with another ship on a collision course will be dealt with through the cooperation between alarming systems on the bridge, the Master, the Officer of the Watch (OOW), the radar and the autopilot, see Fig. 1. below. The cooperative human-machine system perspective is grounded in the Distributed Cognition approach [1] and considers systems, and in particular automation, as team players [2]. Several of the CASCADe partners have been or are involved in the D3CoS [3] and HoliDes [4] European projects, based on the same ideas.
- a model-based approach to bridge study and design, based on a distinction between a functional and an actual level, and the use of a *virtual simulation platform* (VSP) to test and compare design alternatives very early in the design process, on aspects such as situation awareness, communications, perceptive and motor behaviors, cognitive processing (see CASCaS cognitive architecture [5]),... as well as physical moves, head orientation,...
- an experimental approach that relies on experiments on a *physical simulation platform* (PSP) to get answers to specific questions (e.g. is the introduction of that new display desirable from an operation point of view? Does it improve situation awareness? What is the best design between two alternatives) and to evaluate the improvements brought by a new design (e.g., does our new design reduce human error, compared to a baseline?).

3. Conceptual CASCADe bridge design

The overall CASCADe design process is structured into two major stages: conceptual design, where we investigate various design ideas and alternatives, and select the best ones, through evaluation on the virtual and physical simulation platforms (VSP and PSP respectively); and then final design, where we finalize the design in actual terms, through industrial design and advanced evaluation and validation on the VPS and PSP.

The whole process starts by the specification of a series of target operational scenarios where better support or consideration to human factor issues is considered desirable or mandatory.

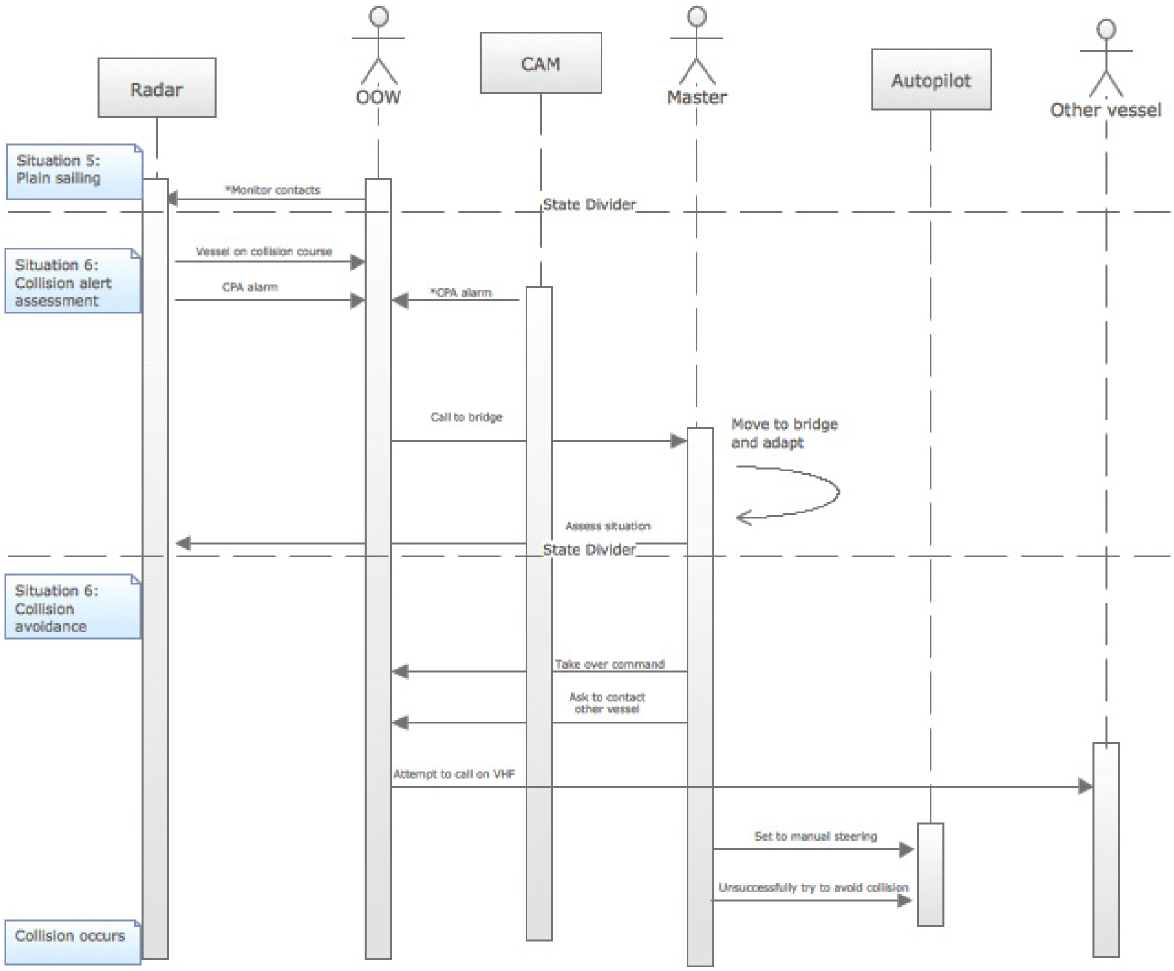

Fig. 1. Model for the collision event situation.

3.1. Scenario specification

The whole bridge design process has to start with a list of requirements specifying what CASCADe should aim at improving on current bridges. To produce these requirements, we have identified a set of relevant operational scenarios, considered as either very regular and frequent (e.g., preparation of a voyage) or abnormal and prone to risk (e.g., collision avoidance, shallow water avoidance). Six scenarios have been produced in a first stage, and four additional ones in a second phase of the project.

The scenarios have been modeled with UML activity diagrams (Fig. 1), which allow identifying the different actors involved in the scenarios (human and machine), their interactions and communications and the different steps the scenario goes through.

3.2. Requirements specification

The target scenarios have then been analyzed in the human-machine cooperative system perspective that underlies the whole project: who are the human and machine agents involved? What are their roles or functions? How do they contribute together to the overall function of the bridge, seen as a cooperative system? How do they interact and exchange information? How do they take information outside the bridge? The UML-based models of the scenarios have been used for extracting that information and characterizing the scenarios in those terms.

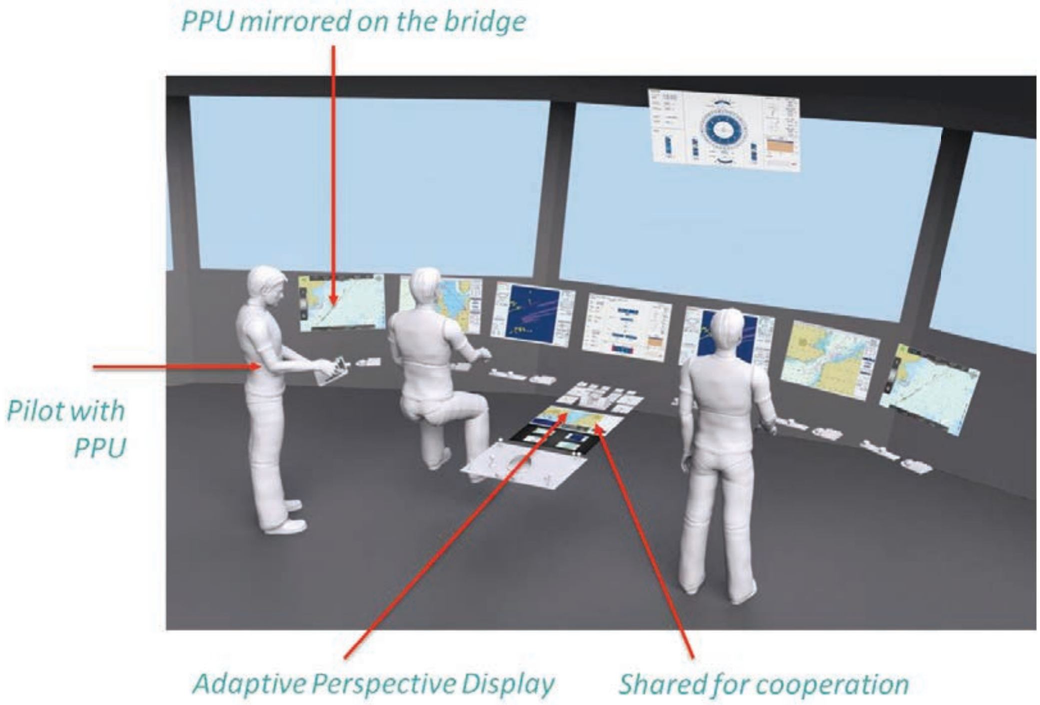

Fig. 2. The shared display, PPU and bridge layout seen as an integrated whole.

Through these detailed scenario analyses, we have been able to derive multiple avenues for improving the safety and efficiency of the bridge, seen as a human-machine cooperative system. This will be achieved by improving support to the preparation of navigation; the verification of trajectory during the voyage; the evaluation of threats and risks; conflict management (e.g., collision avoidance); dynamic adaptation of bridge manning; cooperation on the bridge; better building situation awareness; communication within the bridge and cooperation with other vessels.

These are the target operations we aim to improve through our conceptual and then final bridge design.

3.3. Conceptual solutions for the bridge and the equipment

To satisfy these requirements, the CASCADe consortium investigated various options and came up with the following tentative solutions (Fig. 2):

- a new display, with advanced adaptive, context-aware and annotation capabilities, that will be used to share information between the bridge personnel, prepare navigation phases, enhance situation awareness and support the collaborative resolution of navigation problems (e.g., collision avoidance).
- a Portable Pilot Unit (PPU), a tablet-based unit to be used by the Pilot to prepare a passage before getting on a ship and then supporting information transmission and cooperation with the Master once onboard. The Pilot is a professional seafarer who comes on board to guide the vessel through dangerous or congested waters, such as harbors and river mouths, and perform berthing and un-berthing operations at the harbor.
- a new, modern bridge layout, including the innovative shared display for enhanced situation awareness and better on-bridge cooperation.

To organize the bridge in spatial terms, and in particular in terms of positioning of the shared display(s), several bridge layouts (Fig. 3) have been investigated in conceptual terms.

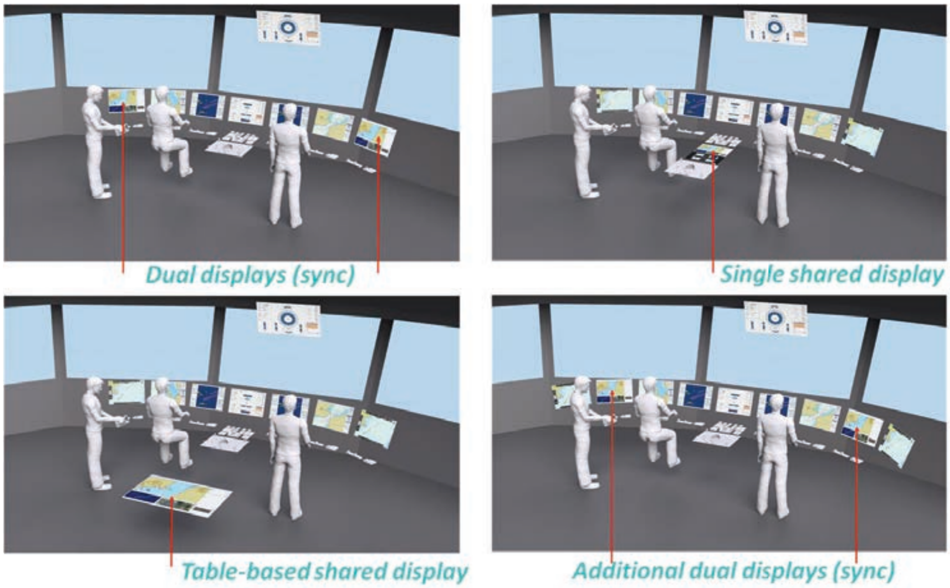

Fig. 3. The four alternative bridge layouts considered in CASCADe.

In CASCADe, we also investigated other conceptual bridge options, beyond the bridge layouts themselves, such as the ability to adjust the height of the console, to support work in a sitting or standing position, and the option of having all computerized equipment in the bridge (i.e., in the piece of furniture itself) or off the bridge (i.e., in a dedicated technical room, or in technical racks outside the bridge), as is now the case in most modern control rooms.

3.4. Evaluation of conceptual solutions on the physical simulation platform

The three solutions above, the shared display, Portable Pilot Unit (PPU), and four alternative bridge layouts, have then been evaluated through a dedicated evaluation campaign. One of the goals in particular was to select one of the four bridge layouts under consideration.

A physical simulation platform (PSP) (Fig. 4a) was manufactured and configured, based on the conceptual design. The platform relied on a simple bridge mock-up, with height adjustment capabilities.

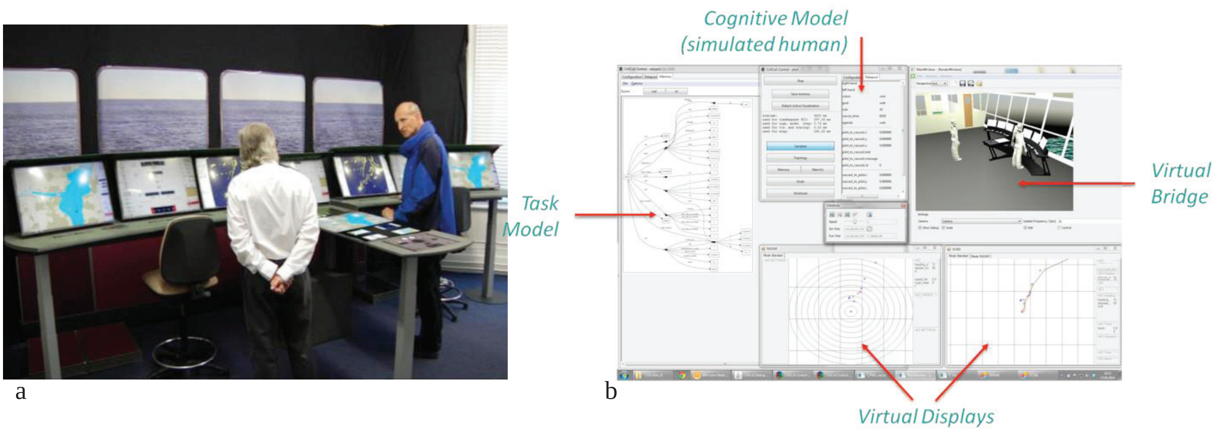

Fig. 4. (a) Physical simulation platform (PSP); (b) Virtual simulation platform.

The platform was then used to perform evaluations with seafarers, targeting in particular the innovative features CASCADe was bringing in: shared display, annotation capabilities, adaptive capabilities, the portable pilot unit (PPU) and the capability to mirror its content on the main bridge displays, and finally height adjustment.

3.5. Evaluation on a virtual simulation platform

Model-based evaluations of the conceptual ideas were also conducted on a virtual simulation platform (VSP). The platform (Fig. 4b), developed by BMT and OFFIS, models all bridge elements, some of the equipment and their user interfaces (including their content) and the seafarers themselves, through task-driven cognitive models. The cognitive model is implemented in the CASCaS cognitive architecture developed by OFFIS [5].

The evaluations on the physical simulation platform (PSP) and the virtual simulation platform (VSP) provided complementary information, with positive to very positive appreciation of the shared display, in particular the annotation capabilities; the Portable Pilot Unit (PPU); PPU mirroring, that is the ability to send the content of the PPU to the bridge systems and displays for further interaction and elaboration with the bridge personnel; the adaptive capabilities for both the shared display and the PPU; bridge layout number 2, the one with the shared display on a central panel; and finally height adjustment capabilities.

4. Final CASCADe bridge design

The evaluations thus confirmed the interest of the shared display, if possible with adaptive and annotation capabilities and placed in central position (layout 2). They also confirmed the interest for the PPU and PPU mirroring capabilities. This therefore opened the door to starting final bridge design, past the conceptual stage.

4.1. Positioning of the shared display and reachability analysis

The bridge layout selected after the first round of evaluation, layout 2, places the shared display on the middle console, between both sides of the bridge. It is however important to determine accurately the best orientation (portrait vs landscape) and position for that display. The display must be easily visible, reachable and usable by the bridge users, sitting or standing up on both sides of the bridge. The shared display is also intended as a touch display, requiring specific types of interactions and postures. It must also allow making annotations.

To address these topics, accurate 3D models of tentative bridge layouts, with various options for the orientation and position of the shared display, have been produced.

Virtual manikins have then been used to perform reachability analysis (Fig. 5), for different types of reach zones, based on arm position, extension and body posture (neutral or non neutral). We have also compared reachability for sitting or standing users. This has allowed us to determine the best orientation (landscape) and positioning for the shared display on the future bridge.

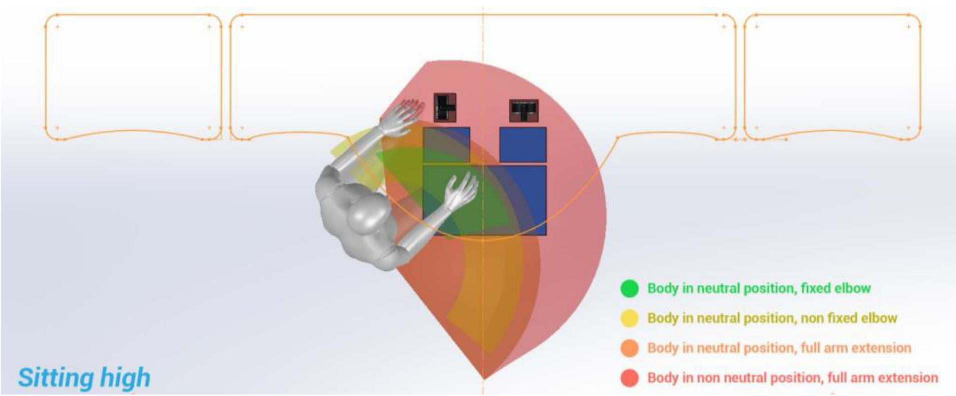

Fig. 5. Reachability analysis for orientation and position of the shared display.

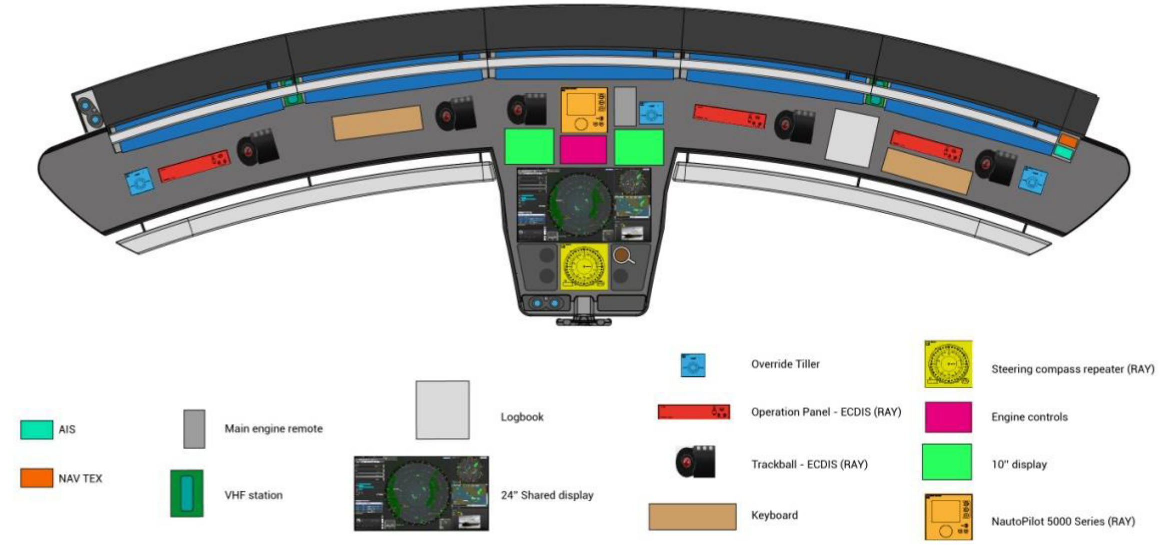

Fig. 6. Tentative layout for the CASCADe bridge.

4.2. Equipment layout

Once a specific orientation and position for the shared display have been determined, the arrangement and position of the other equipment have been studied. The corresponding layout (Fig. 6) has been produced by the consortium, relying on their maritime experience, technical expertise, and human factors and industrial design expertise.

4.3. Industrial design

Once finalized, the layout has been used to produce a complete model of the bridge (Fig. 7a, b) where the equipment is arranged in accordance with the target layout.

4.4. Virtual evaluation of CASCADe bridge

The 3D model of the new bridge will be used on the virtual simulation platform developed by OFFIS and BMT (Fig. 8) to conduct virtual experiments on several operational scenarios, in April and May 2015: the scenarios will be executed and data will be collected on aspects such as situation awareness (individual & distributed); information demand and information supply; information exchanges, effort for information access (including physical effort); information fitness,...

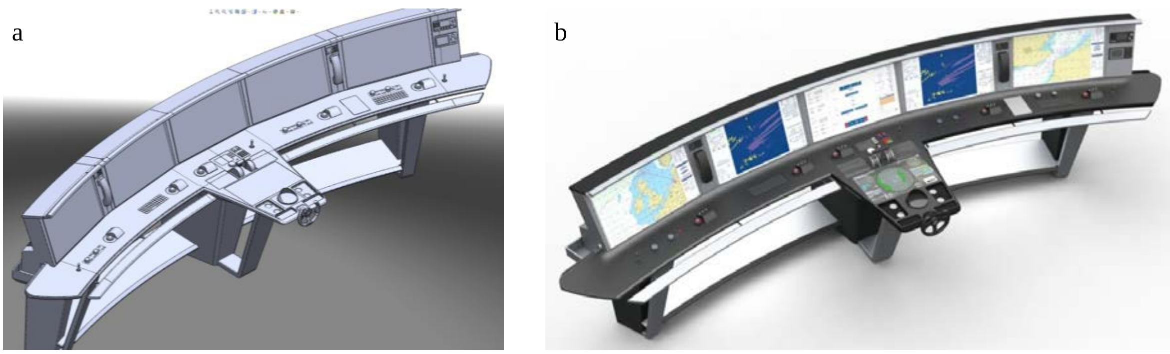

Fig. 7. (a) 3D model for CASCADe bridge; (b) 3D rendering for CASCADe bridge.

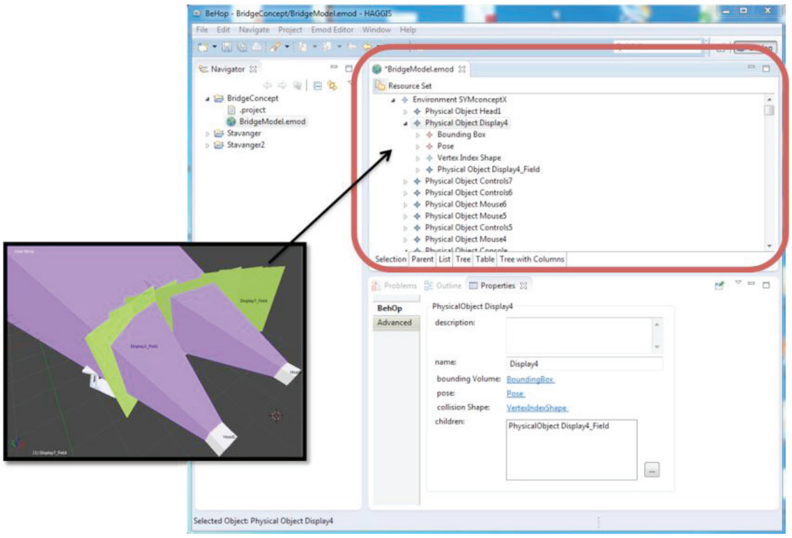

Fig. 8. Automatic, scenario-driven analysis of vision cones on the Virtual Simulation Platform (VSP).

4.5. Physical evaluation of the CASCADe bridge

The results of the virtual experiments on the VSP will be available in early June 2015. They will then be used to improve the design (i.e. layout, Fig. 6 and 3D models, Fig. 7a, 7b). A physical demonstrator will then be produced in June and July 2015, to create a realistic physical simulation platform (PSP), on which human in the loop (HITL) experiments and evaluations will be performed in August and September 2015. The results will be reincorporated into the final version of the CASCADe bridge by the end of the year. The project will then be over.

5. Conclusions

The CASCADe project has for objective to develop new methodologies for ship bridge design that better integrate human factors in the design process, and does this very early in the design process. This is achieved with a model-based design approach and the use of virtual and physical simulations to test alternative design concepts, as well as to evaluate the final bridge design. The design process, coupled with the virtual and physical simulations, aims at improving the preparation of navigation, the verification of trajectory during the voyage, the evaluation of threats and risks, conflict management, situation awareness, and cooperation and communication on the bridge, and therefore reduce error proneness and fatigue and improve the overall safety and efficiency of the operations.

In this paper we have thus shown how this has been achieved through a model-based approach that relies on virtual simulations - complemented by physical, human in the loop, simulations - to allow investigating human factors issues very early in the bridge design process (e.g., at the conceptual design stages), and at any other design or development stage (e.g., when a final virtual prototype is available).

Acknowledgements

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