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An integrated human reliability based decision pool generating and decision making method for power supply system in LNG terminal

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ABSTRACT

In this paper, an integrated model is presented to support human reliability based decision producing and making process by evaluating safety promotion plan for power supply system in LNG (Liquid Natural Gas) terminal. This model is mainly mathematically treated through fuzzy Cognitive Reliability and Error Analysis Method (CREAM) in combination with Genetic Algorithms (GA) and Adaptive Neuro-Fuzzy Inference System (ANFIS). The fuzzy CREAM accounts the operators' individual factors, organization factors, environmental factors and technique factors together to identify the fuzzy membership degree of each control mode and to calculate Human Error Probability (HEP). However, when the calculated HEP fails to meet the requirement, the GA will identify the target membership degree of each CREAM control mode, and adopting such target membership degree and fuzzy logic rule to generate a decision pool for safety promotion. Finally, an experts' evaluation result based ANFIS provides a standard evaluating system for plan choice and update. The proposed model has been tested on a power supply system for an LNG terminal in Beihai China.

1. Introduction

According to the statistical data from 1964 to 2005, the frequency of accidents during LNG off-loading is one of the highest among all (Vanem et al., 2008), and during the shipping LNG off-loading activity in LNG terminal, the power supply system is a key factor to guarantee the operation running normally. So ensuring and improving the safety performance of power supply system is crucial to avoid the consequence. Maintaining the power supply system is mainly human related work, and according to many accidents' reports, human factors are important reasons that trigger the over 60% of catastrophic accidents in the commercial shipping and process industry (Wiegmann and Shappell, 2001; Dhillon, 2007; Casal and Olsen, 2016). Therefore, a human reliability based plan for safety promotion in power supply system is necessary. However, under many situations, the HEP data calculated by Human Reliability Analysis (HRA) methods are mostly viewed as simply values with limited applications and even fail to reach the requirements, and unfortunately, there is inadequate research to tackle such situation. Therefore, this study is aiming to extend HRA application and to find the valuable information behind the HEP data to provide a safety promotion plan evaluating model for power supply system in an LNG terminal.

Human reliability has received systematic research since the Second World War, due to remarkable acceleration in military technology (Swain, 1990). Two generations of Human Reliability Analysis (HRA) methods have been developed. The source idea of the first generation methods mainly results from the inherent deficiencies of human (Marseguerra et al., 2006). The widely used first generation methods include Task-based Technique for Human Error Rate Prediction, Human Error Assessment and Reduction Technique, Success Likelihood Index Methodology, etc. (Kim and Bishu, 2006). However, as extensive studies of human performance have illustrated that the importance of the outside environmental conditions in which the task is performed is greater than the natures of the task itself, the first generation HRA method has been doubted for over 20 years (Yang et al., 2013).

For the sake of addressing the shortcoming of first generation methodology, the second generation method has been developed which includes Cognitive Event Tree System, Human Interaction Time Line, Connection Assessment of Human Reliability, and CREAM. Among them, CREAM is the most well-known method. The CREAM method integrates the operators' individual factors, organization factors, environmental factors, and technique factors together. Nine Common Preference Conditions (CPCs) are introduced to evaluate and decide the Contextual Control Model (COCOM). As listed in Table 1, nine CPCs are adequacy of organization, working condition, adequacy of man-machine interface and operational support, availability of procedures and plans, number of simultaneous goals, available time, time of day, adequacy of training and experience, and crew collaboration quality.

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Table 1
The CREAM evaluation form.

CPC name	Level	Effect on reliability
1. Adequacy of organization	Very efficient	Improved (+1)
	Efficient	Not significant (0)
	Inefficient	Reduced (−1)
	Deficient	Reduced (−1)
2. Working condition	Advantageous	Improved (+1)
	Compatible	Not significant (0)
	Incompatible	Reduced (−1)
3. Adequacy of Man Machine Interface (MMI) and operational support	Supportive	Improved (+1)
	Adequate	Not significant (0)
	Tolerable	Not significant (0)
	Inappropriate	Reduced (−1)
4. Availability of procedures/plans	Appropriate	Improved (+1)
	Acceptable	Not significant (0)
	Inappropriate	Reduced (−1)
5. Number of simultaneous goals	Fewer than capacity	Not significant (0)
	Matching current capacity	Not significant (0)
	More than capacity	Reduced (−1)
6. Available time	Adequate	Improved (+1)
	Temporarily inadequate	Not significant (0)
	Continuously inadequate	Reduced (−1)
7. Time of day	Day	Not significant (0)
	Evening	Reduced (−1)
	Night	Reduced (−1)
8. Adequacy of training and expertise	Adequate high experience	Improved (+1)
	Adequate, limited experience	Not significant (0)
	Inadequate	Reduced (−1)
9. Crew collaboration quality	Very efficient	Improved (+1)
	Efficient	Not significant (0)
	Inefficient	Not significant (0)
	Deficient	Reduced (−1)

The COCOM contains four kinds of control modes: strategic, tactical, opportunistic, and scrambled (Hollnagel, 1998). Each COCOM has its corresponding HEP interval. CREAM has been used in many industrial practices including the offshore oil platform operation (Turan and El-laden, 2012), LPG terminal operation (Akyuz and Celik, 2015), nuclear power plant operation (He et al., 2008; Ribeiro et al., 2016), and maritime industry operation such as oil tanker ship operation (Akyuz, 2015; Ung, 2015; Zhou et al., 2017). Additionally, many improvements have been applied on CREAM, sensitivity and uncertainty of CREAM have been analysed with the consideration of different cognitive failure modes to improve the CREAM (Bedford et al., 2013), and the revised CPCs are provided for tanker shipping activity (Zhou et al., 2017); moreover, for the sake of dealing with the uncertainty and imprecision during CREAM process, fuzzy logic and Fuzzy Analytic Hierarchy Process (FAHP) are introduced to increase the accuracy of CREAM (Konstandinidou et al., 2006; Ung, 2015; Zhou et al., 2017).

This research adopts fuzzy CREAM for HRA, and the defuzzification process on CREAM to give the calculated HEP, but under the situation that such calculated HEP fails to meet the requirement of HEP, some methods should be provided. Facing this situation, implementing GA on defuzzification process, and viewing the required HEP and defuzzification function as the target and the objective function respectively, then the target membership of each COCOM in fuzzy CREAM can be identified. According to the theory of fuzzy CREAM, through changing the performance data of one/some CPCs, the target membership degrees of COCOM will be achieved, and the corresponding calculated HEP will be accepted. Besides, there are 9 CPCs in CREAM form, and each CPC contains several sub-influence factors which are shown in Appendix A. Therefore, there are many potential passages to reach the target membership degrees to fulfil the HEP requirement. In other words, the CREAM can be extended as a tool to construct a plan pool for promoting human reliability and system safety. After that, facing those defined choices, a decision making process is needed. Obviously, this is a multi-criteria decision making (MCDM) problem, and the experienced experts evaluate each defined plan, then an Adaptive Neural Fuzzy Inference System (ANFIS) is constructed based on experts' evaluation results to simulate the experts' decision process for future plan evaluating and updating. (Golmohammadi, 2011; Özkan and İnal, 2014; Azadeh et al., 2016). In summary, the description above forms the major contribution of this paper.

In this paper, the work extending the fuzzy CREAM from a simply HRA method to a method that can generate a pool of safety promotion plans will be presented and based on a power supply system in LNG terminal. Then based on the experts' evaluation results, ANFIS is used to provide a standard system for plan updating and evaluating. The structure of this paper is as following. In Section 2, the framework of this method is explained; in Section 3, the description of chosen methods are presented; in Section 4, a real example is illustrated to approve the method; in Section 5, the conclusion is given, and the future work is discussed.

2. The framework of the proposed approach

A flow diagram of method process is shown in Fig. 1, and the main steps are briefly explained as follows.

Step 1-Fuzzification: The aim of this stage is to determine the fuzzy membership degrees for nine CPCs.

Step 2-Fuzzy CREAM calculation: After defining and inputting the fuzzy membership degree data, through fuzzy logical rules and based on CREAM, the membership of the control mode can be identified.

Step 3-Defuzzification: In this part, with the membership degree of each control mode, the HEP can be calculated by taking membership degree data of COCOM into defuzzification method "Centre of Area (COA)" (Ung, 2015; Ung and Shen, 2011).

Step 4-Finding the target fuzzy membership degrees: If the calculated HEP fails to achieve the requirement, the required HEP value will be set as an objective, and GA will be applied on the defuzzification process (COA equation) to find target membership degree of each COCOM within the objective and each constraint.

Step 5-Potential plans identification: Once the target membership degree of each COCOM is identified, using such membership degree as target, and then through improving the performance of one/some CPCs, a plenty of potential safety promotion plans will be produced. Namely, through different ways to change the performance data of some CPCs to reach the target membership degrees, so to ensure the calculated HEP is acceptable.

Step 6-Construction of decision making model: In this step, all potential plans are evaluated by experienced experts, and the experts' evaluation results based ANFIS is adopted to simulate the human decision making process and to build a standard and robust decision making system for future plan evaluating and updating for this system.