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Integrating Human Factors & Ergonomics in large-scale engineering projects: Investigating a practical approach for ship design

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A B S T R A C T

The human element is a critical component of safe and efficient shipping operations but has struggled to gain comprehensive acceptance across the industry. This investigation explores a practical approach to introduce Human Factors and Ergonomics knowledge early in ship design by utilizing general arrangement drawings as a common platform for stakeholder input throughout ship development. An onboard data collection was completed using a cargo ship and its crew as a case study. A comparative analysis between the ship's two-dimensional general arrangement drawings from which the structure was built, and the constructed onboard work environment was performed. Additionally, the engine crew was job-shadowed and interviewed to gain insight into their work demands and movement within the space. General arrangement drawings were found to be incomplete and when directly compared to a finalized product indicated inaccuracies in design and work environment characteristics, making comprehensive human element evaluations difficult. However, general arrangement drawings were found advantageous in mapping and visualizing logistical routing which can be evaluated early in ship development, positively contributing to crew operations once a ship is constructed. Solving the rudimentary design concerns engine crew struggle with earlier in ship design will provide a better foundation for increasingly detailed development.

Relevance to industry: This research investigates a design approach which integrates Human Factors and Ergonomics knowledge in a pragmatic, resource-efficient manner which can positively impact onboard crew operations. An integrative design approach is necessary for widespread acceptance and adoption of human element considerations within naval architecture design and construction methodologies.

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1. Introduction

The maritime shipping domain is one of the world's oldest and truly international industries, continuing to globalize our society and economies (Bloor et al., 2000; Stopford, 2009). Seafaring is a safety critical domain and has a long history of shipwrecks and disasters. There is a cultural association and acknowledged acceptance of relatively high levels of risk compared to other industries (Bloor et al., 2000; Hetherington et al., 2006; Håvold, 2005). Over the past several decades growing importance has been placed on the role of the human within shipping operations and the benefit of integrating Human Factors and Ergonomics (HF&E) within ship design to contribute to overall safety and efficiency (International Maritime Organization [IMO], 1997, 2006a, 2006b; Maritime Coastguard Agency, 2010). HF&E integration is a particular challenge in the mercantile shipping domain due to the competitive globalized market and a drive for lean economic manufacturing and operating models. This is attributed to, amongst other issues, the difficulty in demonstrating the cost-savings and benefit derived through HF&E practices (Beevis, 2003; Hendrick, 2003; Koningsveld et al., 2005).

Ship design and construction are extensive engineering processes with well-established industry traditions and methodologies. For HF&E to be utilized early and continuously during ship design and construction, methods need to be created and marketed to naval architects and marine designers which are user-friendly, demonstrate cost-efficiency and are easily integrated throughout a project. HF&E has yet to find this balance in ship design and construction, failing to gain widespread organized application and acceptance. Shipping companies are consistently reducing crew in favour of automation in order to cut operational costs. Crew

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downsizing, which alters work demands and organization emphasizes the need to have well designed ships for the reduced onboard personnel operating the vessel (Archer et al., 1996; Barnett et al., 2005; Grabowski and Hendrick, 1993; Grech et al., 2008).

2. Background

2.1. Ship procurement

The procurement of a new ship is a large-scale, multi-disciplinary project which can span years from initial concept to deployment (Rawson and Tupper, 2001; Veenstra and Ludema, 2006). With the opening of international marketplaces, increased domain specialization and economic competition, ship design and construction processes are often split between numerous stakeholders and geographical locations (Stopford, 2009). Marine structural design is dependent upon the purpose and demands specified by stakeholders, and the requirement criteria set by respective regulatory bodies (Schneekluth and Bertram, 1998).

2.1.1. Design methodologies & general arrangement development

The complexity and scale of a new ship design project requires a comprehensive and proactive approach throughout development in identifying inter-dependencies and associated risks (Chalfant et al., 2012). Ship design and construction are seemingly exclusively engineering and economic processes. However, the overall project involves strong skills and organization in project management, teamwork, communication, business, economics, art, creativity, leadership and domain experience (Rawson and Tupper, 2001).

While there are many differing project management methodologies used for ship development, they follow an approach generally divided into two broad phases (i) basic design and (ii) detailed design (Molland, 2008). The basic design stage develops principle ship dimensions and power requirements that will satisfy the ship's defined performance and techno-economic prerequisites (Molland, 2008). As the design and project progresses from initial general requirements and purpose, basic design evolves into increasingly detailed variables which are introduced and evaluated iteratively throughout the process (Evans, 1959; Lyon and Mistree, 1985; Mistree et al., 1990; Han et al., 2014). After being introduced with the general purpose and specifications, naval architects begin rough sketches or “thinking sketches” to pictorially represent and communicate their ideas (Pawling and Andrews, 2011). Sketching is used to externalize ideas and develop new ideas to understand a coherent whole (Fallman, 2003) and may take place first with pencil and paper or immediately using computer-aided design (CAD) software. Sketches and concepts evolve through reiterative cycles into more concrete and complete drawings of a ship's layout and general arrangement (GA). GA drawings illustrate the basic physical dimensions and layout of a ship, including side and cross-sectional views of the different compartments, location and arrangement of bulkheads, superstructures and major equipment (van Dokkum, 2011). The greatest influence on designers formulating a GA is how to best achieve a ship's predefined purpose, deadweight, capacity and speed requirements (Watson, 1998). Ship designers are primarily concerned with ship powering, stability, strength and seakeeping, with less focus and importance placed on the end-users who will eventually operate the constructed ship (Andrews et al., 2008).

Ship designers rarely spend time onboard ships at sea and seldom have the opportunity of forming an understanding of the real working conditions and demands of crew during ship operations (Chauvin et al., 2008). In recent years, ship computerization and automation have been related to a concurrent reduction in onboard crew, changing operational tasks and work organization (Archer et al., 1996; Barnett et al., 2005; Bloor et al., 2000). The addition of new technologies to work systems can create unintended alterations in original work processes for end-users (Barnett et al., 2005; Cook and Woods, 1996; Ivergård and Hunt, 2009; Woods and Dekker, 2000). Recent research has investigated the challenging work environments and dangers crew face onboard contemporary ships, revealing that ship design does not optimally support their operational demands (Forsell et al., 2007; Grech et al., 2008; Lundh et al., 2011; Nielsen and Panayides, 2005; Orosa and Oliviera, 2010). Ship designers are removed from how their conceived end-products are actually used in the real world. With continually evolving technologies and evolving ship operational procedures, designers who are disconnected from the realities of onboard demands will never be able to visualize nor create a ship optimized for the capacities of the end-user.

2.2. HF&E integration in ship procurement

Human-centred design requires integration between the human, machine(s) and work environment (International Organisation for Standardization, 2000). The benefits of thoughtful human-centred design should increase productivity, reduce errors, reduce training and support, improve user trust and enhance system reputation (Maguire, 2001). HF&E participation can facilitate overall system design outcomes, improve project management resources and improve lifecycle cost-savings (Hendrick, 2008). Effectively integrating HF&E into engineering projects such as ship development can be challenging and stakeholders may not realize or understand the full potential of HF&E. The value of HF&E is often questioned by the design community, thus it is important to identify the source of significant cost-savings and human performance benefits due to an HF&E intervention in design (Stanton and Young, 2003). Hendrick (1996, 2008) notes that “good” HF&E is not only appropriately applied knowledge, but also cost-effective.

The earlier HF&E is utilized in a project the better guidance it can give in identifying the most appropriate design (Stanton and Young, 2003). HF&E professionals should be involved as early as the request for authorization to build a new ship, before concept brainstorming begins (Chauvin et al., 2008). Decisions made early in the design process can have large impacts on functionality which cannot necessarily be identified or understood until the design and project progresses (Kassel et al., 2010). In reality, designers place little attention and value on HF&E in ship design and if considered at all are generally late in the development process (Andrews et al., 2008; Dul and Neumann, 2009). Thus, HF&E application must then be made within the overall design constraints of a project, after resources have been allocated and strategic decisions have been made. This leads to a focus on micro-ergonomic solutions within the established design, while larger perspective ergonomic issues, such as personnel movement, cannot be effectively addressed or altered so far into the process (Andrews, 2006).

The later HF&E is applied in a project timeline the less effective its impact on design is, while subsequent changes become increasingly expensive (Alexander, 1999; Dul and Neumann, 2009; Miles and Swift, 1998). Additionally, once in operation, crew devise ways to “work around” poor design solutions in order to increase work efficiency and mitigate the negative impact of poor design on their work tasks. Engaging in this practice can encourage unsafe work procedures, putting engine crew, other ship personnel, passengers, assets and the external environment at risk (Forsell et al., 2007; Lundh et al., 2011). Thus, optimal design of a ship's work environment incorporates knowledge of end-user work demands and tasks that facilitate work efficiency, system usability and safety.

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