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# A new hybrid approach to human error probability quantification–applications in maritime operations

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A R T I C L E  I N F O

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A B S T R A C T

Human Reliability Analysis (HRA) has always been an essential research issue in safety critical systems. Cognitive Reliability Error Analysis Method (CREAM), as a well-known second generation HRA method is capable of conducting both retrospective and prospective analysis, thus being widely used in many sectors. However, the needs of addressing the use of a deterministic approach to configure common performance conditions (CPCs) and the assignment of the same importance to all the CPCs in a traditional CREAM method reveal a significant research gap to be fulfilled. This paper describes a modified CREAM methodology based on an Evidential Reasoning (ER) approach and a Decision Making Trial and Evaluation Laboratory (DEMATEL) technique for making human error probability quantification in CREAM rational. An illustrative case study associated with maritime operations is presented. The proposed method is validated by sensitivity analysis and the quantitative analysis result is verified through comparing the real data collected from Shanghai coastal waters. Its main contribution lies in that it for the first time addresses the data incompleteness in HEP, given that the previous relevant studies mainly focus on the fuzziness in data. The findings will provide useful insights for quantitative assessment of seafarers' errors to reduce maritime risks due to human errors.

## 1. Introduction

Human error has caused many industrial accidents and disasters. Human Reliability Analysis (HRA) has therefore been an essential research issue. With the development of new technologies, the emerge of complex systems such as Nuclear Power Plant (NPP) and Very Large Crude Carrier (VLCC), makes the consequences of accidents more and more serious. Many approaches have been developed for facilitating human error quantification and human reliability analysis, such as Human Cognitive Reliability model (HCR) (Hannaman et al., 1984), Success Likelihood Index Method (SLIM) (Embrey et al., 1984), Technique for Human Error Rate Prediction (THERP) (Swain and Guttmann, 1983), Human Error Assessment and Reduction Technique (HEART) (Williams, 1988), A Technique for Human Error Analysis (ATHEANA) (Cooper et al., 1996), Cognitive Reliability and Error Analysis Method (CREAM) (Hollnagel, 1998), SPAR-H (Gertman et al., 2005) and Bayesian Network approach (Baraldi et al., 2015). There are also some specific methods developed in the literature for Human Error Probability (HEP) quantification (Sun et al., 2012). Such approaches have been widely applied to deal with human error and human factors in various sectors including nuclear (Alvarenga et al., 2014; Jang et al., 2013), spaceflight (Calhoun et al., 2013, 2014), marine and maritime (Akyuz and Celik, 2015a, 2015b, 2016; Yang et al., 2013; Akyuz, 2016; Chen et al., 2013; Wang et al., 2011a, 2011b), and civil infrastructure (Nan and Sansavini, 2016), etc.

### 1.1. CREAM

The well-known CREAM, established by Hollnagel in 1998 (Hollnagel, 1998), has been applied to human error quantification of safety-critical systems. Both retrospective and prospective analyses can be carried out for the diagnosis and prediction of industrial accidents and events. For the prospective analysis, two steps are designed for human error quantification which are a basic method and an extended method, respectively. The basic method is used for determination of control modes and corresponding error rate intervals at a screening stage, while the extended method is employed for error quantification of cognitive functions. However, the two inherently deterministic methods arguably lack capability of dealing with the uncertainties in common performance condition (CPC) configuration (Kim et al., 2006)

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and different weight assignments (He et al., 2008) to the CPCs in traditional CREAM. Recently, some studies have been conducted for the improvement of CREAM and HEP estimation by means of probabilistic techniques (Kim et al., 2006; Fujita and Hollnagel, 2004), fuzzy approaches (Konstandinidou et al., 2006; Marseguerra et al., 2006, 2007; Wang et al., 2001; Yang et al., 2013; Ung et al., 2015), simplification (Sun et al., 2012; He et al., 2008) and combination (Akyuz, 2015; Ribeiro, 2016). Fujita and Hollnagel (2004) designed a new version of basic method of CREAM and Kim et al. (2006) described a probabilistic approach for determining the control modes. Konstandinidou et al. (2006), Marseguerra, and Wang et al., (2006, 2007, 2001) presented fuzzy sets, fuzzy rules and fuzzy-clonal selection methods for contextual and reliability evaluation. However, the fuzzy model of CREAM brings on many redundant, self-contradictory rules, which would consume computational time, and lose the truth degree of the results (Wang et al., 2001). Sun et al. (2012) and He et al. (2008) simplified the CREAM for HEP point estimation while Lee et al. (2011) designed a CREAM-based communication error analysis method (CEAM) for communication error analysis. Akyuz (2015) constructed a risk-based CREAM model for HEP quantification towards the gas inerting process on-board crude oil tankers and Ribeiro et al. (2016) presented a hybrid THERP-CREAM method to analysis the human reliability of Tokai-Mura accidents. Although showing attractiveness in terms of providing solutions to some of the inherent drawbacks of CREAM, such methods have not yet well addressed the incompleteness in subjective data from experts, revealing the need for further studies in the field.

### *1.2. Evidential Reasoning (ER) and DEMATEL technique*

Dempster-Shafer Theory (DST) was developed by Dempster in 1967 (Dempster, 1967) and later refined by Shafer in 1976 (Shafer, 1976). Subsequently, DST is known as one of the most powerful tools to deal with uncertainty problems. The evidential reasoning (ER) approach (Yang and Singh, 1994; Yang et al., 2006; Xu et al., 2006), which was initially oriented to model multiple attribute decision analysis (MADA) problems is further developed for overcoming some weaknesses in DST. It is conducted by generating basic probability assignments (BPA) through the combination of degrees of belief (DoBs) and normalized weights. It is because of the advantage of ER in modelling incompleteness that recently it has been widely applied in many domains such as safety assessment (Xi et al., 2008), environmental impact assessment (Wang et al., 2006) and software selection (Fu and Yang, 2010). In this paper, the ER approach is employed for evaluating the CPCs and combining the DoBs to generate the BPA of CPCs in the modified CREAM methodology.

The DEMATEL technique was developed by the Geneva Research Centre of the Battelle Memorial Institute (Fontela and Gabus, 1976; Gabus and Fontela, 1973). It presents the cause and effect groups within a system or subsystem by applying matrices and digraphs to visualise the structure of complicated causal relationships. The advantages of DEMATEL lie in its capability of effectively modelling and quantifying the causal relationships among interdependent factors. The DEMATEL has therefore been successfully applied in many fields including business (Tseng, 2009; Wu and Lee, 2007), engineering (Seyed-Hosseini et al., 2006), education (Tzeng et al., 2007) and social studies (Tamura and Akazawa, 2005). In this paper, the technique is used to model the dependency among CPCs and further, together with the assigned weights of CPCs, to determine the values of adjusting indices. Given the strengths of ER and DEMATEL in modelling uncertainties, this paper proposes a new modified CREAM method to calculate HEP in a rational way.

Given their strengths in tackling different uncertainties exposed in traditional CREAM, ER and DEMATEL are combined to construct a new modified HEP quantification model of two stages, a general analysis stage and a quantification evaluation stage. The general analysis in Section 2 proposes an ER approach to model the incompleteness associated with CPC configuration and combination of DoBs, and to determine the corresponding control mode(s), probability intervals and the total state of context. The quantification evaluation in Section 3 describes a DEMATEL technique to simulate the interdependency of CPCs and to determine the different weights of CPCs and adjusting index values. Consequently, a rational error probability can be obtained at this stage. In Section 4, an illustrative case study in maritime operations is presented and real data has been recorded to benchmark and validate the modified method and research findings. Section 5 concludes this paper.

## 2. Modified CREAM: a general analysis

The core of CREAM is the Contextual Control Model (COCOM). COCOM focuses on the principle that human cognition is not only a response to a serious input but also a close loop process of continuous purposive adjustment for intension. Four kinds of control modes are defined according to the human cognition and the context, which are determined by nine Common Performance Conditions (CPCs). The four control modes are "*Scrambled*", "*Opportunistic*", "*Tactical*" and "*Strategic*" respectively (Fig. 1) while the nine CPCs are "*Adequacy of organisation* ($CPC_1$)", "*Working conditions* ($CPC_2$)", "*Adequacy of man-machine interface and operational support* ($CPC_3$)", "*Availability of procedures and plans* ($CPC_4$)", "*Number of simultaneous goals* ($CPC_5$)", "*Available time* ($CPC_6$)", "*Time of day* ($CPC_7$)", "*Adequacy of training and experience* ($CPC_8$)" and "*Crew collaboration quality* ($CPC_9$)", respectively (Table 1). Each CPC may be evaluated at different levels indicating an *improved, not significant* or *reduced* effect on human performance accordingly. The control mode and its wide failure interval are determined by the couple of $(\Sigma_{Improved}, \Sigma_{Reduced})$. For example, if an event is evaluated to have 5 CPCs of *improved* effects and 4 CPCs of *reduced* effects, then its corresponding COCOM will be "*Tactical*" according to Fig. 1 and failure probability interval will be $1E-3 < P < 1E-1$ from Table 2.

### *2.1. Evaluating the CPCs using a DoB approach*

The traditional method for evaluating the level and its effect to human reliability is easy and visible. However, it only shows a general principle (Kim et al., 2006) thus revealing some problems in its practical applications. It needs to be further improved and developed in determining the levels of CPCs and its effect to human reliability rationally. It is well known that an exact evaluation of CPCs is important but very difficult for the performance prediction. Nevertheless, it is not always easy to specify CPCs exclusively, due to the insufficiency of information and data of the context under

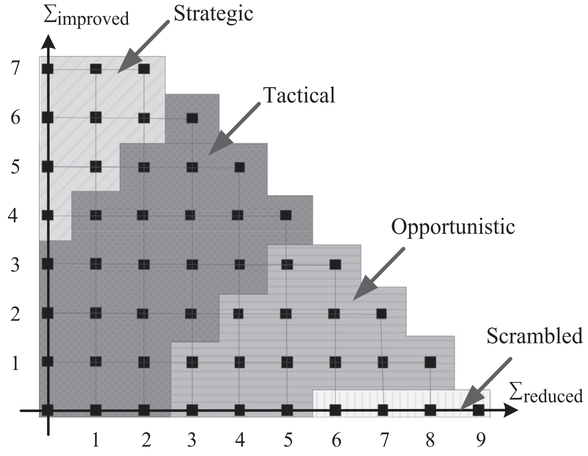

**Fig. 1.** Relation between CPCs and control modes (Hollnagel, 1998).