A Space-Time Accessibility Identification Approach of Railway Emergency Rescue Networks Based on Multi-Resource Allocation

Jing Zuo*, Runqi Wang, Mengxing Shang

Abstract—**The time efficiency and spatial accessibility of emergency resources during transportation are critical factors in evaluating the utility and emergency capacity of the railway emergency rescue network, distinguishing it from other transportation networks. Analyzing the spatiotemporal accessibility of the railway emergency rescue network provides insights into the spatial and temporal dynamics of emergency transport, which are essential for optimizing the structure and configuration of the emergency rescue transport network. This paper employs the classical travel time budget model to assess the spatiotemporal accessibility of resource allocation within the emergency rescue network under varying demand scenarios. Furthermore, the improved DEMATEL (Decision-Making Trial and Evaluation Laboratory) method is utilized to evaluate the existing capability of resource allocation points in identifying spatiotemporal accessibility, effectively addressing the inherent uncertainty in resource allocation states. As a result, the spatiotemporal accessibility capability identified using the classical travel time budget model proves to be more reasonable and accurate. Finally, the feasibility and validity of the model are confirmed through a comparative analysis using actual data from the Xi'an Railway Bureau.**

Index Terms—**Railway emergency rescue network; Maintenance allocation; Space-time accessibility; Lagrangian algorithm**

I. Introduction

The operational efficiency of the railway transportation network is influenced by factors such as construction timelines, design capacity, and operating conditions, resulting in variable performance. This characteristic is similarly reflected in the railway emergency rescue network, which relies on the same infrastructure as conventional transport. Additionally, railway emergency resources, equipment allocation, and rescue operations are managed regionally[1][2], introducing notable differences from conventional transport and complicating accurate estimation of emergency resource allocation times and processes. Assessing the spatiotemporal accessibility of resource allocation points within the railway emergency rescue network is essential for determining how effectively rescue resources can reach demand points within their jurisdiction. This understanding is key to optimizing regional rescue operations, identifying weaknesses in the emergency network, and enhancing the overall response capacity of the railway network[3][4][5].

Currently, the railway emergency rescue network lacks comprehensive descriptions of spatiotemporal accessibility. Most studies have focused on the placement of rescue bases[6][7], decision-making processes[8][9], and related issues, often neglecting the analysis of spatiotemporal rescue efficiency across all points in the network's fixed topology. In other transportation domains, research on spatiotemporal accessibility has emphasized aspects like time equilibrium and travel equity. For example, GUI[10] uses spatial syntax methods to describe transportation network accessibility through topological relationships, while MA et al.[11] examine changes in railway network accessibility with the introduction of high-speed rail and other travel modes.

Moreover, under consistent time conditions, the capacity for resource allocation at rescue points significantly impacts the spatiotemporal accessibility of rescue operations. Previous studies on the accessibility of service facilities' resource allocation have generally adopted two approaches: (i) equivalence assumptions and (ii) weighted sums of equipment. Equivalence assumptions often overlook variations in configuration attributes, which can distort the true accessibility of each facility[12]. The weighted sum approach, while considering the number of configurations, frequently neglects differences in equipment efficiency and the variability of expected outcomes[13]. Given that railway rescue operations are influenced by factors such as the quantity of equipment and the skill levels of shifts at resource points[14][15][16][17], evaluating resource capacity becomes complex. This complexity hinders the isolation of independent factors, leading to ambiguities in capacity assessments[18].

To tackle these challenges, this study enhances the DEMATEL group decision-making model by integrating an expert trust-similarity relationship, improving the precision and reliability of resource allocation capacity assessments at each node within the railway emergency rescue network. Unlike conventional DEMATEL models, which often treat expert opinions uniformly, the refined approach considers varying levels of expertise and trust among experts, resulting in more nuanced and credible evaluations. The optimized results from this enhanced model are further employed to refine the spatiotemporal accessibility model by incorporating time-varying factors such as travel delays and dynamic network conditions. In contrast to static accessibility models, this dynamic framework offers a more

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precise, comprehensive, and practical evaluation of spatiotemporal accessibility within the railway emergency rescue network. The integrated approach provides a robust foundation for decision-makers, enhancing operational efficiency and supporting strategic planning for the allocation of emergency resources.

II. Methods

A. Railway Emergency Rescue Network Definition

When railway emergencies occur, the operating organization implements measures such as blocking lines, halting trains, or altering routes to suspend regular operations in the affected area, depending on factors like location and impact size. The railway emergency rescue operation then leverages the blocked lines to transport and allocate rescue resources from the resource allocation point to the emergency site, referred to as the rescue demand point[19]. Given that the locations of resource allocation points differ from ordinary stations, and each point has a designated jurisdictional service area, the railway emergency rescue network[20] constitutes a distinct transportation network. In this network, emergency rescue resource allocation points serve as nodes, as illustrated in Fig. 1.

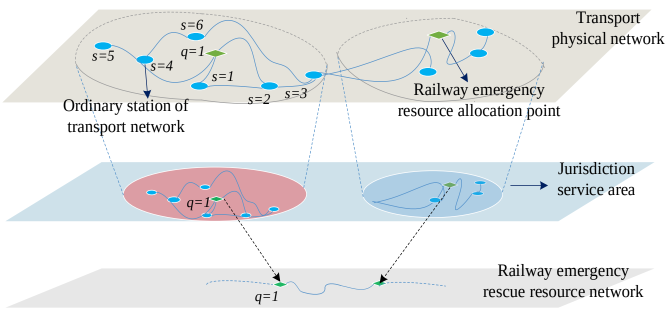


Fig. 1. Schematic diagram of railway emergency rescue network

Where $Q = \{q|1, 2, \cdots, v\}$ represents the set of resource allocation points, and v represent the number of nodes q ,all of which are equipped with professional rescue teams, rescue trains on standby and emergency supplies storage. At the same time, the general stations in each region o_χ are defined as rescue demand points s, where, and N indicate the number of demand points in the region o_χ.

B. Space-time Accessibility

China's railway emergency rescue strategy involves establishing various resource allocation points and assigning specific rescue tasks to each region[21].This management strategy defines the space-time accessibility A_q of each railway resource allocation point q as the ease with which emergency rescue equipment can reach all demand points s within its jurisdiction. This is achieved by adhering to the principle of comprehensive coverage of rescue intervals, as illustrated in Fig. 2.

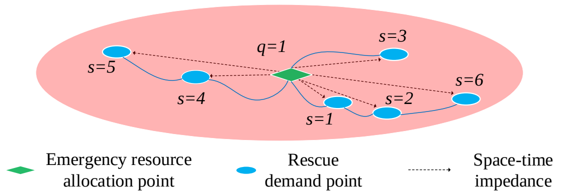


Fig. 2. Accessibility description diagram of emergency resource allocation points

The spatio-temporal system introduces a time coordinate into geospatial space. The horizontal coordinates represent the geospatial railroad transportation network, while the vertical axis represents the travel time $b_{q,s}$, which is the travel time from the resource allocation point q to each rescue demand point s. To calculate $b_{q,s}$, track each rescue demand point's location within the physical network. Determine the travel time $b_{q,s}$ from the resource allocation point to each rescue demand point, then track the position of each rescue demand point at the respective travel times. Connect these positions to form a series of spatio-temporal arc segments, indicated by solid arrows, as shown in Fig. 3.

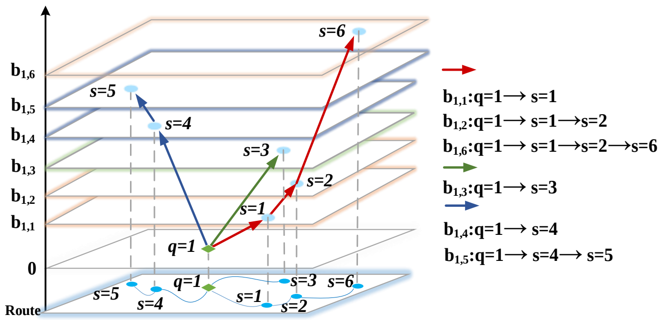


Fig. 3. Spatio-temporal path diagram of emergency resource allocation points

For example, consider the resource allocation point $q = 1$ and the rescue demand point $s = 5$. Starting from the resource allocation point $q = 1$, the route passes through the rescue demand point $s = 4$ before arriving at the rescue demand point $s = 5$, with a total elapsed time of $b_{1,5}$. This process is represented by two spatio-temporal arc segments, depicted by red solid arrows.

Building on this foundation, this paper develops an algorithm to assess the accessibility of multiple demand coverage points using the gravity model. Spatiotemporal accessibility is defined as the average product of an emergency resource allocation capability attribute and the spatiotemporal impedance value for all fully covered demand points from that resource allocation point:

$$A_q = \frac{1}{N} \sum_{s=1}^{N} \xi_q^{(o)} \cdot b_{q,s}^{-\beta} \tag{1}$$

Where N is the number of rescue demand points in the region o; $\xi_q^{(o)}$ is the resourcing capacity of the emergency resourcing point q in the region o; β is the traffic friction factor; $b_{q,s}$ is the travel time value from the resourcing point q to the rescue demand point s.

Resource allocation capacity and time cost are key factors in assessing spatiotemporal accessibility. By analyzing and quantifying these factors using actual data, we can develop an optimization model for evaluating spatiotemporal accessibility, as illustrated in the optimization framework in Figure 4.

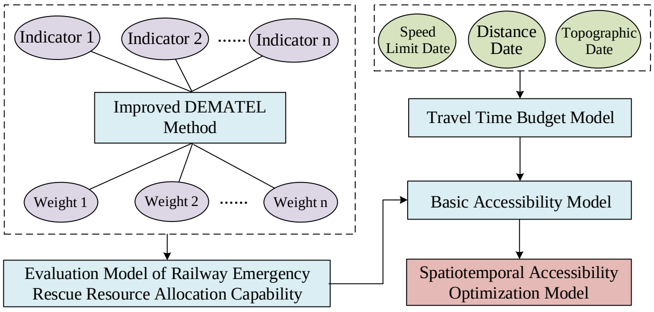


Fig. 4. Optimization framework for spatiotemporal accessibility model of railway emergency rescue network

The analysis of the model reveals that spatial and temporal accessibility is influenced not only by distance decay but also by the capacity of resource allocation points. Specifically, an increase in the resource allocation capacity of emergency response points, coupled with a reduction in the time cost to reach rescue demand locations within the jurisdiction, results in a higher level of spatiotemporal accessibility.

III. Resource allocation capacity assessment

The effectiveness of railway emergency rescue resource allocation points is influenced by various factors, including personnel, settings, environment, and management. These factors encompass underlying elements such as the skill levels of rescue personnel and the frequency of their physical training, which are interrelated and mutually affect one another. Based on the fuzzy description from the improved DEMATEL configuration capability estimation, the spatiotemporal accessibility of railway emergency rescue resource allocation points is analyzed.

Step 1 The set of factors influencing railway emergency resourcing capacity was extracted from a combination of four aspects of people, equipment, environment and management, denoted as $X_i = \{x_1, x_2, \cdots, x_n\}$ $n = 14$. Based on these factors, the following assessment system was constructed, as shown in Table I.

Step 2 The group of experts $E = \{e_k \mid k = 1, 2, \cdots, m\}$ is invited to make judgments about the influence relations x_i on x_j $(i, j = 1, 2, \cdots, n; i \neq j)$. Then convert the experts' linguistic scale evaluation $a_{ij}^{(k)}$ into an interval trapezoidal pythagorean fuzzy number (ITPFN) to account for hesitation uncertainty expression as shown in Table II. Using this, the initial direct influence relation matrix $\tilde{A}^{(k)} = \left[a_{ij}^{(k)}\right]_{n\times n}$ is constructed.

TABLE I
Evaluation Indicators of Railway Emergency Rescue Resource Allocation Point

	Evaluation indicators
Personnel factors	Occupational Skill Levels x_1
	Frequency of physical training x_2
	Number of young people in the squad x_3
	Response dispatch efficiency x_4
Equipment factors	Frequency of mechanical testing x_5
	Number of new equipment x_6
	Number of relief trains x_7
	Number of material categories x_8
Environmental factors	Number of operational stations x_9
	Exercise area x_{10}
	Training ground realism x_{11}
Management factors	Size of regulators x_{12}
	Frequency of safety inspections x_{13}
	Frequency of practical exercises x_{14}

TABLE II
Seven-Level Language Table of Interval Trapezoidal Pythagorean Fuzzy Number

Expert language scales	Interval Trapezoidal Pythagorean Fuzzy Number (ITPFN)
VL (very low)	$\langle[0,0,0,0];[0.00,0.20];[0.85,0.95]\rangle$
L (fairly low)	$\langle[0,0.1,0.2,0.3];[0.20,0.30];[0.70,0.80]\rangle$
AL (a little low)	$\langle[0.1,0.2,0.3,0.4];[0.3,0.45];[0.55,0.70]\rangle$
M (medium)	$\langle[0.3,0.4,0.5,0.6];[0.45,0.55];[0.40,0.55]\rangle$
AH (a little high)	$\langle[0.5,0.6,0.7,0.8];[0.55,0.70];[0.25,0.40]\rangle$
H (fairly high)	$\langle[0.7,0.8,0.9,1,];[0.70,0.80];[0.15,0.25]\rangle$

Step 3 The experts in the rail emergency industry are well-acquainted with each other during the actual group decision-making process, and the experts are invited to evaluate the trust level $(t_{h,k}, b_{h,k})$ between e_k and e_h $(k, h = 1, 2, \cdots, m; k \neq h)$. The existing trust score $TD_{h,k}$ and preference similarity $SD_{h,k}$ are calculated between the experts, and a mixed trust-similarity score $TS_{h,k}$ is then constructed as the basis for determining the dynamic weighting of the experts in the group decision:

$$TS_{h,k} = \lambda SD_{h,k} + (1-\lambda) TD_{h,k} \tag{2}$$

$$\omega_k = \frac{\sum_{h=1,h\neq k}^{m} TS_{h,k}}{\sum_{k=1}^{m}\sum_{h=1,h\neq k}^{m} TS_{h,k}} \tag{3}$$

Where $TD_{h,k} = (t_{h,k} - b_{h,k} + 1)/2$, $t_{h,k}$ and $b_{h,k}$ are the trust and distrust of expert e_h in e_k, $t_{h,k}, b_{h,k} \in [0,1]$; $SD_{h,k} = 1 - d_{\tilde{A}^{(h)},\tilde{A}^{(k)}}$, $d_{\tilde{A}^{(h)},\tilde{A}^{(k)}}$ are the matrix rating distances of experts e_h and e_k; $\lambda \in [0,1]$ is the weighting factor, which characterizes the relative confidence of experts in the assessed values.

Step 4 Combined with the above expert weights ω_k, the initial matrix of direct influence relationships for each expert $\tilde{A}^{(k)}$ is assembled to form a group preference matrix $\tilde{B}=\left[\tilde{b}_{ij}\right]_{n\times n}$. A consensus threshold η is predefined. If the group consensus index $GCI \geq \eta$, proceed to step 5, otherwise, perform the following dynamic feedback and return to step 3:

$$TD_{h,k}^{(t+1)}=\begin{cases}\left(1-\left(\dfrac{GCI-ICI_k}{GCI}\right)\left(1-d_{\tilde{A}^{(h)},\tilde{A}^{(k)}}\right)^{\delta}\right)TD_{h,k}^{(t)} & GCI<\eta \\ TD_{h,k}^{(t)} & GCI\geq\eta\end{cases} \quad (4)$$

Where $ICI_k=1-d_{\tilde{A}^{(k)},\tilde{B}}$ is the individual consensus index of the expert e_k; $GCI=\sum_{k=1}^{m}\omega_k ICI_k$ is the group consensus index, $GCI\in[0,1]$; δ is the adjustment parameter, satisfying $0\leq\delta\leq 1$; when $GCI>ICI_k$, $TD_{h,k}^{(t+1)}<TD_{h,k}^{(t)}$, the larger δ is, the greater the proportion of preserving the initial trust value, and vice versa when $GCI<ICI_k$.

Step 5 Use the score function of IVPTFN fuzzy number to defuzzify $\tilde{B}=\left[\tilde{b}_{ij}\right]_{n\times n}$ in Step 4 to construct the matrix $C=\left[c_{ij}\right]_{n\times n}$, and normalize it to $X=\dfrac{\left[c_{ij}\right]_{n\times n}}{\max_{1\leq i\leq n}\sum_{j=1}^{n}c_{ij}}$. Therefore, the total relation matrix $T=X\left(I-X\right)^{-1}=\left[t_{ij}\right]_{n\times n}$ is constructed, where I is the identity matrix.

Step 6 Solve the influence degree $R_i=\sum_{j=1}^{n}t_{ij}$, influenced degree $D_i=\sum_{i=1}^{n}t_{ij}$, centrality $M_i=R_i+D_i$ and causality $Q_i=R_i-D_i$ of the influencing factors, thus determining the index weight w_i for each influencing factor:

$$w_i=\frac{\sqrt{M_i^2+Q_i^2}}{\sum_{i=1}^{n}\sqrt{M_i^2+Q_i^2}} \quad (5)$$

Where $w_i\in[0,1]$, $\sum_{i=1}^{n}w_i=1$, and the weight vector is denoted as $w_i=\left[w_1,w_2,\cdots w_n\right]$.

Step 7 Set F_{qi} as the original dataset for the resource allocation point q of each influencing factor x_i, and calculate the resource allocation capacity based on the weighted score strategy:

$$\xi_q^{(o)}=\sum_{i=1}^{n}\left(w_i\cdot F_{qi}\right) \quad (6)$$

Where $\xi_q^{(o)}$ is the evaluation value of the resource allocation capacity at the resource allocation point in the rescue area. A higher value indicates better resource allocation capacity at the point.

IV. Assessment method

In the process of railway emergency rescue, the spatiotemporal scope of the rescue resource allocation area is limited. However, the preparation of rescue resources, the selection of rescue personnel, and the development of rescue programs are subject to temporal uncertainty. Determining the spatiotemporal accessibility of resource allocation nodes not only requires considering the fixed network structure but also accounting for the travel time of railway transportation under various factors. The greater spatiotemporal accessibility of railway nodes, the more convenient it is for emergency resources to reach rescue demand points within their jurisdiction, leading to higher transportation efficiency. Therefore, the gravity model is employed to refine the travel time budget model and develop an algorithm for identifying accessibility to multiple demand coverage points. By integrating the travel time budget model with the gravity model, and using the evaluation and measurement results of the multi-attribute resource allocation capacity at each resource allocation point, spatiotemporal accessibility is further assessed by applying Equation 1 and Equation 6:

$$A_q=\frac{1}{N}\sum_{s=1}^{N}\left(\xi_q^{(o)}\cdot b_{q,s}^{-\beta}\right)=\frac{1}{N}\sum_{s=1}^{N}\left(\left(\sum_{i=1}^{n}\left(w_i\cdot F_{qi}\right)\right)\cdot b_{q,s}^{-\beta}\right) \quad (7)$$

Where β is the coefficient of friction, 1 is chosen because the railway emergency rescue process is managed by blocking the line for rescue trains only; $b_{q,s}$ is the budgeted travel time from the resource allocation point q to the rescue demand point s, which is negatively correlated with the space-time accessibility of the point q.

The travel time $b_{q,s}$ from the resource allocation point q to the rescue demand point s is subject to random variation due to factors such as rescue trains, regional route speed limits and the readiness of rescue resources during the rescue process, $b_{q,s}$ is described below:

$$b_{q,s}=E(T_{q,s})+\gamma\cdot\theta_{T_{q,s}} \quad (8)$$

Where $E(T_{q,s})$ is the desired travel time from the resourcing point q to the rescue demand point s, determined by the line speed limit, rescue train speed limit and distance; $\theta_{T_{q,s}}$ is the standard time difference, determined by the actual travel time and the standard deviation of $E(T_{q,s})$; γ is the parameter to reach the demand point s on time from the rescue point q within the time frame of $b_{q,s}$.

Additionally, $T_{q,s}$ can be assumed to follow the normal distribution, according to the definition of normal distribution cumulative distribution function, there are:

$$P\left\{T_{q,s}\leq b_{q,s}\right\}=\Phi\left(\frac{b_{q,s}-\mu}{\sigma}\right)=\Phi\left(\frac{b_{q,s}-E\left(T_{q,s}\right)}{\theta_{T_{q,s}}}\right) \quad (9)$$

Where, $\Phi(\bullet)$ represents the cumulative distribution function of the normal distribution. Let the probability of arriving on time at the rescue demand point be α , combined with $P\left\{T_{q,s} \le b_{q,s}\right\} = \alpha$, then

$$\Phi\left(\frac{E(T_{q,s}) + \gamma \cdot \theta_{T_{q,s}} - E(T_{q,s})}{\theta_{T_{q,s}}}\right) = \alpha \quad (10)$$

$$\therefore \Phi^{-1}(\alpha) = \gamma \quad (11)$$

Where, $\alpha \in [0,1]$ represents the travel time reliability. From this, $b_{q,s}$ can be shown as in equation 12:

$$b_{q,s} = E(T_{q,s}) + \Phi^{-1}(\alpha) \cdot \theta_{T_{q,s}} \quad (12)$$

Combining equation 7 and equation 12, the improved space-time accessibility can be obtained:

$$A_q = \frac{1}{N} \sum_{q=1}^{N} \left(\left(\sum_{i=1}^{n} (w_i \cdot F_{qi}) \right) \cdot \left(E(T_{q,s}) + \Phi^{-1}(\alpha) \cdot \theta_{T_{q,s}} \right)^{-\beta} \right) \quad (13)$$

Where A_q is an optimized model for evaluating the space-time accessibility of the resource allocation point q .

V. Example Analysis and Results

A. Dataset Description

Using actual resource allocation network data from China Railway Xi'an Bureau Group Co., Ltd. as the research subject, the proposed method was validated. The railway bureau oversees 363 passenger and freight stations. To safeguard passengers and cargo owners, emergency resource allocation points have been established at various locations within the bureau, as illustrated in Fig. 5. Among these, Lintong, Yan'an, Lueyang, Yanliang, Jingbian, Baoji, Hanzhong, Wanyuan, and Ankang are equipped with specialized emergency resources such as relief trains and rail cranes, each managing different areas. Additionally, to ensure the accuracy of subsequent calculations regarding rescue times and spatial accessibility, the remaining ordinary sites across the network are designated as rescue demand points, thereby maintaining the completeness and fairness of rescue coverage throughout the network.

The data on emergency rescue operations for this rail authority was compiled to illustrate the regional jurisdiction of each resource allocation point, including details of the resource allocation points and their respective rescue areas, as shown in Table III.

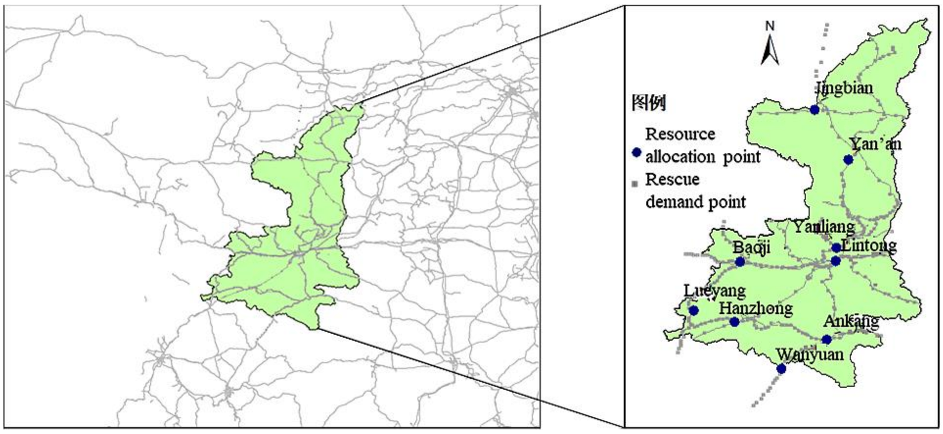


Fig. 5. Study area

TABLE III
Rescue Jurisdictions for Resource Allocation Point

Rescue resource allocation points	Rescue jurisdictions	Speed limit (Km/h)
Lintong	Longhai Line west to Wugong and east to Tongguan; South Tongpu Line from Huashan to the port; West Household Line south to Yuxia; etc.	120
Ankang	East to Hujiaying, south to Ziyang, west to Shiquan, north to Yingzhen	120
Yan'an	Ganzhong Line south to Shengzhi Canal; Baoxi Line south to Huangling South and north to Zhongji; etc.	120
Yanliang	Ham-Tong line south to Xianyang North, north to Qianhe Town, Tongchuan; etc.	85
Jingbian	Taichung Line from Wubao to Dingbian	120
Baoji	East to Wukong, north to Ankou Kiln, west to Shetang, south to Baishui River	120
Lueyang	North to Baishuijiang, south to Guangyuan	120
Hanzhong	Yangan Line north to Shiquan, west to Yangpingguan; etc.	120
Wanyuan	North to Ziyang, south to Shuanglong	120

Based on the data above and the actual layout of the railway lines, each rescue area was defined and visualized. Different colors indicate different jurisdictions, as shown in Fig. 6.

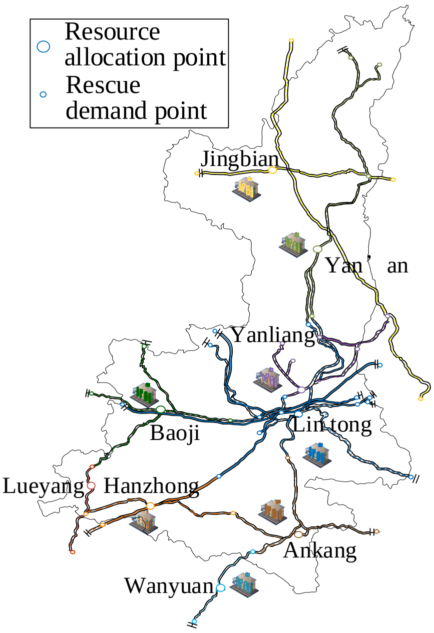


Fig. 6. Physical layout of the railway emergency rescue network in Xi'an

B. *Evaluation Index*

Eight experts from the railway industry were invited to assess the resource allocation capacity for the railway emergency resource points, and a consensus threshold of $\eta = 0.85$ was established. Given their extensive knowledge of the industry, the experts initially needed to evaluate the trust levels of their peers, and the initial trust network diagram among the experts is shown in Fig. 7.

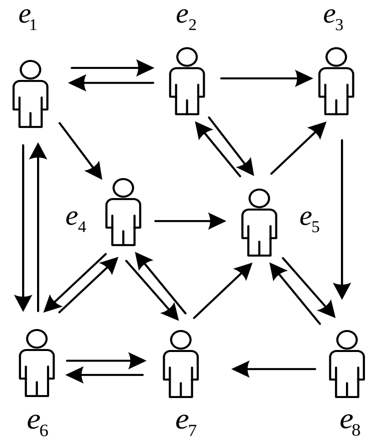


Fig. 7. Initial trust network of experts

Where, $e_1 \to e_2$ represents the existence of trust relationship between expert 1 and expert 2, the corresponding value is $(t_{1,2}, b_{1,2})$. To address the incompleteness of the initial trust network, the indirect trust values between experts are taken as the mean value of the shortest propagation path, and the complete expert trust network $T = (t_{h,k}, d_{h,k})_{8\times 8}$ is constructed using trust transferability:

$$T = \begin{array}{c} \\ e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \\ e_8 \end{array} \begin{array}{cccccccc} e_1 & e_2 & e_3 & e_4 & e_5 & e_6 & e_7 & e_8 \\ \end{array}$$

$$T = \begin{bmatrix} (1,0) & (0.8,0.1) & (0.36,0.29) & (0.5,0.4) & (0.26,0.38) & (0.4,0.3) & (0.30,0.47) & (0.16,0.51) \\ (0.8,0.1) & (1,0) & (0.5,0.2) & (0.36,0.48) & (0.3,0.1) & (0.29,0.39) & (0.15,0.56) & (0.17,0.29) \\ (0.5,0.2) & (0.36,0.29) & (1,0) & (0.20,0.56) & (0.25,0.47) & (0.12,0.73) & (0.31,0.47) & (0.6,0.2) \\ (0.08,0.39) & (0.53,0.29) & (0.538,0.29) & (1,0) & (0.7,0.2) & (0.3,0.3) & (0.7,0.2) & (0.45,0.38) \\ (0.62,0.20) & (0.8,0.1) & (0.6,0.1) & (0.20,0.64) & (1,0) & (0.17,0.6) & (0.38,0.47) & (0.7,0.2) \\ (0.4,0.1) & (0.29,0.2) & (0.12,0.41) & (0.4,0.3) & (0.26,0.33) & (1,0) & (0.8,0.1) & (0.15,0.50) \\ (0.15,0.48) & (0.29,0.2) & (0.19,0.2) & (0.5,0.4) & (0.4,0.1) & (0.5,0.4) & (1,0) & (0.24,0.29) \\ (0.16,0.58) & (0.36,0.29) & (0.25,0.39) & (0.25,0.63) & (0.5,0.3) & (0.25,0.63) & (0.6,0.3) & (1,0) \end{bmatrix}$$

Request all experts to score the interactions between evaluation indicators, and convert their linguistic scale evaluations into corresponding fuzzy numbers as outlined in Table II. Table IV shows the index evaluation table for Expert 1.

TABLE IV
EVALUATION INDICATOR TABLE OF EXPERT 1

Indicator	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	-	M	AH	L	AH	H	H	AL	M	L	AH	H	AL	M
2	M	-	AH	L	AL	M	AL	AL	VL	M	M	H	AL	VL
3	VL	AL	-	AL	M	AL	AL	M	L	AH	VL	L	M	L
4	VH	H	VH	-	AH	AH	H	AH	H	AH	H	H	AH	H
5	M	AH	H	AL	-	M	AL	L	AL	M	VH	AH	L	AL
6	M	H	H	AL	M	-	M	AH	L	AL	H	AH	AH	L
7	AL	M	AH	L	AL	M	-	L	AH	L	M	M	L	AH
8	AL	AH	H	L	AL	H	H	-	M	AL	L	AL	H	H
9	M	VH	H	M	H	H	AH	AH	-	M	AH	L	H	AH
10	H	AL	M	L	H	AH	H	AH	M	-	M	H	AL	AL
11	AL	AH	H	M	AL	AL	M	AL	L	AL	-	AH	M	M
12	VL	M	AH	AL	M	M	AL	M	AL	VL	L	-	H	H
13	AL	M	AH	L	AH	H	H	AL	M	L	AH	H	-	L
14	AH	H	L	AL	H	H	H	M	AL	L	AL	L	AL	-

The initial expert weights of 0.132, 0.142, 0.130, 0.109, 0.133, 0.108, 0.125 and 0.120 were determined by equation 2 to equation 3, at which time the group consensus index $GCI = 0.823$, which did not reach the consensus threshold of 0.85, entered the iteration. The iterative process of the individual consensus index ICI_k and the group consensus index GCI is shown in Fig. 8.

Where the consensus threshold was reached $\eta = 0.85$ after 23 iterations, the final expert weights were determined to be 0.211, 0.132, 0.132, 0.057, 0.262, 0.107, 0.050 and 0.048. The final expert weights were known and the evaluation index weights were determined using equation 4-5, as shown in Table V.

Therefore, by using Equation 6, the resource allocation capacity of each resource allocation point in this bureau is evaluated, as shown in Table VI.

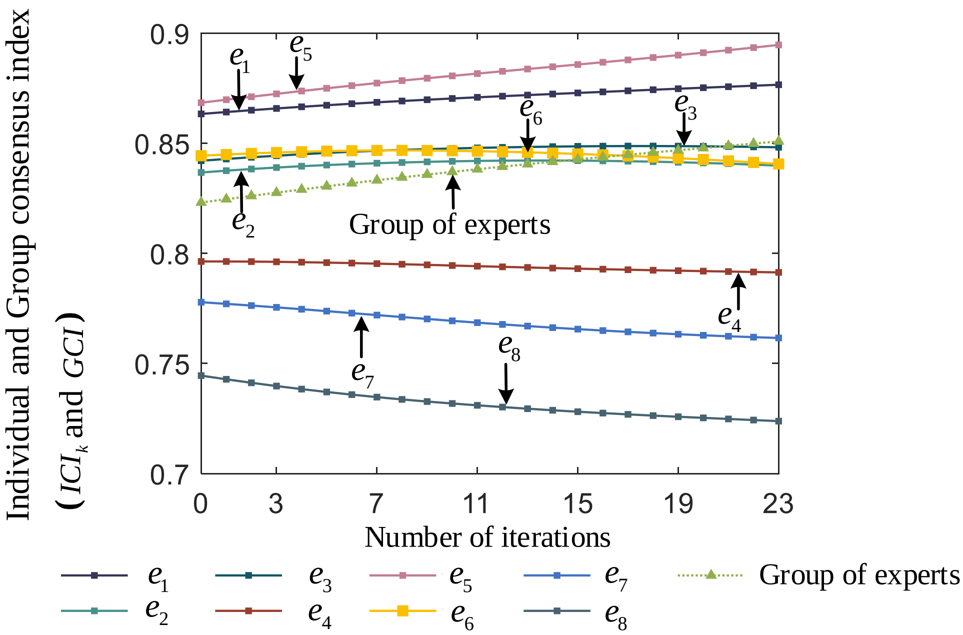


Fig. 8. Expert trust network

TABLE V
EVALUATION INDICATOR WEIGHT OF RAILWAY RESOURCE ALLOCATION ABILITY

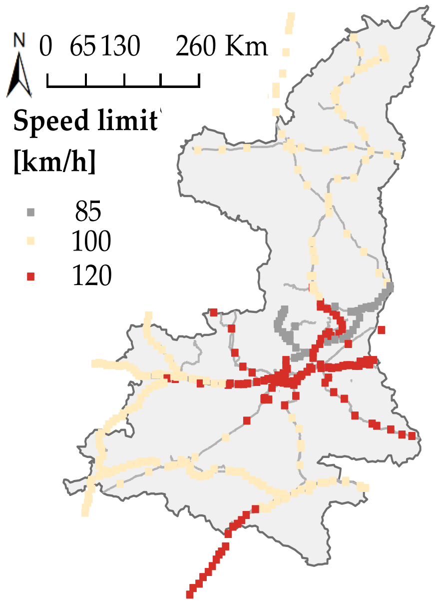
	Evaluation indicators	Centrality	Causality	Weight
Personnel factors	Occupational Skill Levels x_1	2.059	-0.072	0.104
	Frequency of physical training x_2	1.471	0.048	0.074
	Number of young people in the squad x_3	0.506	0.255	0.029
	Response dispatch efficiency x_4	1.535	-0.802	0.087
Equipment factors	Frequency of mechanical testing x_5	1.144	-1.103	0.080
	Number of new equipment x_6	0.843	-0.040	0.042
	Number of relief trains x_7	1.159	0.964	0.076
	Number of material categories x_8	1.743	-1.184	0.106
Environmental factors	Number of operational stations x_9	0.912	0.680	0.057
	Exercise area x_{10}	0.884	0.638	0.055
	Training ground realism x_{11}	1.279	0.935	0.080
Management factors	Size of regulators x_{12}	0.932	-0.708	0.059
	Frequency of safety inspections x_{13}	1.062	-0.965	0.072
	Frequency of practical exercises x_{14}	0.771	1.352	0.078

TABLE VI
EVALUATION RESULTS OF RESOURCE ALLOCATION ABILITY

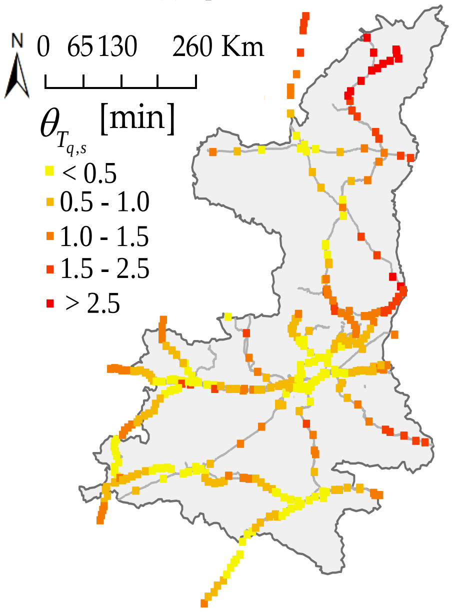
Resource allocation point	Lintong	Ankang	Yan'an	Yanliang	Jingbian	Baoji	Lueyang	Hanzhong	Wanyuan
$\xi_q^{(o)}$	6.0237	5.0144	4.4106	5.4512	5.2302	5.5084	3.9239	4.1239	3.8353

C. Accessibility Assessment Results

Combined with the actual layout of the Bureau's emergency rescue network, the data for all resource allocation points are compiled, and the railway emergency rescue network is constructed using the ArcGIS platform. Fig. 9(a) illustrates the speed limit values of the entire emergency rescue network, while Fig. 9(b) depicts the standard time differences for the rescue trips $\theta_{T_{q,s}}$.



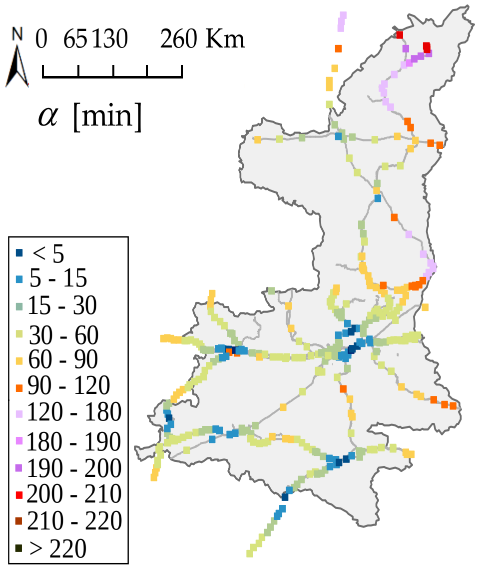
(a) Speed limit



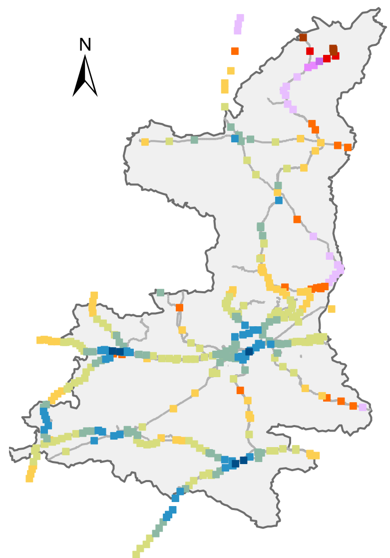
(b) Standard time difference

Fig. 9. Space-time accessibility related variables schematic

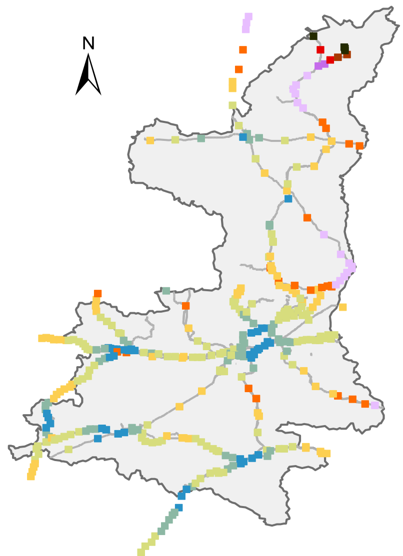
Combining the above actual data with travel time reliability set at 15%, 50%, and 95%, the travel time budget values at each reliability level $b_{q,s}$ are shown in Fig. 10(a), (b), and (c). Since the accessibility values vary significantly across the three reliability levels, Fig. 10 displays a histogram of the changes in spatiotemporal accessibility values for these nine resource allocation points.



(a) =15%



(b) =50%



(c) =95%

Fig. 10. Different reliability

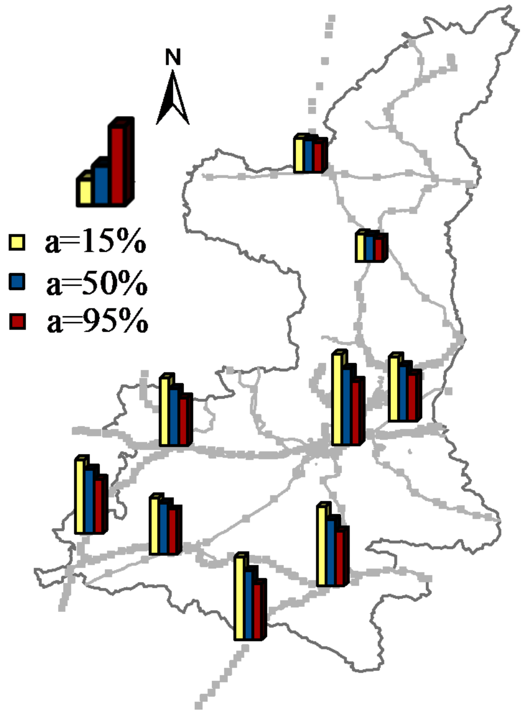


Fig. 11. Accessibility diagram under different reliability

As illustrated in Fig. 10 and Fig. 11: (1) The temporal accessibility of each resource allocation point decreases significantly with increasing reliability levels, although the relative magnitude remains consistent. This trend suggests that higher reliability levels, which imply a greater need for on-time arrival, result in a larger travel time budget, leading to reduced accessibility. (2) There are significant variations in spatiotemporal accessibility among different resource allocation points within this emergency response network at a single reliability level. The Lintong resource allocation point demonstrates the highest spatiotemporal accessibility due to its enhanced resource capacity and a travel time budget of up to 120 minutes for demand points within its jurisdiction, facilitating rapid rescue operations. However, routes in this area are primarily linear, and the rescue time budget for several demand points exceeds 180 minutes, complicating travel and diminishing overall accessibility.

VI. Conclusion

To systematically and intuitively analyze the spatiotemporal characteristics of emergency rescue nodes within the railway network, this paper introduces an enhanced DEMATEL method. This improved approach integrates expert judgments through a group soft consensus mechanism, effectively addressing uncertainties in resource reserve capacity by evaluating the relative weights of key performance indicators. On this foundation, an accessibility model is developed, incorporating travel time budgets and rescue time reliability to assess operational effectiveness. The applicability and efficiency of the proposed method are validated through case studies. Experimental results demonstrate that the method accurately captures the characteristics of resource allocation points within the railway bureau, reflecting the actual service capacity of the railway emergency rescue network. Furthermore, it accounts for the dynamic nature of the system, providing a robust framework for optimizing resource allocation and guiding the maintenance and upgrading of resource points.

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