Reliability Engineering and System Safety 118 (2013) 93–105

Contents lists available at SciVerse ScienceDirect

Reliability Engineering and System Safety

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

Incorporation of formal safety assessment and Bayesian network in navigational risk estimation of the Yangtze River

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ARTICLE INFO

Article history:
Received 23 May 2011
Received in revised form
1 March 2013
Accepted 10 April 2013
Available online 25 April 2013

Keywords:
Maritime safety
Formal safety assessment (FSA)
Bayesian network
Risk matrix
Yangtze River

ABSTRACT

Formal safety assessment (FSA), as a structured and systematic risk evaluation methodology, has been increasingly and broadly used in the shipping industry around the world. Concerns have been raised as to navigational safety of the Yangtze River, China's largest and the world's busiest inland waterway. Over the last few decades, the throughput of ships in the Yangtze River has increased rapidly due to the national development of the Middle and Western parts of China. Accidents such as collisions, groundings, contacts, oil-spills and fires occur repeatedly, often causing serious consequences. In order to improve the navigational safety in the Yangtze River, this paper estimates the navigational risk of the Yangtze River using the FSA concept and a Bayesian network (BN) technique. The navigational risk model is established by considering both probability and consequences of accidents with respect to a risk matrix method, followed by a scenario analysis to demonstrate the application of the proposed model.

1. Introduction

The Yangtze River has become the world's busiest navigable inland waterway, according to People's Daily of August 30, 2010 [1]. The number of the foreign ships sailing through the Yangtze River has increased sharply from an average of hundreds per year in the 1970s to an average of hundreds per day in the 2010s, mainly due to China's opening up policy.

The increase of the traffic in the river has also seen an growth in accidents such as collisions, groundings, contacts, oil-spills and fires, causing serious consequences to the sustainable development of the Yangtze River. Greater attention has therefore been paid to the safety assessment of the Yangtze River from government, industry and academics.

1.1. Maritime risk assessment of the Yangtze River

A management mechanism of emergency response has been established by Chang Jiang Maritime Safety Administration (MSA) in order to minimise the consequences of maritime accidents [2], while various methods such as Analytic Hierarchy Process (AHP), grey synthetic evaluation, fuzzy mathematics and Formal Safety Assessment (FSA) have been introduced to investigate the occurrences of accidents. Previous studies include the following:

Zhang et al. [3] established a model for navigational risk assessment using the AHP approach. Yang [4] evaluated the risk level in a typical confined channel of the Yangtze River based on the grey synthetic evaluation. A FSA method was applied by Gao [5] to estimate the risk in a multi-bridge waterway. Several approaches including AHP, fuzzy mathematics and FSA, were demonstrated by Qin [6], dealing with various maritime safety issues.

The above studies have identified the main hazards and several measures to control the navigational risk of the Yangtze River. However, these risk analysis studies are mainly based on subjective data with expert judgements or questionnaires used. Furthermore, while quantitative methods have become more and more popular in maritime risk assessment and the FSA approach is highly appreciated worldwide, few researchers have made use of the strengths of both approaches together. Lastly, none of the above publications consider risk probability and consequences simultaneously.

Therefore, this study estimates the navigational risk of the Yangtze River using a quantitative method, Bayesian network (BN) incorporating both objective and subjective data, in line with the FSA concept.

1.2. FSA framework

In 2002, a FSA framework, proposed by the UK Maritime and Coastguard Agency (MCA) was approved by the International

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http://dx.doi.org/10.1016/j.ress.2013.04.006

Nomenclature

ALARP	As low as reasonably practicable
BN	Bayesian network
CPT	Conditional probability table
FSA	Formal safety assessment
IWTS	Inland water transportation system
MSA	Maritime safety administration
PSA	Parameter sensitivity analysis
RCOs	Risk control options
SCFs	Safety critical factors
CoA	Consequences of accident
PoA	Probability of accident

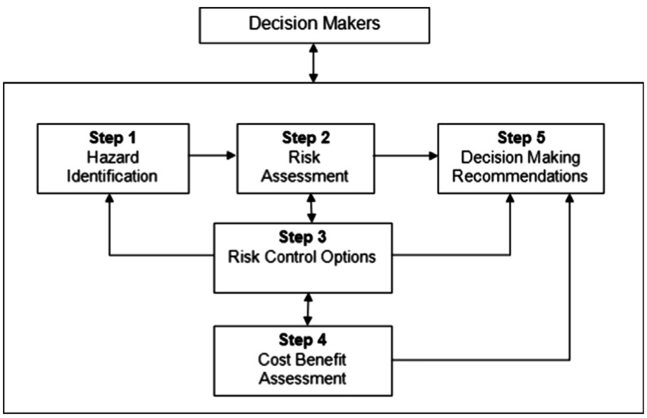

Fig. 1. FSA framework.

Maritime Organization (IMO, 2002) as a formal policy making tool, consisting of the following five steps:

1) The identification of hazards.
2) The assessment of risks associated with those hazards.
3) Ways of managing the risks estimated.
4) Cost benefit assessment of the risk control options (RCOs).
5) Decisions on which options to be selected.

The logical structure of FSA is shown in Fig. 1·[7].

FSA is a proven approach to marine safety which involves using the techniques of risk and cost–benefit assessment to assist in making decisions. It has been applied to many aspects of world-wide maritime systems [8–14], however few of its applications are in the Yangtze River and most of them use qualitative judgement only. For example, the work in Gao [5] briefly discusses the risks in a multi-bridge waterway using the FSA method and provides a few risk control suggestions for safety management.

1.3. Paper origins

The Inland Waterway Transportation System (IWTS), is a low energy consuming and low air pollution transportation method, but the increasing national concern as to the safety and efficiency of the 2838 km navigable waterway of Yangtze have to be addressed. Though FSA has been acknowledged as one of the proven methods in maritime risk analysis, a literature search shows that few of its applications are in the IWTS and even fewer have been combined with quantitative risk analysis methods. In view of such findings, this paper incorporates the FSA method and BN technique in an estimation of navigational risk in order to create a basis for the stake holders to make rational risk-based decisions and thus enhance the navigational safety of the Yangtze River.

This paper will focus on the application of the first route of the FSA framework (including Steps 1, 2 and 5) to the Yangtze River. The risk influencing factors which could cause or substantially contribute to a major accident are defined as Safety Critical Factors (SCFs). They will be identified with reference to historical data statistics, followed by accident consequences modelling based on a data-based BN process. Finally, the navigational risk of the Yangtze River will be modelled in a BN in accordance with a typical risk matrix, considering both consequences and probability of the navigational risk. The following section will start the procedure with hazard identification.

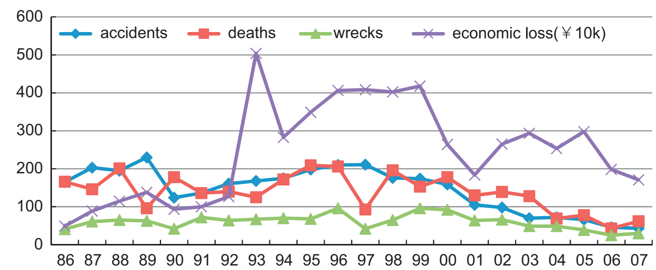

Fig. 2. Shipping accident statistics in research area, Chang Jiang MSA [15].

2. Hazard identification

This section is developed based on the database of the accidents that happened between 1986 and 2007 in the Yangtze River [15]. During the 21 year period, 3180 accidents occurred, resulting in 3053 fatalities, 1288 wrecks and more than 540 million Yuan direct economic loss.

2.1. Statistical indicators

The numbers of accidents, fatalities, wrecks and direct economic loss are selected as the four main statistical indicators as used by the Ministry of Transport, China (previously named as Ministry of Communications until 2008).

Fig. 2 shows that these four indicators fluctuated over a period of 30 years, although an obvious drop can be recognised around the start of the 21st century. Since then the number of accidents, fatalities and wrecks has generally declined. However, the economic loss remains at a certain level, possibly because of the larger size of ships involved.

2.2. Accidents categories

The accidents have been categorised into seven classes according to the Water Transportation Accident Statistics from the Ministry of Transport, China [16], namely, collision, grounding, contact, swell damage, wind damage, fire and others. Their individual shares/percentage in terms of accident numbers in the past years from 1986 to 2007 are shown in Table 1.

Collisions, contacts and groundings made the most contribution with the percentage of 49%, 21% and 15%, respectively (all together up to 85%), whereas wind damage, fire and swell damage were comparatively trivial.