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ScienceDirect
Reliability Engineering and System Safety 93 (2008) 823–834
RELIABILITY ENGINEERING & SYSTEM SAFETY
www.elsevier.com/locate/ress

A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation

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Received 26 September 2006; received in revised form 19 March 2007; accepted 21 March 2007
Available online 1 April 2007

Abstract

The paper presents an innovative approach to integrate Human and Organisational Factors (HOF) into risk analysis. The approach has been developed and applied to a case study in the maritime industry, but it can also be utilised in other sectors. A Bayesian Belief Network (BBN) has been developed to model the Maritime Transport System (MTS), by taking into account its different actors (i.e., ship-owner, shipyard, port and regulator) and their mutual influences. The latter have been modelled by means of a set of dependent variables whose combinations express the relevant functions performed by each actor. The BBN model of the MTS has been used in a case study for the quantification of HOF in the risk analysis carried out at the preliminary design stage of High Speed Craft (HSC). The study has focused on a collision in open sea hazard carried out by means of an original method of integration of a Fault Tree Analysis (FTA) of technical elements with a BBN model of the influences of organisational functions and regulations, as suggested by the International Maritime Organisation's (IMO) Guidelines for Formal Safety Assessment (FSA). The approach has allowed the identification of probabilistic correlations between the basic events of a collision accident and the BBN model of the operational and organisational conditions. The linkage can be exploited in different ways, especially to support identification and evaluation of risk control options also at the organisational level. Conditional probabilities for the BBN have been estimated by means of experts' judgments, collected from an international panel of different European countries. Finally, a sensitivity analysis has been carried out over the model to identify configurations of the MTS leading to a significant reduction of accident probability during the operation of the HSC.

Keywords: Bayesian Belief Network; Risk analysis; Human and organisational factors; Maritime industry

1. Introduction

Despite the remarkable effort performed at different levels to achieve a safe Maritime Transport System (MTS), the occurrence of accidents and incidents at sea is still increasing. Statistics published by the European Transport Safety Council [1] reveal that in Europe maritime accidents are responsible yearly for 140 deaths and 1.5 billion € of goods loss and damages. Globally, the MTS is responsible for 0.33 deaths per 100 million person-km, 4 times riskier than the air transport system, that accounts for 0.08 deaths per 100 million person-km. Grounding (32%), striking (24%) and collision (16%) are the most frequent occurrences and they have the highest rate of casualties.

It is widely recognised that the human element plays the major role in most accidents involving modern ships. Thus, the Lord Carver report of the UK House of Lords summed it up succinctly when stating that it "is the received wisdom that four out of five ship casualties [...] are due to human error [...]". Also national statistics shown in Fig. 1 (Transportation Safety Board of Canada [2]), attribute 74% of the accidents at sea to human errors and only 20% to technical failures. As shown in Fig. 2, 45% of the accident reports assess the misjudgement (mistake) of ship masters and pilots as predominant causes; in another 42% of cases human errors refer to lack of comprehension between the pilot and the master, inattention of the pilot and of the officer of the watch (OOW) or lack of communication among crew members.

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doi:10.1016/j.ress.2007.03.035

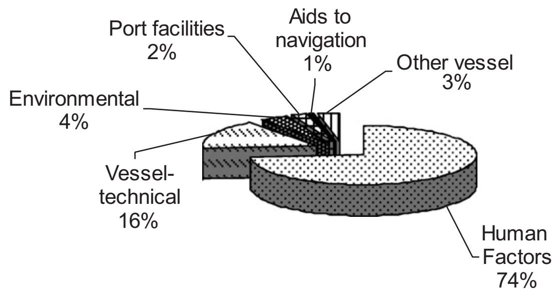

Fig. 1. Main causes of accidents at sea.

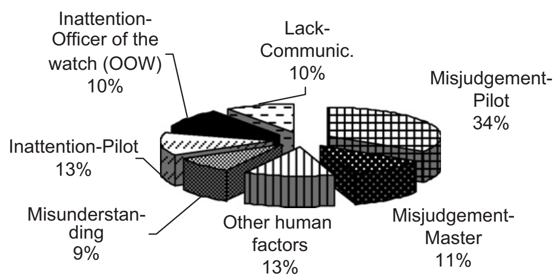

Fig. 2. Types of human errors in accidents at sea.

Similar results are pointed out by a statistical analysis based on data of the Lloyds Informative Maritime Service [3] concerning more than 15,000 accidents in a time span of 10 years. Lloyds' statistics show that an uncorrected course and an excessive speed with respect to the traffic in the sea zone are responsible for about 50% of all the maritime accidents, particularly groundings. Moreover, 70–80% of the accidents are due to human mistakes or other events attributed to the human behaviour.

While technical solutions will continue to play an important role, there is widespread agreement that the key means of tackling the human element contribution to accidents will be via safety management, including inspection and training.

Starting with a deeper understanding of the role of the human element in the safety performance of maritime transport, a new issue is emerging; indeed, the official report concerning the Zeebrugge incident (capsizing of a passenger ship) [4] already pointed out that it was not due to a coincidence of independent technical failures and human errors, but a systematic change in the organisational behaviour of operators under the influence of economic pressure in a strongly competitive environment. Thus, a systematic safety analysis of the MTS needs to be enlarged to include interactions and effects of decisions taken by various actors of the MTS, and workplace and context conditions, including the economic pressure affecting the maritime sector.

Various parties (operators, shipyards, regulators and government) in their respective working contexts are very often involved in a sequence of events leading to an accident; this is the most critical issue in developing an effective risk or accident analysis. The error of the operator onboard a ship is only the final act of a long and complex chain of organisational and systemic errors (i.e. the so-called latent failures). Rasmussen highlighted the conflicting interactions between parties in MTS, evidenced by his accident analysis of oil tankers and ferryboats [5–7].

The need for a systemic approach to analyse the MTS safety is therefore clear, not only focused on mistakes and violations of the operators, but also aimed at finding, if they exist, the causes at the various levels of the socio-technical system, which competes for determining the accidents. The International Maritime Organisation (IMO) provides a rational and systematic approach for assessing risk in shipping activity: a comprehensive model is suggested to take into consideration different influences with an impact on the technical and engineering system of a ship. In fact the Formal Safety Assessment (FSA) describes a generic model (shown in Fig. 3) that considers the ship's technical and engineering system, in the centre of the model, as related to the functions representing the passengers and crew behaviour that subsequently is influenced by management and the organisational structure; finally, the model shows the outer influence of the environmental context that represents the influences of all parties interested in shipping. Each subsystem is dynamically affected by the others both directly and indirectly; a complex model is requested to represent these relationships between variables of each subsystem.

This approach and the necessity of incorporating human reliability analysis into the FSA process [8], suggests the use of a Risk Contribution Diagram (RCD) for modelling the network of influences on an event in a complex system [9] as development of Risk Contribution Tree (RCT) described by FSA: this method allows the linkage between failures at the operational level with their direct causes, and the underlying organisational and regulatory influences.

Also Bayesian Belief Network (BBN) [10] has been used for the purpose of integrating the analysis of human and hardware failures and reflecting the hierarchical nature of influence domains. Thus the BBN model can be regarded as a RCD in which the effects of such factors are represented in terms of conditional probabilities. Moreover, from a risk reduction standpoint, the European Commission (EC) funded a project, called S@S—Safety at Speed [11]—to develop a Functional Model (FM) of the MTS. The FM helps in identifying the critical interactions among actors that

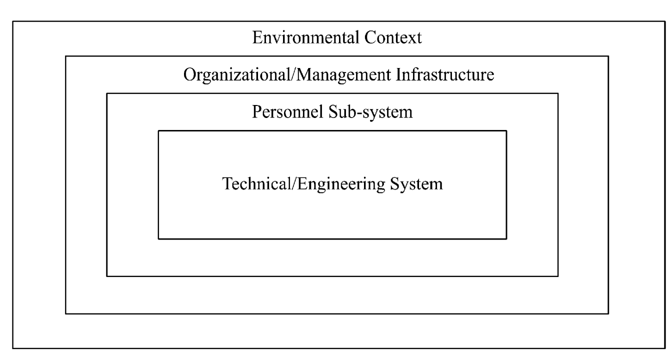

Fig. 3. Components of the integrated system for application of the Formal Safety Assessment (FSA) [8].