Design of a Communication Management System on Board in the Framework of e-Navigation Concept

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Abstract - **In the e-navigation concept of the International Maritime Organization (IMO) the availability of information received via communication equipment in real-time with possible presentation on the navigational displays is considered as an advantage for mariners regarding informed decision making and safety of navigation. In this paper a design of a communication management system for information handling and processing on board is described. For the development of design requirements the Applied Cognitive Work Analysis (ACWA) was adopted. ACWA is a methodology for the analysis, design and evaluation of complex socio-technical systems and interfaces, which focuses on the analysis of cognitive demands of decision makers. A concept for a communication management system on board was developed.**

Keywords
Applied cognitive work analysis, communication management system, e-navigation, human-machine interface, integrated navigation systems.

INTRODUCTION

The e-navigation concept of the International Maritime Organization (IMO) aims to harmonize the collection, integration, exchange, presentation and analysis of maritime information on board and ashore by electronic means to enhance berth to berth navigation and related services (IMO, 2007a). The integration and presentation of information on board pertaining to planning and execution of voyages, assessment of navigational risk and compliance with regulations is an essential part of the e-navigation concept. The current separation of communication systems and navigational systems doesn't meet the e-navigation requirements of safe navigation. The availability of information received via communication equipment in real-time with possible presentation on the navigational displays is considered as an advantage for mariners regarding informed decision making and safety of navigation (IMO, 2009a).

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A communication management system should be employed on the bridge as an aid for the mariner in the accomplishment of communication tasks and as a mean for the provision of information to navigational systems to support decision making and enhance the safety of navigation. A communication management system must not only manage the transfer of information, but also the integration of information, which are received via the communication equipment, as this information must be processed and forwarded to a relevant work station in real-time to guarantee quick response.

To develop the requirements for design of a communication management system on board the Applied Cognitive Work Analysis (ACWA) was adopted (Potter et al., 2001). ACWA is a methodology for the analysis, design and evaluation of complex socio-technical systems and interfaces, which focuses on the analysis of cognitive demands of decision makers. ACWA is a process of successive engineering steps, which lead from the analysis of the demands of a work domain to the identification of an effective decision-aiding visualization.

In this paper we describe the development of requirements for the design of a communication management system on board and present a preliminary concept of the system, which comprises the specification of the work domain of maritime communication, identification of cognitive work requirements as well as functional and information requirements, which build a basis for further analysis in order to define design requirements for a communication management system.

SHIP COMMUNICATION NEEDS

Communication management functionality can be integrated in the task-oriented concept for presentation and integration of navigational information. This is described within the Integrated Navigation Systems (INS) performance standards (IMO, 2007b) and the modular bridge concept (IMO, 2008a). As a new INS task or as part of the

INS task "status and data display" it allows the management and routeing of the information received via communication equipment into the bridge systems for presentation and use. A communication management system can improve navigation safety by means of data and information fusion.

In the framework of e-navigation concept shipboard user needs considering communication were identified (IMO, 2009b). According to these needs the following requirements for successful communication management were specified:

- Presentation of information received via communication systems on the navigational displays of the ship's bridge (e.g., vessel in distress, wind speed/direction, restricted areas).
- Presentation and processing of information according to user-set parameters to prevent information overload (e.g., only information from relevant sea areas).
- Integration of information from multiple sources.
- Provision of source and channel management (selection of best connection according to certain criteria, e.g., availability, content, integrity, costs).
- Increased availability and reliability due to efficient use of different communication channels to ensure safe, secure and economic transmission.

Strong emphasis has been placed on the need to reduce the administrative burden, which includes:

- Navigational administration, e.g. update of charts and nautical publications.
- Protocol and documentation of voyage, e.g., ship's logbook.
- Mandatory reporting to authorities, e.g., arrival/departure reporting.

To reduce administrative burden harmonization of mandatory reporting to authorities should take place. In order to achieve this it is necessary to standardize the reporting procedures and forms in order to avoid repetition of reporting and to reduce workload. Standardised information reported to a single point of contact that forwards the information or allows access of information to other respective authorities is necessary to ensure consistency and reduce the reporting burden by ship personnel. Standard data exchange protocols, formats and data structures must be developed.

Adequate communication management can help to solve some challenges related to administrative burden. Following measures could be supported by a communication management system:

- Presentation of maritime information and documentation in an electronic form, which enables an easy location and automatic update of information and herewith improves efficiency and reduce administrative burden.
- Provision of automated reporting in order to reduce the amount of ship/shore reporting and to enter information such as static and dynamic information pertaining to the vessel, cargo, crew and voyage into the system only once.

METHOD

Problem Description

Ship's bridge systems are currently designed by aggregation of different computer-based systems, which may be developed independent from each other by different suppliers. In this manner new technologies are developed and integrated separately and the Human-Machine Interface (HMI) design is based on available technical functions. That means, in case of technical innovations, introduction of new regulations, changes in procedures or basic changes of technology the need of a new HMI occurs. It is quite different, if the HMI design is conducted according to cognitive demands of the task and is not dependent on technology. To develop HMIs, which support efficient decision making of nautical officers, design methods are required, which examine human cognitive processes and determine human cognitive needs.

Task analysis methods describe task steps and sequences, but experienced decision makers do not follow specific steps, hence, "we need to go beyond task decompositions and understand the users' point of view – how they are viewing the work, how they are interpreting the task, how they are adopting or rejecting strategies, and how they are modifying or abandoning standard procedures" (Crandall et al., 2006). The other problem is that communication procedures differ depending on the ship type, routes or port facilities.

For these reasons a cognitive approach for the development of a communication management system on board was chosen.

Applied Cognitive Work Analysis

ACWA is a methodology for the development of visualization concepts for decision aids by providing the framework for modelling the relationships in the work domain and by identifying the cognitive

demands of operators. ACWA (Elm at al., 2003) helps to understand, how experts make decisions and why they make certain decisions, what cues they need, what knowledge and strategies they use. The process begins with the identification of the critical decisions that operators must make and ends with the identification of visualization and decision-aiding concepts (see Figure 1).

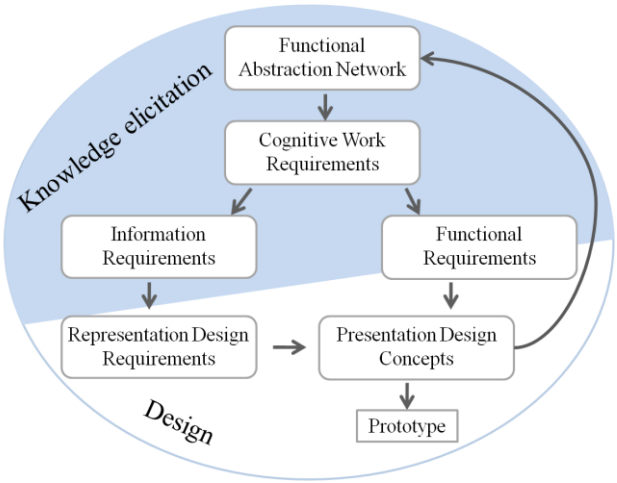

Figure 1. Development process of a HMI based on ACWA.

The ACWA begins with the development of a Functional Abstraction Network (FAN), which is a model of functional relationships between work domain elements. FAN is a multi-level recursive representation (a network) of a work domain. Each node in the network represents a goal, links represent support. Each goal has a process that provides a description how to achieve the goal. Processes define supporting functions for achieving the goals above in the hierarchy.

The FAN provides the basis for the definition of cognitive demands, which arise in a domain and need support – Cognitive Work Requirements (CWR) or decision requirements. CWR are to be defined for each goal node in the FAN. This ensures understanding what decisions are to be made to achieve the defined goals. At this point no differences are made between decisions/actions performed by humans and automated tasks performed by computer systems.

On the basis of CWR functional requirements could be identified, which define data manipulation and processing and other functions to be accomplished by a system.

The next step is to identify the Information Requirements (IR). At this point information required to make certain decisions should be defined. The identification of information requirements is not limited by available data, but identifies all data needed to make a decision.

Representation Design Requirements (RDR) define how the information needs to be represented. Appropriate information visualization can improve information processing and thus the process of decision making. In this step the decision-aiding concepts on basis of information requirements should be developed taking into account human perception and cognition.

The last step of ACWA is the implementation of representation requirements into a powerful visualization of the domain context – Presentation Design Concepts (PDC). After this step a prototype can be developed to evaluate the effectiveness of a new system. The prototype can help to identify additional decision and information requirements for decision support, which were missed in the first steps. Thus, the ACWA approach is an iterative process.

CONCEPT DEVELOPMENT

Data acquisition

Different knowledge elicitation methods, such as interviews with subject matter experts and analyses of documents and operational procedures, were used to gather the domain knowledge of the work domain "maritime communication".

Communication plays an important part in gaining and forwarding of information. The ship needs to provide information to diverse authorities on shore. The shore authorities, e.g., Vessel Traffic Services (VTS), shipping companies or port facilities, need to communicate important information to ships. Furthermore, the ship needs to receive navigational, hydrological, meteorological and other information and its updates on a regular basis.

A communication management system is considered to provide support in the management of electronic communication information, ship's reporting and documentation. The primary purpose of the system is the management of transmission of digital messages from/to ship. Voice communication must also be considered as messages should be documented in electronic form.

Three main fields of communication activities on board to be supported by the communication management system were identified:

- Navigational communication and administration (information needed for navigational tasks, update of charts/nautical publications).
- Operational communication and administration (communication and documentation related to ship operations,

such as cargo, passenger handling, ship maintenance etc.).

- Mandatory reporting to authorities (communication with authorities related to arrival/departure procedures, customs/ISPS procedures, documentation etc.).

Based on diverse communication needs during the different phases of the voyage communication activities could be subdivided into three groups:

- Pre-departure communication,
- En-route communication and
- Pre-arrival communication.

Each of these phases has different information exchange needs and different procedures regarding navigation needs or administrative formalities.

Based on considerations named above, a preliminary concept for a communication management system was built. In the following it is described how the ACWA approach was applied to determine requirements for the development of a HMI for the communication management system.

Definition of requirements

Description of the work domain "maritime communication"
The domain of communication management was described by means of a FAN that is the first step of ACWA. The FAN provided a model of the domain, which describes the goals to be achieved and their relationships. A detail of the FAN is depicted in Figure 2. The rectangles represent goals, which are organized hierarchically; the links represent the supporting connections to higher-level goals.

The three main functional areas of the communication management system (see Figure 2) were identified, which are:

1. Exchange of information with the outside world, e.g., shore authorities, other ships.
2. Information management, which comprises retrieval and processing of both external and internal information.
3. Exchange of information with other systems or work stations, which comprises forwarding of information received through communication equipment to these systems and the request of information from these systems, which is intended for transmission via communication equipment.

First of all, at the top level in the FAN hierarchy the purposes and external constraints in the work domain were identified, which are not depicted in Figure 2. These high-level goals are:

- Ensuring safety and security,
- Attending administrative matters (organizational norms and goals) and
- Attaining commercial goals (achieving the optimum turnover).

To ensure these goals it is necessary to navigate the ship safely and efficiently, to keep the ship in an operable state and to provide communication and information processing.

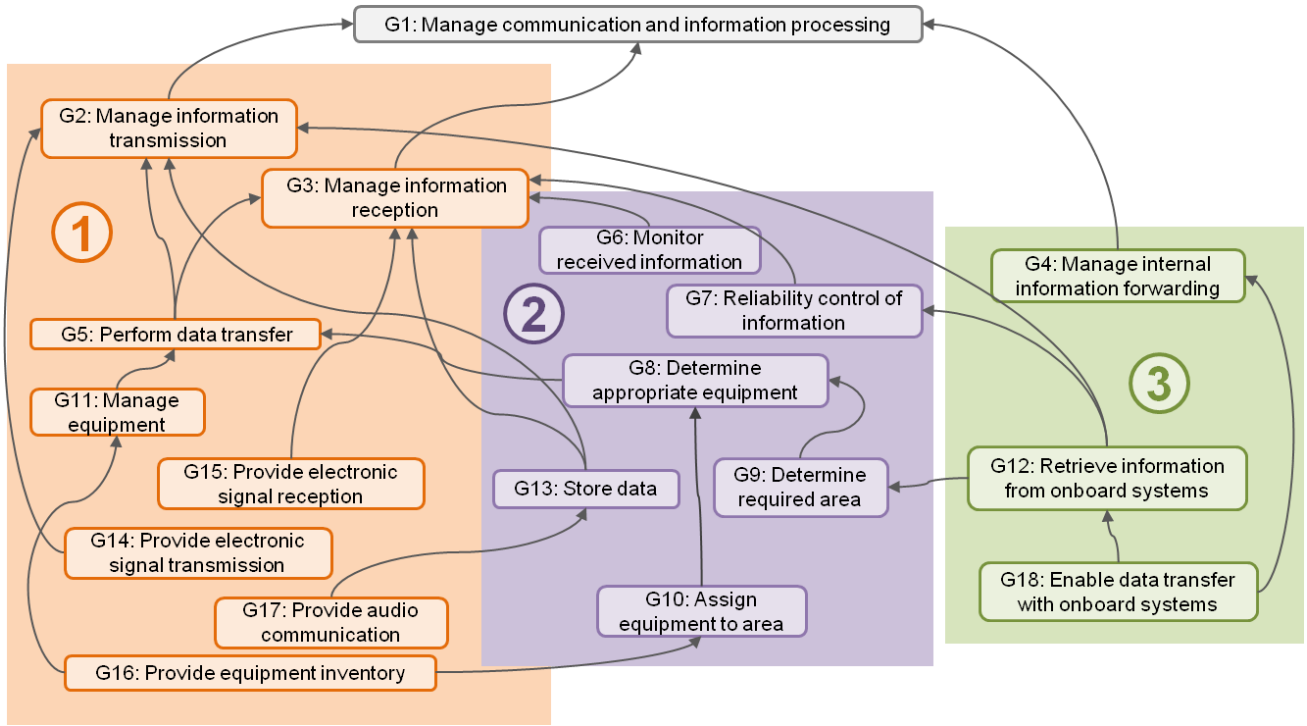

Figure 2. FAN with three functional areas of the communication management system.

To successfully manage the communication and information processing (goal G1) the management of transmission (G2) and reception (G3) of information and also forwarding of the received information to eligible ship systems (G4) are required (see Figure 2). Monitoring of the received information (G6) enables detection of new information or updates, so that notifications of the availability of new information can be made or existing information can be updated. It is essential to enable secure and error-free data transfer and to provide the possibility to restore messages in case of transfer failures. Reliability control of information (G7) is, therefore, important to ensure security and safety of ship operations.

In order to successfully perform data transfer (G5), which comprises also monitoring in order to detect failures, it is necessary to provide appropriate equipment (G8). This includes the determination of the communication area (G9), where the ship operates, and the assignment of equipment to an area (G10). For planning the data transfer it is important to determine whether the available equipment is optimal, suitable or inappropriate in respect to its content, required bandwidth and costs. The equipment management (G11) comprises checking of functions, configuration and troubleshooting of equipment. To enable successful equipment management a proper equipment inventory (G16) must exist. Location, connections, description and state of the communication equipment should be provided to support the user in taking required measures, e.g., in case of failures.

Further, transferred data should be stored (G13) and communication log should be generated. Arrangement of data according to the type of communication equipment, the information type or the transmitting station should be provided.

Information retrieval from onboard systems (G12), which comprises the sending of a data request to other own ship systems and the reception of data from them, is necessary to provide intern ship information in order to transmit it via communication equipment, to compare incoming information with intern ship data for verification purposes, and to determine the communication area. The supporting goal (G18) is to enable the data exchange with onboard systems.

At last, the supporting goals at the lower level are to be mentioned: the provision (G14) and reception (G15) of electronic signal transmission as well as the provision of audio communication (G17). The latter is necessary to allow for the possibility to log audio communication information.

The FAN in Figure 2 was used as an analytical tool to determine cognitive and information needs of operators.

Cognitive work requirements

In the following exemplarily cognitive work requirements are described.

To successfully manage the information transmission (G2) first of all it is necessary to collect the relevant information, which is requested by others or is scheduled to be transmitted (e.g., as a report). After the information is sent the storage of transmitted data should take place in order to provide a proper documentation of communication activities.

To manage the information reception (G3) it is important to control the incoming information in order to enable secure and faultless data transfer, which comprises recovery, decoding, and verification of received data. All information received via communication equipment should be identified, evaluated and stored before it can be forwarded to other systems or used in any other manner. The classification of information should take place in order to identify the belonging of information to a certain information type.

To successfully manage the internal information transmission (G4) the observation of incoming information should take place. The actual information, which is necessary to fulfil navigational or other tasks should be forwarded to eligible onboard systems and information requests from those systems should be processed.

Functional requirements

Identified cognitive work requirements provided a basis for definition of functional requirements, which are, e.g.:

- Source and channel management based on adjustable criteria, e.g., integrity, content and costs.
- Evaluation and storage of data clustered according to information type.
- Automatic conversion of internal data into standard form and external data into internal format.
- Automatic updates of previously received information, avoidance of information doubling and selection of information relevant to the vessel’s type and route.
- Automatic routeing to the navigational and other bridge systems.
- Automatically generated transfer protocols and ship reports.

Information requirements

Based on the CWR information requirements were identified. Exemplary requirements are depicted in Table 1.

Goal	CWR	IR
G2	Determine what information is needed to be sent	Requirements for reporting Conversion rules for data to be sent
G3	Control received information	Rules for information integrity checks
G4	Choose information necessary to fulfil certain tasks	Information requests Assignment of information to tasks
...	...	...
G13	Analyze transferred data	Date and time stamp Information type Information source

Table 1. Exemplary cognitive work requirements (CWR) and information requirements (IR).

Database for saving of sent and received data is an essential part of a communication management system as all transferred information should be stored for further processing, documentation, trouble shooting etc. Data should be stored as it is. Additional information should be stored, such as:

- Time and date stamp, source and/or destination of data.
- Information type, e.g., navigational, meteorological, geographical data.
- Assignment of received data to tasks for forwarding to relevant work stations.
- Data conversion rules.

CONCLUSION AND OUTLOOK

With the aim to develop a concept for communication management on ship's bridge the current communication infrastructure and procedures were analyzed. ACWA, which is a framework for designing a system by modelling the relationships in the work domain and by identifying the cognitive demands of nautical officers, was applied. The defined requirements will be used in further ACWA steps to develop decision-aiding visualization concepts for the HMI of the communication management system.

The developed concept for communication management will be evaluated in expert reviews. Interviews and observations on board of ships are planned to gain further insight into the circumstances and challenges of communication during usual operating procedures. Solutions for the design of a HMI of the communication management system will be developed as a paper prototype and evaluated in user tests. A prototype can help to identify additional cognitive and information requirements for decision support, which were missed in the first steps.

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