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Assessing contributory factors in potential systemic accidents using AcciMap and integrated fuzzy ISM - MICMAC approach

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ABSTRACT

The Rasmussen's AcciMap approach is an important system thinking method widely used to guide accident analysis and assess potential contributory factors. However, the AcciMap approach cannot quantify interaction relationships among contributory factors and the hierarchical representation of these factors, and it also cannot identify the dominant contributory factors in potential systemic accident. These limitations influence applications of the AcciMap method. The purpose of this paper is to propose a new AcciMap approach combining fuzzy Interpretive Structural Modeling (fuzzy ISM) and Matrix of Cross Impact Multiplications Applied to Classification (MICMAC) to overcome the limitations of current AcciMap approach. Firstly, the fuzzy ISM method is adopted to determine the interaction relationships among contributory factors and the hierarchical representation of these factors. Secondly, the MICMAC method integrated with fuzzy ISM is applied to classify the contributory factors into different categories on the basis of their driving and dependence power values. Then, the degree of a vertex is introduced into the MICMAC approach to determine the dominant contributory factors in potential systemic accident. Finally, the proposed extended AcciMap approach is applied to a ship grounding accident to demonstrate its feasibility, and then a sensitivity analysis is also performed to validate the effectiveness of the new AcciMap approach.

1. Introduction

With the development of techniques, it leads to the shift of system from simple to socio-technical, and makes the identification of contributory factors for potential accidents more difficult (Leveson, 2004). The conventional cause-effect accident theory is incapable of identifying the contributory factors of potential accidents in socio-technical system. As a consequence, a series of systemic accident analysis theories and/or models have been developed to evaluate contributory factors of potential accidents in sociotechnical systems, such as, AcciMap approach (Rasmussen, 1997), HFACS (Human Factors Analysis and Classification System) (D.A. Wiegmann, 2003), STAMP (Systems Theoretic Accident Modeling and Processes model) (Leveson, 2004), and FRAM (Functional Resonance Analysis Method) (Hollnagel, 2004).

The AcciMap approach, as a systemic accident analysis tool originally proposed by Rasmussen (1997), is becoming increasingly prominent in accident systems analysis approach (Dallat et al., 2017; Goode et al., 2017). It has been applied to learn accident causation in various domains such as the led outdoor activity sector (Goode et al., 2017; Salmon et al., 2010), railway (Salmon et al., 2012; Underwood and Waterson, 2014), aviation (Debrincat et al., 2013), public department (Salmon et al., 2014), marine industry (Akyuz, 2015; Kee et al., 2017), food production plant (Nayak and Waterson, 2016) and roadway (Stevens and Salmon, 2016). Although the AcciMap approach has been widely utilized in numerous domains, it still possesses some limitations in assessing contributory factors of potential systemic accidents (Goode et al., 2017): (i) the hierarchy levels of accident contributory factors are not considered from the perspective of accident causation, (ii) the interaction relationships among the contributory factors are not appreciated, and (iii) the most dominant contributory factors of an accident cannot be identified.

To overcome these shortcomings of AcciMap approach, some methods have been introduced into it to improve its feasibility. Trotter et al. (2014) proposed an improvisation AcciMap to identify the factors affecting improvisation, in which the social network analysis metric was incorporated into AcciMap approach to determine the interaction

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among the influence factors. Akyuz (2015) combined AcciMap approach with ANP (Analytic Network Process) to determine the main accident contributory factors by considering interaction relationships among these factors. Goode et al. (2017) developed a novel accident contributory factors classifying scheme for AcciMap approach, and examined the degrees of inter-rater reliability of the proposed classifying scheme. Salmon et al. (2017) integrated the UPLOADS (Understanding and Preventing Led Outdoor Accidents Data System) with AcciMap approach to determine the interaction relationships among accident contributory factors, in which the statistical method is adopted.

Although these methods mentioned above can help to capture the interaction relationships among contributory factors in potential systemic accidents and to improve the effectiveness of AcciMap approach, there are still weaknesses of these extended AcciMap approaches. The ANP method should conduct a high complex calculation when all the interaction relationships among accident contributory factors are considered. The social network analysis metric and the statistical method should be performed on the basis of a large number of accident information. On the other hand, the crucial procedures for prevention of contributory factors in potential systemic accidents are quantifying interaction relationships among contributory factors and the hierarchical representation of these factors, and determining the dominant contributory factors (Akyuz, 2015). Therefore, to solve these problems, this paper aims at developing an extended AcciMap approach for assessing contributory factors in potential systemic accidents by using the integrated fuzzy ISM-MICMAC method (fuzzy Interpretive Structural Modeling and Matrix of Cross Impact Multiplications Applied to Classification). The ISM method is considered as an effective system structure modeling tool to study various safety related problems. Ai et al. (2014) applied the ISM method to construct the hierarchical structure of contributory factors in work safety. Wu et al. (2015) estabilished a structure model of risk factors in offshore pipeline projects by using ISM method. Wang et al. (2018) combined the DEMATEL (Decision Making Trial and Evaluation Laboratory) with ISM to detrmine the contributory factors in coal mine production safety. Specifically, the MICMAC (Matrix of Cross Impact Multiplications Applied to Classification) approach is introduce into the ISM method to analyze the interaction status of factors and to recognize the dominant contributory factors across many fields. Examples are analysis of the main influence factors of lean remanufacturing implementation (Vasanthakumar et al., 2016), investigation of the main barriers influencing implementation of green lean (Cherrafi et al., 2017), and identification of the influence factors of supply chain resilience (Jain et al., 2017).

According to the aforementioned discussion, little attention has been paid to the extended AcciMap approach assessing contributory factors in potential systemic accidents within a hierarchical evaluation structure. In this context, the AcciMap approach is a useful technique to identify contributory factors in potential systemic accidents within a hierarchical structure. Meanwhile, the integrated fuzzy ISM-MICMAC method can be regarded as one of the most effective analysis tools to quantify the complex interaction relationships among factors and the hierarchical representation of these factors. Therefore, it is justifiable to develop an extended AcciMap approach with integrated fuzzy ISM-MICMAC method for assessing contributory factors in potential systemic accidents. Motivated by this idea, the triangular fuzzy linguistic terms are adopted to express the strength of interaction among contributory factors, which will help to depict the uncertainty of expert's judgments. In addition, the fuzzy ISM method is applied to quantify interaction relationships among contributory factors and the hierarchical representation of these factors, which will help to obtain the hierarchical structure of contributory factors in a more visual way. Besides, the developed MICMAC based on the degree of a vertex is used to determine the dominant contributory factors in potential systemic accidents, which will help to derive a more reasonable result and to improve the effectiveness of the AcciMap approach. Finally, a case of a ship grounding accident is selected to illustrate the proposed extended AcciMap approach.

The contributions of this paper can be summarized as the following ways:

(i) First time in literature, the fuzzy ISM method is combined with AcciMap approach to assess contributory factors in potential systemic accidents. The fuzzy ISM method is introduced to construct a semi-quantitative method for quantifying interaction relationships among contributory factors and the hierarchical representation of these factors.
(ii) The dominant contributory factors in potential systemic accidents are identified by using the MICMAC approach. The distinctive aspect of the proposed AcciMap is that the MICMAC approach is utilized to derive the priority of each contributory factor within a hierarchical evaluation structure.
(iii) The proposed AcciMap approach can not only quantify interaction relationships among contributory factors and the hierarchical representation of these factors, but also can identify the dominant contributory factors. A case study of a ship grounding accident is provided to demonstrate the implementation of the proposed extended AcciMap approach. In addition, a sensitivity analysis is performed to evaluate the feasibility of the proposed approach.

We organize the framework of this paper as follows. This section provides an introduction. In section 2, the approaches chosen for system accidents analysis are presented. Section 3 illustrates the procedures of the proposed AcciMap approach. In section 4, an illustrative example of a ship grounding accident is introduced to validate the proposed extended AcciMap method. The final section gives the conclusions of this study and points out directions for future research.

2. Research methodologies

This paper introduces a developed version of AcciMap which not only can be employed to explore the interaction relationships among contributory factors in potential systemic accidents, but also can be used to identify the dominant ones in all of the contributory factors. The fuzzy ISM approach is adopted in this study to clarify the interaction relationships among contributory factors and to establish a hierarchical structure of these factors. The MICMAC approach integrated with fuzzy ISM is employed to determine the dominant contributory factors in potential systemic accidents from the perspective of their interaction status. The subsections introduce the description of all approaches.

2.1. AcciMap approach

The AcciMap modeling approach is a graphic and systemic thinking analysis tool for representing accidents causes that happen in a complex social-technical system (STS), which was first introduced by Rasmussen (1997). The AcciMap approach focuses on factors out of control across six levels, when it is conducted to identify contributory factors in systemic accidents and to represent the relationships among these factors. The six systemic levels from the bottom to the top are equipment and surroundings, physical process and actor activities, technical and operational management, company management, regulatory bodies and associations, and government policy and budgeting. As stated above, the AcciMap approach adapted from Svedung and Rasmussen (2002) is as shown in Fig. 1.

2.2. Fuzzy interpretive structural modeling (Fuzzy ISM)

The interpretive structural modeling (ISM) approach was primarily proposed by Warfield (1974), which is employed as a complex system analysis tool to identify fundamental interaction relationships among specific elements by constructing a hierarchical structure model (Fu

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