A hybrid human and organizational analysis method for railway accidents based on HFACS-Railway Accidents (HFACS-RAs)

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\textbf{A B S T R A C T}

Accidents continue to be the major concern in the railway industry, and human factors have been proved to be the prime causes to railway accidents. In this paper, the Human Factors Analysis and Classification System-Railway Accidents (HFACS-RAs) framework is proposed to identify and classify human and organizational factors involved in railway accidents. To establish an applicable HFACS-RAs framework, large amount of incident and accident data are collected and the existing safety flaws are identified by safety experts, manufactures and railway managers who have attended the HFACS workshop. To find out the leading accident casual factors, the Analytical Network Process (ANP) method combined with Fuzzy Decision Making Trail and Evaluation (DEMATEL) method is adopted to analyze the influence relationships of human and organization factors classified by HFACS-RAs framework after its reliability is demonstrated. The expert judgement is required in most phases in this study for the uncertainty and complexity of the human and organizational factors and the proposed method to identify the main casual factors is elaborated in the case study. The relevant preventative measures can be raised to avoid the recurrence of similar accidents after the investigation. Finally some considerations on further work are discussed.

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1. Introduction

With the vigorous development of the railway industry in China, lots of lines have been built and the mileage has reached 19,000 km by the end of 2015, ranking first in the world. Since the Beijing-Tianjin Inter-City railway was constructed and operated in 2008, the high-speed railway has been regarded as the future of the railway industry of China with advantages of timesaving, lower operating costs and bringing us considerable economic and social benefit. However, the complex control system and serious operation circumstance of the railway system have led to numerous accidents although a lot of labor and financial forces have been put into safety. The shocked high-speed-rail crash accident at Wenzhou in July 2011 caused 40 fatalities and 172 injuries with the direct economic losses reaching 193.7165 million Yuan (Liu and Yang, 2015). With the application of innovative technologies, the more complex functions of control system make the operators interact more difficulty with equipment and human factors have been regarded as the major causes of most accidents in many industry domains such as railway, aviation, maritime and mining.

From the statistics, there are many accidents caused by human factors in daily operation and maintenance in railway domain. Given that there exist remarkable interaction and feedback among human factors, the human factor analysis methodologies are required to identify the human and organization factors involved in railway accidents.

Over the years many researchers have devoted to researching and developing theories and models to understand how and why accidents occur and they’ve got fruitful achievements (Katsakiori and Sakellaropoulos, 2009). Various accident causation models have been introduced and then modified for specific application. The first accident causation model is the Domino Theory proposed by Heinrich in 1931. The domino theory considers accidents as the result of the chain of incidents which are visualized as a series of dominos. Once one of the dominos falls, the following dominos will fall one by one and accidents will occur ultimately. Therefore, the interaction relationship exists between two neighboring dominos and the latter is affected by the former from Domino Theory (Heinrich, 1941).

Edward developed SHEL model in 1972 to depict the interactions between human and machine. The original model consists of four types of system interfaces which are described as Software, Hardware, Environment and Liveware respectively (Molloy and O’Boyle, 2005). Functional disorder among these interfaces may
lead to errors, and then safety flaws can be revealed. Later Hawkins brought Central Liveware into SHEL model surrounding by previous components. Since the original model didn't take management and organizational factors into account, Kawano introduced Management factor and formed the m-SHEL model for Japanese electric power industry (Akyuz and Celik, 2014).

The Normal Accident Theory (NAT) suggested by Perrow in 1984 are widely applied to characterize potential failures within complex technological systems such as air traffic, marine traffic, chemical plants and especially nuclear power plants. Perrow argued that the conventional engineering approach for safety do not work because the intensive complexity of systems makes failures inevitable, and the failures should be regarded as part of normal operations (Sammacco, 2005). Based on Perrow’s theory, systems can be sort into linear system, in which failures propagate interactively, and complex system which means system failures behave unpredictably. Perrow further classified systems as loosely coupled and tight coupled system in terms of their ability to detect and respond to failures (Bhishamjit and Mazur, 2015).

One of the most significant contribution to analyze human errors in accidents is known as “SPK” framework developed by Rasmussen (1983). Rasmussen defined three types of human performance and corresponding errors with Skill-based, Rule-based, and Knowledge-based behavior taxonomy, which describes three levels of conscious control by individuals during task respectively (Drivalou and Marmaras, 2009). The framework decides human operation at one of the three categories from the nature of the mission and the level of experience with particular situation. Reason raised the derivation of SPK framework which is known as the Generic Error Modeling System (GEMS) seven years later (Embrey, 2005).

Swiss Cheese Model, as the most widely used accident causation model, was introduced by Reason by the end of 1980s to explain how accident could be regard as the result of interrelations between “unsafe acts” of front operators and latent conditions from a systems perspective (Dong and Wan, 2013). Swiss Cheese Model has become the dominant paradigm for aviation safety investigation, so it has been successfully applied in various industries (Uderwood and Waterson, 2014). In Swiss Cheese Model Reason defined four levels of safety barriers for a system which is visualized as slices of cheese with holes referring to unintended defects of the system in each slice. The holes in the slice affecting accidents directly indicate active failures and others represent latent failures of the system, and an accident will be motivated once the holes of each barrier align in a straight line (Reason, 2000). The Swiss Cheese Model is a systemic accidents analysis model, but the meaning of holes in the slice are not explained exhaustively and its application in reality is not easy.

Based on Reason’s Swiss Cheese Model, the Human Factors Analysis and Classification System (HFACS) was developed by Shappell and Wiegmann in 2000. The research on HFACS framework was sponsored by the Office of Aviation Medicine of the US Federal Aviation Administration for incident/accident analysis. The HFACS framework is a hierarchical framework (Shappell and Wiegmann, 2001) and the original framework are made up of four levels represented by Unsafe Acts, Preconditions of Unsafe Acts, Unsafe Supervision and Organization Influence respectively. The HFACS framework is a widely applicable human factors taxonomy and has been proved to be reliable. The most obvious difference between HFACS and other accident causation model is HFACS framework particularly illustrated the role of the management and organization in the safety part of systems (Wiegmann and Shappell, 1997).

The more comprehensive and reliable control systems eliminate accidents caused by mechanical failures, while the accompanying high integrity and automation degree make it difficult for operators to understand inner function of systems. Considering these findings, the research for genesis of human reasons should be emphasized in order to reduce accidents (Reason, 1990). There are many other proposed accident causation models concerning human factors apart from previous introduction, but concrete practice for specific applications should be further studied.

Most of the accident causation models depend on experts’ judgement for model construction and parameterization. Experts’ domain knowledge plays a pivotal role especially when historical data for the accident investigation are not enough to conduct analysis and calculation. Therefore, the accident causation models are often equipped with the expert elicitation during accident analysis and investigation.

This study proposed a novel accident analysis method based on the HFACS framework aiming at addressing the human and organization factors in railway accidents. Considering the complexity of the accident analysis, the expert judgement is also adopted and involved in most phases of the proposed method. Specifically, since the source data of the accident investigation are generally some reports in the text format and the human and organizational factors involved in railway accidents are of high uncertainty and complexity, the experts’ knowledge is conducive for the extraction of related information. On the other hand, the expert judgement can afford the initial input for the quantitative analysis in some decision making processes of our study. This paper is organized as follows: the current section describes the development history and the significance of the research on accident causation for human factors; Section 2 briefly introduced the modeling theory and quantitative approach involved in this paper. In order to compute the relative weights of human factors in accidents, the proposed method is elaborated concretely in Section 3. The method illustrated in Section 3 is demonstrated through a case study in Section 4. In the final section, the outcomes and contributions of the research are summarized and discussed.

2. Literature review

2.1. Human Factor Analysis and Classification System (HFACS) application

Human Factor Analysis and Classification System (HFACS) is a classification framework modified from the Swiss Cheese Model by Wiegmann and Shappell, and it was initially proposed to analyze and classify the pilot errors in naval aviation accidents and incidents (Shappell and Wiegmann, 2000). The HFACS framework shed new light on the definition of the “holes” in the cheese slices by specifying the classification of Unsafe Acts, Preconditions for Unsafe Acts, Unsafe Supervision and Organizational Influences in detail, so that it can be applied conveniently in practice. The legible hierarchies containing supervision and management factors make HFACS framework available to fully deal with human problems in accidents. Furthermore, the HFACS framework is capable of exploring the possible causes of accidents with different complexities. In recent years, the HFACS framework has been widely introduced into civil aviation and other domains to study human errors in accidents because of its high reliability (Olsen, 2011).

The study and application of the HFACS framework in the past can be basically divided into two phases. In the early stages, some changes of the original HFACS framework were made by different authors in order to adapt the HFACS tool to the features of different domains and analyze human factors in the accidents qualitatively. The common approach of modification is increasing levels or altering the categories according to specific requirements. In the aviation industry, Scarborough and Pounds modified the original HFACS framework into the HFACS-ATC in 2001 by changing the
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