

Classification of Emergency Responses to Fatal Traffic Accidents in Chinese Urban Areas

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Abstract: Fatal traffic accidents in urban areas can adversely affect the urban road traffic system and pose many challenges for urban traffic management. Therefore, it is necessary to first classify emergency responses to such accidents and then handle them quickly and correctly. The aim of this paper is to develop an evaluation index system and to use appropriate methods to investigate emergency-response classifications to fatal traffic accidents in Chinese urban areas. This study used a multilevel hierarchical structural model to determine emergency-response classification. In the model, accident attributes, urban road network vulnerability, and institutional resilience were used as classification criteria. Each evaluation indicator was selected according to importance ranking and independence screening and was given an interpretation and a quantitative criterion. The Fuzzy Delphi Method was used to rank the importance of the evaluation indices and the combined weight of each index was calculated using the G1 method. Finally, the case of a fatal traffic accident was used to validate the model. The results showed that the multilevel hierarchical structural model, Fuzzy Delphi Method, and G1 method can effectively address the problem of emergency-response classification. Because of its simplicity and adaptability, the approach presented here could be useful for decisionmakers and practitioners for determining emergency-response classifications.

Keywords: Emergency-response classifications; fatal traffic accidents; Chinese urban areas; fuzzy Delphi method; G1 method; institutional resilience; evaluation

1 Introduction

Today, various natural and manmade disasters, such as earthquakes, hurricanes, floods, epidemics, fires, terrorist attacks, chemical spills, and explosions, are frequent occurrences. An *emergency* can refer to more than a disaster or catastrophe; smaller disruptive incidents, such as serious traffic accidents, can be called emergencies as well [1]. The World Health Organization



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(WHO) reported that the number of traffic deaths has remained high, with 1.35 million fatalities worldwide in 2016, about one-fifth of which occurred in China [2]. Traffic fatalities therefore pose a public health issue in China. By the end of 2018, the number of China's urban and town residents had reached 83.13 million, nearly 60% of whom inhabited cities [3]. A population-based study of 21 cities showed that road traffic injury prevalence among urban Chinese residents was 13.2%, based on a retrospective 12-month reporting window [4]. Compared to rural areas, urban areas are more densely populated, highly modernized, and concentrated in social wealth. Moreover, fatal traffic accidents in Chinese urban areas have a greater effect on the road traffic system in a wider scope, which poses a new challenge to the urban road traffic management. As such, quick and proper emergency-response measures must be taken when serious traffic accidents occur.

In the *Procedural Regulations for Handling Road Traffic Accidents* [5], traffic accidents are classified as property-damage-only accidents, injury accidents, and fatal accidents. A fatal accident is one that causes human deaths. Therefore, emergency-response activities should be conducted quickly and properly after a fatal accident in an urban area. An emergency response is a type of public service provided by the government [6]. In China, the first responders to emergencies differ based on the emergency type and scale.

The main purpose of classifying emergency responses to fatal traffic accidents in Chinese urban areas is to quickly and accurately determine the emergency-response providers, measures, and resources that must be mobilized to avoid "insufficient responses or overreactions." Determining the appropriate emergency-response providers is the primary target of emergency response. Furthermore, in China, the higher the level of emergency response is, the higher the level of corresponding authorities is, the stronger the coordination ability is, and the wider the range of available resources becomes. Thus, the simple and easy classification of emergency responses to fatal traffic accidents is conducive to rapidly determining the appropriate emergency-response providers, emergency-management procedures, and traffic-operation measures. It is also important to minimize the impact of accidents on the urban traffic system and maintain normal traffic operations.

2 Literature Review

Emergency classifications are mainly divided into three types: early warning classifications, emergency-response classifications, and rehabilitation and reconstruction [7]. Each has different objects and evaluation indices. In early warning classification, emergency attributes such as degree, development trend, and possible damage are considered, with the purpose of determining which emergency preparedness plan should be activated. The rehabilitation and reconstruction classification, meanwhile, is a kind of accountability classification that is intended to derive lessons from emergency handling, pursue liabilities, and take improvement measures. Finally, emergency-response classification is a link between early warning classification and post-emergency evaluation classification. The evaluation index system for emergency-response classification should consider not only the attributes of the emergency but also the vulnerability of hazard-affected bodies and the institutional resilience of emergency-response providers.

Emergency classification has been widely studied in various emergency-management fields, including nuclear plant management [8,9], earthquakes [10], chemical spills [11], mine disasters [12], urban emergencies [13,14], transportation [15,16], meteorological disasters [17], and emergency supply chains [18].

There are many recent studies of emergency classification. Burnett [19] outlined a crisis-classification matrix to determine the emergency level (0–3) using a 16-cell matrix based on the threat level, response options, time pressure, and degree of control. Paul [20] proposed a five-class approach to determine emergency classification using the number of people killed (or injured/displaced/affected) and the area of impact as criteria. Emergency situations are usually classified according to the following types of criteria: time pressure, socioenvironmental factors (e.g., human victims, epidemics, and use of natural resources), socioeconomic factors (e.g., great hazard and increase in international tensions), economic factors (e.g., economic detriment, threat to financial and material resources, and traffic disruption), and organizational and managerial factors (e.g., unpredictable situations and the need to secure different types of expertise and organizations). Although the color-coded Homeland Security Advisory System has been repealed in the US, such a system is still widely adopted in China in early warning classifications, such as forecasting adverse weather, forest fire classification, and the *Master State Plan for Rapid Responses to Public Emergencies* [21]. Today, many practical methods have been applied to emergency classification, including the crisis matrix [17,19], analytic hierarchy process (AHP) [22], fuzzy analytic hierarchy process (FAHP) [23], fuzzy evaluation [24], support vector machine [25], cluster algorithm [26,27], decision-tree model [28], large group emergency decision [29], and other intelligent methods [30].

These previous studies have provided some classification criteria and analysis methods for emergency classification. However, the existing classification indicators mainly focus on early warning classification. There are more factors that influence emergency-response classification than early warning classification, including both internal and external factors. Some special evaluation indicators and quantitative methods should be specifically considered in the classification of emergency responses to fatal traffic accidents in Chinese urban areas.

Therefore, for the timely and effective handling of fatal traffic accidents in Chinese urban areas, it is necessary to further study the classification of emergency responses to fatal traffic accidents considering their characteristics. Such classification is a comprehensive evaluation process. The general steps in this study were as follows. First, a multilevel hierarchical structural evaluation index system was constructed based on the principles of establishing an evaluation index system. Next, a quantitative treatment of the determined evaluation index was conducted, and the index weight was calculated using the G1 method. Third, a comprehensive evaluation was carried out—that is, the comprehensive evaluation score was obtained by synthesizing all types of index values. Fourth, the comprehensive evaluation score was divided into several grades according to the preset classification method. Lastly, the emergency-response grade was determined.

3 Evaluation Index System

3.1 Principles for Establishing Evaluation Index System

An evaluation index is the basis for accurately judging the emergency-response classification of fatal traffic accidents. Whether the index selection is appropriate will directly affect the feasibility of the evaluation process as well as the validity and reliability of the final evaluation result. In establishing a hierarchical evaluation indicator system for emergency responses, the proposed evaluation indicators should be guided by the following principles:

- (1) Minimization and simplification of indicators

Rapid response is the first problem to be considered in emergency-response classification. Provided the evaluation index system can cover the basic content needed for evaluation and basic

information about the evaluation objects, a concise index system can reduce the time and cost of evaluation and meet the need for a “rapid response.”

(2) Independence of indicators

Each indicator should be clear and relatively independent, and indicators of the same level should not overlap. Furthermore, the index system should be hierarchical.

(3) Representativeness and otherness of indicators

The indicators, which should be representative, should suitably reflect the characteristics of the research objects. There should also be obvious differences between the indicators (i.e., comparability).

(4) Feasibility of evaluation index

Feasibility means the evaluation indices can be obtained in a timely and effective way and be easily quantified [31]. Data collection should be simple and feasible. Hard-to-obtain indicators should not be adopted for emergency-response classification.

3.2 Construction of Evaluation Index System

Constructing an evaluation index system is a “concrete–abstract–concrete” thinking process, where the characteristics of the evaluation objects are gradually deepened, refined, and perfected. This process mainly includes the preliminary index system formulation, index system selection, and index system perfection.

3.2.1 Preliminary Index System Formulation

Based on the relevant literature and investigations, a three-layer evaluation index system was adopted in this study, since the purpose of emergency-response classification is to quickly and accurately determine the response providers and there should not be too many layers in the evaluation index system. The first layer was the object level. The second layer was the criterion level, containing attributes of accident, vulnerability of urban road networks, and institutional resilience of emergency-response providers. The third layer was the indicator level, containing some quantifiable indicators. A preliminary evaluation index system was proposed, as shown in [Tab. 1](#).

3.2.2 Index System Selection

A questionnaire was specially designed for index system selection. From March to June 2019, the questionnaire was sent to experts, scholars and professional technicians of the traffic management field by email. A total of 23 valid copies were collected. On this basis, the evaluation indices were screened and optimized.

(1) Importance ranking

Importance refers to the extent each evaluation index within the same level is relative to the upper level. Based on the analysis of the relative importance, some unimportant indices to the evaluation results were eliminated. The Fuzzy Delphi Method uses statistical analysis and fuzzy operation to transform the subjective opinions of experts into quasi objective data [32]. In this study, the Fuzzy Delphi Method based on triangular fuzzy number was used to rank the importance of the evaluation indices [33].

Table 1: Preliminary evaluation index system for emergency responses to fatal traffic accidents in Chinese urban areas

Object level	Criterion level	Indicator level	
		Serial number	Evaluation indicators
Preliminary evaluation index system for emergency responses to fatal traffic accidents in Chinese urban areas	Attributes of accident	(1)	Nature of the accident
		(2)	Severity
	Vulnerability of urban road networks	(3)	Controllability
		(4)	Affected scope
		(5)	Topological structure of road network
		(6)	Density of road network
		(7)	Travel time reliability of road network
		(8)	Average speed of road network
		(9)	Saturation of traffic flow
		(10)	Accident location (sensitivity of accident occurrence and impact area)
		(11)	Urban-road types
		(12)	Traffic conditions when the accident occurred
	(13)	Residual capacity where the accident occurred	
	Institutional resilience of emergency-response providers	(14)	Weather conditions
		(15)	Visibility conditions
		(16)	Personnel composition
		(17)	Equipment allocation
			(18)

A fuzzy number is called triangular if the fuzzy number \tilde{A} in the real number field R can be determined by (a, b, c), and the membership function is as follows:

$$\mu_{\tilde{A}}(X) = \begin{cases} 0, & X < a \\ \frac{X-a}{b-a}, & a \leq X \leq b \\ \frac{c-X}{c-b}, & b \leq X \leq c \\ 0, & X > c \end{cases}, \tag{1}$$

where \tilde{A} is called the triangular fuzzy number and is written as $\tilde{A} = (a, b, c)$.

The evaluation index “a” is experts’ most conservative evaluation value (lower bound value of \tilde{A}), “b” is experts’ most likely evaluation value, while “c” is experts’ most optimistic evaluation value (upper bound value of \tilde{A}). The larger the value of “c–a” is, the greater the fuzziness is, and the more discrete the evaluation of this index by experts is. The smaller the value of “c–a” is, the smaller the fuzziness is, and the more consistent the evaluation of this index by experts tends to be.

1) Establishing triangular fuzzy number

According to experts’ feedback (regardless of the influence of experts’ academic statuses and practical experience on the evaluation weight), the Fuzzy Delphi Method was used to integrate the fuzzy evaluation values of 23 experts to calculate the triangular fuzzy number of the importance of each preliminary evaluation index. Taking “the nature of the accident” as an example, no expert thought it was extremely unimportant (we assigned it to be 0.1), two experts thought it was unimportant (we assigned it to be 0.3), six experts thought it was important (we assigned it to be 0.5), eight experts thought it was very important (we assigned it to be 0.7), and seven experts thought it was extremely important (we assigned it to be 0.9). Thus, $a_1 = 0.3$, $b_1 = \frac{1}{23}(0 \times 0.1 + 2 \times 0.3 + 6 \times 0.5 + 8 \times 0.7 + 7 \times 0.9) = 0.67$, and $c_1 = 0.9$.

Therefore, $\tilde{A}_1 = (0.3, 0.67, 0.9)$. The calculation of the triangle fuzzy numbers for the other evaluation indices’ importance is shown in [Tab. 2](#).

2) Defuzzification

There are many methods for defuzzification [34]. The simple center of gravity method was used for deblurring in this study, and the triangular fuzzy number was transformed into a single value S_k . Similarly, considering the evaluation index of “nature of accident” as an example, $S_1 = (0.3 + 0.67 + 0.9)/3 = 0.62$. Finally, the evaluation index was selected by the preset threshold (the threshold was set as 0.6 in this study), as shown in [Tab. 2](#).

(2) Independence screening

Independence means that all indicators are relatively independent from an overall point of view, and there is no redundant crossing phenomenon. If there are highly related indicators in the index system, they will inevitably affect the objectivity of the evaluation results. Therefore, it is necessary to analyze the correlation of each index in the index system, combine or eliminate the highly correlated indicators, and ensure the independence of each evaluation index. According to experts’ suggestions, the nature of accident was combined with the controllability of the accident, and the travel time reliability of the road network, the average speed of the road network, and the saturation of the traffic flow were deleted, as they were covered by the traffic conditions when the accident occurred. The index of the road network density was also deleted because it was highly correlated with the accident location (sensitivity of accident occurrence and impact area). In addition, some professional technicians of the traffic management field believed that it was not easy to quantify the three evaluation indices of institutional resilience of the traffic administrative departments of public security organs (TADPSOs), and they recommend that the related evaluation indices be selected from the *Evaluation Index System of Urban Road Traffic Management* (2012) [35]. As a result, the traffic command system and the traffic management service mechanism in this study were selected from the *Evaluation Index System of Urban Road Traffic Management* as the evaluation indices of the institutional flexibility of TADPSOs.

Table 2: Index system selection for emergency responses to fatal traffic accidents in Chinese urban areas

Object level	Criterion level	Indicator level		(a_k, b_k, c_k)	S_k	Y/N
		Serial number	Evaluation indicators			
Index system selection for emergency responses to fatal traffic accidents in Chinese urban areas	Attributes of accident	(1)	Nature of accident	(0.3, 0.67, 0.9)	0.62	✓
		(2)	Severity	(0.7, 0.84, 0.9)	0.81	✓
	Vulnerability of urban road networks	(3)	Controllability	(0.3, 0.69, 0.9)	0.63	✓
		(4)	Affected scope	(0.5, 0.77, 0.9)	0.72	✓
		(5)	Topological structure of road network	(0.1, 0.4, 0.7)	0.4	×
		(6)	Density of road network	(0.1, 0.46, 0.9)	0.49	×
		(7)	Travel time reliability of road network	(0.1, 0.39, 0.9)	0.46	×
		(8)	Average speed of road network	(0.3, 0.56, 0.9)	0.59	×
		(9)	Saturation of traffic flow	(0.3, 0.63, 0.9)	0.61	✓
		(10)	Accident location (sensitivity of accident occurrence and impact area)	(0.3, 0.67, 0.9)	0.62	✓
		(11)	Urban-road types	(0.3, 0.63, 0.9)	0.61	✓
		(12)	Traffic conditions when the accident occurred	(0.5, 0.71, 0.9)	0.7	✓
	Institutional resilience of emergency-response providers	(13)	Residual capacity where the accident occurs	(0.5, 0.70, 0.9)	0.7	✓
		(14)	Weather conditions	(0.1, 0.45, 0.9)	0.42	×
		(15)	Visibility conditions	(0.1, 0.45, 0.9)	0.42	×
		(16)	Personnel composition	(0.3, 0.47, 0.9)	0.49	×
		(17)	Equipment allocation	(0.3, 0.53, 0.9)	0.58	×
		(18)	Technical conditions	(0.3, 0.66, 0.9)	0.62	✓

3.2.3 Index System Perfection

Based on the preliminary index system formulation and index system selection, an evaluation index system with a hierarchical structure was then established (Fig. 1). The hierarchy is composed of the object level (*O*), criterion level (*C*), and indicator level (*P*). Each indicator is graded on a five-point system; the higher the score is, the higher the level of emergency response is.

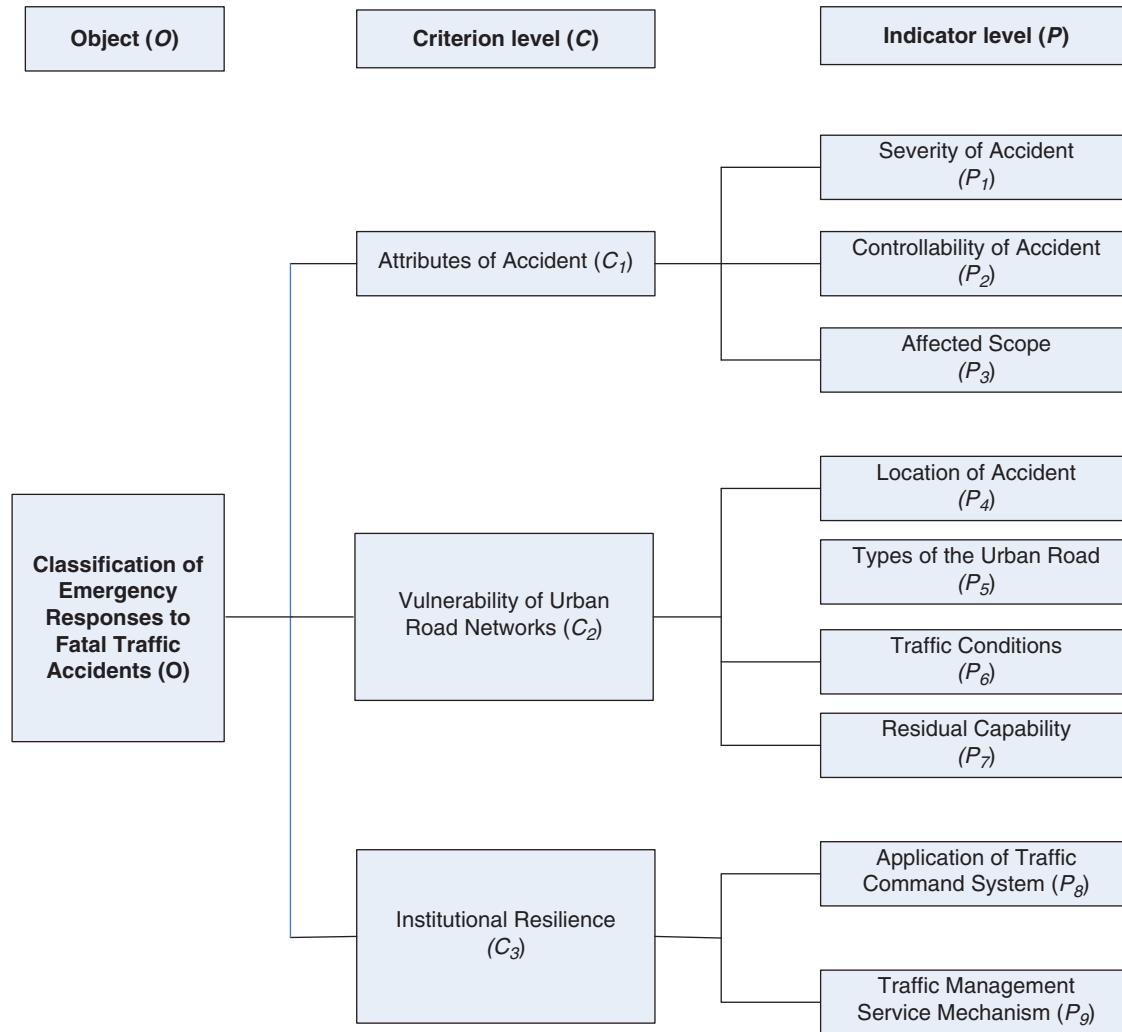


Figure 1: Classification evaluation index system for emergency responses to fatal traffic accidents in Chinese urban areas

3.3 Description and Quantification of Evaluation Indices

3.3.1 Attributes of Accident (*C*₁)

The attributes of an accident usually include its severity, controllability, and scope of impact.

(1) Severity of accident (*P*₁)

The direct economic loss and number of casualties are normally used to measure accident severity. Since direct economic loss is difficult to calculate in some situations, the equivalent

number of deaths is adopted as the indicator to evaluate the severity of the accident [36]. According to the *Announcement About Revision Standard of Road Traffic Accidents Classes* released by China’s Ministry of Public Security in 1991, the equivalent number of deaths can be calculated as

$$D_d = D_1 + 0.33D_2 + 0.1D_3, \tag{2}$$

where D_d is the equivalent number of deaths, D_1 is the death toll, D_2 is the number of disabling injuries, and D_3 is the number of minor injuries.

In *Road Traffic Accident Information Investigating* [37], fatal accidents are divided into four levels: general fatal accidents, major fatal accidents, serious fatal accidents, and particularly serious fatal accidents. A general fatal accident causes one or two deaths, a major fatal accident causes three to nine deaths, a serious fatal accident kills 10–29 people, and a particularly serious fatal accident leads to 30 or more deaths.

According to the *Specifications for Road Traffic Accident Handling* [38], traffic accidents with three to five fatalities should be submitted to the traffic administrative departments of provincial public security organs through administrative levels. Traffic accidents killing more than five people should be reported to the Traffic Management Bureau of the Public Security Ministry through administrative levels. [Tab. 3](#) shows the scores assigned to the equivalent number of deaths.

Table 3: Quantitative criteria for accident attributes

Description of partition criterion			Assigned scores
P_1	P_2	P_3	
$D_d \geq 30$	$N > 30$	$R \geq 7$ km	5
$30 > D_d \geq 10$	$30 \geq N > 10$	7 km $> R \geq 5$ km	4
$10 > D_d \geq 5$	$10 \geq N > 5$	5 km $> R \geq 3$ km	3
$5 > D_d \geq 3$	$5 \geq N > 2$	3 km $> R \geq 2$ km	2
$3 > D_d \geq 1$	$N \leq 2$	$R < 2$ km	1

(2) Controllability of accident (P_2)

Accident controllability is an important basis for launching an emergency response. In the *Specifications for Road Traffic Accident Handling* [38], the main factors affecting the controllability of an accident include

- 1) how many vehicles are damaged in the accident;
- 2) whether leakage, explosion, or combustion occur for vehicles carrying dangerous goods;
- 3) whether the accident involves the overturning, falling, or burning of large or medium-sized buses;
- 4) whether a school bus is involved in the accident and leads to casualties of students or children.

It is more difficult to quantitatively evaluate the indicator P_2 . However, in China’s relevant laws and policy documents, there are special procedures for dealing with deaths related to 2), 3), and 4). Specifically, in cases 2), 3), or 4), the emergency-response classification is directly improved. Since neither 2), 3), nor 4) was involved in the accident in this study, the quantitative evaluation

of P_2 was conducted only on the basis of the number of vehicles (N) damaged in the accident. [Tab. 3](#) shows the scores assigned to accident controllability.

(3) Affected scope (P_3)

The affected scope can be evaluated by the affected radius (R) of the accident as the evaluation indicator. According to the change rate of the travel time exponent λ , an area with $\lambda > 20\%$ was selected as the affected scope of the accident [39]. Since the shape of the affected scope is usually irregular, the maximum radius of the affected scope was chosen as the affected radius of the accident. The classified radius of the affected scope (five levels have four boundary radii) can be calculated as

$$R_i = p_i \sqrt{\frac{S}{\pi}}, \quad i = 1, 2, 3, 4, \quad (3)$$

where R_i is the classified radius for each grade, S is the area of built-up urban area, and p_i is the percentage of each grade.

According to the *Evaluation Index System of Urban Road Traffic Management* (2012) [35] the built-up urban area of Class A (megacity) is above 320 km², and the built-up urban area of Class B (large city) is above 120 km². Thus, the mean of the two areas, 220 km², was adopted as the built-up urban area. From largest to smallest, 80%, 60%, 40%, and 20% of the radius of the built-up urban area were set up as the classified percentages of the five-level demarcation [36]. After the results calculated by [Eq. \(3\)](#) were rounded down to the nearest integer, the scores were assigned to classified radii, as shown in [Tab. 3](#).

3.3.2 Vulnerability of Urban Road Networks (C_2)

Berdica [40] was the first to define the road network vulnerability. He argued that the vulnerability of a road transport system is a sensitive coefficient that is vulnerable to the influence of events, which can lead to a great decline in road network service. The factors of road network vulnerability usually include the following: network topology, network density, reliability of network travel time, average speed of the road network, traffic-flow saturation, sensitivity of the accident's occurrence and impact area, urban-road types, traffic conditions before the accident, residual capacity, and weather and visibility. According to the chosen basic principles of the representativeness and otherness of indicators, the adopted evaluation indices were as follows: accident location, urban-road types, the traffic conditions when the accident occurred, and the residual capacity where the accident occurred.

(1) Accident location (P_4)

For some Chinese cities, when conducting urban traffic impact analysis (TIA) for construction projects, local authorities and researchers tend to divide the city into several types of areas. A first-class area is the core area of the city, which is densely populated with the most heavy and sensitive traffic. Other types of areas are arranged in descending order of location sensitivity and traffic density. Based on the classified areas, [Tab. 4](#) shows the scores assigned to the accident location.

(2) Urban-road types (P_5)

Based on their function, urban roads can usually be divided into freeways, major arterial roads, minor arterial roads, and local roads. Different types of urban roads have different traffic functions, and accidents have different effects on different types of urban roads. If an accident occurs on the road segment, the road type where the accident occurs is taken as the evaluation

indicator; if the accident occurs at an intersection, the highest class of the intersecting road is taken as the evaluation indicator. [Tab. 4](#) shows the scores assigned to each type of urban road.

Table 4: Quantitative criteria for urban road network vulnerability

Description of partition criterion				Assigned scores
P_4	P_5	P_6	P_7	
First-class area	Freeways	Serious congestion	$K \leq 1/8$	5
Second-class area	Major arterials	Moderate congestion	$1/8 < K \leq 1/6$	4
Third-class area	Minor arterials	Light congestion	$1/6 < K \leq 1/4$	3
Fourth-class area	Local roads	Near-free-flow conditions	$1/4 < K \leq 1/2$	2
Other area	Others	Free-flow conditions	$1/2 < K \leq 1$	1

(3) Traffic conditions when the accident occurred (P_6)

In the *Urban Road Traffic Performance Index* (DB11/T 785-2011) [41], urban traffic conditions fall into five types: free-flow conditions, near-free-flow conditions, light congestion, moderate congestion, and serious congestion. [Tab. 4](#) shows the scores assigned to the different traffic conditions when an accident occurs. If the accident occurs in the road section segment, the worse traffic condition of the two opposite directions approaching the accident scene is taken as the evaluation index. If the accident occurs at the intersection, the worst traffic condition among all directions approaching the intersection is taken as the evaluation index.

(4) Residual capacity where the accident occurs (P_7)

The ratio of the number of normally working lanes to the number of original lanes is adopted to express the index of the residual capacity where the accident occurs. It can be calculated as

$$K = \frac{n}{N}, \quad (4)$$

where n is the number of normally working lanes, and N is the number of original lanes. [Tab. 4](#) shows the specific scores.

3.3.3 Institutional Resilience (C_3)

Institutional resilience refers to an emergency institution's ability to adapt to the decline in system function due to incident disposal and to recover from a tolerably low operation level to the optimal operating status [42]. The better the institutional resiliencies are, the lower the emergency-response level becomes; the worse the institutional resiliencies are, the higher the emergency-response level becomes. Two main groups of factors affect institutional resilience: emergency attributes (e.g., the type, severity, and affected scope of the incident) and institutional characteristics (e.g., personnel composition, equipment rationing, and technical conditions). Since emergency attributes have been considered, as mentioned earlier, they are not repeated here to adhere to the principle of evaluation index independence. Based on the *Evaluation Index System of Urban Road Traffic Management* (2012) [35], the traffic command system application and the traffic management service mechanism were selected as the indices to measure the institutional resilience of the TADPSOs.

(1) Traffic command system application (P_8)

The traffic command system application refers to establishing a traffic command system composed of an integrated information system, execution system, communication system, and command system platform in an evaluated city. This can collect, process, integrate, store, manage, and analyze traffic data. This index reflects the extent to which urban road traffic management is scientized and modernized, as well as the ability of traffic administrative departments to respond to and manage fatal traffic accidents. The evaluation is based on the Technical Specifications in the *Construction of Public Security Traffic Command System (GA/T445-2010)* [43], which mainly include the following:

- 1) having the function of regional or line coordination signal control;
- 2) using a traffic TV surveillance system to inspect road conditions regularly and spot traffic incidents and illegal behaviors;
- 3) establishing and using an integrated command platform based on police geographic information system (P-GIS), which has emergency command and dispatch, organization and coordination, decision support, and executive supervision capabilities;
- 4) setting up the positioning system for police vehicles and policemen and guaranteeing their effective functioning;
- 5) building a system for traffic flow and traffic event collection and exerting its function effectively;
- 6) having a traffic information issuance function;
- 7) having grassroots police forces establish a service command room with the functions of local command, dispatch, control, and guidance.

Based on each city's traffic command system application, it is determined how many of the above requirements are met, and grades are assigned according to a five-point system. When more of the seven indicators are met, institutional resilience is better, and a lower corresponding score is assigned (Tab. 5).

Table 5: Quantitative criteria for the institutional resilience of the TADPSOs

Description of partition criterion		Assigned scores
P_8	P_9	
No more than three survey indicators can be met	No more than two survey indicators can be met	5
Four survey indicators can be met	Three survey indicators can be met	4
Five survey indicators can be met	Four survey indicators can be met	3
Six survey indicators can be met	Five survey indicators can be met	2
Seven survey indicators can be met	Six survey indicators can be met	1

(2) Traffic management service mechanism (P_9)

The traffic management service mechanism in the evaluated city, refers to the traffic administrative department of the public security organ that has a reasonable police force, clear assessment goals, a high level of answering and handling alarms, and the ability to react quickly. This is

an important index that reflects the police's level of effort and ability to respond. The evaluation contents are as follows:

- 1) establishing a police situation analysis system and deploying the police force dynamically according to the police situation;
- 2) implementing a scientific and reasonable appraisal mechanism for policemen on duty;
- 3) posting policemen near the intersections, road segments, entrances, and exits of important roads;
- 4) actively dredging traffic and investigating and dealing with illegal behaviors;
- 5) having an average time of 10 min from answering the alarm to police arriving at the scene during the day and less than 15 min at night;
- 6) implementing civility standards for on-the-road law-enforcement behavior for police on duty.

This is graded by a five-point system based on how many of the above requirements are met in each city. As before, when more indicators are met, the institution has better resilience, and the score is lower (Tab. 5).

4 Evaluation Index Weights

As shown in Fig. 1, the hierarchical evaluation index system for emergency responses is a hierarchical structural model, which would normally use AHP [44] or FAHP [45] to determine weights. However, AHP and FAHP can both face the problem of not satisfying the consistency requirements of the judgment matrix in the face of numerous factors. The more factors there are, the larger the problem is. In view of these shortcomings, Guo proposed using the G1 method [46], which overcomes certain shortcomings of the AHP method, does not require a consistency check, and appears to be simpler and more practical. G1 is essentially a kind of order-relation analysis method; thus, this study used the G1 method to obtain the weights of each index. The steps for calculating the combined weight of each evaluation index are as follows:

- (1) Establish a hierarchical system of the evaluation index

Forming a hierarchy is the most important step in hierarchical relationship analysis. The hierarchical evaluation index system for emergency responses to fatal traffic accidents is shown in Fig. 1.

- (2) Determine the order relation

The upper layer element C_k is supposed to be the criterion, and it is dominant over the next layer elements: P_1, P_2, \dots, P_m . If an evaluation indicator P_i is more important than (or not less than) P_j to C_k , it is recorded as $P_i \succ P_j$. If there are m evaluation indicators, their relations to the evaluation criterion C_k are expressed as

$$P_1^* \succ P_2^* \succ \dots \succ P_m^*. \quad (5)$$

The evaluation indices P_1, P_2, \dots, P_m are then said to have determined their order relationship by using “ \succ .” In this case, P_i^* represents the i th evaluation index after reordering ($i = 1, 2 \dots m$). It is convenient to describe the order relation in (5) as follows:

$$P_1 \succ P_2 \succ \dots \succ P_m. \quad (6)$$

- (3) Determine the relative importance of the adjacent indices

Supposing experts make rational judgments about the ratio of the importance r_k between adjacent indices P_{k-1} and P_k based on a certain criterion, this can be represented as

$$r_k = \frac{\omega_{k-1}}{\omega_k} \quad k = m, m - 1, m - 2, \dots, 3, 2, \tag{7}$$

where ω_k is the weight of the indicator P_k . The values of r_k are shown in [Tab. 6](#). When the value of m is extremely large, r_m can be taken as 1 in [Eq. \(7\)](#).

Table 6: Assigned values of r_k

r_k	Inscription
1.0	P_{k-1} is as important as P_k
1.2	P_{k-1} is slightly more important than P_k
1.4	P_{k-1} is more important than P_k
1.6	P_{k-1} is much more important than P_k
1.8	P_{k-1} is extremely more important than P_k

(4) Calculate the value of the weight

Based on the value of r_k , the weight of the m th evaluation index in the level can be obtained by the following equation:

$$\omega_m = \left(1 + \sum_{k=2}^m \prod_{i=k}^m r_i \right)^{-1}. \tag{8}$$

The weights of the other indicators in the level can be obtained by the recursion equation

$$\omega_{k-1} = r_k \omega_k \quad k = m, m - 1, m - 2, \dots, 3, 2. \tag{9}$$

(5) Calculate the combined weights

Generally, if a system consists of three levels (as in [Fig. 1](#)), the highest level is O , the second level is $C = (C_1, C_2, \dots, C_m)$, and the third level is $P = (P_1, P_2, \dots, P_n)$. The weight vector of C to O is shown as follows:

$$\omega_O(C) = (\omega_O(C_1), \omega_O(C_2), \dots, \omega_O(C_m))^T. \tag{10}$$

The weight vector of P to C_i is shown as follows:

$$\omega_{C_i}(P) = (\omega_{C_i}(P_1), \omega_{C_i}(P_2), \dots, \omega_{C_i}(P_j))^T. \tag{11}$$

The combined weight of P_j to O is shown as follows:

$$\omega_O(P_j) = \sum_{i=1}^m \omega_{C_i}(P_j) \omega_O(C_i) \quad j = 1, 2, \dots, n. \tag{12}$$

This method is also applicable for multilevel cases.

5 Emergency-Response Classification

Based on the indices and their corresponding combined weights, this study presents the classification function by the following equation:

$$Y = \omega_j P_j, \quad j = 1, 2, \dots, n, \quad (13)$$

where Y is the comprehensive evaluation score of the emergency-response classification, ω_j is the combined weight of the j th evaluation index, and P_j is the score of the j th evaluation index.

Referring to the *Master State Plan for Rapid Responses to Public Emergencies* [21], this study divided emergency responses to fatal traffic accidents in Chinese urban areas into four classes: Class I, Class II, Class III, and Class IV. Each class and its corresponding comprehensive evaluation score are shown in [Tab. 7](#).

Table 7: Comprehensive evaluation scores for the classification of emergency responses

Class of emergency response	Score range of comprehensive evaluation
Class I	[4, 5]
Class II	[3, 4]
Class III	[2, 3]
Class IV	[1, 2]

6 Case Study

6.1 Background Information and Assigned Scores for Each Evaluation Index

At 13:53 on June 20, 2015, a fatal traffic accident occurred at the intersection of Shiyang Road and Youyihe Road in Nanjing, China ([Fig. 2](#)). The accident caused two deaths and one injury, and three vehicles were damaged. The maximum radius of the impact was 2.4 km. This accident occurred in downtown Nanjing (Class II area), and Shiyang Road is a major arterial road in the city. Before the accident, traffic conditions in the nearby areas were near-free-flow conditions, but the accident caused significant congestion in all lanes of Shiyang Road and Youyihe Road, with slow access to only two of 15 entryways at the intersection. The accident was handled by the Nanjing administrative traffic department of the public security organ. All evaluation indices of the traffic command system application and the traffic management service mechanism were met during the handling process. Based on the background above and referring to the quantitative criteria of each evaluation index, column 2 of [Tab. 8](#) lists the specific scores for each evaluation index.

6.2 Calculation of Combined Weights

According to the hierarchical structural model of the evaluation index system established in [Fig. 1](#), experts provided the order relation of the criterion level (C) to the object level (O) as follows:

$$C_1 > C_2 > C_3 \Rightarrow C_1^* > C_2^* > C_3^*.$$

The following comparison is made:

$$r_2 = \frac{\omega_1^*}{\omega_2^*} = 1.6, \quad r_3 = \frac{\omega_2^*}{\omega_3^*} = 1.4.$$

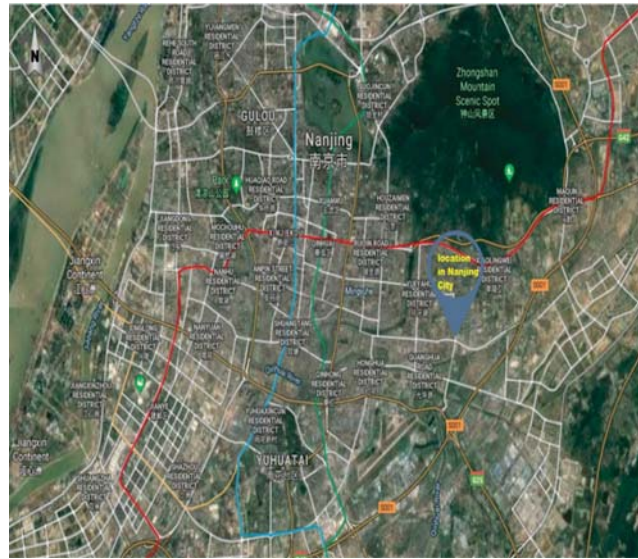


Figure 2: Location where the accident occurred

Table 8: Indices, assigned scores, combined weights, and comprehensive evaluation scores for the classification of emergency responses

Index	Assigned score	Combined weight	Comprehensive evaluation score
Severity of accident (P_1)	1	0.191	$Y = 2.043$
Controllability of accident (P_2)	2	0.159	
Affected scope (P_3)	2	0.133	
Location of accident (P_4)	4	0.094	
Type of urban road (P_5)	4	0.065	
Traffic conditions when accident occurred (P_6)	2	0.079	
Residual capacity where accident occurs (P_7)	4	0.065	
Application of traffic command system (P_8)	1	0.117	
Traffic management service mechanism (P_9)	1	0.097	

Thus,

$$\omega_3^* = (1 + r_2 r_3 + r_3)^{-1} = 0.215,$$

$$\omega_2^* = r_3 \omega_3^* = 1.4 \times 0.216 = 0.302,$$

$$\omega_1^* = r_2 \omega_2^* = 1.6 \times 0.302 = 0.483.$$

Therefore, the weight coefficients of the elements C_1 , C_2 and C_3 in the criterion level were 0.483, 0.302, and 0.215, respectively, so the weight vector of C to O was $\omega_O(C) = (0.483, 0.302, 0.215)^T$.

Similarly,

$$\text{for } C_1: P_1 \succ P_2 \succ P_3 \Rightarrow P_1^* \succ P_2^* \succ P_3^*; r_2 = \frac{\omega_1^*}{\omega_2^*} = 1.2, r_3 = \frac{\omega_1^*}{\omega_3^*} = 1.2,$$

$$\text{for } C_2: P_4 \succ P_6 \succ P_5 \succ P_7 \Rightarrow P_1^* \succ P_2^* \succ P_3^* \succ P_4^*; r_2 = \frac{\omega_1^*}{\omega_2^*} = 1.2, r_3 = \frac{\omega_2^*}{\omega_3^*} = 1.2, r_4 = \frac{\omega_3^*}{\omega_4^*} = 1.0,$$

$$\text{for } C_3: P_8 \succ P_9 \Rightarrow P_1^* \succ P_2^*; r_2 = \frac{\omega_1^*}{\omega_2^*} = 1.2.$$

With the same calculation method of $\omega_O(C)$, the weight vectors of P to C_i were obtained as follows:

$$\omega_{C_1}(P) = (0.395, 0.330, 0.275)^T, \omega_{C_2}(P) = (0.310, 0.215, 0.260, 0.215)^T, \omega_{C_3}(P) = (0.545, 0.455)^T.$$

Using Eq. (12), the combined weight of each evaluation index was obtained, as shown in column 3 Tab. 8.

6.3 Confirmation of Emergency-Response Class

Based on the evaluation indicator scores for the accident (column 2, Tab. 8) and the corresponding combined weights (column 3, Tab. 8), the comprehensive evaluation score of the emergency response classification can be calculated by Eq. (13), as follows:

$$Y = 0.191 \times 1 + 0.159 \times 2 + 0.133 \times 2 + 0.094 \times 4 + 0.065 \times 4 + 0.079 \times 2 + 0.065 \times 4 + 0.117 \times 1 + 0.097 \times 1 = 2.043$$

The results are shown in column 4 of Tab. 8. According to the classification of the emergency responses in Tab. 7, the emergency-response class of the accident was Class III.

7 Conclusion

This study established a multilevel hierarchical structural model comprising an object level (O), criterion level (C), and indicator level (P). A comprehensive evaluation score for emergency-response classification was calculated using the G1 method. The classification of emergency responses to fatal traffic accidents in Chinese urban areas was then determined according to the comprehensive evaluation score. Based on these analyses, the following conclusions can be drawn:

(1) The main contribution of this study is the selection and quantification of the evaluation indices for emergency-response classifications to fatal traffic accidents in Chinese urban areas. First, a preliminary evaluation index system was proposed based on relevant literature and investigations. Second, the Fuzzy Delphi Method was used to rank the importance of the evaluation indices, and the independence screening of the evaluation indices was presented on the basis of experts' suggestions. Third, the multilevel hierarchical structural model was set up after the index system was perfected. Furthermore, each evaluation indicator was given an interpretation and a quantitative criterion.

(2) It is feasible to classify emergency responses using a multilevel hierarchical structural model. Furthermore, it is appropriate for the Fuzzy Delphi Method to be used to rank the importance of the evaluation indices, and the G1 method is adopted to calculate the combined

weight of each index. Using the model and method, the evaluation indices are easy to obtain and quantify, and the combined weights are simple to calculate. Therefore, this model and methods can provide a fast and accurate way to determine the necessary responders, measures, and emergency-response resources, thus aiding the efficient management of fatal traffic accidents in Chinese urban areas.

(3) Though the aim was to classify emergency responses to fatal traffic accidents in Chinese urban areas, the methods of model establishment, index quantification, and weight calculation are applicable to different types of emergency responses. However, the evaluation indices must be selected in accordance with the particular emergency.

It should be noted that the main purpose of this paper is to help traffic administrative departments manage fatal traffic accidents in Chinese urban areas. In the evaluation-index selection, this study referred to previous literature and incorporated practical experience of traffic administrative departments. However, some evaluation indices that are only available in China and some difficult-to-obtain indices were excluded. Therefore, in future research, evaluation index systems and scoring methods should be further established and perfected. Furthermore, clustering and some artificial intelligence methods can also be adopted to study the classification of emergency responses.

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