Research on the Evaluation of the Emergency Response Capacity of Highway Maintenance Squad

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Abstract. According to the connotation of the emergency function of the highway maintenance squad, the evaluation system of the emergency response capability of the highway maintenance squad was constructed with the emergency management capability, resource guarantee capability and base guarantee capability as the primary indicators, and the base area, road network density, emergency team, emergency equipment, emergency plan, emergency drill and emergency training as the secondary indicators. The Analytic Hierarchy Process (AHP) was used to determine the weights of the evaluation indicators for the emergency response capability of the highway maintenance squad. Based on the research, a secondary indicator evaluation standard for the emergency response capacity of the highway maintenance squad was established. The results of the case application analysis show that the established emergency evaluation capacity system and method can objectively and quantitatively evaluate the emergency capacity of the highway maintenance squads, which has a positive significance for the construction of the emergency capacity of highway squads.

Keywords: Highway; Emergency response capacity; Evaluation system; Maintenance squad; Analytic Hierarchy Process (AHP)

1 Introduction

As a modern transport infrastructure, highways play an important role in promoting economic development and social prosperity and facilitating travel among the people. Emergencies are characterized by their instantaneous nature, unpredictability, consequences' seriousness and rescue complexity. Once it happens on a fast, closed highway, the severity of the consequences grows exponentially as the rescue time increases [1]. As an important part of the highway system, highway maintenance squads play an increasingly important role in the emergency management system of highway maintenance. Improving the emergency response capability of the highway maintenance squad is of great significance to ensure the safety of people's traffic.

In recent years, some scholars have conducted relevant research on emergency response capacity assessment work in transportation. For example, Yang et al. used mutation theory to analyze and study the emergency response capacity of urban road traffic

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safety emergencies [2]. Ding used the Analytic Hierarchy Process to determine the weights of each index for the emergency evaluation of highway service areas to conduct a fuzzy comprehensive evaluation of the Jilin section of the Beijing-Harbin Highway [3]. Zeng et al. used Analytic Hierarchy Process to study and analyze the emergency response capacity of road tunnels [4]. Zhang et al. proposed the focus of emergency response capacity assessment at different stages of the full life cycle of a highway. They proposed an index for the efficiency of emergency response to emergencies [5]. Tu et al. established an evaluation index system for the emergency response capacity of road and bridge construction projects using neural networks [6]. Zhao et al. constructed an evaluation index system for tunnel construction emergency systems based on resilience theory [7]. In general, there are more theoretical studies on emergency response capacity, numerous evaluation index systems, no unified standards, and fewer studies evaluating emergency response capacity for the most basic units of highway maintenance.

This study will construct a model for evaluating the emergency response capability of the highway maintenance squad to quantitatively evaluate the emergency response capability of the squad, given the characteristics of highway emergencies and the function of the highway maintenance squad.

2 Functions of highway maintenance squads

A highway maintenance squad is an operational group established to carry out routine maintenance and repair of a road within a certain section of the road, referred to as a squad [8]. The highway maintenance squads undertake maintenance tasks and emergency response functions along the highway [9], as shown in Table 1. Currently, the highway maintenance mode of operation implements the market-oriented enterprise maintenance mode, highway maintenance squad machinery and equipment, materials and personnel team equipped basically by the maintenance enterprises under the market competition. The main equipment is configured to meet the standard of daily maintenance, minor repairs and daily emergencies, with inspection vehicles, sweepers, sprinklers, small pavement pothole repair and grouting equipment, etc. [10]. The corresponding team of maintenance technicians is equipped with some maintenance engineers, technical management teams, and maintenance workers for pothole repair and cracking, cleaning, emergency response, etc. In general, there is a crossover between routine maintenance operations and emergency response work, so routine maintenance staff often combine with emergency response staff [9]. Each highway operation and maintenance unit emergency response forces into the highway emergency rescue system, by the principle of unified command, graded response, division of labor and cooperation, to carry out highway emergency response and rescue work [10].

Table 1. Functions content of highway maintenance squads

Squad function	Function content
Routine maintenance	Daily operation of all components of the highway (including ancillary facilities) to maintain the original good condition and service level of the highway, including inspection and cleaning, road maintenance, roadbed maintenance, maintenance of ancillary facilities along the highway, greening maintenance, etc.
Emergency response	To improve the level of highway emergency response, in addition to safeguarding the daily emergency repair work, strengthen the emergency response work of highway in bad weather (typhoons, rainstorms, ice, and snow days) to ensure the safe and smooth operation of highway, including road repair and maintenance, flood prevention and typhoon prevention, ice and snow removal, general natural disaster road dredging, clearing scattered materials on the road, etc.

3 Construction of a model for evaluating the emergency response capability of highway maintenance squads

3.1 Establishing the evaluation system

According to the connotation and composition of the emergency response capability of the highway squad, three primary evaluation indicators of emergency management capability, resource guarantee capability and base guarantee capability and seven secondary platform indicators such as base area, road network density, emergency team, emergency equipment, emergency plan, emergency drill and emergency training have been formed. The evaluation system constructed to reflect the content of the emergency response capability of the highway maintenance squad is shown in Figure 1.

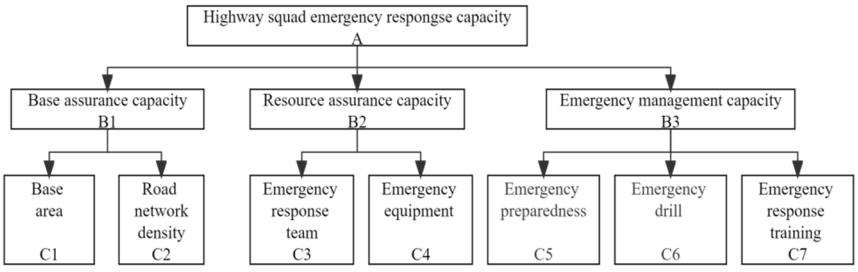

Fig. 1. An evaluation system for the emergency response capacity of highway maintenance squads

3.2 Assessment of evaluation index weightings

The determination of the index weights directly determines the reliability of the evaluation results. To improve the accuracy of the evaluation of the emergency response capability of the highway squad, this study uses the Analytic Hierarchy Process to determine the weights of each index of the evaluation system.

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method proposed by the famous American mathematician Saaty in the 1970s. The basic principle is to decompose the problem into several different components according to the problem's fundamental nature and the overall objective to be achieved. Based on the basic properties of the factors and their correlation with each other, the factors are grouped at different levels to form a multi-level analytical structure model. Ultimately the problem boils down to the determination of the relative importance weights of the lowest tier relative to the highest tier (the overall objective) or the ranking of relative merits [11]. The Analytic Hierarchy Process is divided into three main steps for determining weights [12].

(1) Build a hierarchical analysis model. The objectives, primary and secondary indexes in the assessment index system are divided into objective, guideline and index levels according to their relationships.

(2) Construct the judgment matrix. Using a scale of 1-9, experts are invited to make a two-by-two comparison of primary and secondary indexes, respectively, to judge the importance of the indexes and construct a judgment matrix.

(3) Calculate the index weights. The eigenvector corresponding to the largest eigenroot of the judgment matrix is calculated. The normalized elements are the ranking weights of the relative importance of a factor at the same level as a factor at the previous level. A consistency test was performed, and the judgment matrix consistency indicator (CI) values were calculated using the formula:

$$CI = \frac{\lambda - n}{n - 1} \tag{1}$$

Where CI is the consistency index. If CI is equal to 0, then there is perfect consistency; if CI is close to 0, then there is good consistency; the larger the CI, the more serious the inconsistency.

For each factor of the emergency response capacity of the highway squad, a factor judgment matrix is constructed, and the values of the factors in the judgment matrix are based mainly on the statistics of the structure of the expert questionnaire. The ranking between the three factors of the primary index is: resource assurance capacity > emergency management capacity > base assurance capacity. Table 2 shows the matrix of judgments for the primary indexes.

Table 2. Judgment matrix for the first-level evaluation index of emergency response capacity

Emergency response capacity	Base assurance capacity	Resource assurance capacity	Emergency management capacity
Base assurance capacity	1.00	1/5	1/3
Resource assurance capacity	5.00	1.00	3.00
Emergency management capacity	3.00	1/3	1.00

Using the Analytic Hierarchy Process, ranking weights are assigned to base assurance capacity, resource assurance capacity and emergency management capacity relative to the importance of emergency response capacity (hierarchical total ranking). A single ranking weight vector is calculated and tested for consistency. Using the decision hierarchy model, we obtained a single ranking weight vector of (0.11, 0.63, 0.26) for the importance of base assurance capacity, resource assurance capacity and emergency management capacity about emergency response capacity. The order of importance for the three first-level indexes of emergency response capacity is: resource assurance capacity > emergency management capacity > base assurance capacity.

Similarly, the judgment matrix of the secondary indexes is constructed based on the questionnaire data, and the weight of each secondary index is calculated and tested for consistency through the judgment matrix to obtain the secondary indexes' weight value. Table 3 shows the weights of the emergency response capacity evaluation indexes derived using the Analytic Hierarchy Process. A ranking of the synthetic weights of the secondary indexes that affect the emergency response capability of the highway squad is obtained, and the impact of emergency equipment is at the top, followed by emergency team building.

Table 3. Evaluation index weights for emergency response capacity of highway maintenance squad

Objective level A	Criteria level B	B-level weights	Index level C	C-level weights
Highway maintenance squad emergency response capability	Base assurance capacity	0.11	Base area	0.33
			Road network density	0.67
	Resource assurance capacity	0.63	Emergency response team	0.33
			Emergency equipment	0.67
	Emergency management capacity	0.26	Emergency preparedness	0.54
			Emergency drill	0.30
			Emergency response training	0.16

3.3 Index-level evaluation criteria

The research was conducted on the base area, road network density, number of emergency teams, number of major equipment, number of emergency plans, number of emergency drills carried out and number of emergency training carried out in 50 highway squads, with each research index described as follows:

(1) Base area: investigating the area of the base of the squad, in square meters, mainly reflects the size of the site used by the squad.

(2) Road network density: with the center of the road base as the center of the circle, according to the 5 km search radius of the total length of roads in the ratio of the area, the unit is km/km^2; this index is mainly used to evaluate the traffic situation around the base of the road class.

(3) Emergency response team: investigate the number of people in the emergency response team in the squad.

(4) Emergency equipment: investigate and count the number of professional equipment for engineering, equipment for flood and typhoon prevention, and equipment for snow and ice.

(5) Emergency plans: investigate the type and number of special emergency plans that have been prepared.

(6) Emergency drills: investigate the type and number of emergency drills organized or attended annually.

(7) Emergency training: investigate the type and number of emergency training sessions organized or attended annually.

Based on the research data, experts were organized to conduct thematic discussions on the emergency needs of highway maintenance, resulting in a scoring criteria system for the index level, as shown in Table 4.

Table 4. Evaluation criteria for secondary indexes of emergency response capacity of highway squads

Evaluation Indexes	Outstanding（90）	Good（80）	Medium（70）	Below averag（60）	Poor（50）
Base area	Squad base area≥4000 m^2	3000m^2≤Squad base area <4000m^2	2000m^2≤Squad base area <3000m^2	1000m^2≤Squad base area <2000m^2	Squad base area <1000m^2
Road network density	Road network density≥2	1.5≤Road network density <2	1≤Road network density <1.5	0.5≤Road network density <1	Road network density <0.5
Emergency response team	No. of people≥40	30≤No. of people <40	20≤No, of people <30	10≤No. of people <20	No. of people <10
Emergency equipment	No. of major	20≤No. of major	10≤No. of major	5≤No. of major equipment <10	No. of major equipment <5

	equipment≥30	equipment <30	equipment <20		
Emergency preparedness	Complete emergency planning system, with at least four special plans	The emergency plan is relatively complete, with three special emergency plans	Preparation of emergency plans, with 2 specific emergency plans	Preparation of emergency plans, with 1 specific emergency plan	No specific emergency plan prepared
Emergency drill	Conduct or participate in at least 4 special emergency drills of different types a year	Conduct or participate in at least 3 special emergency drills of different types a year	Conduct or participate in at least 2 special emergency drills of different types a year	Conduct or participate in at least 1 special emergency drill of different types a year	Failure to conduct or participate in emergency drill within one year
Emergency response training	Conduct or participate in at least 4 different types of specific emergency training a year	Conduct or participate in at least 3 different types of specific emergency training a year	Conduct or participate in at least 2 different types of specific emergency training a year	Conduct or participate in at least 1 different type of specific emergency training a year	Failure to conduct or participate in emergency training within one year

4 Examples of applications

The four highway classes were surveyed, and the survey results and the score values obtained by comparing the scoring criteria for the secondary index are shown in Table 5.

Table 5. Highway squad survey score sheet

Indexes	Squad A		Squad B		Squad C		Squad D	
	Survey value	Score	Survey value	Score	Survey value	Score	Survey value	Score
Base area	3600m^2	80	2500m^2	70	5380m^2	90	1800m^2	60
Road network density	1.969	80	1.566	80	0.927	60	1.447	70
Emergency response team	23	70	15	60	52	90	15	70
Emergency equipment	9	60	3	50	26	80	32	90
Emergency preparedness	2	70	2	70	4	90	1	60
Emergency drill	1	60	1	60	3	80	0	50
Emergency response training	0	50	1	60	0	50	0	50

According to the evaluation index weights, the results of the evaluation of the emergency response capacity of the four highway squads were calculated as shown in Table 6. The evaluation results show that the ranking of the four squads in terms of the magnitude of their emergency response capacity is, in order, Squad C (81.1) > Squad D (74.3) > Squad A (65.3) > Squad B (59.0). Squad A and Squad B should focus on strengthening capacity building for resource assurance, Squad C should focus on strengthening capacity building for base assurance, and Squad D should focus on strengthening capacity building for emergency management.

Table 6. Highway squad emergency response capacity evaluation results

Squad	Criteria level			Objective level
	Base assurance capacity	Resource assurance capacity	Emergency management capacity	Emergency response capacity
Squad A	80.0	63.3	63.8	65.3
Squad B	76.7	53.3	65.4	59.0
Squad C	69.9	83.3	80.6	81.1
Squad D	66.7	83.4	55.4	74.3

5 Conclusion

(1) In this paper, based on the analysis of the characteristics and emergency requirements of the highway maintenance squad, a model for assessing the emergency response capability of the highway maintenance squad is constructed. The model index system consists of three primary indexes, including base security capacity, resource security capacity and emergency management capacity, and seven secondary indexes, including base area, road network density and emergency response team.

(2) Applying the Analytic Hierarchy Process, the order of importance related to the 3 primary indexes of emergency response capacity is: resource assurance capacity (0.63) > emergency management capacity (0.26) > base assurance capacity (0.11). The ability to secure resources is extremely important to the evaluation of the emergency response capability of the squad. A ranking of the synthetic weights of the secondary indexes affecting the emergency response capacity of the highway squad revealed that the impact of emergency equipment was the priority, followed by emergency team building. Therefore, in daily emergency safety management, the focus should be on strengthening emergency equipment and emergency teams.

(3) Using the emergency response capacity evaluation model to analyze the emergency response capacity of the four highway squads, the ranking of the emergency response capacity of the four squads in order is: Squad C (81.1) > Squad D (74.3) > Squad A (65.3) > Squad B (59.0). The emergency response capability evaluation model can quantitatively analyze and evaluate the emergency response capability of highway squads, which has a certain guiding significance for improving the emergency response capability of the highway squads.

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