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Aggregation of group fuzzy risk information in the railway risk decision making process

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ABSTRACT

Railway risk assessment is a hierarchical process where risk information obtained at lower levels may be used for risk assessment at higher levels. Fuzzy analytical hierarchy process (FAHP) is widely used in risk decision making process to solve imprecise hierarchical problems where the risk data are incomplete or there is a high level of uncertainty involved in the risk data, particularly, in the process of railway safety and risk decision making. However, the application of FAHP in risk decision making the risk analysts often face the circumstances where a large number of pairwise comparison matrices have to be established by expert knowledge and engineering judgements. There may be a lack of confidence that all comparisons associated with a railway system are completely justified in a rigorous way. This is particularly true when a complex railway system needs to be analysed or when subjective judgements should be involved. This paper presents a modified FAHP approach that employs fuzzy multiplicative consistency method for the establishment of pairwise comparison matrices in risk decision making analysis. The use of the proposed method yields a higher level of confidence that all of comparisons associated with the system are justified. In the meanwhile, the workload in determining the consistency of the judgements can be reduced significantly. A case example is used to demonstrate the proposed methodology. The results indicate that by using the proposed method, risks associated with a railway system can be assessed effectively and efficiently, and more reliable and accurate results can be obtained.

1. Introduction

Comparison with road transportation, railways are by far one of the safest means of ground transportation, especially for their passengers and employees. But comparison with airspace, there are some issues involved in both maintaining this position in reality and sustaining the public perception of railway safety excellence. The railway now finds itself in a situation where actual and perceived safeties are real issues, to be dealt with in a new public culture of rapid change, short-term pressures, and instant communications. The principal risks in the railway industry appear to be to people and property as a result of collision, derailment and fire. The concepts of design and construction for railway safety are introduced in the standards of EN 50126(1, 2, 3) (BS EN 50126-1, 1999; BS EN 50126-2, 2007; BS EN 50126-3, 2006), EN 50128 (BS EN 50128, 2009), and EN 50129 (BS EN 50129, 2003), which are widely applied to manage and control risks in the design and construction of railway systems. However, there are many possible causes, in operation and maintenance of vehicles and rail infrastructure, and also from outside the railway such as vandalism and road incidents. Specifically, in the modification and maintenance of plain line, the largest incidences are of derailments and vehicles fouling infrastructure such as station platforms. There are many chains of potential causes, and each involves several disciplines and work-groups. Incorporating safety aspects into the railway management and maintenance process can increase the level of safety (An et al., 2011, 2007; Bojadziev and Bojacziev, 1997; Chiclana et al., 2001). This shows the need for increased awareness and better safety management.

Railway risk analysis is to increase the level of safety to safeguard their assets, customers and employees while improving safety and reducing railway asset maintenance cost and environmental impacts. Any risk information produced from risk estimation phase may be used through the risk response phase to assist risk analysts, engineers and managers to make maintenance and future investment decision purposes. If risks are high, risk reduction measures must be applied or the maintenance work has to

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be considered to reduce the occurrence probabilities or to control the possible consequences. If risks are negligible, no actions are required but the information produced needs to be recorded for audit purpose. However, the acceptable and unacceptable regions are usually divided by a transition region. Risks that fall in this transition region need to be reduced to as low as reasonably practicable (ALARP) (An et al., 2008, 2006; Railway Safety and Standard Board, 2007).

The purpose of railway risk assessment is to determine the risk likelihood and magnitude to assist with the decision-making. As discussed above, if risks are high, risk reduction measures must be applied or the maintenance work has to be considered to reduce the occurrence probabilities or to control the possible consequences. Many of the railway risk analysis techniques currently used are comparatively mature tools (An et al., 2007, 2006; Chen et al., 2007; Chen and An, 2011; Huang et al., 2007). The results of using these tools highly rely on the availability and accuracy of the risk data (An et al., 2011, 2007, 2008, 2006; Bojadziev and Bojacziev, 1997; Chiclana et al., 2001; Huang et al., 2007). However, railway risk analysts often face the circumstances where the risk data are incomplete or there is a high level of uncertainty involved in the risk data. This requires the involvement of expert knowledge and engineering judgement in the risk analysis process. Additionally, railway risk analysis is also a hierarchical process where risk information obtain at lower levels may be used for risk assessment at higher levels. In many circumstances, it may be extremely difficult to conduct probabilistic risk assessment to assess the occurrence of likelihood of hazards and the magnitudes of their possible consequences because of the uncertainty with risk data (An et al., 2006). Therefore, it is essential to develop new risk analysis methods to identify major hazards and assess the associated risks in an acceptable way in various environments where such mature tools cannot be effectively or efficiently applied (An et al., 2011, 2007, 2008, 2006; Bojadziev and Bojacziev, 1997; Chiclana et al., 2001; Railway Safety and Standard Board, 2007). The railway safety problem is appropriate for examination by fuzzy reasoning approach (FRA) combined with fuzzy analytical hierarchy process (FAHP). FRA method provides a useful tool for modelling risks and other risk parameters for risk analysis that involves the risks with incomplete or redundant safety information (An et al., 2011, 2007, 2008, 2006). The FRA allows imprecision or approximate information in risk assessment process (Berredo et al., 2005; Buckley, 1985; Bojadziev and Bojacziev, 1997; Chen et al., 2006; Dubois and Prade, 1980; BS EN 50126-2, 2007; Laarhoven and Pedrycz, 1983). However, because the contribution of each risk factor to the safety of a railway system is different, the weight of the contribution of each risk factor should be taken into consideration in order to represent its relative contribution to the risk level of the railway system. A FAHP technique is therefore required to be incorporated into the risk analysis to use its advantage in determining the relative importance of the risk factors so that the risk assessment can be progressed from hazardous event level to the identified hazard group level and finally to a railway system level. The FAHP is a very useful technique that has been applied in many fields of, for example, design and maintenance planning, reliability analysis, selecting a best alternative and resource allocations, etc. (An et al., 2011; Bojadziev and Bojacziev, 1997; Ekel et al., 2006; Fan et al., 2006; Gu and Zhu, 2006; Herrera et al., 2001; Herrera-Viedma et al., 2004; Leung and Cao, 2000). An advantage of the FAHP is its flexibility to be integrated with different techniques (An et al., 2006; Satty, 1980, 1994; Wang and Fan, 2007; Wang and Chen, 2008; Xu, 2004). The application of FAHP may solve the problems of risk information loss in the hierarchical process so that risk assessment can be carried out from hazardous event level to a railway system level (An et al., 2011, 2007, 2008, 2006). Both of these processes result in a set of probability distributions, which can be used not only to predict risk levels but also to design safety maintenance intervals. The use of these techniques is especially appropriate in the railway environment because of the volume of experience, which is still available from long-term employees. In order to show compliance with safety targets and to make future investment decisions, a railway risk assessment support system using FRA and FAHP has been developed. Details of fundamentals of a railway risk assessment support methodology will not be presented due to space constraints and the reader is referred to An et al. (2011, 2007) for details. This paper will focus on aggregation of group fuzzy risk information in the railway risk decision making process, particularly, to develop a methodology on the basis of fuzzy preference relations to deal with the consistency of the comparisons.

The application of FAHP in a risk decision making process is to determine the fuzzy priorities to produce weights of the contribution of risk factors to the safety of a railway system by conducting pairwise comparisons produced from a safety management team. In other words, it is based on preference relations, which the judgements are based on the expert experience and engineering knowledge to provide some degree of preference of any risk factor over another. However, when applying FAHP, the risk analysts often face the circumstances where a huge number of pairwise comparison matrices have to be established. Even if it is single pairwise comparison matrix, it still requires $n(n-1)/2$ judgements at a certain level with n risk factors. With the number of risk factors increasing, the numbers of comparisons are increased rapidly. As a result, the judgements produced from safety management team will high likely become inconsistent. Therefore, consistency tests are required to avoid the misleading solutions. If a comparison matrix fails the consistency test, the risk analysts must request the safety management team to make the judgements again until the comparison matrix passes. However, perfect consistency is difficult to obtain in practice (Herrera et al., 2001; Herrera-Viedma et al., 2004), particularly, when measuring preferences on a set with a large number of risk factors. Consequently, the lack of consistency in decision making can lead to inconsistent conclusions. Additionally, the judgements are crisp values which are fuzzy numbers. The inconsistent crisp numbers may be far greater. Therefore, this work would be laborious and highly unrealistic. The literature review carried out by the authors indicates that some methods have been developed in the literature to use consistency tests to avoid inconsistency in risk analysis (An et al., 2006; Berredo et al., 2005; Buckley, 1985; Chen et al., 2007, 2006; Chen and An, 2011), but, however, these methods are very complex, particular, when the number of risk factors increases. It is particular by true when:

- thousands of risk factors (or hazard/failure modes) are identified within a system;
- the system consists of hundreds of sub-systems and components; and
- expert experience and engineering knowledge are involved in decision making process.

Therefore, numbers of comparisons will be increased rapidly with the numbers of the identified risk factors/sub-systems/components increased. There may be a lack of confidence that all comparisons associated with a railway system are completely justified in a rigorous way. Furthermore, too much workload is required in determining the consistency of the judgements.

To solve the above problems, a modified FAHP methodology has been proposed. In this method, the comparison matrix is established by using the additive transitivity property and consistency so that only $n-1$ comparison judgements are required at a level with n risk factors, which a comparison matrix can be established