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A knowledge-based decision support system for shipboard damage control

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ABSTRACT

The operational complexity of modern ships requires the use of advanced applications, called damage control systems (DCSs), able to assist crew members in the effective handling of dangerous events and accidents. In this article we describe the development of a knowledge-based decision support system (KDSS) integrated within a DCS designed for a national navy. The KDSS uses a hybrid design and runtime knowledge model to assist damage control operators through a kill card function which supports damage identification, action scheduling and system reconfiguration. We report a fire fighting scenario as illustrative application and discuss a preliminary evaluation of benefits allowed by the system in terms of critical performance measures. Our work can support further research aimed to apply expert systems to improve shipboard security and suggest similar applications in other contexts where situational awareness and damage management are crucial.

1. Introduction

Navy ships have been traditionally manned with a large crew involved in the manual control of onboard systems. The reduction of through-life costs of vessels is today a priority and there is an interest towards reducing crew without affecting damage control capabilities or jeopardizing the ability of ships to complete their missions (Cosby & Lamontagne, 2006). Beside efficiency pressures, factors like the increased complexity of modern vessels, the requirements for easy maintainability and more sophisticated operational demands generate a need for intelligent functionalities and leading-edge technologies (Bøgh & Severinsen, 2009) which can assist human decisions and actions onboard.

In this endeavor, one relevant area is related to the management of events which may lead to shipboard damage and crew danger. These events require rapid actions, also without on-site human intervention, to prevent serious injuries to personnel or damages to vital ship systems. Whereas damage control has been traditionally a manual and manpower-intensive function, the automation of emergency management operations is today driven by complex technology architectures called *damage control systems* (DCSs) and related progresses in human-system integration, which gets increasing attention in ship design (Runnerstrom, 2003). A DCS is an information-retrieval and equipment-control system that gives ship personnel the ability to detect, analyze, and handle various types of damage situations, based on the collection and processing of vast quantities of shipboard information.

In the navy context, a damage control system (DCS) is aimed to assure the timely and informed application of men and equipment in scenarios such as fire or flooding, violation of the ship closure state, threats to essential equipments, ventilation close down, and atomic/biological/chemical issues. DCSs are also relevant for emergency training and damage instructor assistance purposes (Bulitko & Wilkins, 1999; Peters, Bratt, Clark, Pon-Barry, & Schul, 2004). The noteworthiness of these systems is proven by the number of leading market players (e.g. ABB, L3, Northrop Grumman, Rockwell, and Siemens) involved in the design and development of innovative solutions for damage control.

The assistance to damage control operators, with recommendations for counteractions and reconfigurations, requires a highly structured approach to problem identification and action planning. The field of expert and decision support systems can thus provide a relevant contribution to design more performing DCSs. However, the study of expert systems and DSS in navy contexts has mostly focused on the design process whereas a very limited number of contributions have addressed the implementation of integrated systems to ensure the safety and operational stability of modern ships.

In this paper, we show the development of a knowledge-based decision support system (KDSS) which has been integrated within the DCS designed for the operating needs of a national navy. We start from the analysis of the typical damage control process and identify a model of knowledge acquisition and reuse in damage management scenarios. The model is implemented through the development of a *kill card* function providing an interactive

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interface and a shared decision and action platform for damage control personnel onboard. The tool provides a graphical information-retrieval and equipment-control dashboard that gives damage crew the ability to handle various types of damage control situations.

The remainder of the paper is structured as follows: Section 2 reviews existing literature on damage control and DSS applications in the navy context; Section 3 introduces the research requirements and describes the overall architectural design; Section 4 illustrates the KDSS developed; Section 5 presents an illustrative application related to a fire-fighting scenario and proposes a preliminary evaluation of quali-quantitative benefits; Section 6 concludes the paper and draws avenues for future research.

2. Damage control and DSS

The concept of damage control is not limited to the navy industry. In fact, it is largely used in the field of medicine, surgery, and injury prevention as well as in project management, politics, media, and industrial production. In general, the term is used to describe the process of identifying, monitoring and dealing with any problem that may jeopardize a given system or endeavor.

A first area in which information and decision support systems have been developed for damage control purposes is the field of dynamic emergency response and resource intervention (Minciardi, Sacile, & Trasforini, 2007; Turoff, Murray, de Walle, & Yao, 2003). The use of expert systems and virtual reality to support decision making in emergency management situations has been also studied (Beroggi, Waisel, & Wallace, 1995; Caro, 1992). Other contributions have investigated the use of computer-based systems to support human improvisation in extreme events (Mendonca, 2007) and the inter/intra-organizational communication and coordination in emergency response (Kanno & Furuta, 2006). As a specific area of application, the response logistics to roadway network incident (Zografos, Androutsopoulos, & Vasilakis, 2002) has been studied. Besides emergencies, damage management has represented an area of interest for expert systems and neural networks in manufacturing and engineering contexts, with a focus on structural damage detection and assessment (Barai & Pandey, 2000; Jiang, Zhang, & Zhang, 2011; Mehrjoo, Khaji, Moharrami, & Bahreininejad, 2008; Ubeyli & Ubeyli, 2009).

Despite the relevance of the topic and the applicability of decision support and expert system principles, few contributions have instead focused on the development of intelligent systems for shipboard damage control. An effective damage control system (DCS) needs a systemic approach to realize key functions such as provide support to control personnel to make informed and real-time decisions, enhance total ship, coordinated, real-time control of men and equipment at the scene of damage, and allow changeover from remote-automated to local-manual control in case of emergency (Geer, 1988).

In the area of intelligent applications for shipboard damage control, an expert system was created to support the cognitive processes involved in ship piloting and collision avoidance (Grabowski & Wallace, 1993). With a more specific focus on damage management, a rule-based expert system based on information from navy damage control tactics, procedures, doctrine, and experts was presented (Tate, 1996). A fuzzy distributed expert system was built to assist command and control activities (Simoes-Marques & Pires, 2003) and a virtual environment has been developed to support emergency planning decisions by considering what could occur when fluids disseminate through ship compartments, such as flooding, fire, or contamination (Varela & Guedes Soares, 2007). Finally, an expert system was developed for ship auxiliary machinery troubleshooting (Cebi, Celik, Kahraman, & Deha Er, 2009).

The design and development of expert and decision support systems in ship contexts has been mostly focused on the design process (Park & Storch, 2002). Different contributions have addressed the aided design of ship systems automation (Arendt, 2004; Arendt & van Uden, 2011; Kowalski, Arendt, Meler-Kapcia, & Zielnski, 2001; Kowalski, Meler-Kapcia, Zielinski, & Drewka, 2005), the support of the conceptual design stage based on knowledge engineering (Lee, 1999; Lee & Lee, 1999), and the analysis of design problems and assessment of trade-offs between performance and cost (Chou & Benjamin, 1992). Two specific studies have developed an expert system to support compartment design of a crude oil tanker (Lee & Lee, 1997) and a DSS for vessel fleet scheduling (Fagerholt, 2004).

All these studies can provide a larger background to define the requirements for ship design, building and management, with the purpose to extend the research on decision support systems applied for ship personnel security and control of casualties to ship systems.

3. Overview of the DCS

The development of our KDSS was framed within a collaborative project with Avio SpA. This a leading company operating both in the aerospace propulsion (participates in military programs such as the F-35 JSF and civil partnerships with General Electric, Pratt & Whitney, and Rolls Royce) and in the marine industry for the provision of control, automation and propulsion systems and components (e.g. turbine control, lubrication and fuel systems). The company is a Marine System Supplier (MSS) of General Electric.

In the last years, Avio has worked in the development of innovative damage control systems (DCSs) for national navies. The DCS is a supervisor system embedded in the *Integrated Platform Management System* (IPMS), which is a distributed hardware architecture used for real-time monitoring of the ship propulsion, mechanical, electrical, auxiliary and damage control systems. Monitored components include gearboxes, pitch propellers, power generation sets, power distribution switchboards, electrical distribution centers, fire pumps, systems for heating, ventilation, air conditioning, chilled water, and so forth.

In practice, the IPMS controls all the onboard equipment, excluding weapons/sensors (for military ships) and the ship's communication and navigation equipment. The general IPMS architecture comprises *Multi-Function Consoles* (MFCs) and *Remote Terminal Units* (RTUs). MFCs are mostly laptops and workstations providing the human–machine interface for the operators at various shipboard locations whereas RTUs are used for data acquisition and control and they are connected to sensors and actuators (e.g. FDS – *fire detection sensors, pumps, fans*). The IPMS is endowed with a runtime application allowing to monitor the whole ship from each MFC.

Whereas the IPMS represents the hardware backbone for damage control operations, the DCS is the software platform configured within the IPMS with functions such as monitoring of ship subsystems, longitudinal, planar and isometric views, Tiled Layered Graphics (TLGs) approach (for automatic de-cluttering and display of complex information), casualty management, support to manage emergency states, event log and report, and compartment monitoring.

These functionalities are integrated into four modules: (1) *Damage Control Management System* (DCMS), which enables to automatically acquire all the relevant ship safety and other data needed to handle damages, display data to the operator in an optimized way, handle alarms, and rapidly share/communicate the information between the different MFCs; (2) *On Board Stability Software* (OBSS), to obtain and visualize ship stability data (e.g. tanks