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Identifying hazardous road sections using a fuzzy expert system

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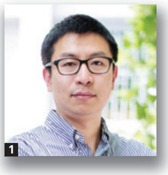
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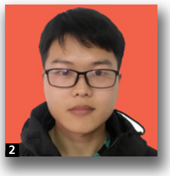
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To identify hazardous sections of newly built mountainous highways, decision-makers require assistance to determine the sections that may pose risks to road users, thereby enhancing the level of road safety management and capital utilisation efficiency. In this research, traffic accident economic losses were used as evaluation indices to characterise 30 horizontally curved sections of roadways. These highway sections were divided into five levels based on their evaluated level of risk. With the effects of multiple factors and the characteristics of uncertainty, mathematical statistics and fuzzy expert systems (FESs) were used to determine the factors contributing to hazardous sections of mountainous highways. The membership functions and fuzzy rule base were decided according to accident data and expert experience and a method for identifying hazardous sections based on the expert systems was established. The risk values of another 35 horizontally curved sections were obtained by this method and good results were achieved using the method to identify hazardous sections. The results showed that hazardous section classification is greatly affected by the horizontal radius, grade and declination angle of the horizontal curve. The results obtained from the FESs agreed overall with actual accident data.

Notation

a	declination angle
d	danger value
i	grade
R	horizontal radius
r^2	coefficient correlation
Y	traffic accident economic losses

1. Introduction

The highway network in China has grown rapidly in recent years, reaching a total mileage of 110 000 km in 2014. Mountainous and hilly areas comprise more than two-thirds of the total land area in China (NBS, 2014) and, with the rapid growth of the highway network, the total mileage of mountainous highways is increasing dramatically. The indices adopted in the construction of mountainous highways are lower than those for other areas and the road structures used in these hilly areas have resulted in frequent accidents (Zhang *et al.*, 2011). The number of casualties in road traffic accidents in China reached nearly 300 000 in 2011, second only to the number in India (Wang *et al.*, 2015). Furthermore, the number of accidents occurring on horizontally curved road sections comprises 10·5% of the total number of highway accidents, meaning that horizontal curves are the most common cause of accidents aside from speeding (MPS, 2014). With further developments in the transportation network, improvements in highway traffic safety require large capital investments. However, because of limited funds, financial decision-makers are only willing to invest in those segments most urgently in need of improvement. If the most dangerous segments can be identified and then improved, money will be saved, the efficiency of the financial system will be enhanced and highway safety will be improved.

Comprehensive overviews of the different methods used to predict road accident events are available in the literature (Hauer, 2009; Lord and Mannering, 2010; Savolainen *et al.*, 2011). Many scholars have used the empirical Bayes method to develop models for the multivariate prediction of accident events and hotspot identification (Huang and Abdel-Aty, 2010; MacNab., 2003, 2004; Miaou and Song, 2005;

Park *et al.*, 2010; Persaud *et al.*, 2010; Song *et al.*, 2006). More recently, a Bayesian probabilistic network (BPN) method was developed to predict the expected number of accidents and has gradually shown the advantages of hotspot identification (Deublein *et al.*, 2013; Hossain and Muromachi, 2012; Oña *et al.*, 2011, 2013). Cheng and Washington (2005) used experimentally derived simulated data to evaluate the three methods of hotspot identification that are typically observed in practice: simple ranking, confidence intervals and empirical Bayes analysis. Their results showed that the empirical Bayes technique significantly outperformed both the ranking and confidence interval techniques. Jasiūnienė and Čygas (2013) applied the empirical Bayes method to develop an accident prediction model for the roads of national significance in Lithuania and built computer software (Tarva LT) to calculate the expected number of accidents. Luo and Zhou (1999) adopted stepwise cluster analysis to determine dangerous road sections, and a method and standard for identifying accident hotspots were established with the Bayesian probabilistic theory and the stepwise cluster analysis results. Deublein *et al.* (2014) compared the empirical Bayes method and the BPN method in predicting accidents. They showed that both methods can be used to develop models for the multivariate prediction of accident events, but the BPN models showed a better result in predicting accident hotspots. Many other researchers have used geographic information systems (GISs) and other methods to predict the hazardous segments of highways. Erdogan *et al.* (2008) used a GIS as a management system for accident analysis, determining hotspots in a highway network by two different methods: kernel density analysis and repeatability analysis. They realised that the hotspots identified with the two methods reflected extraordinarily problematic locations, such as cross-roads and junction points. Qi *et al.* (2007) developed a random effects ordered Probit model to predict the likelihood of freeway accidents; the model performed well in identifying the factors associated with traffic accidents and forecasting the likelihood of accidents. Abdulkabir *et al.* (2015) used time series analysis to predict trends in the number of accidents in Ibadan and their results predicted an increase in the number of accidents occurring in the future. Pei and Ding (2005) proposed the outstanding factor method for hotspot analysis. In this method, when differentiating hotspots, outstanding and composite factors are considered as those more likely to cause accidents when compared with other factors. Shao *et al.* (2008) developed a dynamic system for simulating and identifying road accident hotspots. They established models for vehicles, roads and vehicle–road coupling and, based on these, proposed an identification method for road accident hotspots. The feasibility of the system was validated using dynamics simulation examples of vehicles running on roads with a low friction coefficient and braking on curved roads.

Fuzzy expert systems (FESs) have been used in many studies. Lin and Chang (1998) developed a FES for incident detection and classification. This system can detect not only the occurrence of incidents, but also their lane locations and the resulting severity. Kaur and Tekkedil (2000) developed an expert system based on fuzzy logic to predict the rut depth of asphalt pavements. They found that the FES gave a much better estimate of the prediction of the performance of the pavement than the original data. Koduru *et al.* (2010) used fuzzy logic and expert system approaches to evaluate the distress in a flexible pavement and developed an expert system in C language. This research helped to automate pavement condition evaluations completely and provided strategy development for the maintenance and rehabilitation of pavements. A few scholars have conducted research using this method to identify hazardous segments of mountainous highways (HSOMH).

No statistical information is available for newly built routes and therefore the majority of established methods cannot be used for newly constructed transportation networks. In addition, accident information recorded by public security organisations is subjective and arbitrary, causing deviations in the findings of different evaluations. A certain deviation also exists between actual data and the results obtained by simulation. Geometric factors, environmental factors and driver behaviour can lead to traffic accidents. Considering the characteristics of fuzzy data and data capturing, a new general method for the identification of mountainous highway segments with high accident potentials based on mountainous highway geometric factors is introduced. HSOMH can be identified when the design is completed, thereby assisting financial decision-makers in locating risky sections before the road is opened. The level of safety management and the efficiency of funds utilisation may be greatly improved in China through the use of this method.

The area selected for study was the Xi'an–Hanzhong highway, which connects Xi'an to the southwest of Shaanxi. It is located in a mountainous region that has a great many factors for accident occurrences. Because the geometric factors are dangerous and sight distances are inadequate, drivers are under great psychological pressure while driving. Since the studied road is old and precise accident data are unavailable, among the many factors that can affect traffic accident occurrence, only roadway design indices were considered in this research. A FES was utilised to identify the HSOMH. A FES integrates expert experience with fuzzy mathematics, introduces the concept of membership functions to the fuzzy knowledge representation in the expert system and transforms expert experience into fuzzy reasoning rules. This research shows how a FES can be properly applied to identify HSOMH.

This paper is organised as follows. The basic principle of the FES is introduced in Section 2. The factors contributing to the risks of various HSOMH are presented in Section 3. The model to identify HSOMH is established in Section 4. Implementation of the model and its applications are described in Section 5. Finally, the conclusions from this research and the scope of future work are discussed in Section 6.

2. Basic principle of the FES

Considering the fuzzy nature of the geometric factors of roads and expert experience of road danger levels, precise mathematical models cannot describe highway risks. The identification process is based not only on symbolic reasoning, but also on numerical calculations. By transforming expert experience into fuzzy reasoning rules, a FES can achieve faster and higher quality comprehension of fuzzy reasoning (Lin *et al.*, 2011). Fuzzy reasoning rules play a critical role in FESs. In this research, many experts were asked about the contributory factors in identifying HSOMH and the influence degree of combinations of different influencing factors on road safety. The fuzzy reasoning rules were generated after processing this expert experience. The FES developed can make full use of different expert experiences and simulates the human thought processes of the experts. Meanwhile, qualitative expert experience can be transformed into quantitative expressions and thus HSOMH can be identified before road construction.

The core of the FES in this study is the Mamdani fuzzy reasoning model, which consists of a fuzzy generator, fuzzy rules, a fuzzy inference engine and a defuzzifier. Figure 1 shows the architecture of the Mamdani fuzzy model.

3. Contributory factors for HSOMH

Due to the rough terrain of mountainous areas, more horizontal curves are used to adapt the landform. Meanwhile, in order to reduce the amount of earthworks, the radii of the horizontal curves of highways in mountainous areas are usually smaller than those in other areas and the road grade is also much larger; the geometric features of a mountainous highway are thus more dangerous than those in other areas.

Figure 2 shows an actual situation of the highway in the mountainous area. In the figure, JD indicates the road intersection point, R is the horizontal radius, L indicates the transition curve and a is the declination angle of the horizontal curves. ZH is the junction point of a straight line and the transition curve, HY is the junction point of the transition curve and the circle curve, YH is the junction point of the circle curve and the transition curve, HZ is the junction point of the transition curve and a straight line and QZ indicates the middle point of the horizontal curve.

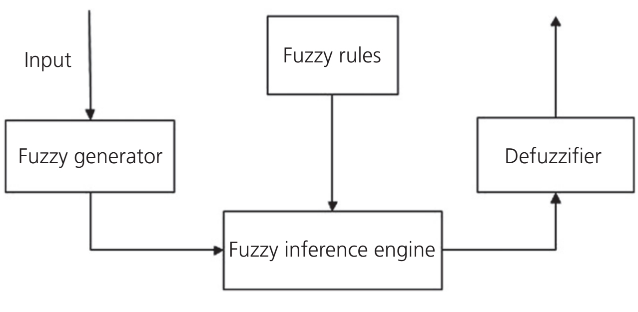

Figure 1. Architecture of Mamdani fuzzy model

A significant component of this research was the selection of contributory factors in identifying HSOMH. To judge whether a horizontally curved section of the road is dangerous, different geometric factors were considered for the following reasons. Centrifugal forces act on cars driving on horizontally curved sections of the road; these greatly affect the stability of a vehicle travelling on the circular curve and can cause the vehicle to move outwards by sliding or overturning (Zhang *et al.*, 2015b). For curves with smaller radii, the centrifugal forces are stronger, and cars travelling on these curves are less stable and thus more prone to traffic accidents (Zhang *et al.*, 2015a). The grade of road segments in mountainous highways is generally large; because cars brake more frequently when travelling uphill or downhill, the temperature of the brake friction plate increases and may cause brake failure (Zhang *et al.*, 2009).The declination angles of horizontal curves in a mountainous highway may be too big or too small because of the topographical constraints in mountainous areas. When the declination angle of a horizontal curve is too small, even for curves of a very large radius, the arc length of the horizontal curve visible to the driver is shorter than the actual length. This causes the driver to perceive a sharp bend, adding to the burden of driving. Meanwhile, when the declination angle of a horizontal curve is too large, the field view angle of the driver becomes larger, which leads to poor sight distance and increases the possibility of accidents (Yang, 2009). Therefore, the horizontal radius, grade and declination angle of a horizontal curve all significantly affect the likelihood of traffic accidents on that curve. Traffic accident economic losses (TAEL) are used as a representative of road hazards in this study. TAEL mean the whole economic losses of a single traffic accident and are measured in terms of monetary losses; these data were collected from the public sector. While TAEL are not the best evaluating indicator for accident severity, it is difficult to obtain data on accident casualties in China. It was thus considered that TAEL are thus a rational choice to represent road hazards in this research.

Data from 35 road sections on the Xi'an–Hanzhong highway (horizontal radii, grades, declination angles of horizontal curves) and TAEL were used. The correlations between these factors were then quantitatively analysed.

3.1 Correlation analysis

Scatter diagrams can depict general trends between independent and dependent variables, and appropriate functions can be selected to fit the data points. In this study, scatter diagrams were first plotted and then the relationships among horizontal

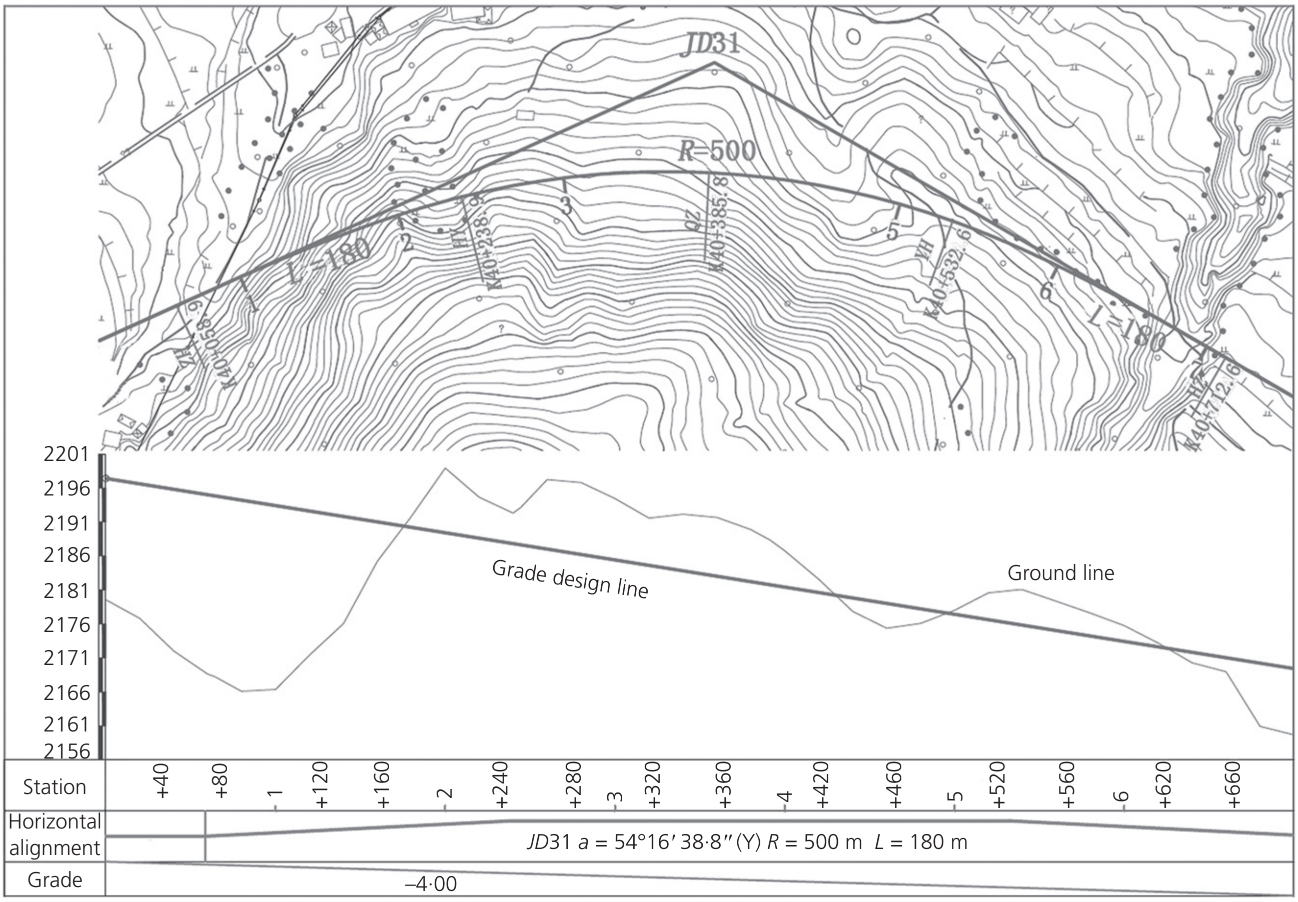

Figure 2. Actual situation of highway in mountainous area

radii, grades, declination angles of horizontal curves and TAEL were established for further analysis. The scatter diagrams of the different road geometry elements and TAEL (in Chinese yuan (CNY); 10 CNY ≈ £1) are shown in Figures 3–5. The following qualitative conclusions can be drawn from these figures.

(*a*) Figure 3 shows TAEL decrease with an increase in the horizontal radius; TAEL is thus negatively correlated with the horizontal radius of curvature.
(*b*) Figure 4 shows that TAEL increase with an increase in the grade; these quantities are thus positively correlated.
(*c*) According to Figure 5, when the declination angle of the horizontal curve is less than 35°, TAEL decrease with an increase in the declination angle; for declination angles greater than 35°, TAEL increase with an increase in declination angle. TAEL thus have a quadratic relationship with horizontal curve declination angle.

In summary, the horizontal radius, grade and declination angle of a horizontal curve contribute to the hazards of a horizontal curve on a mountainous highway.

3.2 Model establishment

In order to enhance the reliability and applicability of the research results, the horizontal radius, grade and declination angle of a horizontal curve were selected as the independent variables and the TAEL of that curve served as the dependent variable. Mathematical relations between these factors were then developed. Regression analysis was performed using SPSS data analysis software, adopting power functions and quadratic polynomials separately. The mathematical relationships between the independent variables and the dependent variable were established with parameter confidence levels of less than 0·05 and confidence values of 95%. The mathematical models are given by

$$Y = 41008867{\cdot}41 \times R^{-1{\cdot}146} \quad (r^2 = 0\cdot 658) \tag{1}$$

$$Y = 270{\cdot}11 \times i^{2{\cdot}7692} \quad (r^2 = 0{\cdot}648) \tag{2}$$

$$Y = 93{\cdot}633a^2 - 6739{\cdot}5a + 135\,626 \quad (r^2 = 0{\cdot}834) \tag{3}$$

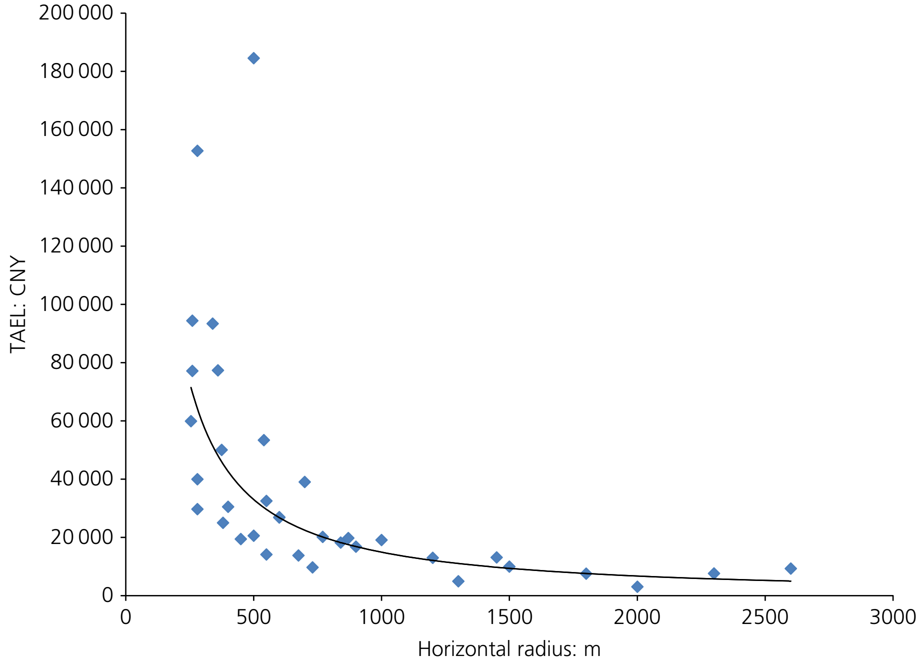

Figure 3. Scatter diagram of horizontal radius and TAEL

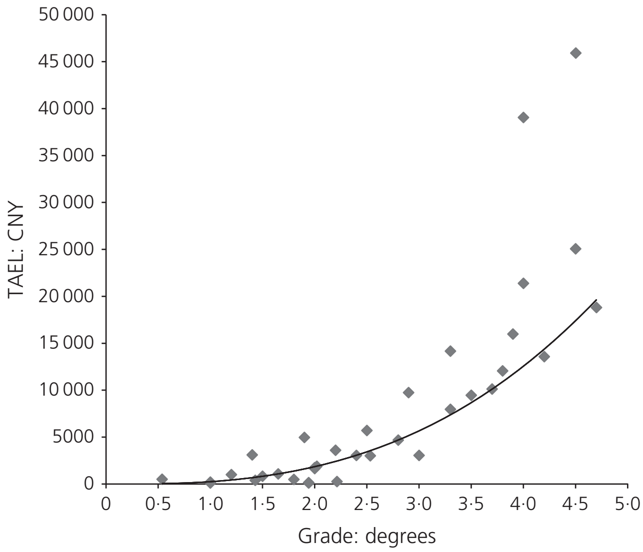

Figure 4. Scatter diagram of grade and TAEL

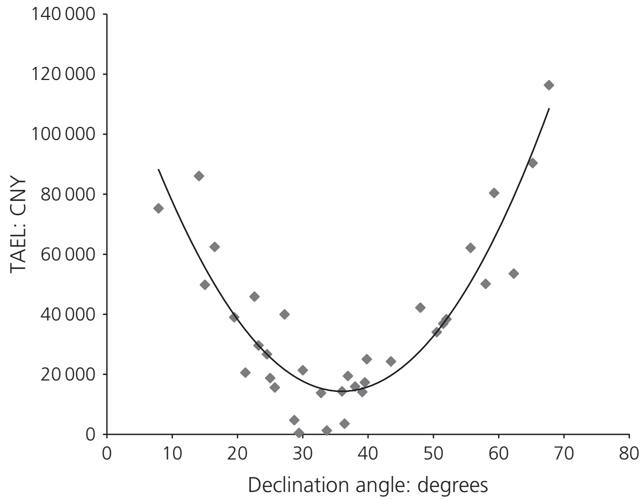

Figure 5. Scatter diagram of declination angles and TEAL

where Y is used to represent TAEL, R is the horizontal radius, i is the grade and a is the declination angle of the horizontal curve; r^2 is the correlation coefficient.

From Equations 1–3, a strong correlation can be concluded to exist between the TAEL and the horizontal radius, grade and declination angle of a horizontal curve. Moreover, TAEL can be used to represent the danger level of a horizontally curved section. The horizontal radius, grade and declination angle of a horizontally curved road segment were thus selected as contributory factors in HSOMH identification.

4. Method for HSOMH identification based on FES

4.1 Blurring inputs and output

The input values for horizontal radius, grade and declination angle were obtained for a given horizontally curved

Table 1. Horizontal radius and ranges

Linguistic variable	Symbol	Horizontal radius, *R*: m	
		Range	Standardised range
Small	S	[0, 0, 400, 1500]	[0, 0, 0·08, 0·30]
Medium	M	[400, 1500, 2500, 3500]	[0·08, 0·30, 0·50, 0·70]
Large	L	[2500, 3500, 5000, 5000]	[0·50, 0·70, 1·00, 1·00]

highway section. These input values were then checked and categorised for each fuzzy set. The output is the danger value of the horizontally curved highway section. The *Design Specification for Highway Alignment* (JTG, 2006) was referred to in this work and the relationships between TAEL and the contributory factors were considered, using expert experience (Meng *et al*., 2011; Saha and Ksaibati, 2016).

For this research, 25 scholars in the field of traffic safety were asked to participate. All are from universities, highway and transportation societies, traffic management departments or transport design and research institutes. Their ages ranged from 40 to 65 years; 60% are male and the rest are female. All the participants have in-depth insight and profound knowledge about this field of research, and have won a number of national awards, so the conclusions drawn from them can be considered authoritative. The participants were asked to complete a questionnaire concerning contributory factors, influence ranges and fuzzy rules and then the results were gathered and analysed. In this research, all the expert opinions were given the same weight. For questions where different answers were possible, the first answer was selected.

Table 2. Grade and ranges

Linguistic variable	Symbol	Grade, *i*: degrees	
		Range	Standardised range
Small	S	[0, 0, 1, 2]	[0, 0, 0·17, 0·33]
Medium	M	[1, 2, 3, 5]	[0·17, 0·33, 0·50, 0·83]
Large	L	[3, 5, 6, 6]	[0·50, 0·83, 1·00, 1·00]

Table 3. Declination angle and ranges

Linguistic variable	Symbol	Declination angle, *a*: degrees	
		Range	Standardised range
Small	S	[0, 0, 7, 18]	[0, 0, 0·12, 0·30]
Medium	M	[7, 18, 35, 50]	[0·12, 0·30, 0·58, 0·83]
Large	L	[35, 50, 60, 60]	[0·58, 0·83, 1·00, 1·00]

According to the expert experience, the level of each contributory factor was first defined. Then, on the basis of Figures 3–5, the value of the contributory factor when the TAEL fluctuated greatly was found and thresholds were determined. Finally, the range and classification of the input and output values were obtained, as shown in Tables 1–4.

4.2 Determining fuzzy sets

The horizontal radius, grade and declination angle of a horizontal curve were used as inputs and the danger value of the horizontally curved section was the output, adopting a trapezoidal-shape membership function. All the fuzzy sets of linguistic variables were designated as listed in Tables 1–4 and shown in Figures 6–9.

4.3 Construction of fuzzy rules

As already mentioned, many experts were asked about the influence degree of the combination of different influencing factors on road safety. With this expert experience of the inputs and output (three inputs and one output) 27 fuzzy rules were obtained. These are listed in Table 5 and depicted in Figure 10 in the form of a cube.

Table 4. Danger value and ranges

Linguistic variable	Symbol	Danger value, *d*	
		Range	Standardised range
Very safe	VS	[0, 0, 0·11, 0·22]	[0, 0, 0·11, 0·22]
Safe	S	[0·11, 0·22, 0·33, 0·44]	[0·11, 0·22, 0·33, 0·44]
Danger-prone	P	[0·33, 0·44, 0·55, 0·66]	[0·33, 0·44, 0·55, 0·66]
Dangerous	D	[0·55, 0·66, 0·77, 0·88]	[0·55, 0·66, 0·77, 0·88]
Very dangerous	VD	[0·77, 0·88, 1, 1]	[0·77, 0·88, 1·00, 1·00]

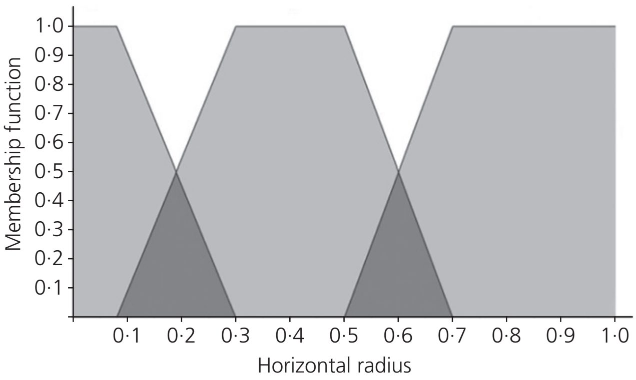

Figure 6. Fuzzy set of horizontal radius

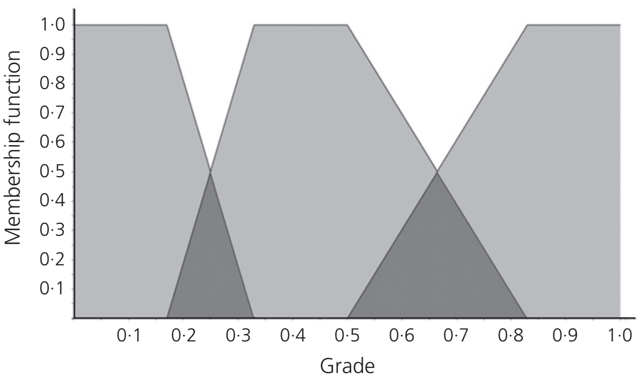

Figure 7. Fuzzy set of grade

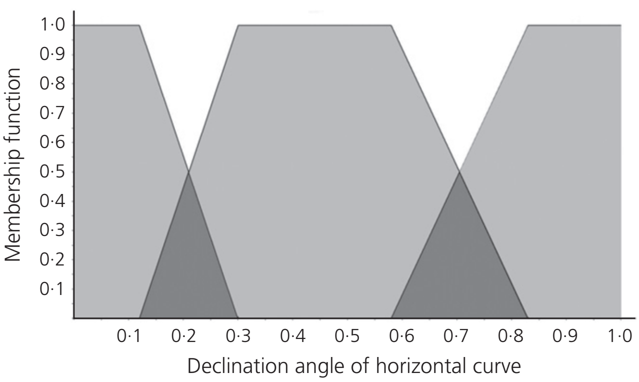

Figure 8. Fuzzy set of declination angle

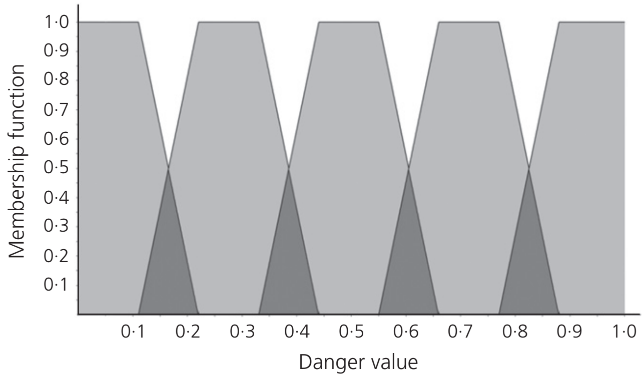

Figure 9. Fuzzy set of danger value

Table 5. Rule base

Rule	*R*	*i*	*a*	*d*
1	S	S	S	D
2	M	S	S	D
3	L	S	S	VD
4	S	S	M	S
5	M	S	M	P
6	L	S	M	D
7	S	S	L	D
8	M	S	L	D
9	L	S	L	VD
10	M	S	S	P
11	M	M	S	P
12	M	L	S	D
13	M	S	M	VS
14	M	M	M	S
15	M	L	M	P
16	M	S	L	P
17	M	M	L	P
18	M	L	L	D
19	L	S	S	P
20	L	M	S	S
21	L	L	S	P
22	L	S	M	VS
23	L	M	M	VS
24	L	L	M	S
25	L	S	L	S
26	L	M	L	S
27	L	L	L	D

4.4 Identification of HSOMH based on the FES

After defining the fuzzy set and fuzzy rules, the FES for identifying HSOMH was established using the fuzzy logic toolbox included in the Matlab platform (Michael, 2012). Figure 11 shows the reasoning figure of the FES; in this figure, the danger value of each horizontally curved section can be obtained by dragging the dotted line in the reasoning system to fit the values of the radius of the horizontal curve, the grade and the declination angle of the horizontal curve. Clearly, higher danger values correspond to more dangerous horizontally curved road sections.

Figures 12–14 show three-dimensional representations of the FES, taking the pairs *R* and *i*, *R* and *a*, and *a* and *i* as the input values and returning the danger value (d) as the output.

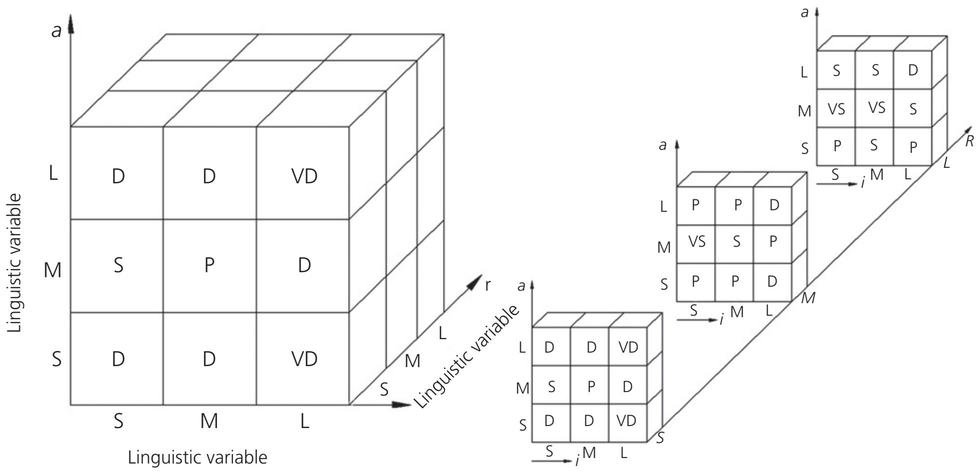

Figure 10. Fuzzy rule base

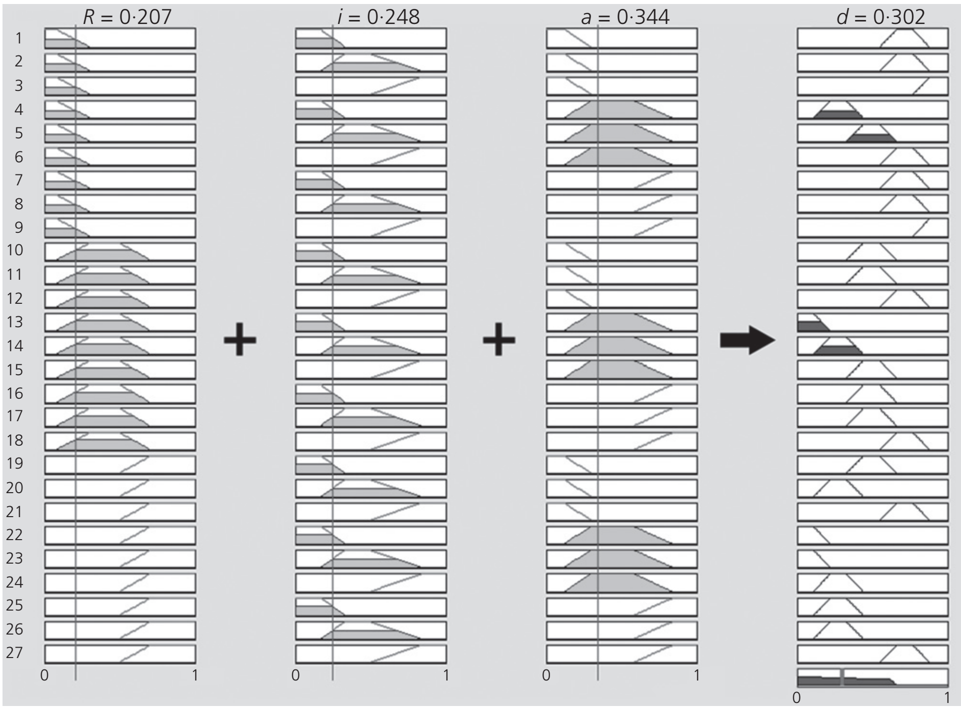

Figure 11. FES reasoning

When a newly built road is designed, the values of the horizontal radius of curvature, grade and declination angle of horizontal curves can be obtained from the design information. Upon standardising these values, they can be substituted into the FES, thereby automatically obtaining the danger value. With the help of the FES, the road segments with a high potential for accidents can be identified before the road is opened and relevant measures can be taken to prevent accidents. In this way, the FES evaluation of a road design can greatly improve road safety.

5. Implementation and examples

5.1 Computing danger values

Data from 35 road sections characterised by horizontal curves on the Xi'an–Hanzhong highway were obtained. The FES was

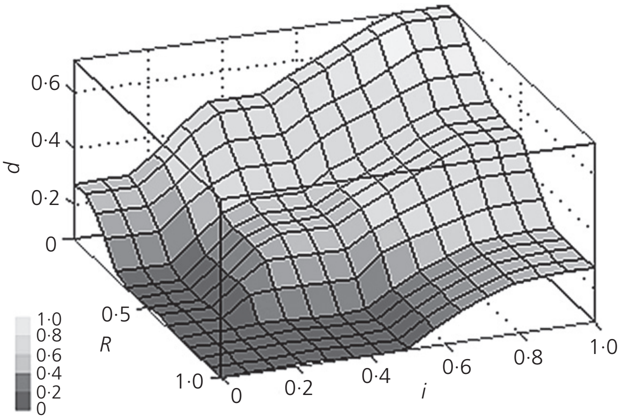

Figure 12. Three-dimensional FES representation of horizontal radius of curvature and grade of horizontal curve

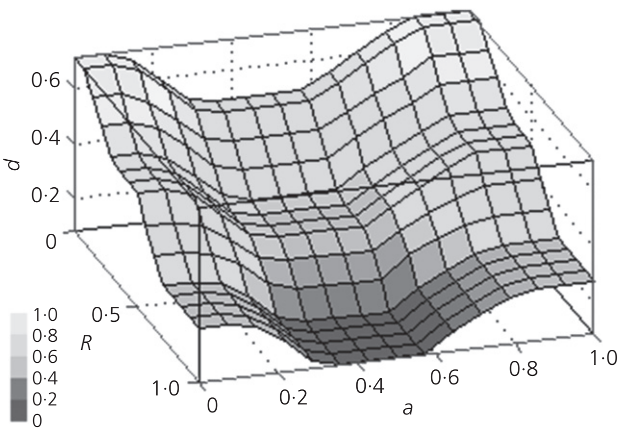

Figure 13. Three-dimensional representation of horizontal radius of curvature and declination angle of horizontal curve

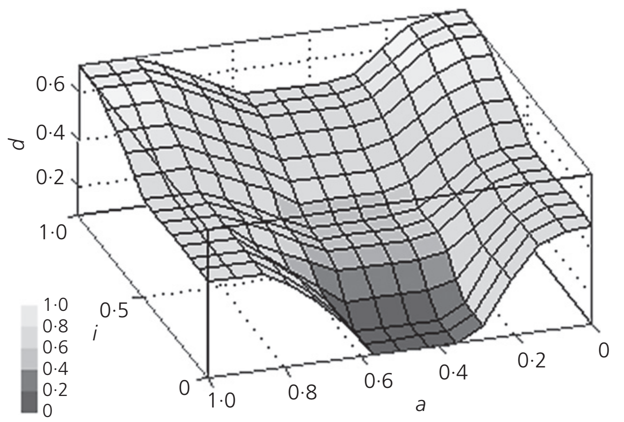

Figure 14. Three-dimensional representation of grade and declination angle of horizontal curve

then used to calculate and rank the danger values of these horizontally curved segments and the calculated danger value was then compared with TAEL data.

Using the method described in Section 4.1, standardised values of the 35 sets of data characterising horizontally curved road sections were computed. The established FES was then used and danger values were ranked using the method described in Section 4.4. Table 6 shows the details.

5.2 Verification of results

As already mentioned, higher danger values correspond to more dangerous road sections. Figure 9 and Table 4 show that when the danger value is greater than 0·44, the membership of 'safe' and 'very safe' is zero, while membership of 'danger-prone', 'dangerous' and 'very dangerous' increases. Therefore, in this research, a road section is considered a black spot when the danger value calculated by the FES is greater than 0·44. Otherwise, the road section is safe.

The last two columns of Table 6 compare existing black spots and black spots identified by the FES. For all the 35 road sections, the 29 black spots identified by the FES are consistent with existing black spots. As regards the remaining six road sections, road geometric factors are not the primary cause of traffic accidents. In fact, by analysing the actual sections, it was found that environmental factors and driver behaviour play more important role in traffic accident occurrence. Therefore, the proposed FES is a reliable method to identify HSOMH.

5.3 Model establishment

The TAEL and danger value of each segment were collected from Table 6 and analysed with SPSS software to determine the relationship between them. The relational model of TAEL and danger value was found to be

$$Y = 130\,756d - 47\,271 \quad (r^2 = 0{\cdot}8604) \tag{4}$$

where Y is TAEL, d is the danger value and r^2 is the correlation coefficient.

The conclusions drawn from the relational model are as follows.

(*a*) The correlation coefficient r^2 of the relational model is close to 1, implying that danger values calculated by the FES fit well with the TAEL data. Meanwhile, as mentioned above, this study used TAEL as representatives of road black spots. Therefore, the results from the FES and the actual TAEL data are approximately equivalent.

(*b*) For road sections 3, 4, 13 and 16, the grades and declination angles of the horizontal curves in these sections are similar, but the TAEL and the danger value

Table 6. Real road segment data and danger values

Road section	*R*: m	*i*: degrees	*a*: degrees	TAEL: CNY	*d*	Black spot identified by FES	Existing black spot
1	450	0·540	29·420	500	0·270	No	No
2	1020	1·240	62·300	31 600	0·593	Yes	Yes
3	550	2·200	39·100	14 150	0·523	Yes	Yes
4	600	2·200	36·400	13 600	0·476	Yes	No
5	660	2·800	33·670	1300	0·438	No	No
6	800	2·793	19·500	300	0·412	No	No
7	290	1·000	36·00	200	0·316	No	No
8	500	1·430	18·00	400	0·357	No	No
9	400	1·941	21·00	14 500	0·484	Yes	Yes
10	255	2·550	80·00	55 920	0·715	Yes	Yes
11	270	1·600	43·500	24 330	0·527	Yes	Yes
12	500	1·600	21·200	11 600	0·391	No	Yes
13	450	2·500	36·900	19 460	0·515	Yes	Yes
14	1400	3·000	12·500	11 640	0·415	No	Yes
15	540	2·850	73·200	53 455	0·683	Yes	Yes
16	340	2·400	39·500	27 350	0·565	Yes	Yes
17	320	1·350	47·000	16 210	0·588	Yes	Yes
18	2000	1·400	9·800	3100	0·383	No	No
19	360	5·050	5·000	77 390	0·912	Yes	Yes
20	340	2·800	25·700	15 655	0·495	Yes	Yes
21	260	5·360	2·800	77 175	0·912	Yes	Yes
22	770	4·502	22·600	30 920	0·564	Yes	Yes
23	730	2·900	18·000	9740	0·425	No	No
24	675	4·500	32·800	13 800	0·577	Yes	Yes
25	1500	2·020	3·100	10 000	0·495	Yes	Yes
26	280	1·650	43·500	29 760	0·529	Yes	Yes
27	1500	2·213	15·000	250	0·341	No	No
28	700	4·000	19·500	25 055	0·533	Yes	Yes
29	350	4·000	30·000	21 387	0·605	Yes	Yes
30	714	2·000	14·500	15 730	0·502	Yes	Yes
31	230	2·800	32·500	22 370	0·495	Yes	Yes
32	1300	1·900	8·00	4960	0·504	Yes	No
33	295·25	1·000	42·800	5360	0·503	Yes	No
34	260	1·000	38·500	11 650	0·396	No	Yes
35	2600	2·900	9·800	9730	0·419	No	No

both decrease with increasing horizontal radius. For sections 6, 22, 23, and 28 the horizontal radii of curvature and declination angles of the horizontal curves are similar, and the TAEL and danger values both increase with increasing grade. For sections 8, 9, 11, 17, 26 and 30, the horizontal radii of curvature and grades are similar; for these sections, the TAEL and danger value decrease at first, reach minimum values and then increase with increasing declination angle of the horizontal curve. In general, sections of road with smaller horizontal radii of curvature, larger grades and either large or small declination angles of horizontal curves are more dangerous.

The above analysis indicates that the FES is a reliable and effective method for HSOMH identification.

6. Conclusions and future work

A reliable and effective method for the identification of HSOMH under uncertain conditions was introduced, which is particularly valuable for newly built roads for which statistical data regarding accident occurrences do not yet exist. Using the theory of mathematical statistics and data from actual traffic accidents, this research showed that the horizontal radius of curvature, the grade and declination angle of a horizontally curved section of a mountainous highway have great impacts on the occurrence of traffic accidents. Consequently, all traffic accident data from the Xi'an–Hanzhong highway between stations K33+052 and K118+346 were analysed. Fuzzy sets and membership functions were generated for the road data. Moreover, a fuzzy rule base was established based on the experience of experts in the field of traffic safety. The FES built to identify HSOMH successfully evaluated a selection of road design parameter sets for the relative risk of accident on these road sections. The HSOMH ranks generated by this method can guide decision-makers in selecting road segments that urgently require improvement; in this way, road safety management and capital utilisation efficiency can be enhanced.

In the analysis of the factors contributing to traffic accidents, this study only addressed geometric factors of a section of the roadway, ignoring environmental and vehicular factors. However, these factors also play an important role in traffic accident occurrence. The datasets used to test the FES were also not comprehensive in that they only considered single circular curves. The influences of compound, reverse or adjacent curves with the same direction and long or steep longitudinal grades were not properly considered. These limitations should be considered comprehensively in future studies on the identification of HSOMH.

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摘要: To identify hazardous sections of newly built mountainous highways, decision-makers require assistance to determine the sections that may pose risks to road users, thereby enhancing the level of road safety management and capital utilisation efficiency. In this research, traffic accident economic losses were used as evaluation indices to characterise 30 horizontally curved sections of roadways. These highway sections were divided into five levels based on their evaluated level of risk. With the effects of multiple factors and the characteristics of uncertainty, mathematical statistics and fuzzy expert systems (FESs) were used to determine the factors contributing to hazardous sections of mountainous highways. The membership functions and fuzzy rule base were decided according to accident data and expert experience and a method for identifying hazardous sections based on the expert systems was established. The risk values of another 35 horizontally curved sections were obtained by this method and good results were achieved using the method to identify hazardous sections. The results showed that hazardous section classification is greatly affected by the horizontal radius, grade and declination angle of the horizontal curve. The results obtained from the FESs agreed overall with actual accident data.

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