Reliability Engineering and System Safety 159 (2017) 283–300

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Enhancing human performance in ship operations by modifying global design factors at the design stage

Jakub Montewka[a,b,c,*], Floris Goerlandt[a], Gemma Innes-Jones[d], Douglas Owen[d], Yasmine Hifi[e], Romanas Puisa[e]

[a] Aalto University, Department of Applied Mechanics, Marine Technology, Research Group on Maritime Risk and Safety, 02150 Espoo, Finland
[b] Finnish Geospatial Research Institute, 02430 Masala, Finland
[c] Gdynia Maritime University, Faculty of Navigation, Department of Transport and Logistics, 81-225 Gdynia, Poland
[d] Lloyd's Register, EMEA, Bristol, UK
[e] Brookes Bell R & D, Glasgow, UK

ARTICLE INFO

Keywords:
Human performance
Ship design
Collision
Grounding
Bayesian Belief Networks

ABSTRACT

Usually the improvements of human performance in the course of ship design process is carried out by modifying local ergonomics, like electronic visualisation and information display systems on the bridge or in the engine control room, stair or hatch covers design. However, the effect of global design factors (GDFs), such as ship motion, whole body vibration and noise, on human performance has not been given attention before. Such knowledge would allow the improvements of human performance by effective design modification on very early stage of ship design process.

Therefore, in this paper we introduce probabilistic models linking the effect of GDFs with the human performance suitable for ship design process. As a theoretical basis for modelling human performance the concept of Attention Management is utilized, which combines the theories described by Dynamic Adaptability Model, Cognitive Control Model and Malleable Attentional Resources Theory.

Since the analysed field is characterised by a high degree of uncertainty, we adopt a specific modelling technique along with a validation framework that allows uncertainty treatment and helps the potential end-users to gain confidence in the models and the results that they yield. The proposed models are developed with the use Bayesian Belief Networks, which allows systematic translation of the available background knowledge into a coherent network and the uncertainty assessment and treatment.

The obtained results are promising as the models are responsive to changes in the GDF nodes as expected. The models may be used as intended by naval architects and vessel designers, to facilitate risk-based ship design.

1. Introduction

Reduced human performance is reported as one of major factors contributing to the maritime accidents, [1–4]. In the recent years the studies related to the quantification of human performance for various shipborne operations have been gaining an increasing attention, resulting in a number of models and approaches, see for example [5–8] . At the same time, significant efforts have been made to study and implement local design modifications of ships improving the ergonomics thus human performance on board a ship and ultimately ship safety, [9–13].

A major recent advance in the field of maritime safety is the development of risk-based ship design methodology (RBSD), resulting in development of larger and potentially safer ships, [14,15]. Within RSBD the assessment of the risk level with respect to predefined types of accidents is conducted in the early design stage, where a design modification is easy and cost-effective and risk is treated as a design objective, [12]. In risk analysis two aspects of the analysed accident are covered, its likelihood (accident prevention) and the anticipated consequences (accident mitigation). The latter is addressed by improving technical and structural reliability of a ship and it has been extensively studied over past years, [16–20]. The former is addressed usually by improving performance of a human, however the research on the effect of the overall ship design on human performance is in its infancy, [21–24], despite its relevance to the field of ship design, [25]. Such a method could be incorporated into the RBSD, improving human performance through modification of appropriate global design factors (GDFs), thus reducing the risk of accidents already at the early design

* Corresponding author at: Aalto University, Department of Applied Mechanics, Marine Technology, Research Group on Maritime Risk and Safety, 02150 Espoo, Finland.

http://dx.doi.org/10.1016/j.ress.2016.11.009
Received 9 February 2016; Received in revised form 26 August 2016; Accepted 17 November 2016
Available online 23 November 2016

Nomenclature

AMC	Attention Management Capability
AH	Alternative Hypothesis
BBN	Bayesian Belief Networks
CCM	Cognitive Control Model
DAAct	a triplet of Detection, Assessment, Action
APOA	Assessed Proportion of Affect
DAM	Dynamic Adaptability Model
EPC	Error Producing Conditions
GDFs	Global Design Factors (noise, whole body vibration, motion)
GTT	Generic Task Type
HEP	Human Error Probability
HRA	Human Reliability Assessment
MART	Malleable Attentional Resources Theory
MII	Motion Induced Interruptions
MIS	Motion Induced Sickness
NARA	Nuclear Action Reliability Assessment
OOW	Officer Of the Watch
RBSD	Risk-Based Ship Design
SCT	Safety Critical Tasks
WBV	Whole Body Vibration

stage.

However, the possible risk reduction remains unknown until now, since the common human error quantification frameworks do not readily account for the specific effect of the GDFs.

Therefore, this paper presents advances, focusing on modelling the effect of GDFs on human performance which is measured with the probability of ship-ship collision and ship grounding, which in turn is a recognized proxy for risk in the RBSD process and can easily be incorporated therein.

As a results of extensive literature survey on the effects of human exposure to the following three GDFs: ship motion, noise and vibration see [24–26] a workable approach has emerged for modelling human performance focussing on attention management, which is found suitable for the given purpose. It is based on three theories: the Dynamic Adaptability Model, [29] Cognitive Control Model [30] and Malleable Attentional Resources Theory [31].

These foundations are used as a guide for constructing two models presented here, which are developed using Bayesian Belief Networks (BBNs). BBNs is capable of representing background knowledge about the analysed accidents, the evaluation of associated uncertainties, efficient reasoning and updating in light of new evidence, see for example [6,32–37].

Finally the models are validated adopting a framework as proposed by [38], which is found suitable for a given purpose, [39]. The framework allows for rigorous checks of the models along with the evaluation of uncertainty. As result, the models are found to behave in response to GDF inputs as intended, and the obtained results are found valid for a given purpose. The models can offer a valid comparative assessment of ship designs with respect to human performance, which is their primary intention.

The remainder of the paper is organized as follows: Section 2 introduces the modelling framework, upon which the human performance models are developed. The models development process is presented in Section 3. Section 4 discusses the validation of the models and Section 5 concludes the paper.

2. Structure of the models

The aim of the presented models is two-fold. First they quantify the human performance in the presence of motion, noise and whole body vibration that are specific for each ship designs. Second they allow differentiation of various ship designs with respect to the human performance.

In this section we introduce a modelling framework adopted here that fits requirements of RBSD and recommendations by IMO regarding human performance modelling in maritime [40]. Subsequently the causal pathway linking the GDFs with human performance is described.

2.1. Modelling framework

To develop the models we adopt a generic modelling framework by

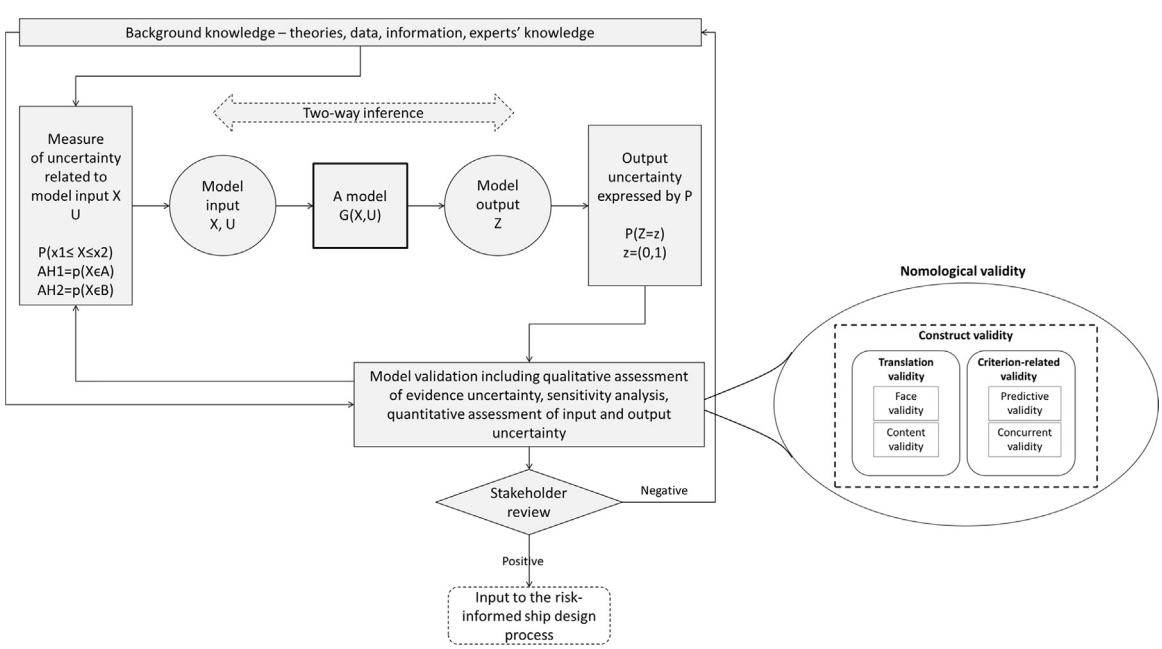

Fig. 1. A modelling framework adopted for human performance evaluation subjected to GDFs, suitable for risk-informed ship design.