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Reliability estimation of maritime transportation: A study of two fuzzy reliability models

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ABSTRACT

The progressive increase in marine vessel transportation, in recent years, is often a cause of congestion at sea and main cause of highly irregular vessel's travel time. This greatly affects scheduling of the facilities at the harbor and also related logistics. As a result, the reliability value of any marine vessel becomes a crucial factor in associated decision making. Modeling the uncertainty in estimation of marine vessel reliability has been a research interest for quite some time now. This paper investigates the problem in a different sense and tries to model the uncertainties using expert's opinions and their imprecise responses. Marine vessel transportation reliability is viewed in an entirely different perspective and framework. This paper initially proposed a transportation reliability estimation procedure considering 12 decision variables divided into three stages. Two realistic models based on fuzzy sets are subsequently developed; with two scenarios for the first model. The first model utilizes fuzzy arithmetic; whereas the second one is based on rule bases. The paper demonstrates how information based on experience of the experts on marine vessels could be used to obtain its reliability value. Both the models would be helpful where imprecision is an intrinsic attribute of the accessible data in case of sea going vessels.

1. Introduction

Risk and reliability are significant operational issues of any transportation system. Sumalee and Kurauchi (2006), in a guest editorial of a special issue of Networks and Spatial Economics Journal focused on the reliability and emergency issues in transportation network analysis. In view of stringent international statutory requirements in the maritime transport segment, risk appraisal has become an important managerial tool for making critical decisions. Growing concern about the accidents, disasters and resulting environment impact has forced the attention on the hazards and associated risks involved in all the activities of every transportation system. Nowadays, a wide range of approaches and methods are available to estimate the risk and reliability. Both these are concerned with safety aspect of the system. Improved safety performances as regards to safety of the people, equipments and machineries, and protection of the environment are the prime aims. Risk and reliability assessment also helps in assessing the system's operational performance measures and life cycle costing. It as well aids in optimizing various processes in the system. Risk management approaches have been universally adopted in the maritime transportation sector with the key objective of providing improved safety and enhanced protection to the environment. Development of risk-based practices, over the years, addressed both quantitative and qualitative techniques, suitable for investigation in diverse applications and purposes.

Recently, Celik et al. (2010) developed a risk based modeling approach to enhance the execution process of shipping accident investigation. Specifically, the paper addressed a fuzzy extended fault tree analysis that combined the effects of organizational faults and shipboard technical system failures under a unique risk assessment scheme. Balmat et al. (2009) presented a fuzzy approach for the MAritime RISk Assessment (MARISA) applied to safety at sea. In this analysis, a fuzzy risk factor composed of a static risk factor and a dynamic risk factor has been considered. In a recent paper, (Balmat et al., 2011) developed a decision-making system to maritime risk assessment. Ren et al. (2009) proposed an offshore risk analysis method using fuzzy Bayesian network. Yang et al. (2009b) suggested a subjective security-based assessment and management framework for maritime security using a fuzzy evidential reasoning approach. Additional recent papers in risk assessment and safety in maritime transportation include (Eleye-Datubo et al., 2008; Hu et al., 2008; Koç, 2009; Liu et al., 2008a;

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Ting-rong et al., 2008; Yang et al., 2009a). Hadjimichael (2009) and Shyur (2008) studied risk assessment in aviation industry. Furthermore, other research investigations in marine transportation systems are (Grabowski et al., 2007; Kolowrocki and Soszynska, 2006; Kolowrocki et al., 2007; Liu et al., 2005; Sii et al., 2001; Wang, 2006; Wang et al., 2004).

The notion of the travel time reliability researched in transportation means, mostly rail and road transport, provided a diverse perspective in this area. Chang (2010), in his recent work, considered a way of assessing travel time reliability in transport appraisal and discussed two requirements for the evaluation and guidance of the appraisal. The requirements represented the measurement and valuation of travel time uncertainties. The gap between actual and planned journey times is used for the quantification and logic based choice model is developed to derive monetary values of travel time variation. Fosgerau and Karlstrom (2010) obtained the value of reliability in the scheduling of an activity of random duration i.e. travel under congested conditions. Hollander and Liu (2008) examined the methodological, statistical and computational aspects of estimation of travel time distribution by repeated simulation; while the paper (Margulici and Ban, 2008) recommended methodology for benchmarking the travel time estimates. Prabhu Gaonkar et al. (2011) presented a methodology of maritime transportation system reliability evaluation by the application of fuzzy sets and fuzzy logic techniques. Prabhu Gaonkar et al. (2013) considered the maritime travel time reliability in a possibilistic manner, and then the reliability optimization problem with budgetary constraints and stage-time limitations is formulated and solved. Contributions in similar direction in the literature are (Al-Deek and Emam, 2006; Batley, 2007; Ettema and Timmermans, 2006; Li et al., 2010; van Lint, 2008; van Lint et al., 2008; Wu et al., 2008) and Tzannatos (2005) looked into technical reliability of the Greek coastal passenger fleet. Fang and Das (2005) studied the survivability and reliability of damaged ships after collision and grounding.

All the above literature citations explored and examined the diverse facets of risk, safety and reliability quantitatively and qualitatively. This paper uses fuzzy sets approach in estimating maritime transportation reliability, which is quite different and not yet explored by the researchers working in this field. The paper looks into the problem in a different way. Firstly, it considers the uncertainties in variable data values demanded for estimating transportation reliability of marine vessel or ship in a sort of qualitative manner. Secondly, the variables are modeled using expert's opinions and their imprecise responses. Section 2 explains the perspective of the term reliability in context with maritime transportation, as presumed in this paper. Reliability estimation procedure is stated in the same section. Two models based on the fuzzy sets are developed in Section 3. Two different scenarios for the first model have been formulated. Fuzzy set and fuzzy logic concepts are used as part of the model solution process. This novel work, in fact elucidates that the information based on experience of the experts on marine vessels could be used to find out its reliability value. The models would be helpful where imprecision is an intrinsic attribute of the accessible data in case of sea going vessels.

2. Marine vessel transportation reliability

Fuzzy reliability developed at the end of the last century has grown multifold and has numerous directional facets in its application. Various current advancements in the fuzzy reliability theory include (Gholizadeh et al., 2010; Huang et al., 2006; Liu et al., 2007; Liu et al., 2008b; Marano and Quaranta, 2010; Rotshtein, 2010; Viertl, 2009; Zhang and Huang, 2010). The marine vessel transportation reliability has been viewed in a different perspective and is modeled on the basis of qualitative variables in this paper. The subjective linguistic nature of the variables and acquisition of the same from the expert's responses necessitated the modeling and estimation in the form of fuzzy reliability.

Marine vessel transportation reliability is considered specifically with respect to three aspects: intended mission completion, timeliness and safety of the mission. These aspects depend on several decision variables and may vary as per the analysts. However, 12 most suitable decision variables have been considered in three stages, as given in Table 1. The categorization in these three stages scales down the problem to the smaller magnitude and also matches to the three aspects of the transportation reliability to a modest extent. These decision variables are finalized based on the experienced personnel working in marine transportation environment. Table 1 also shows the scale and the range of values that a variable can take. The linguistics terms defining the range of the variables have been stated later during second model development process.

The two models developed in this paper use similar reliability estimation procedure. It is depicted in Fig. 1. As seen, there are four levels of computation for *Stage I*, two levels for *Stage II* and three levels for *Stage III*. Final reliability of marine vessel transportation is obtained from the outputs of all three stages. Since modeling in this paper has been carried out in the fuzzy domain, the reliability output would be in the form of membership function. The output is then converted to estimate the crisp value of reliability by application of defuzzification method(s).

3. Model development and illustrations

This section explains the development process of two models along with a brief description on modeling the aggregation of

Table 1
Various Decision Variables.

Stage	Decision variable	Scale	Variable notation
I	Experience of the navigation crew	0–30 years	X_1
	Experience of the maintenance workforce	0–30 years	X_2
	Effectiveness of the maintenance programs	0–10	X_3
	Overall past operational history of the vessel	0–10	X_4
	Unforeseen events	0–10	X_5
II	Congestion at the source harbor	0–1 (congestion factor)	X_6
	Congestion at the sea	0–1 (traffic intensity factor)	X_7
	Congestion at the destination harbor	0–1 (congestion factor)	X_8
III	Weather or environmental conditions	0–10	X_9
	Delivery date of vessel	Year 1970–2009	X_{10}
	Technological up-gradation of the vessel	0–10	X_{11}
	Region, place or yard where the vessel was built	0–10	X_{12}