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Subjective operational reliability assessment of maritime transportation system

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ABSTRACT

System reliability assessment is one of the major acts in the operation and maintenance of every industrial and service sector, which also holds true for maritime transportation system. The complexity of the maritime transportation system is a prime obstacle in the evaluation of the operational reliability of the system; mainly due to the fact that statistical data on the important parameters and variables is scarce. This makes the application of fuzzy sets and fuzzy logic a viable option to overcome the data problem with regards to imprecision or vagueness in parameters and variables values. In this paper, the different decisive factors, affecting maritime transportation systems, are modeled in the form of linguistic variables. Techniques such as aggregation, mapping of fuzzy sets using distance measure and fuzzy logic rule base are used to arrive at subjective operational reliability value. The complete procedure is demonstrated with an example.

1. Introduction

In recent era, the development of large scale complex and technologically advanced systems such as nuclear power plants, space missions and systems, infrastructure and transportation systems (Kolowrocki & Soszynska, 2006) has changed the world scenario to a great degree. This has affected society in a number of ways; particularly in helping to develop more progressive global economies and allowing the rise in productivity and standard of living. This has further led to the enhancements of current methods and techniques, as well as the development of new ones, associated with reliability and safety issues of these complex systems (Kolowrocki & Kwiatuszewska-Sarnecka, 2008; Wang, 2006). The use of practical applications based research in these areas has also grown significantly in recent times.

One particular industry that is of key importance to the world economy is the maritime industry. It contributes billions of dollars per annum and employs millions of people in diverse maritime operations. It also provides humans with commercial operations such as cargo, oil, goods, ore transport; recreation based operations such as tours, passenger transport; defense linked operations and so on. Many laws, regulations and acts have also been established world-wide that principally focus on ensuring efficiency, reliability and safe operation of marine vessels. Though marine environment is considered to have rather good safety record, accidents and near-miss incidences are not at zero-level. As such, maritime reliability, risk and safety have turned out to be of great interest to research community.

The increasing technical complexity of maritime engineering systems has resulted in a wide range of literature in academic and industrial publications. Many papers have been published concerning mainly with safety and risk issues of maritime systems. Sii, Ruxton, and Wang (2001) and Balmat, Lafont, Maifret, and Pessel (2009) noted that risk and safety assessment based on probabilistic approach may not be well suited with systems having high level of uncertainty characterized by vague, ambiguous or imprecise information. Relatively few papers have incorporated fuzzy set approaches and fuzzy logic in risk and safety issues of the maritime systems. Sii et al. (2001) suggested a safety model using fuzzy logic approach employing fuzzy IF-THEN rules to model the qualitative aspects of human knowledge and reasoning processes without employing precise quantitative analyses. Yang, Wang, Bonsall, and Fang (2009) proposed a subjective security-based assessment and management framework using fuzzy evidential reasoning approaches. Yang, Bonsall, and Wang (2009) then proposed a hybrid multiple uncertain attribute decision making techniques in safety management with an illustration applied to container transportation delay related case study. There are some other papers that combined fuzzy and Bayesian approaches. Liu, Yang, Wang, and Sii (2005) proposed a framework for modeling, analyzing and synthesizing safety of engineering systems on the basis of a generic rule-based inference methodology using the evidential reasoning approach. Eleye-Datubo, Wall, and Wang (2008) presented a fuzzy-Bayesian network to enable a bridge between probabilistic and possibilistic risk based model. Liu, Yang, Ruan, Martinez, and Wang (2008) investigated the method for self-tuning a Fuzzy Belief

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Rule Base for engineering system safety analysis. Ren, Jenkinson, Wang, Xu, and Yang (2009) also proposed a fuzzy Bayesian network approach to model causal relationships among risk factors, which may cause possible accidents in offshore operations. Some other related papers are Hashemi, Le Blanc, Rucks, and Shearry (1995), Wang et al. (2004), Alexopoulos and Konstantopoulos (2006), Grabowski, Ayyalasomayajula, Merrick, and Mccafferty (2007), Krzysztof, Joanna, Miroslaw, and Przemyslaw (2007).

In addition, a few recent papers include Hu, Li, Fang, and Yang (2008), Shyur (2008), Ting-rong, Wei-jiong, and Xiang-kun (2008), Cebi, Celik, Kahraman, and Er (2009), Hadjimichael (2009). In a recent paper on fuzzy set applications in marine sector, Balmat et al. (2009) presented a fuzzy approach for the MAritime RISk Assessment (MARISA) applied to safety at sea. They developed a modular and hierarchical structure using fuzzy logic that obtains a fuzzy risk factor composed of a static risk factor and a dynamic risk factor. The static risk factor assessment takes into account several static data relative to the ship (age, flag, gross tonnage, number of companies, duration of detention and type). The dynamic risk factor is evaluated by considering the meteorological conditions (sea state, wind speed and visibility) and the moment of the day. Their work aims at defining an individual ship risk factor automatically which could be used in a decision making system. Celik, Lavasani, and Wang (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 combines the effects of organizational faults and shipboard technical system failures under a unique risk assessment scheme.

It can be observed from the review that most of the papers primarily focus at safety issues of maritime systems. Literature emphasizing on maritime transportation reliability is scarce. Since no paper is directly dealing with reliability issues; this paper is an effort towards providing operational reliability assessment model for maritime transportation system. The scope of this paper is limited to assessment of reliability from the source harbor to the destination harbor. The activities and the major factors affecting the maritime operations since departure of a marine vessel from one harbor till its arrival at another harbor have been considered. Maritime system safety is one of the issues of concern that too is considered in the analysis. The whole maritime transportation system is composed of several sub and sub–sub systems; as a result the complexity of the entire system is at high dimension level. The major challenge is how to model the decision variables and assess the operational reliability of the maritime transportation system in the domain of the scope as mentioned. The problem can be tackled in case statistical data or information could be obtained about the relevant variables. Availability of statistical data is a primary hindrance here as well, as always in any large scale system. However, the complexity of the problem magnifies in case of lack of statistical data or availability of imprecise or vague data. Hence, the fundamental thought of this paper is based on modeling vague or ambiguous information and evaluation of subjective operational reliability. Imprecision or vagueness could be dealt with application of fuzzy set methods, fuzzy logic and use of expert opinions or judgment; which is attempted in this paper. The model proposed in this paper, since it depends on expert opinions or their judgment in the form of linguistic terms, is titled as Subjective Operational Reliability Model for Maritime Transportation System.

In this paper, a generalized approach has been explained in Section 2 along with the proposed architecture of Subjective Operational Reliability Model. Initially the definition of operational reliability is stated and then various parameters or factors affecting the operational reliability are explained. The three tier structure of the proposed model is subsequently depicted. This is then followed by details of the modeling approaches that have been used in this paper in Section 3. The two approaches utilized for the problem under investigation related to maritime transportation system are: aggregation of expert opinions and mapping of fuzzy sets; and rule based fuzzy logic. The additional details, i.e. the linguistic terms in the form of triangular membership functions for reliability criteria and the decisive factors and formulated fuzzy logic based rule bases for decisive factors and final output of subjective operational reliability are given in the Appendices. The solution methodology for the proposed model has been demonstrated in Section 4 with detailed illustrative problem. The paper ends with concluding remarks and possible future extensions in Section 5.

2. Proposed architecture

While dealing with reliability analysis, statistical data is a prime input. In the absence of the same, fuzzy set based techniques can be well applied in practice. The following procedure elaborates a generalized approach for resolving the reliability assessment issue subjectively. Initially, reliability is defined in the context of application and the criteria's for the same are decided. The decisive factors (inputs) that affect the reliability are then identified through either brain storming or discussion among experts panel. Subsequently, input-output model for the reliability is developed. This would involve one or more levels depending upon the definition of reliability and its criteria's in the application context. A linguistic scale in the form of one or more type of fuzzy sets or fuzzy numbers is next developed for all decisive factors and reliability criteria's. Further on, fuzzy-logic rule base is framed for each level or sub-level of the model developed previously. The opinions or judgments of the experienced personnel's are gathered for each decisive factor, and their responses are aggregated for each factor and 'mapped' to the nearest fuzzy set scale of that factor. Lastly, using fuzzy-logic rule base, the output, i.e. subjective value for the reliability is obtained. This generalized approach has been utilized in this paper. Assessment of reliability for maritime transportation system is carried out similarly with suitable illustration.

2.1. Operational reliability

First and foremost, defining the meaning of operational reliability in the context of maritime transportation system is essential in continuing with the assessment methodology. The criteria considered for defining operational reliability are:

1. *Intended mission completion:* The intended purpose would depend on the type of marine vessel considered, i.e. cargo ship, passenger cruise, oil tanker/ container or naval ship, etc. The planned purpose, in case of cargo carrier, is the delivery of the particular materials in undamaged condition; in the cruise case, it is the comfort and pleasant journey of the passengers or it could be specific secret mission in the case of a naval ship.
2. *Timeliness*: This criterion is very essential when defining the operational reliability. It is concerned with whether the marine vessel reaches in time at the destination harbor, i.e. whether there is timely delivery of cargo or oil container.
3. *Safe mission:* In general, safety is characterized by safe mission of the marine vessel. This would involve accident free arrival of the ship at the destination harbor ever since its departure from the source harbor. This in fact, considers safety of the passengers or cargo or naval crew and weapons on board etc.

These three criteria define what one meant by in realizing the operational reliability of maritime transportation system. As stated earlier, this paper deals with subjective operational reliability, i.e., there are uncertainties such as imprecision, ambiguity or vagueness associated with reliability. As a result, operational