Developing Fuzzy Logic Strength of Evidence and Integration for System Risk Management

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Introduction

Digitalization is becoming a trend in our modern society and systems. Meanwhile, risk analysis and management has rooted and been applied in various fields. Therefore, there is an increasing need to integrate risk analysis and management into the coming digital society. Risk has been represented digitally by the product of probability and consequence i.e. $R = P \times C$ traditionally. However, it has been increasingly discussed to include strength of evidence (SoE) in addition to the traditional consequence (C) and probability (P). Although much advance has been achieved along this direction, there still remains challenges, e.g. ambiguity in rating SoE and visual expression of risk diagrams. This paper focuses on addressing these issues and meanwhile aims to make the risk expression fully digital so that it is more efficient and flexible to be included in a system analysis and visualization.

Materials and methods

Fuzzy logic is a widely used theory in computer science to compute with words, i.e. the linguistic variables, whose values are not numbers but words or sentence in a natural or artificial language. A linguistic variable is characterized by a quintuple (X, T(X), U, G, M), in which X is the variable name; T(X) is the term-set of X, i.e. the collection of its linguistic values; U is a universe of discourse; G is a syntactic rule which generates the terms in T(X); and M is a semantic rule which associates with meaning of each linguistic value X. A fuzzy subset of a universe of discourse U is characterized by a membership function μA, which associates with each element of U in the interval [0, 1], with μA(u) representing the grade of membership (Zadeh, 1965). Classical set $A = \{x | \ x \ \in U\}$ only permits conclusions which are either true or false. While fuzzy set $A_{fuzzy} = \{(x, \mu_A) | \ x \ \in U, \mu_A \in [0,1]\}$ is characterized by the membership function, providing a measure of the degree of similarity of an element in U to the fuzzy subset. Therefore, fuzzy set provides a means of approximate characterization of phenomena to be amenable to description in conventional quantitative terms.

Bayesian networks (BNs) is a widely applied risk modelling and safety management tool (Fenton & Neil, 2012), e.g. in maritime risk analysis (Lim et al., 2018; Hänninen, 2014; Goerlandt and Montewka, 2015). And it has been proposed by the International Maritime Organization risk assessment (MSC, 2013). One feature is that BNs can present relatively complex problems and cope with uncertain and unobserved variables, while also having a graphical dimension. This makes BNs suitable for modeling complex systems, with the additional benefit of being able to incorporate different types of evidence in the model construction. The establishment of the BNs structure is based on a specific background knowledge, and consequences are reflected by a finite number of mutually exclusive states with corresponding probabilities of occurrence. The feature that the probability and consequence are in one-to-one association makes BNs have potential to improve the issues, i.e. the probability and consequence in the event-based risk diagram are expressed only by expected value or in intervals, which is not always sufficiently clear. In addition, the visible graphical structure serves as a useful frame of reference to analyze the strength of evidence, see e.g. Mazaheri et al. (2016). Therefore, BNs are adopted to be utilized as the base QRA tool to integrate with developed fuzzy SoE index.

Results

This paper firstly reviews start-of-the-art discussions on SoE assessment in risk management and identifies the remaining challenges. Then, the paper proposes an approach to address the challenges by forming a fuzzy logic SoE index based on fuzzy logic theory, which enables a transfer from linguistic variable to a digital one with the ambiguity avoided. After the SoE index is formed, it is integrated to BNs to demonstrate its practical application. Meanwhile, with the combination of the features of BNs, it showcases a new system risk management approach. All the variables in the system can be expressed in a risk diagram. This further enables an improved risk visualization, risk management and risk communication for system analysis.

Implications on sustainable maritime operation

The combination of BNs and SoE index plays both features from them thus addresses some issues in risk management and forms a new visual-efficient tool suitable for system risk management, which is applicable for maritime risk management and operations.

Additionally, the fuzzy SoE index is not only limited to the application here with BNs, it can be more widely applied in risk analysis and management. The digitalized SoE enables easily full digital parameters in term of risk expression $R \sim (C, P, SoE \mid BK)$, thus has good potential in the coming digital systems to contribute to sustainable society.