Early Warning Classification of Urban Road Traffic under Emergencies

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***Abstract* — Urban Road Traffic (URT) congestion happen very frequently due to all types of emergencies in urban areas. The early warning classification of URT can effectively determine what measures that should be taken to solve URT problems. However, existing early warning classification studies, mainly considering the factors about the attributes of emergency, rarely involve the factors about the vulnerability of hazard-affected bodies. In order to effectively handle URT problem under emergencies, this paper presents a multi-level hierarchical structure model to study early warning classification of URT. In the model, attributes of emergency and vulnerability of urban road network are used as the first-level evaluation indices, and every second-level evaluation index is given interpretation and quantitative criterion. The total order weight of every index is calculated by Analytic Hierarchy Process (AHP) method. Furthermore, a classification function is built to determine the early warning level. Finally, a social security incident is used as an example to validate the model. The result shows that AHP method can effectively solve the problem about early warning classification of URT. Because of its simplicity and adaptability, the presented work should be useful for decision makers and practitioners to determine the early warning classification.**

Keywords - emergency; urban road traffic; early warning classification; vulnerability of Urban Road Network;AHP

I. INTRODUCTION

With the acceleration of urbanization in China, population, vehicles, and other properties have increased rapidly in the urban area during the last decades. Emergencies, such as natural disasters, industrial accidents, infectious diseases and terrorist attacks happen in the urban area, not only causing casualties and property damages, but also having negative effects on urban road traffic (URT) system. In these cases, timely and effective URT early warnings can not only help people to take actions to adjust their travel time and travel model, but also provide aids for the Department of Urban Traffic Management to take appropriate emergency management activities earlier. Therefore, it is advantageous to keep the balance of the URT system.

Some studies on early warning classification have been done during these years. Burnett outlines a crisis classification matrix which uses a sixteen cell matrix based on threat level (high versus low), response options (many versus few), time pressure (intense versus minimal) and degree of control (high versus low)[1].The Homeland Security Advisory System, a color-coded terrorism threat advisory scale which consists of five color-coded threat levels, is intended to reflect the probability of a terrorist attack and its potential gravity .In the system, red color means severe risk, orange color means high risk, yellow color means significant risk, blue color means general risk, and green color means low risk. Many warning classifications have got inspiration from the color-coded system. For example, a combinatorial method combined with color warning was proposed to evaluate the forewarning grades of emergency in urban mass transit [2].Nowadays, classification is a topic widely studied in a variety of emergency management fields including earthquake [3], mine disaster [4], meteorological disaster [5], dangerous chemical accident [6], transportation field [2][5], and so on. Many practical methods have been applied to classification, including Analytic Hierarchy Process (AHP)[7][8], fuzzy evaluation[9], decision tree model[10], dynamic event tree model[11], risk matrix[5] , and other intelligent methods[12].

Existing studies have made significant contributions to early warning classification of URT, providing various analysis methods for classification. These classification studies mainly considered the attributes of emergency，such as casualties, property losses, affected area, time urgency, degree of control, and so on. However, URT system is a complex giant system, and it complies with itself rules when it runs. It may be different early warning level of URT when the same emergency takes place in different time and area. Therefore, in o000rder to reduce the impact on URT system under emergencies, it is necessary to further study the early warning classification of URT considering the vulnerability of urban road network based on current Chinese conditions.

In the following section of the paper, a multi-level hierarchical structural model is presented to analyze factors of classification and each factor is given the interpretation and quantitative criterion. AHP Method is used to determine weights. According to the scores and total order weights of the second-level indexes, a classification function is built to determine the early warning level. Finally, in the case study section, a social security incident is adopted to explain how to determine the early warning level.

II. EVALUATION INDEX SYSTEM

This paper uses a multi-level hierarchical structural model to study early warning classification of URT. Attributes of emergency and vulnerability of urban road network are the first-level indexes. In the second-level, this paper chooses some quantitative indexes to describe the first-level indexes. The chosen fundamental principles of the second-level indexes for early warning classification of URT are as follows:

- Indexes are independent, and they are not contradictory;
- Each index should be quantified easily and could be got timely and effectively;
- Index system can reflect completely the whole feature of warning levels.

Fig.1shows the index system of early warning classification of URT, which includes 2 first-level indexes and 6 second-level indexes, in accordance with above fundamental principles. Scores of 0-100 are assigned to each second-level index， and the higher score indicates the higher early warning classification.

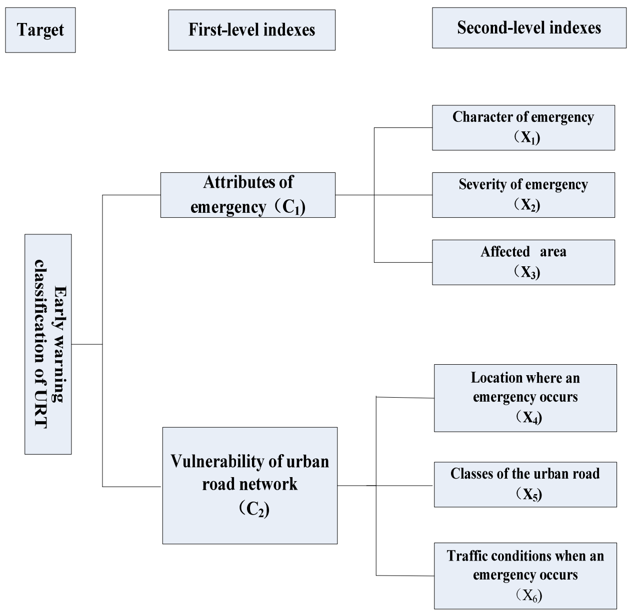

Fig. 1 Evaluation Index System of Early Warning Classification of URT

A. *Attributes of Emergency(C_1)*

Attributes of emergency usually include the character of emergency, severity of emergency and affected area.

1) *Character of Emergency （X_1）*

The character of emergency directly impacts its controllability. Therefore, it is a key index for early warning classification of URT. According to the controllability, the assigned score ranges to some emergencies which can directly impact URT system are shown in table I.

2) *Severity of Emergency（X_2）*

The direct economic loss and the number of casualties are usually used to measure the severity of emergency. Considering the direct economic loss is difficult to calculate in early warning phase, the equivalent death value is adopted as the index to evaluate the severity of emergency. Based on the Announcement about Revision Standard of Road Traffic Accidents Grades, which is released by the Ministry of Public Security of the People's Republic of China in 1991, the equivalent death value can be calculated as :

$$D_d = D_1 + 0.33D_2 + 0.1D_3 \quad (1)$$

Where $D_d$is the equivalent death value, D_1 is death toll, D_2 is serious injuries and D_3 is slight injuries.

Referring to the relative rules and procedures about how to deal with traffic accidents, the assigned score ranges to the equivalent death value are shown in table I.

3) *Affected area（X_3）*

This paper adopts the affected radius value of the urban arterials (major arterials and minor arterials)as the index to evaluate the affected area of emergency. There is a transportation management center in almost each big city in China. Therefore, it is easy to obtain the vales about the affected radius. There are 4 classified radiuses for 5 grades, which can be calculated as

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

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

According to "*Evaluation Index System of Urban Road Traffic Management*"(edition 2012), the area of built-up urban area of ***A*** class city (metropolis) is more than 320km^2 ,and the *B* class city (megacity) is more than 120km^2 .Therefore, this paper adopts the mean of the both area (220km^2) as the area of built-up urban area. According to the order from big to small, 80%, 60%, 40% and 20% are used as the classified percentages. Based on the calculation results of formulation (2), the assigned score ranges to classified radiuses are shown in table I.

TABLE Ⅰ.QUANTITATIVE CRITERIA OF ATTRIBUTES OF EMERGENCY

Description of partition criterion			Assigned score ranges
***X*₁**	***X*₂**	***X*₃**	
Catastrophes(severe natural disaster, terrorist attack)	D_d≥10	R≥7km	(80,100]
Social security incidents	10>D_d≥5	7km>R≥5km	(60,80]
Environmental pollution incidents	5>D_d≥3	5km>R≥3km	(40,60]
Severe traffic accidents	3>D_d≥1	3km>R≥2km	(20,40]
Traffic incidents	D_d<1	R<2km	[0,20]

B. *The Vulnerability of Urban Road Network (C_2)*

Vulnerability in the road transportation system is a susceptibility to incidents that can result in considerable reductions in road network serviceability [13]. According to the chosen fundamental principles of evaluation indices (2), this paper adopts the location where an emergency occurs, the classes of urban roads, and the traffic conditions when an emergency occurs as the evaluation indexes.

1) *Location Where an Emergency Occurs（X_4）*

Usually, when evaluating the Traffic Impact Analysis

(TIA) of construction projects in some Chinese cities, the governments and researchers tend to divide the city into some different areas. Among them, the first class area refers to the core area with the most intensive population, the heaviest traffic, and the most sensitive area. The other class areas are successive decrease. Based on the classified area, the assigned score ranges to location of emergency are shown in table Ⅱ.

2) Classes of Urban Roads（X_5）

The typical urban roads are classified into freeways, major arterials, minor arterials and local roads. The each class of urban road has its special function for transportation. Emergencies have different impact intensity to each class of urban road. The assigned score ranges to each class of urban roads are shown in table II.

3) Traffic Conditions When an Emergency Occurs（X_6）

When an emergency occurs, the traffic conditions mainly refer to the traffic stream characteristics. Based on the fundamental theory of traffic engineering, the traffic volumes regularly change in a city. Generally, the traffic volumes keep steady in the same period of weekdays. But the traffic volumes are different between weekdays and weekends. Therefore, the assigned score ranges to the traffic conditions when an emergency occurs are shown in table II.

TABLE Ⅱ.QUANTITATIVE CRITERIA OF THE VULNERABILITY OF URBAN ROAD NETWORK

Description of partition criterion			Assigned score ranges
X4	***X5***	***X6***	
The First Class Area	Freeways	Rush hours period of weekday	(80,100]
The Second Class Area	Major arterials	Rush hours period of weekend	(60,80]
The Third Class Area	Minor arterials	Normal traffic volume period of weekday	(40,60]
The Fourth Class Area	Local roads	Normal traffic volume period of weekend	(20,40]
Others Area	Others	Valley period	(0,20]

This paper just presents the score ranges of six second-level indices according table Ⅰ and Ⅱ. The specific scores are assigned should consider the realistic conditions and experts' experiences. If it is difficult to determine the specific scores, midpoint score can be adopted for each class.

III. CALCULATING THE TOTAL ORDER WEIGHTS BY AHP METHOD

The AHP method, developed by Saaty in the seventies of the last century [14]is widely used for tackling multi-criteria decision making problems in real situations. It reduces a complex issue into key elements, individually compared in a pairwise fashion on a numeric, reciprocal scale from one to nine. The tool quantifies which strategy is most attractive to the group of interest providing a clear rationale for selecting one pathway.

Based on the building multi-level hierarchical structural index system, the total order weights are calculated by the steps as follows:

Step 1: This paper presents a (T-C) comparison matrix which is to judge the relative importance of the first-level with respect to the target, and assess the consistency. The method was presented by Saaty [14][15]and widely used in decision support system.

In this comparison matrix, we assume that experts can compare two arbitrary elements C_i and C_j (both are in the same layer of the hierarchical structure) and provide a relative importance rate c_{ij} (n elements in the layer).If C_i is superior to C_j ,then $c_{ij} > 1$, vice versa. $c_{ji} = 1/c_{ij}$, $c_{ii} = 1$. $i,j = 1,2,\dots,n$. c_{ij} is assigned from 1 to 9 according to the importance (table III),obtaining the aggregated comparison matrix $C = (c_{ij})_{n\times n}$, where n is the number of the compared criteria. $\boldsymbol{C}$ should be square, positive, symmetric and consistent. After normalization, If $\lambda_{\max}$ is the maximum eigenvalue, then its corresponding eigenvector $(\omega = (\omega_1, \cdots, \omega_n)^T)$ is the evaluation weights of the relevant indexes.

TABLEⅢ.SCALE AND MEANINGS OF ELEMENTS IN COMPARISON MATRIX

Relative importance rate c_{ij}	Meanings
1	C_i is as important as C_j
3	C_i is more important than C_j slightly
5	C_i is more important than C_j obviously
7	C_i is more important than C_j sharply
9	C_i is more important than C_j extremely
2,4,6,8	Between the adjacent values listed above, for example, 2 means the value between equal important and more important slightly

To ensure the comparison result that we make non-contradictory and the result of AHP method meaningful, itis necessary to check consistency. According to AHP method, a square matrix C can be considered consistency if the Consistence Ratio (CR) is smaller than or equal to 0.1:

$$\mathrm{CR} = \frac{CI}{RI} \le 0.1 \tag{3}$$

Where $\mathrm{CI} = \frac{\lambda_{max} - n}{n-1}$ is called Consistency Index. RI is called Random Index.

Values of RI are the function of n, which are indicated in table IV.

TABLEⅣ.VALUES OF RANDOM INDEX

n	*1*	*2*	*3*	*4*
RI	0.00	0.00	0.58	0.90
n	*5*	*6*	*7*	*8*
RI	1.12	1.24	1.32	1.41

When $CR \leq 0.1$, the level of a single order that has the satisfactory consistency of the results, AHP method for solving the result is valid, otherwise the values of elements need to be adjusted to comparison matrix. The computed results are shown in table V. A second-order matrix always meets the consistency. Therefore, it doesn't have to check the consistency in table Ⅴ.

TABLE Ⅴ T-C COMPARISON MATRIX

	C_1	*C_2*
Attributes of emergency (C_1)	1	2
Vulnerability of urban road network (C_2)	1/2	1
$\lambda_{\max} = 2$ ω = $(0.666,0.333)^T$		

Step 2: To build a (C-X) comparison matrix which is to judge the relative importance of the second-level with respect to the first-level, and assess the consistency. The specific method is the same as the step 1. The computed results are shown in tableⅥ-Ⅷ.

TABLEⅥ. C_1-X COMPARISON MATRIX

	X_1	*X_2*	*X_3*
Character of emergency (X_1)	1	3	5
Severity of emergency (X_2)	1/3	1	2
Affected area(X_3)	1/5	1/2	1
$\lambda_{\max} = 3.005$,ω = $(0.648,0.230,0,122)^T$,$CI = 0.0025, CR = 0.004 \leq 0.1$.			

TABLEⅦ. C_2-X COMPARISON MATRIX

	X_4	*X_5*	*X_6*
Location where an emergency occurs (X_4)	1	2	1/2
Classesof urban roads (X_5)	1/2	1	1/3
Traffic conditions when an emergency occurs (X_6)	2	3	1
$\lambda_{\max} = 3.009$,ω = $(0.297,0.164,0.539)^T$, $CI = 0.0045$, $CR = 0.008 \leq 0.1$.			

Step 3: According to the times results of weights in step 1 and the relative weights in step2, we can get the total order weights, which can be seen in tableⅨ.

TABLEⅨ.TOTAL ORDER WEIGHTS FOR SECOND-LEVEL INDEXES

first-level indexes and weights	***Second-level indexes and relative weights***	***the total order weights***
Attributes of emergency (C_1)(0.666)	Character of emergency (X_1) (0.648)	ω_1 (0.432)
	Severity of emergency (X_2) (0.230)	ω_2(0.153)
	Affected area (X_3) (0.122)	ω_3 (0.081)
Vulnerability of urban road network (C_2) (0.333)	Location where an emergency occurs (X_4) (0.297)	ω_4 (0.099)
	Classes of urban roads (X_5) (0.164)	ω_5 (0.055)
	Traffic conditions when an emergency occurs (X_6) (0.539)	ω_6 (0.179)

IV. BUILDING UP CLASSIFICATION FUNCTION

This paper presents the classification function based on the second-level indexes and their total order weights:

$$Y = \omega_1 X_1 + \omega_2 X_2 + \omega_3 X_3 + \omega_4 X_4 + \omega_5 X_5 + \omega_6 X_6 \quad (4)$$

Where Y is the score of classification function for early warning, $X_i (i = 1,2,3,4,5,6)$ is the score of each second-level index and $\omega_i (i = 1,2,3,4,6)$ is the weight of each second-level index. This paper presents a 5-level classification method to early warning classification of URT. The assigned score ranges for each level are shown in tableⅩ. The early warning classification is usually divided into 4 levels in Chinese emergency management field. Therefore, this paper suggests level 0 is no early warning. Blue, yellow, orange and red color early warnings are shown from level 1 to level 4 .

TABLE Ⅹ.ASSIGNED SCORE RANGES FOR EACH EARLY WARNING LEVEL

Level of early warning	***Level 0***	***Level 1***	***Level 2***	***Level 3***	***Level 4***
Assigned scores range	[0,20]	(20,40]	(40,60]	(60,80]	(80,100]

V. CASE STUDY

A. Fundamental Facts

On Monday, October 7, 2013, at about 9:00 a.m., crowd stopped all the passing buses No. 34 during the rush hour at the crossroad of Hubu Street and Hongwu Road, in the central area of Nanjing city (the location is shown in fig.2in China, which attracted hundreds of spectators and caused traffic chaos. As a result, a number of people were late for work that day due to traffic jam. The reason why the crowd choked off the traffic was that a 18-year-old young girl had been knocked over and crushed by a bus No. 34 at about 6:20 p.m. on October 2, 2013. The girl had died after she had been taken to hospital. So her parents and relatives took the radical actions 5 days later, thinking it was handled improperly.

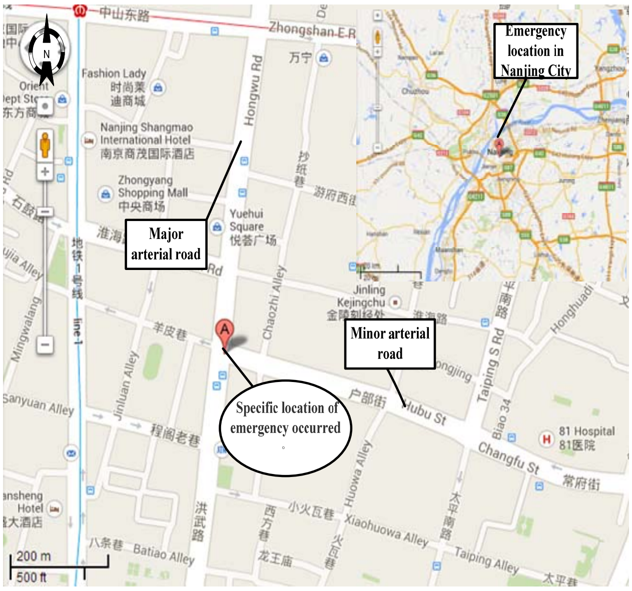

Fig.2 Location of Emergency Occurred

B. Background Information on the Event

As a typical social security case, the emergency did not lead to any casualty, only influencing road traffic in a 3-5km radius area. It occurred at Hongwu Road, which is an major arterial road in the central business district (CBD) of Nanjing city(the first class area), during the rush hour of Monday morning, a weekday. The emergency caused the traffic congestion of all the lanes of Hongwu Road and Hubu Street.

C. Early Warning Level

TABLE XI. CALCULATION OF CLASSIFICATION FUNCTION VALUE

The second indexes	X_1	X_2	X_3	X_4	X_5	X_6
Assigned scores	70	10	50	90	70	90
Total order weights	0.432	0.153	0.081	0.099	0.055	0.179
classification function vale Y **= 64.69**						

Based on the background information and the quantitative criteria of the second-level indexes, all the specific assigned scores are adopted midpoint scores. Each total order weight of the second-level index can be got from table Ⅸ .By applying weighted summation method, the classification function vale is calculated and shown in table Ⅺ. According to table X, the event should be early warning as level 3 (orange).

VI. CONCLUSION

In this paper, a multi-level hierarchical structural model containing target level (T), first-level (C) and second-level(X)is established. The score ranges of each second-level index are presented, and its total order weights can be calculated by using AHP method. A classification function is presented to determine the early warning level, which is the weighted summation value of assigned score of each second-level index and its total order weights. From the above analysis and research, it is natural to draw the following conclusions:

(1)It is feasible to determine the early warning level of URT by using AHP method. The evaluation indexes are easy to obtain, and the scoring and calculation are simple. Therefore, AHP method is effective to solve the problem of early warning classification of URT.

(2)Although the primary aim is to determine the early warning level of URT, the method of model establishment is also applicable to other early warning classification. However, the evaluation indexes must be selected in accordance with the practical situations.

It is necessary to point out that this paper refers to a lot of literatures, combines the practical experience of traffic administrative departments of public security organin evaluation index selection, but excludes the difficult-to-obtain indexes. As for different types of emergencies, some evaluation indexes are not applicable, and some important evaluation indexes may be ignored. In the ongoing research and practice, the evaluation index system and the scoring method are subject to further establishment and perfection.

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