critical factors influencing community governance from four aspects: government, society, voluntary organizations or enterprises and residents. Subsequently, suggestions for improving the new-type community governance in the context of rural revitalization strategy in China were provided, which can be beneficial to the researchers and policy-makers. Given this research is an exploratory study, many other related issues need to be investigated deeply in the future. For example, from the perspective of residents, what methods can be adopted to improve the participation of residents can be studied to build the resident's autonomy system. From the perspective of voluntary organizations or enterprises, how to improve their initiative and responsibility can also be studied.

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Assessment for Safety Capacity of Metro Construction Workers Based on SPA

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ABSTRACT

In order to objectively evaluate the safety capability of metro construction workers, a safety assessment model for metro construction workers based on set pair analysis (SPA) method is proposed. Firstly, according to the definition of safety capacity and the characteristics of metro construction, the evaluation index system of subway construction personnel safety capability was established. Fuzzy priority planning theory and entropy weight method are combined to determine the index weight. Secondly, according to SPA, the safety capacity evaluation model of metro construction workers was established. Finally, models are used to evaluate the safety capability of several construction workers who randomly selecting in Chengdu Metro Line 11 and the evaluation results were consistent with the actual situation.

INTRODUCTION

With the continuous expansion of the scale of metro construction, metro construction safety accidents occur frequently. According to the accident causation chain theory, accidents caused by unsafe behavior accounted for 89.9% (Heinrich 1932), and the occurrence of unsafe behavior is directly related to the lack of safety competency. Therefore, how to establish a scientific evaluation model for the safety capability of metro construction workers to objectively evaluate the safety capability of metro construction workers is of great significance for reducing the occurrence of metro construction accidents.

At present, relevant scholars have conducted some research on personnel safety capabilities. On the basis of comprehensive safety and competence, scholars (Wang et al. 2009) defined the connotation of safety capability of construction workers, and qualitatively analyzed the constraints of construction workers' safety capacity and safety production. Scholars (Narang 2006) used fuzzy signal detection theory to measure the safety ability of construction workers. Scholars (Yang and Li 2018) used DEMATEL-ISM to quantitatively analyze the mutual influence relationship between the safety indicators of civil aviation pilots and their influence on the comprehensive safety capability of civil aviation pilots. Scholars (Deng et al. 2011) only evaluate the safety capabilities of subway shield construction workers from the perspective of psychology. The scholar (Ma 2015) established the evaluation index system of construction workers' safety ability from safety awareness, emotional intelligence, and knowledge and skills. The AHP was used to calculate the index weight, and the fuzzy comprehensive evaluation method was used for systematic evaluation, but it is impossible to know the follow-up development trend of the safety capacity of construction workers. Scholars (Du et al. 2015) used the set pair analysis method (SPA method) to evaluate the safety capability of civil aviation pilots. Through the calculation of the connection degree, it can be known that the civil aviation pilots follow-up development trend and develop targeted measures. The scholar (Liang 2015) believes that the definition of the required knowledge, skills and application level is different for

specific jobs. The above research mainly focuses on the safety capabilities of construction workers, and there are few studies on the safety capabilities of metro construction workers, and the weight calculation is also subjective.

In view of this, the author intends to combine the fuzzy priority planning theory with the entropy weight method to determine the index weights, so as to weaken the adverse effects of the subjective preferences of experts and make up for the defects of the single weighting method.

Then establish a systematic evaluation model of the metro construction workers' safety capability according to SPA, taking into account its uncertainty and ambiguity, and at the same time can know the development trend of subway construction personnel safety capabilities, and help managers to take targeted measures. Finally, the construction workers of Chengdu Metro Line 11 are selected for verification. The related research mainly provides the basis for improving the safety capacity of metro construction workers and reducing the occurrence of metro construction safety accidents.

Table 1. Evaluation Index System for Safety Capacity of Metro Construction Workers.

Primary indicator	Secondary indicators	Three-level indicator
Safety capability index for metro construction workers C	Physical fitness C_1	Physiological condition C_{11}
		Anti-fatigue degree C_{12}
		Emotional control C_{13}
	State of consciousness C_2	Safety awareness C_{21}
		Responsibility awareness C_{22}
		Learning consciousness C_{23}
		Active awareness C_{24}
	Work skill C_3	Safety protection skills C_{31}
		Proficiency of metro construction C_{32}
		Experience of metro safety construction C_{33}
		Training status C_{34}
	Behavioral ability C_4	Strain capacity C_{41}
		Self-control ability C_{42}
		Communication ability C_{43}
		Acceptability C_{34}

METRO CONSTRUCTION WORKERS' SAFETY CAPACITY AND EVALUATION INDEX SYSTEM

Definition of safety capabilities of metro construction workers: At present, scholars' understanding of personnel safety capabilities is based on implications of capabilities and security. The definition of competence in national standards is that the proven ability to apply knowledge and skills. For specific jobs, the definition of knowledge, skills and application level is related to actual situation of the job. "No-risk, zero-accident state" is called safety. It is a relatively vague concept. Without absolute security, as long as the risk is controlled within acceptable limits, it can be considered a safe state. Therefore, synthesizing the connotation of safety and capability and basing on relevant research results, the author defines the safety capability of metro construction workers as follows: during the construction process of the subway, the construction personnel use their own knowledge, skills and other inherent qualities

to control risk factors within a reasonable range.

Safety capability evaluation index system: According to the definition of safety capacity of metro construction workers (Wang 2017; Zhou et al. 2018), analyzing the factors from results of relevant research, the construction characteristics of metro and relevant expert opinions, the metro construction workers' safety capability evaluation index system is established, see Table 1.

Division of evaluation criteria: The division of evaluation criteria directly affects the accuracy of the evaluation results. On the basis of relevant research results and practical operability, the standard level of safety capacity of metro construction workers is divided into five levels, worse, bad, general, good and excellent. According to the evaluation criteria, the range of values for each indicator is divided into [0, 60), [60, 70), [70, 80), [80, 90), [90, 100).

THE EVALUATION OF INDEX WEIGHT CALCULATION

Calculating the weight of indicators plays an important role in the evaluation of the safety capability of metro construction workers. Subjective weighting method, the results are more consistent with the actual situation, but will be affected by the preference of experts. Objective weighting method, pays more attention to the situation under ideal conditions, but sometimes deviates from reality. The effective combination of the two is conducive to giving full play to the advantages of their respective empowerment and making up for the shortcomings of single empowerment. In this paper, the triangular fuzzy number and fuzzy priority programming theory are combined to determine the subjective weight of the index. The entropy weight method is used to determine the objective weight of the index. Finally, the two weights are combined to determine the comprehensive weight of the indicator.

Table 2. Values of Triangular Fuzzy Numbers.

Meaning	Equally important	Slightly important	More important	Very important	Extremely important
Triangular fuzzy number	1	3	5	7	9
Triangular fuzzy number expression	(1,1,1)	(2,3,4)	(4,5,6)	(6,7,8)	(8,9,9)
Triangular fuzzy number reciprocal	(1,1,1)	(1/4,1/3,1/2)	(1/6,1/5,1/4)	(1/8,1/7,1/6)	(1/9,1/9,1/8)

Fuzzy priority planning theory to calculate subjective weight: From the definition of the safety capacity of metro construction workers and established index system, it can be found that the evaluation of the safety capability of metro construction workers is highly ambiguous, and it is difficult to quantify the evaluation indicators. Therefore, triangular fuzzy language will be used to quantify indicators. Compared with the single relative importance of AHP, triangular fuzzy number theory can make the relative importance between indicators more reasonable. The basic form of triangular fuzzy numbers is $M= (l, m, u)$, l, u, m respectively represent upper

bounds, optimal value and lower bounds. The membership function form is shown in formula 1, and the value of the triangular fuzzy number is shown in Table 2.

$$U(x)=\begin{cases}\dfrac{x-l}{m-l} & l\le x\le m\\ \dfrac{u-x}{u-m} & m\le x\le u\\ 0 & x<lorx>u\end{cases} \tag{1}$$

Among them, $x\in R$ and $0<l\le m\le u$.

According to the value of the triangular fuzzy number in Table 2, and the method of constructing the judgment matrix through AHP, the fuzzy judgment matrix of the safety capacity index of the metro construction workers is constructed.

For the fuzzy judgment matrix constructed with triangular fuzzy numbers, the idea of nonlinear optimization is used to solve the weight set. The specific ideas are as follows:

(1) Convert Formula 1 to Formula 2 with w_i / w_j as a variable:

$$\mu_{ij}(\frac{w_i}{w_j})=\begin{cases}\dfrac{\frac{w_i}{w_j}-l_{ij}}{m_{ij}-l_{ij}} & \dfrac{w_i}{w_j}\le m_{ij}\\ \dfrac{u_{ij}-\frac{w_i}{w_j}}{u_{ij}-m_{ij}} & \dfrac{w_i}{w_j}\ge m_{ij}\end{cases} \tag{2}$$

$\mu_{ij}(\frac{w_i}{w_j})$ is expressed the membership of $(\frac{w_i}{w_j})$ for the fuzzy matrix.

(2) Order γ for the minimum membership:

$$\gamma=\min\left\{\mu_{ij}(\frac{w_i}{w_j})\middle| i=1,\cdots,n-1;\ j=i+1,\cdots,n\right\} \tag{3}$$

(3) According to Formula 3, the extreme value solution is solved by the method of maximum value and minimum value, which can be transformed into a nonlinear optimization model (see Formula 4):

$$s.t.\begin{cases}\max\gamma\\ (m_{ij}-l_{ij})\gamma w_j-w_i+l_{ij}w_j\le 0\\ (u_{ij}-m_{ij})\gamma w_j+w_i-u_{ij}w_j\le 0\\ \sum_{k=1}^{n}w_i=1, w_i>0\end{cases} \tag{4}$$

Using MATLAB to solve the inequality group, get the optimal vector (w^*,γ^*), w^* is the subjective weight of the metro construction workers' safety capability indicators w_i.

Entropy weight method to calculate objective weight: In this paper, the triangular fuzzy number is used to represent the relative importance between the indicators. Therefore, the fuzzy interval algorithm is used to transform the triangular fuzzy matrix, and the judgment matrix

suitable for the entropy weight principle is obtained. Then the weight is calculated by the entropy weight method.

Select confidence level for triangular fuzzy matrix $\alpha = 0.5$ to replace and take the optimistic index coefficient $\beta = 0.5$ to represent judgment satisfaction, the triangle fuzzy judgment matrix is transformed into the following Formula 5 (Cai et al. 2010):

$$C = \begin{bmatrix} c_{11}^{\ \alpha} & c_{12}^{\ \alpha} & \cdots & c_{1n}^{\ \alpha} \\ c_{21}^{\ \alpha} & c_{22}^{\ \alpha} & \cdots & c_{2n}^{\ \alpha} \\ \cdots & \cdots & \cdots & \cdots \\ c_{n1}^{\ \alpha} & c_{n2}^{\ \alpha} & \cdots & c_{nn}^{\ \alpha} \end{bmatrix} \tag{5}$$

Among them:

$$\begin{aligned} c_{ij}^{\ u} &= u - (u - m)\alpha \\ c_{ij}^{\ l} &= (m - l)\alpha + l \\ c_{ij}^{\ \alpha} &= \beta \times c_{ij}^{\ u} + (1 - \beta) \times c_{ij}^{\ l} \end{aligned} \tag{6}$$

Using the entropy weight calculation formula to obtain objective weight q_i.

Calculate the comprehensive weight: Combine w_i and q_i through weighted average, and use Formula 7 to obtain the combined weight of the construction workers' safety capability index W_i.

$$W_i = \frac{w_i q_i}{\sum_{k=1}^{n} w_i q_i} \tag{7}$$

CONSTRUCTION OF EVALUATION METHOD FOR SAFETY CAPABILITY OF METRO CONSTRUCTION WORKERS

Principle of SPA: SPA method is a systematic analysis method for dealing with uncertain problems (Feng et al. 2019). The core idea is to treat the research object as a system that is both sure and uncertain to process. The basic idea of SPA as follows: in the specific background, there are set *A* and set *B* forming pair *H (A, B)*. Analyzing the characteristics of *H*, *H* has *K* Elements, among them, *S* for collection part, *P* for the opposite part, *F* = *K* – *S* – *P* for neither common nor opposite part. Therefore, the degree of contact of pair *H (A, B)*. can be expressed as (see Formula 8):

$$\mu = \frac{S}{K} + \frac{F}{K} i + \frac{P}{K} j = a + bi + cj \tag{8}$$

In the formula, $\frac{S}{K}$ is expressed as the same degree, recorded as *a*; $\frac{F}{K}$ is expressed as degree of difference, recorded as *b*; $\frac{P}{K}$ is expressed as degree of opposite, recorded as *c*; among them $a + b + c = 1$; i for the coefficient of difference, $i \in [-1, 1]$; j for the coefficient of opposite, generally takes *-1*.

SPA method of metro construction workers' safety capability: (1) Calculate degree of single indicator connection. The connected evaluation index set *A* of metro construction workers' safety capability and the evaluation standard set *B* of safety capability are composed of pair *H (A, B)*, and degree of similarity, difference and inverse association of pair *H (A, B)* is calculated.

There are many uncertainties in the evaluation of metro construction workers' safety capability, and the number of multiple connections has a great advantage in dealing with complex uncertainties. Therefore, according to the set evaluation criteria, the standard ternary contact number is converted into a five-way contact number, and the five-element relationship expression is obtained as (see Formula 9):

$$\mu = \frac{S}{K} + \frac{F_1}{K} i_1 + \frac{F_2}{K} i_2 + \frac{F_3}{K} i_3 + \frac{P}{K} j = a + b_1 i_1 + b_2 i_2 + b_3 i_3 + cj \tag{9}$$

According to the established index system, the safety ability index of metro construction workers is the larger the better, so the connection degree with the standard evaluation is (see Formula 10):

$$\mu = \begin{cases} 0 + 0i_1 + 0i_2 + 0i_3 + 1j & x < x_1 \\ 0 + 0i_1 + 0i_2 + \dfrac{x - x_1}{x_2 - x_1} i_3 + \dfrac{x_2 - x}{x_2 - x_1} j & x_1 \le x < x_2 \\ 0 + 0i_1 + \dfrac{x - x_2}{x_3 - x_2} i_2 + \dfrac{x_3 - x}{x_3 - x_2} i_3 + 0j & x_2 \le x < x_3 \\ 0 + \dfrac{x - x_3}{x_4 - x_3} i_1 + \dfrac{x_4 - x}{x_4 - x_3} i_2 + 0i_3 + 0j & x_3 \le x < x_4 \\ \dfrac{x - x_4}{x_5 - x_4} + \dfrac{x_5 - x}{x_5 - x_4} i_1 + 0i_2 + 0i_3 + 0j & x_4 \le x < x_5 \\ 1 + 0i_1 + 0i_2 + 0i_3 + 0j & x \ge x_5 \end{cases} \tag{10}$$

In the formula, x is the measured value of the evaluation index, x_1-x_5 demarcation value for is the cutoff value of the indicator evaluation criteria. (2) Calculate the comprehensive connection degree. Introducing the same-inverse matrix vector, multiplying the weight vector of the evaluation index, the correlation component and the same-inverse coefficient matrix to obtain the pair *H (A, B)* Comprehensive connection μ_{AB} (see Formula 11):

$$\mu_{AB} = W \mu E \tag{11}$$

In the formula, W for evaluation index weight vector, u for single indicator contact; $E = (1, \ i_1, \ i_2, \ i_3, \ j)$ for the same-inverse coefficient matrix. The safety capability level of metro construction workers is calculated by taking the principle of equalization for i to take out μ. According to the principle of proportional value, the security capability level $\mu \in [-1,1]$ is divided into 5 equal parts, the safety capability level of the subway metro construction workers corresponding to the degree of contact is shown in Table 3.

Table 3. Classification of Safety Capacity of Metro Construction Workers.

Grade	I	II	III	IV	V
Level description	excellent	good	general	bad	worse
Contact interval	(0.6,1]	(0.2,0.6]	(-0.2,0.2]	(-0.6 ,-0.2]	[-1 ,-0.6]

CASE ANALYSIS

Taking the metro construction workers of Chengdu Metro Line 11 as an example, five subway construction workers are randomly selected and the safety capability is evaluated using the model built above.

Calculate indicator weights: Using the method described in Section 2 to calculate the weight of the index. Inviting experts in the field to score the importance of the evaluation index to construct the judgment matrix. The subjective weights of all secondary factors and three-level factors can be obtained. Please see Table 4.

Table 4. Evaluation Index Weight.

Primary indicator	Secondary indicators	Weight	Three-level indicator	Weight
Safety capability index for metro construction workers C	Physical fitness C_1	0.348	Physiological condition C_{11}	0.151
			Anti-fatigue degree C_{12}	0.054
			Emotional control C_{13}	0.143
	State of consciousness C_2	0.169	Safety awareness C_{21}	0.073
			Responsibility awareness C_{22}	0.067
			Learning consciousness C_{23}	0.016
			Active awareness C_{24}	0.013
	Work skill C_3	0.315	Safety protection skills C_{31}	0.055
			Proficiency of metro construction C_{32}	0.045
			Experience of metro safety construction C_{33}	0.118
			Training status C_{34}	0.097
	Behavioral ability C_4	0.168	Strain capacity C_{41}	0.083
			Self-control ability C_{42}	0.053
			Communication ability C_{43}	0.012
			Acceptability C_{44}	0.020

SPA analysis: Relevant experts score the safety performance indicators of selected 5 subway construction personnel, and then calculate the comprehensive contact degree according to the formula (6) ~ (9) of the SPA method to determine the safety capability level of the construction personnel ($i_1 = 0.5, i_2 = 0.01, i_3 = -0.5, j = -1$). The results are shown in Table 5.

Table 5. Subway is the Safety Level of Construction Workers.

Selected person	a	b_1	b_2	b_3	c	μ	Level
A	0.009	0.111	0.117	0.039	0.001	0.045	general
B	0.011	0.110	0.103	0.054	0	0.040	general
C	0.009	0.169	0.090	0.010	0	0.089	general
D	0.006	0.148	0.110	0.015	0	0.074	general
E	0	0.060	0.064	0.110	0.043	- 0.024	bad

Analysis of calculation results: (1) From the calculation of index weights, physical weight and work skills have a greater weight, which have a greater impact on the safety capacity of

metro construction workers. It is recommended to take corresponding measures to improve the safety capacity of metro construction workers to reduce the occurrence of metro construction safety accidents. (2) From the connection degree of safety capacity of metro construction workers, it can be known that if only the same degree is considered for each contact degree function, the safety ability of the evaluated metro construction workers is ranked from strong to weak as $C>D>A>B>E$. The evaluation results of *A*, *B*, *C*, and *D* are general, and the result of *E* evaluation is poor. In fact, the selected construction workers *A*, *B*, *C*, and *D* are workers who have been in the metro construction for more than two years, and *E* was originally engaged in railway construction lack of metro construction experience. It can be seen that the evaluation results are consistent with the actual construction workers safety ability, indicating the feasibility of the method. Secondly, although *C* has the largest comprehensive connection, the same degree is smaller than *A*, *B* and *D*. It is more difficult to improve. *A*, *B*, and *D* can start from the indicators corresponding to the positive difference, and make targeted improvements, which can quickly improve the security capabilities, and *D* has the largest room for improvement.

CONCLUSION

The evaluation index system of metro construction workers' safety capability was established, and the safety evaluation model of subway construction personnel based on SPA method was constructed. Case analysis was carried out to prove that the model is feasible.

The triangular fuzzy language to quantify the qualitative index was introduced. The subjective and objective weights were calculated by using the fuzzy priority programming theory combined with the entropy weight method. The importance of the first-level indicators can be ranked as Physical fitness, work skill, state of consciousness, behavioral ability because physical fitness is 0.348, work skill is 0.315, and state of consciousness is 0.169.

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