Hindawi
Complexity
Volume 2019, Article ID 5453184, 10 pages
https://doi.org/10.1155/2019/5453184

Research Article

Risk Analysis of Emergency Based on Fuzzy Evidential Reasoning

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Received 26 July 2019; Revised 12 October 2019; Accepted 1 November 2019; Published 22 November 2019

Guest Editor: Baltazar Aguirre-Hernandez

Risk analysis of emergency is vital to effective emergency management. However, conventional analysis is challenged by the emerging problems as risk of emergency appearing increasingly complicated. The risk attributes of emergency originate in complicated sources, and their information is always incomplete. To ensure the efficiency and stability of emergency risk analysis, we proposed an elaborative approach composed of structural description framework and fuzzy evidential reasoning. Firstly, the risk attributes are identified by structural description framework. The information as evidence is obtained and normalized for further analysis. Secondly, risk analysis model with fuzzy evidential reasoning is constructed, and risk grade is evaluated. Finally, a certain railway project accident is taken as an example to test the model and some managerial insights are demonstrated. An approach combining structural description framework and fuzzy evidential reasoning model is feasible and effective; furthermore, it provides stable support for emergency risk analysis.

1. Introduction

Over the past decades, research on emergency management has gained enormous attention in both academia and practice [1–4]. Due to the complexity of emergency and its severity consequence, it is vital to investigate deeply on the emergency management involving risk analysis, development control, and evolution management [5]. There are various types of emergency, and they make emergency management even more complicated. In China, according to the overall state emergency plan, emergency mainly contains four categories: natural disasters, social security, public health, and technical accidents. Taking earthquakes, a typical natural disaster, as an example, it performs complex on its consequence [6]. The consequence usually appears as a complex disaster chain including casualties, economic loss, fires, landslides, floods, plague, and social panic. Another example is railway project accident [7], which is even harder to cope with for the reason that such accident combines industrial technology and natural situation with social environment factors together. So, many works are carried on by the lens of complexity science [8–10], and a series of positive progress is made [11–13]. Considering the complexity of the emergency and its consequence, it will benefit to emergency management if the decision maker could react as early as possible [14]. Therefore, the risk analysis of emergency is of great significance.

As a critical part of emergency management, risk analysis of emergency is actually a complicated work [15]. Accurate and stable analysis of emergency risk means great on many aspects [16], such as to reduce frequency of occurrence [17], lower the initial loss [18], and control the evolution process effectively [19]. Therefore, it is necessary to propose advanced approach to better solve problems of risk analysis. Taking China emergency management as an example, risk management with characteristics of all-phase, all-stakeholder, and all-type was not informed until 2003. Therefore, to make further progress on risk analysis research, especially on coping with the increasingly complicated risk circumstance, it is suggested to develop more flexible and adaptable analysis approach.

Some researchers notice that emergency risk usually performs poor due to the imperfect information either inadequate or loss [20, 21]. To deal with such decision scenarios, evidential theory and evidential reasoning method are introduced [22]. In a basic evidential model, it focuses on solving problem with the characteristic of proposition uncertainty to set uncertainty [23]. This could be realized by contrasting the propositions and sets one by one. Take $\Theta = \{G_1, G_2, \ldots, G_n\}$ as a set, in which the elements are mutually exclusive and exhaustive. The set is so called identification framework. Besides, the mass (m) describes the belief of the framework, which satisfies $m(\varnothing) = 0$, and $\sum_{A\subseteq\Theta} m(A) = 1$, wherein $\varnothing$ signifies empty set and A stands for any subset of Θ. As it develops to evidential reasoning, its advantage of dealing with decision scenarios without complete information is increasingly obvious [24–29]. Therefore, a common knowledge for decision makers as well as researchers is formed that evidential reasoning could solve problems with characteristics of multiattributes.

Recent relevant works on evidential reasoning approach concentrate on the update of evidential reason rule, the implementation of this method in practice, and the integration with other methods. Among the extensive research dedicated to the evidential reasoning, the following works are very representative. Wang and Elhag [30] model the bridge risk by artificial neural network, evidential reasoning, and multiple regression analysis. After a comparison of their modelling mechanisms, they argue the remarkable advantage of evidential reasoning is its ability of modelling quantitative and qualitative data using the distributed modelling framework. Some works focus on updating the evidential rule. Yang and Xu [31] improve the evidential reasoning approach by a new rule considering evidence weights and reliabilities. Liu et al. [32] concern the hesitant fuzzy information and highlight the importance of information processing in emergency management. Some works focus on how to use evidential reasoning to solve the problems. Kong et al. [33] develop the belief rule-based inference methodology using the evidential reasoning approach and help the decision maker to predict trauma outcome. Xu et al. [34] investigate a purely data-driven work and propose a classification method using evidential reasoning. Zhang et al. [35] consider a fuzzy rule and conduct a navigational risk assessment. Some works establish novel analysis framework by integrating evidential reasoning with other approaches. Wang et al. [36] incorporate the analytic hierarchy process with evidential reasoning, by which they help contractors to select appropriate subcontractor. Evidential reasoning in this work contributes to rank the alternative subcontractors. Ng [37] takes evidential reasoning-based approach as a fast-track and objective tool and uses it to rank the available design alternatives. Working with the combination of multiattribute decision and non-life cycle assessment, it is proved that evidential reasoning benefits the evaluation of design alternatives' environmental performances. Kong et al. [38] make a combination of the principal component analysis and the evidential reasoning approach and provide a new framework to assess patient satisfaction.

To sum up, two streams of research are closely related to our work: emergency management, especially risk analysis, and approach that may contribute to risk analysis, especially evidential reasoning. The existing studies have made significant contributions to risk analysis and evidential reasoning. However, it is worth mentioning that little attention was paid to risk analysis of technical accident such as railway project accident. It may be induced by the lack of understanding for the risk analysis of such emergency. Considering the information in emergency is always uncertain and incomplete, we adopt the fuzzy evidential reasoning. Further, to better understand risk attributes, we introduce structural description framework to the fuzzy evidential reasoning. Therefore, we propose an analysis approach by incorporating the structural description framework in fuzzy evidential reasoning. To prove the validity of the model we proposed, we run a case study on railway project accident. Railway project accident is a complex system which may contain transportation accidents, public facility accidents, equipment destruction, environmental pollution, industrial hazard, and economic loss [39]. Furthermore, it is a typical technical accident and is seldom analyzed in emergency research. Therefore, our work is different from previous studies. We propose a novel approach for risk analysis by combining structural description framework with fuzzy evidential reasoning, especially when the information is imperfect either uncertain or incomplete. We firstly establish accident structural description framework, identification framework, and it helps to identify risk attributes rapidly and accurately. Secondly, we construct fuzzy belief structural model and normalize all the information we collected as evidence. Thirdly, the fuzzy evidential reasoning model is used to further processing of risk attributes. Finally, we obtain the risk analysis results, so as to provide solution for risk analysis of emergency.

The remainder of this paper is organized as follows. Section 2 establishes structural description framework for identification of risk attributes. Section 3 illustrates the model, and Section 4 takes certain railway project accident as an example to test the validity of our work. Finally, Section 5 concludes our work and offers directions for the future research.

2. Analysis of Risk Attributes

The accurate identification of emergency risk attributes is the premise of risk analysis. The core object is to identify the general attribute and basic attribute [40]. As there is no universal or uniform model for different emergencies [41], we propose a reasonable analysis framework. We determine the basic risk sources followed by their possible outcome and set them as the evidence. After that, we assign the reasoning rules and transform all the evidence to the general attribute. Till then, we accomplish emergency risk attributes analysis and lay foundation for the construction of fuzzy evidential reasoning model.

2.1. Identification of Emergency Risk Attributes. With regarding to the complicated characteristics of emergency, may be high uncertainty and severity consequence, we ought to consider both internal and external risk attributes of such complex system. To systematically illustrate emergency, it adopts a set form to establish structural description framework as Emergency = {{Emergency Type}, {Key Attribute}, {Secondary Attribute}, {Environmental Attribute}, {Hazard Attribute}} [40]. This framework significantly helps to understand the emergency and its severity as well. Looking back to the framework, it provides a simple way to identify risk attributes, covering the risk source, pattern, trend, and consequence. Therefore, this framework could also be applied to emergency risk attribute identification and correspondingly simplified as Emergency = {{Key Attribute}, {Secondary Attribute}, {Environmental Attribute}}. Among which, key attribute is the risk factor inside the emergency. To some extent, the risk grade (risk value) directly determines the severity of the initial consequences once the event occurs. The secondary attribute also stems from the inside of emergency and usually affects emergency indirectly. The environmental attribute exists outside of emergency, affects the emergency observably and measurably, but not necessarily controllably. For the convenience of further analysis, these three attributes are collectively referred as general attributes. Besides, to illustrate specific emergency risk, each general attribute could be subdivided to basic attribute. That is, the general attributes are extracted to describe the common characters, while the basic attributes are used to highlight the specific status. Then, the identification framework for emergency risk attribute is established as shown in Figure 1.

Considering the relationship among general attributes, basic attributes, and emergency risk grade, we obtain the reasoning rules as follows. If no basic attribute of certain general attribute belongs to certain risk grade, then the general attribute does not belong to this risk grade either. If all the basic attributes of certain general attribute belong to a certain risk grade, then the general attribute also belongs to this risk grade. If the basic attribute of the general attribute belongs to multiple grades, then the general attribute should be allocated to different grades under specific rules. Using the framework shown in Figure 1, we can identify the risk attributes, find the sources for risk, evaluate the occurrence probability, and predict the possible consequences. Once the risk attribute analysis framework is set up, it would support the subsequent modelling research on risk analysis of emergency.

2.2. Fuzzy Belief Model of Emergency. Considering the complicated characteristics of risk attribute, it is necessary to normalize all the risk attributes for further analysis. Usually, it takes grade to describe emergency risk. The grade should contain several standards to assess risk. The standards may cover severity of the emergency, frequency of emergency occurrence, and emergency consequence. Taking CRH brake system failure risk as an example, the risk grade is defined by grade I to grade IV. As to natural disaster risk, it is subdivided to five grades. There are also some emergency risk grades described by the qualitative method. For example, fault mode severity can be classified to insignificant, marginal, critical, and catastrophic; incident frequency can be described as seldom, little, average, usually, and always. Additionally, there are also some quantitative description methods, such as the risk value. The evidence for risk attribute is so diverse that the evidence ought to be normalized before further analysis. Combining the fuzzy set theory and the belief structure model, we establish fuzzy belief structure.

Assume emergency has N fuzzy risk grades and the adjacent two grades may intersect. Given membership functions, we symbol fuzzy numbers for each grade as FG_n and further describe them with triangular fuzzy number or trapezoidal fuzzy number. The intersection between FG_n and FG_{n+1} is denoted as $\mathrm{FG}_{n,\ n+1}$, as is shown in Figure 2. Then, the emergency fuzzy risk can be illustrated by $\mathrm{FG} = \{\mathrm{FG}_1, \mathrm{FG}_2, \ldots, \mathrm{FG}_n, \ldots, \mathrm{FG}_N\}$. Together with the belief model, we obtain the fuzzy belief model as follows:

$$\mathrm{FBS}(\mathrm{E}) = \{(\mathrm{FG}_n, \beta_n), \quad n = 1, 2, \ldots, N\}, \tag{1}$$

wherein FG_n represents fuzzy risk grade, N depicts the total number of grades, and β_n denotes the belief of emergency risk grade falling on grade FG_n. Moreover, we have $\beta_n \geq 0, 0 \leq \sum_{n=1}^{N}\beta_n \leq 1$. Specifically, $\sum_{n=1}^{N}\beta_n = 1$ indicates that the risk attribute information is completely known, while $\sum_{n=1}^{N}\beta_n = 0$ indicates that people know nothing about risk attribute at all.

3. Model

Based on the aforementioned analysis, the evidential reasoning model would be proposed. The model would be ultimately established through the following four steps. Firstly, risk attributes are identified. By the structural description framework for emergency, we could obtain the general attribute and further get the basic attribute through experience on emergency management. Secondly, information of risk attributes is normalized. We collect the information of all the risk attributes and take them as evidence for further reasoning. Then, we set the normalization rules for evidence both qualitative and quantitative. Thirdly, the general attributes contributing to risk are calculated. The major work in this step is mainly composed of calculation on mass value and correspondingly belief for all the general attributes, as well as allocation of the intersection reliability. Finally, the emergency risk analysis results are obtained. The framework of evidential reasoning model is shown in Figure 3. As the first step has been prepared by risk attribute analysis, we would pursue the model construction from the second step.

3.1. Conversion of Fuzzy Belief Structure. Evidence of risk attribute has the characteristics of multifeature, multistandard, and multilength, which increases the complexity of risk analysis. Therefore, it is necessary to normalize the evidence of risk attributes before subsequent analysis. To solve this problem, we adopt fuzzy belief structure model. Given fuzzy risk grades $\mathrm{FG} = \{\mathrm{FG}_n, n = 1, 2, \ldots, N\}$, fuzzy belief structure is $\mathrm{FBS}(\mathrm{E}) = \{(\mathrm{FG}_n, \beta_n), n = 1, 2, \ldots, N\}$. Assuming that risk attribute R has evidence with length l, its

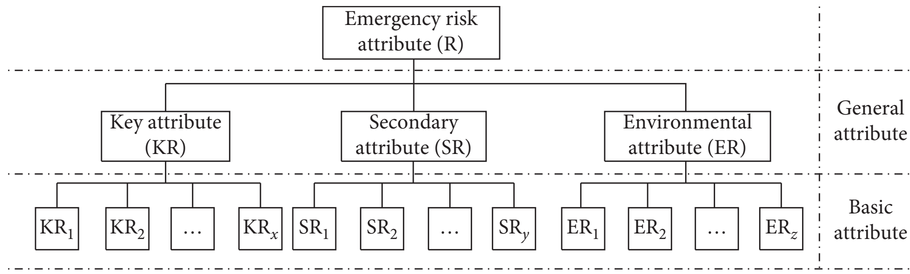

Figure 1: Emergency risk attribute identification framework.

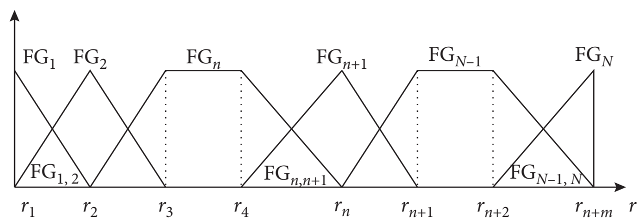

Figure 2: Fuzzy risk grade.

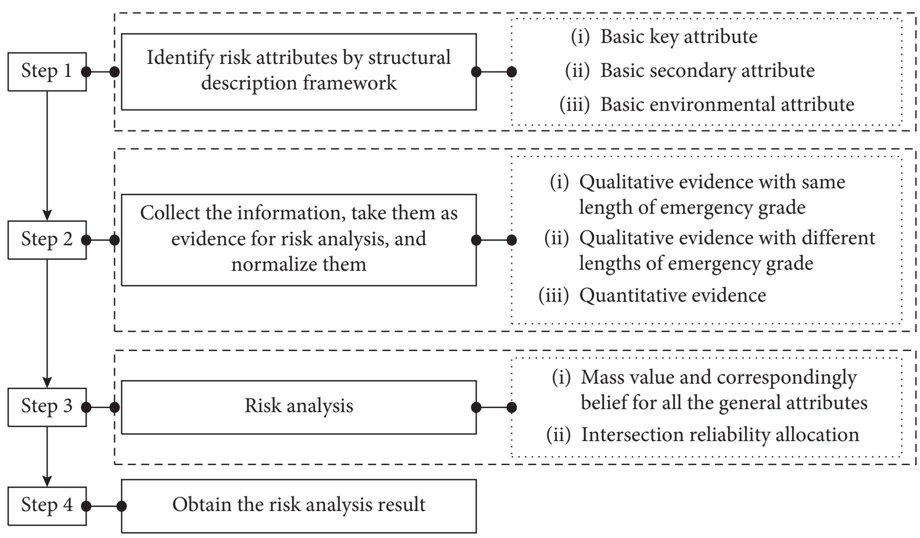

Figure 3: Framework of fuzzy evidential reasoning model.

risk grade is $FG^{Rl} = \{FG_{nl}, n = 1, 2, \ldots, N\}$ and its fuzzy belief structure could be labeled as $FBS(Rl) = \{(FG_{nl}, \alpha_n), n = 1, 2, \ldots, N\}$. Regarding that evidence could be illustrated either qualitatively or quantitatively (even with different lengths), we set the processing rules as follows.

If the risk attribute has qualitative evidence with the same length comparing to emergency fuzzy risk grade, i.e., $N_l = N$, then the evidence could be converted directly by

$$\left(FG_{n2}^{Rl}, \alpha_{n2}\right) \Longleftrightarrow \left(FG_{n1}, \beta_{n1}\right), \quad n_1 = n_2, n_1 \in N, n_2 \in N_l. \tag{2}$$

If the evidence is qualitative with different lengths comparing to fuzzy risk grade, i.e., $N \neq N_l$, then we could convert it to FG_{n1} by belief $\gamma_{n1,n2} (n_1 \in N, n_2 \in N_l)$. Therefore,

$$\left(FG_{n2}^{Rl}, \alpha_{n2}\right) \Longleftrightarrow \left(FG_{n1}, \gamma_{n1,n2}\right), \quad n_1 \in N, n_2 \in N_l, \tag{3}$$

wherein $0 \leq \gamma_{n1,n2} \leq 1$ and $\sum_{n1=1}^{N} \gamma_{n1,n2} = 1$.

If the risk attribute has quantitative evidence and its risk value belongs to fuzzy risk grade FG_n and FG_{n+1} with membership μFG_n and μFG_{n+1} separately, then it converts as

$$\left(FG_{n2}^{Rl}, \alpha_{n2}\right) \Longleftrightarrow \left(FG_{n1}, \frac{\mu_{FGn}}{\mu_{FGn} + \mu_{FGn+1}}\right), \left(FG_{n+1}, \frac{\mu_{FGn+1}}{\mu_{FGn} + \mu_{FGn+1}}\right), \quad n_1 \in N, n_2 \in N_l. \tag{4}$$

By (2)–(4), the basic risk attribute evidence is normalized.

3.2. Fuzzy Evidential Reasoning Model. As aforementioned, we establish a structural description framework consisting of key attributes, secondary attributes, and environmental attributes; we could use this framework, i.e., $R = \{\{KR\}, \{SR\}, \{ER\}\}$ to describe emergency risk attributes. Each general attribute could be subdivided into some certain basic attributes. From then on, we take KR as an example to construct model. Assume the number of KR's basic attributes is X and get $\mathrm{FBS}_x^{\mathrm{KR}} = \{(\mathrm{FG}_n, \beta_n^x)\}, n = 1, 2, \ldots, N, x = 1, 2, \ldots, X$ after fuzzy belief structure converting. Setting the corresponding weight of KR_xas ω_x, and $\sum_{x=1}^{X} \omega_x = 1$, the mass value of each basic risk attributes could be obtained by

$$m_n^x = \omega_x \beta_n^x, \quad n = 1, 2, \ldots, N, x = 1, 2, \ldots, X. \tag{5}$$

Additionally, there also exists some risk which could not be ascertained due to incomplete or even totally unknown information in practice, which is measured by

$$m_G^x = 1 - \sum_{n=1}^{N} m_n^x = 1 - \sum_{n=1}^{N} \omega_x \beta_n^x, \quad n = 1, 2, \ldots, N, x = 1, 2, \ldots, X. \tag{6}$$

By normalization weights ω_x to ω', we can further process the evidence of KR. The risk evaluation result of KR is $\mathrm{FBS}(\mathrm{KR}) = \{(\mathrm{FG}_n, \beta_n^{\mathrm{KR}})\}, n = 1, 2, \ldots, N, x = 1, 2, \ldots, X$. Therefore, we obtain the mass value of KR by using the following equation:

$$m_n^{\mathrm{KR}} = \omega' \left\{ \prod_{x=1}^{X} [m_n^x + m_G^x] - \prod_{x=1}^{X} m_G^x \right\}, \quad n = 1, 2, \ldots, N. \tag{7}$$

The mass value of the intersection between two adjacent risk grades is

$$m_{n,n+1}^{\mathrm{KR}} = \omega' \mu_{\mathrm{FG}n,n+1}^{\max} \left\{ \prod_{x=1}^{X} (m_n^x + m_{n+1}^x + m_G^x) - \prod_{x=1}^{X} (m_n^x + m_G^x) - \prod_{x=1}^{X} (m_{n+1}^x + m_G^x) + \prod_{x=1}^{X} m_G^x \right\}, \quad n = 1, 2, \ldots, N-1. \tag{8}$$

The mass value of uncertain risk grades due to imperfect information is

$$m_G^{\mathrm{KR}} = \omega' \left\{ \prod_{x=1}^{X} m_G^x \right\}. \tag{9}$$

Specially, ω' is determined by $\sum_{n=1}^{N} m(G_n) + \sum_{n=1}^{N-1} G_{n,n+1} = 1$.

Belief for each mass value is

$$\beta_n^{\mathrm{KR}} = \frac{m_n^{\mathrm{KR}}}{1 - \overline{m}_G^{\mathrm{KR}}}, \quad n = 1, 2, \ldots, N, \tag{10}$$

$$\beta_{n,n+1}^{\mathrm{KR}} = \frac{m_{n,n+1}^{\mathrm{KR}}}{1 - \overline{m}_G^{\mathrm{KR}}}, \quad n = 1, 2, \ldots, N-1. \tag{11}$$

We obtain the primary analysis result by $\{(\mathrm{FG}_n^{\mathrm{KR}}, \beta_n^{\mathrm{KR}}), (\mathrm{FG}_{n,n+1}^{\mathrm{KR}}, \beta_{n,n+1}^{\mathrm{KR}}), (\mathrm{FG}_G^{\mathrm{KR}}, \beta_G^{\mathrm{KR}})\}$. However, the intersection between two grades does not exist in reality. Therefore, it still needs further analysis on $(\mathrm{FG}_{n,n+1}^{\mathrm{KR}}, \beta_{n,n+1}^{\mathrm{KR}})$.

3.3. Allocation of Fuzzy Intersection Belief. Considering the risk grade is regulated clear in reality, it is necessary to process the intersection between adjacent risk grades. To insure the analysis is reasonable, we set the reasoning rules as follows. If the intersection $\mathrm{FG}_{n,n+1}$ totally belongs to FG_n or FG_{n+1}, then its belief also belongs to FG_n or FG_{n+1}. If the intersection $\mathrm{FG}_{n,n+1}$ varies from FG_n to FG_{n+1}, as shown in Figure 4, and the endpoints are set by FG_n and FG_{n+1}, then we allocate $(m_{n,n+1}^{\mathrm{KA}}, \beta_{n,n+1}^{\mathrm{KA}})$ within this interval.

As it is shown in Figure 4, the proportion of grade FG_n in $S_{n,n+1}$ is $\delta_n^{\mathrm{KR}'}$, while the proportion of grade FG_{n+1} is $\delta_{n+1}^{\mathrm{KR}'}$. $\delta_n^{\mathrm{KR}'} + \delta_{n+1}^{\mathrm{KR}'} = 1$, and they are determined by (12) and (13) separately:

$$\delta_n^{\mathrm{KR}'} = \frac{1}{2}\left[\left(1 - \frac{d_n}{d_n + d_{n+1}}\right) + \frac{S_n}{S_n + S_{n+1}}\right], \tag{12}$$

$$\delta_{n+1}^{\mathrm{KR}'} = \frac{1}{2}\left[\left(1 - \frac{d_{n+1}}{d_n + d_{n+1}}\right) + \frac{S_{n+1}}{S_n + S_{n+1}}\right]. \tag{13}$$

Therefore, the belief allocated to grade FG_n is

$$\beta_n^{\mathrm{KR}'} = \frac{S_n + \delta_n^{\mathrm{KR}'} S_{n,n+1}}{S_n + S_{n,n+1} + S_{n+1}}. \tag{14}$$

However, the belief allocated to grade FG_{n+1} is

$$\beta_{n+1}^{\mathrm{KR}'} = \frac{S_{n+1} + \delta_{n+1}^{\mathrm{KR}'} S_{n,n+1}}{S_n + S_{n,n+1} + S_{n+1}}. \tag{15}$$

Then, combining with$\{(m_n^{\mathrm{KR}}, \beta_n^{\mathrm{KR}}), (m_{n,n+1}^{\mathrm{KR}}, \beta_{n,n+1}^{\mathrm{KR}}), (m_G^{\mathrm{KR}}, \beta_G^{\mathrm{KR}})\}$, we get the initial risk analysis result of accident as

$$\left\{\left(m_n^{\mathrm{KA}}, \beta_n^{\mathrm{KA}} + \beta_n^{\mathrm{KA}'}\right), \left(m_G^{\mathrm{KA}}, \beta_G^{\mathrm{KA}}\right)\right\}. \tag{16}$$

Since the key attribute, secondary attribute, and environmental attribute have been differentiated when we identify general risk attribute, it is not necessary to rank the risk attributes like risk analysis paradigm in general.

3.4. Analysis of Fuzzy Evidential Reasoning Results. To understand the risk grade more intuitively, we take a further analysis. It also benefits emergency management, such as release warning signals and formulate emergency response in different stages of the emergency. To solve this problem, we use the expected risk value. As the risk grade and its belief could be obtained by (16), we determine the grade risk values as follows. Assuming the risk value of the highest grade to 1 and the lowest grade to 0, the $n-2$ grades among them could be determined by specific accident. The analysis result would be finally obtained by the summation of all the risk values:

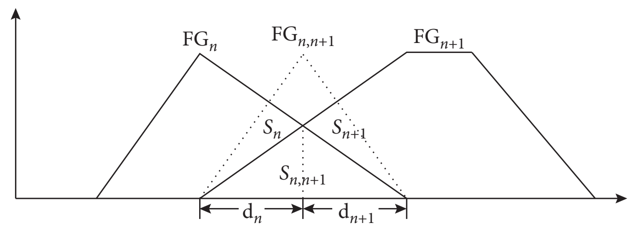

Figure 4: Fuzzy intersection reliability allocation.

$$U^{\mathrm{KA}} = \sum_{n=1}^{N} \beta_n r_n. \qquad (17)$$

Based on the analysis of the key attribute, we can analyze the risk of the secondary attribute and environmental attribute as the same way proposed by (1)–(17). With regarding to the expected risk value of KR, SR, and ER, it would exactly help to analyze accident risk. That is, given the information of risk attributes, the fuzzy evidential reasoning model would make sense on estimating to what extent the accident would happen. Besides, this approach also helps to evaluate the severity of the accident consequence.

4. Model Analysis on Case Study

Here, we take railway project accident as an example. Railway project accident is a typical technical accident and seldom researched in previous works. We determine the information and evidence of risk attribute mainly from the following two documents: *Technical Code for Risk Management of Railway Construction Engineering* (issued by China Railway in 2014), *Statistics of Construction Risk* (a series of documents declared by certain railway project in 2018).

4.1. Model Solution

4.1.1. Step 1. Using the emergency risk attribute identification framework, we determine the general attributes and their basic attributes. Then, calculate the risk grade, weight, and value of all attributes. Finally, we obtain 21 basic attributes, and their information is summarized as shown in Table 1.

4.1.2. Step 2. Considering the specific condition of railway project in China, we measure the risk grade of railway project accident by {Catastrophic, critical, general, Marginal, insignificant}, which simplifies as $FG = \{FG_1, FG_2, FG_3, FG_4, FG_5\}$. With regard to Figure 2, finally, we determine the fuzzy risk grade for railway project accident as in Figure 5.

4.1.3. Step 3. We take further process of basic risk attributes. To simplify but without loss of generality, we omit the process of getting the ultimate evidence from multi-information. Calculation starts from *cut slope height*, whose risk value is 2; triangular fuzzy number for FG_1 is (0, 0, 4) and for FG_2 is (0, 4, 8). Then, we obtain fuzzy belief of *cut slope height* as $\{(FG_1, 0.5), (FG_2, 0.5), (FG_3, 0), (FG_4, 0), (FG_5, 0)\}$, take (0.5, 0.5, 0, 0, 0) for short. All the basic attribute analysis results are demonstrated in the third column in Table 2. Then, we get the mass value by (5)–(7), and the result is shown in the fourth column in Table 2. Based on equations (8)–(11), we get the primary result on railway project accident risk analysis and it is shown in the fifth column in Table 2. Note that there is still an intersection between the adjacent grades; therefore, we pursue to allocate the intersection by the following steps.

4.1.4. Step 4. By equation (12)–(16), we allocate the intersection belief to the two adjacent grades and get the result on risk evaluation considering risk grade and its belief. As mentioned before, we further calculate the expected risk value for each basic attribute by using equation (17). Finally, we conclude the results of this step and list them in Table 3.

4.2. Results Analysis. We could draw some managerial insight out of the above results. One interesting point is that the risk value of the key attribute is not significantly high comparing with the traditional recognition. We explain this counterintuitive result from the perspective of practice. In reality, people tend to spend enormous money and high effort on this aspect, and it leads to technology progress and effective regulation. Therefore, although the key attribute is vital to railway project accident, the failure rate and risk value is low. It is in line with the development status of China railway project.

Secondary attribute performs relatively average in risk grade and belief, which is basically consistent with the actual situation. Unexpectedly, the belief allocated for the environmental attribute is relatively high. It may be due to the geological condition which is important to railway project and its operation. As it is shown in the statistics data of railway project accident, major economic losses and casualties are usually caused by environmental attribute.

To some extent, these findings will push managers to rethink the role of traditional experience recognition and related training. Moreover, we also provide reference for risk prevention, early warning, and response of railway project accident. Especially, it would obviously benefit to the railway company with capital constraints.

Table 1: Railway project accident risk analysis and evident definition.

General attribute	Basic attribute	Risk consequence	Risk grade	Risk weight	Risk value
Key attribute	Cut slope height	Slide slump, blocks peeling off, roadbed deformation	FG_1	0.2	2
	Bank slope height	Embankment settlement, slope collapse	FG_3	0.1	9
	Special construction conditions	Casualty, economic loss, postproject risks	FG_2	0.2	6
	Special construction technologies	Project failure, economic loss, derivative project failure, postproject risks	FG_1	0.2	1
	Deep foundation pit	Structural design failure, settlement deformation, unexpected accidents	FG_2	0.2	7
	Existing railway effects	Technological bottleneck, roadbed deterioration, schedule delay	FG_4	0.1	16
Secondary attribute	Project schedule	Go over budget, alleviate function, interface project delay	FG_4	0.1	15
	Function loss	Below the market demand	FG_3	0.05	9
	Project investment	Project abandon, poor quality, social conflicts	FG_4	0.1	11
	Environment protect	Destroy environment like cultural relics and natural habitats. Social conflict and welfare	FG_1	0.15	1
	Social status along the project	Social conflict, go over budget, schedule delay	FG_5	0.05	17
	Locomotive depot configuration	Operational risk, social investigation	FG_4	0.05	14
	Vehicle configuration	Operational risk	FG_5	0.05	18
	Terminal location	Project abandon, infrastructure settlement	FG_3	0.05	14
	Project interface	Project isolation, project failure	FG_3	0.2	9
	Infrastructure relocation	Go over budget, schedule delay, group conflict	FG_2	0.15	6
	Residual risk	Unexpected loss	FG_3	0.05	—
Environmental attribute	Weather condition	Project duration, operational risk	FG_3	0.15	9
	Underground water	Settlement, roadbed deformation, water pollution	FG_5	0.25	18
	Geological condition	Roadbed risk, social conflict, project abandon, karst water and mud inrush disaster, bombing	FG_3	0.25	7
	Stuff quality	Casualty, operational risk, project failure	FG_2	0.35	3

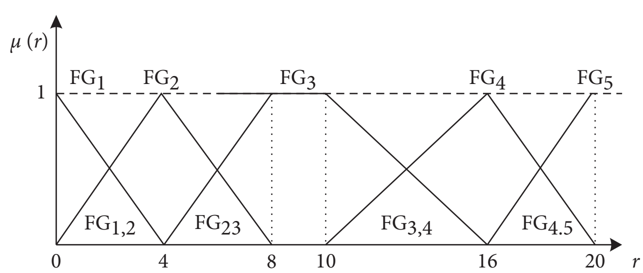

Figure 5: Fuzzy risk grade of railway project accident.

Table 2: Analysis results of risk attributes (I).

General attribute	Basic attribute	Belief	Mass	Primary result
Key attribute	Cut slope height	(0.5, 0.5, 0, 0, 0)	(0.1, 0.1, 0, 0, 0)	$\{(FG_1, 0.0241), (FG_{1,2}, 0.0136), (FG_2, 0.1906), (FG_{2,3}, 0.1742), (FG_3, 0.1814), (FG_{3,4}, 0.0258), (FG_4, 0.048), (FG_{4,5}, 0.0127), (FG_5, 0)\}$
	Bank slope height	(0, 0, 1, 0, 0)	(0, 0, 0.1, 0, 0)	
	Special construction conditions	(0, 0.5, 0.5, 0, 0)	(0, 0.1, 0.1, 0, 0)	
	Special construction technologies	(0.3333, 0.6667, 0, 0, 0)	(0.0666, 0.1333, 0, 0, 0)	
	Deep foundation pit	(0.875, 0.125, 0, 0, 0)	(0.1750, 0.025, 0, 0, 0)	
	Existing railway effects	(0.0, 0, 1, 0)	(0.0, 0, 0.1, 0)	

Table 2: Continued.

General attribute	Basic attribute	Belief	Mass	Primary result
Secondary attribute	Project schedule	(0, 0, 0, 0.625, 0.375)	(0, 0, 0, 0.0625, 0.0375)	{(FG_1, 0.1002), ($FG_{1,2}$, 0.0106), (FG_2, 0.1057), ($FG_{2,3}$, 0.059), (FG_3, 0.1067), ($FG_{3,4}$, 0.0871), (FG_4, 0.1323), ($FG_{4,5}$, 0.0144), (FG_5, 0.1632)}
	Function loss	(0, 0, 1, 0, 0)	(0, 0, 0.05, 0, 0)	
	Project investment	(0, 0, 0.1667, 0.8333, 0)	(0, 0, 0.0167, 0.0833, 0)	
	Environment protect	(0.5, 0.5, 0, 0, 0)	(0.075, 0.075, 0, 0, 0)	
	Social status along the project	(0, 0, 0, 0.875, 0.125)	(0, 0, 0, 0.0438, 0.0625)	
	Locomotive depot configuration	(0.0, 0, 0.6667, 0.3333)	(0, 0, 0, 0.0333, 0.0167)	
	Vehicle configuration	(0.0, 0, 0.8889, 0.1111)	(0, 0, 0, 0.0444, 0.0056)	
	Terminal location	(0, 0, 0.4286, 0.5714, 0)	(0, 0, 0, 0.0214, 0.0286)	
	Project interface	(0, 0, 1, 0, 0)	(0, 0, 0.2, 0, 0)	
	Infrastructure relocation	(0, 0.8571, 0.1429, 0, 0, 0)	(0, 0.1286, 0.0214, 0, 0)	
	Residual risk	(0, 0, 0, 0, 0)	(0, 0, 0, 0, 0)	
Environmental attribute	Weather condition	(0, 0, 1, 0, 0)	(0, 0, 0.15, 0, 0)	{(FG_1, 0.1123), ($FG_{1,2}$, 0.0344), (FG_2, 0.1031), ($FG_{2,3}$, 0.0357), (FG_3, 0.1708), ($FG_{3,4}$, 0.0258), (FG_4, 0.0746), ($FG_{4,5}$, 0.0322), (FG_5, 0.0096)}
	Underground water	(0, 0, 0, 0.3333, 0.6667)	(0, 0, 0, 0.0833, 0.1667)	
	Geological condition	(0, 0.25, 0.75, 0, 0)	(0, 0.0625, 0.1875, 0, 0)	
	Staff quality	(0.8571, 0.1429, 0, 0, 0)	(0.3, 0.05, 0, 0, 0)	

Table 3: Analysis results of risk attributes (II).

	FG_1	FG_2	FG_3	FG_4	FG_5	Expected risk value
Key attribute	0.0319	0.2805	0.2764	0.0672	0.0064	0.5742
Secondary attribute	0.1057	0.1395	0.1787	0.1831	0.1704	0.5649
Environmental attribute	0.1295	0.1392	0.2015	0.1036	0.0257	0.4151

5. Conclusions

Emergency risk analysis is vital to emergency management; especially, it plays an important role on learning emergency operational mechanism. Aiming at providing a stable approach to analyze emergency risk, this paper proposes an analytical approach incorporating structural description framework and fuzzy evidential reasoning. It starts from the establishment of risk attribute identification, which is taking emergency structural description framework as the foundation. Then, we assess the risk grade of risk attributes by evidential reasoning. By a case study on railway project accident, it is proved that the approach outperforms comparing to current risk management. It could provide theoretical support for the risk prevention and decision-making involving in each stage.

To conclude, our study proposes a novel approach for accident risk analysis by combining structural description framework and fuzzy evidential reasoning, especially when the information is imperfect either uncertain or incomplete. We firstly establish accident structural description framework, identification framework; it helps to recognize risk attributes rapidly and accurately. Secondly, we construct fuzzy belief structural model and normalize all the information. Thirdly, the fuzzy evidential reasoning model is used to combine basic attributes. Finally, we obtain the analysis results, so as to assist the decision-making of emergency risk prevention or response.

The limitations of our work are also obvious due to the model construction. Firstly, the evidential reasoning rule we used here is very basic. It is in premise of the implicit assumption that the fuzzy risk grade is defined clearly. However, the grade may be obscure in reality, and it may induce the fact that the evidence belongs to three or more different grades. Secondly, the basic attributes of our case study are relatively small. We obtain such attributes from deep analysis of daily records of specific railway project and statistics of construction risk, and they are undoubtedly helpful to make risk analysis. Considering the analysis result, especially the analysis of key attribute, it still needs more detailed works on the basic attributes to highlight the critical of the key attribute. Finally, our work merely focuses on the occurrence risk of emergency, indeed risk is always developing. So, we have to further alleviate the difficulty of evidential reasoning application or do the risk analysis taking emergency development or evolution under consideration.

Regarding above limitations and the fact that risk management is the basic of emergency development management and evolution research, it needs further study. As to future work, the research could enrich the evidential reasoning rule by new tools of data mining and expand the attributes' scope from occurrence risk to development risk and evolution risk. Further, the research could enrich the works on risk prevention and early warning. In addition, future work may introduce various constraints to close the reality, especially the resource constraints. After that, it could finally provide great references for relevant managers and help to make scientific and efficient decisions.

Data Availability

All the data generated or analyzed during this study are included in this paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The first author acknowledges support from the Humanities and Social Science Foundation of Ministry of Education of China (grant no. 17YJC630113) and NSFC (grant nos. 71572115 and 91646117). The second author acknowledges support from NSFC (grant nos. 71702021 and 71802143) and the Fundamental Research Funds for the Central Universities (DUT18RC(4)021).

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