

Research on the Satisfaction Evaluation of High-Speed Railway Passenger Service Based on the Vague Set

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Abstract

With the rapid development of high-speed railways, improving passenger service satisfaction has become an important issue facing the railway sector. Aiming at the limitations of a single evaluation method and high cost of questionnaire survey, this study constructs a high-speed railway passenger service satisfaction evaluation model based on the Vague set theory. Through the analysis of passenger demand, a complete evaluation system including three first-level indicators of station service, on-board service and extended service, as well as eight second-level indicators such as ticket service, crew service and urban traffic connection service, is established. The index is quantified based on the Vague set language variable, and the weight is determined by the expert scoring method. The model-solving algorithm is designed to realize the multi-dimensional comprehensive evaluation of service satisfaction by calculating the fitness and confidence interval of the target satisfaction criterion. The research results show that the model can effectively identify service shortcomings, provide a theoretical basis for optimizing the layout of station facilities, improving crew response capabilities, and improving emergency public services, and promote the transformation of railway passenger transport services to passenger-centric.

Keywords

High Speed Railway, Passenger Service Satisfaction, Vague Set, Evaluation Model

1. Introduction

With the improvement of people's living standards, high-speed railways with the

advantages of high running speed, high safety, high punctuality, comfort and environmental protection have been rapidly popularized in China, and even developed into other countries [1]-[3]. Compared with the ordinary speed railway, high-speed railway has the advantages of advanced equipment and facilities, higher comprehensive quality of crew, and passengers' demand for high-speed railway passenger service quality is also higher, which requires high-speed railway passenger service personnel to fully adhere to the 'people-oriented' principle. In order to improve the service level, many developed countries will continue to do the passenger satisfaction questionnaire survey, and according to the results of the statistical analysis, they will make improvements and suggestions as soon as possible [4] [5].

The evaluation method of the passenger service satisfaction index is widely used in many fields. Domestic and foreign scholars have widely used this evaluation method in the field of transportation, and achieved good results, mainly including service satisfaction analysis and modeling, passenger service quality research, questionnaire design and investigation, evaluation methods [6]-[10]. However, there are still some limitations in the current research. Most of the research basically adopts fuzzy comprehensive evaluation or analytic hierarchy process, and the model is relatively simple. There is no better combination of the railway passenger service market and more advanced and reasonable model [11]. The collection method of the questionnaire has the disadvantages of great limitations, great difficulty in research, and more financial and material resources [12]; most of the research is based on the quality of service as the main evaluation target, but not the passenger satisfaction as the final foothold, can not better reflect the railway passenger service sector "people-oriented" principles and purposes [13].

The main transportation markets at home and abroad are railways, aviation and highways. The core of its competition is the quality of transportation services. However, some passenger demand has not been fully considered by the railway passenger transport department, and the passenger demand trend has not been accurately grasped [14]. Therefore, it is the only way for the development of railway passenger transport to carry out the satisfaction evaluation of high-speed railway passenger transport service in time, comprehensively and objectively evaluate the quality of high-speed railway passenger transport service, find out the defects and deficiencies in the service process, and continuously improve the satisfaction of railway passenger transport service. It is also an inevitable requirement to urge the transformation of railway passenger transport service to passenger-centered.

In order to improve the competitiveness of railways in the industry, it is necessary to evaluate the satisfaction of passenger service objectively and truly, fully consider the demand of passenger transport, and make up for the defects in the service process. Therefore, the establishment of a high-speed railway passenger service satisfaction evaluation system can not only comprehensively and objectively reflect the current situation of the railway passenger service department, find specific deficiencies and defects, but also propose better designs and solutions

through analysis of deficiencies. It has a strong guiding significance for improving the quality of railway passenger service, improving passenger ride comfort, and promoting modern unified management.

In summary, based on the evaluation of high-speed railway passenger service satisfaction as an important part of railway passenger transport management, this study analyzes the demand for high-speed railway passenger service, quantifies the corresponding evaluation indicators according to the passenger travel demand classification, and uses Vague set to establish the high-speed railway passenger service satisfaction model. At the same time, the method of determining the index weight and the algorithm of Vague set model are systematically expounded. The research results help to better find the shortcomings of railway passenger transport services, help high-speed railway passenger transport service departments to improve their service quality faster, improve passenger travel comfort and convenience, improve passenger service satisfaction, and then enhance the competitiveness of the railway transport industry in the transport market.

2. Analysis of High-Speed Railway Passenger Service Demand

In the process of selecting the evaluation model index of high-speed railway passenger service satisfaction, it is necessary to start with the demand of passenger travel to better improve passenger travel satisfaction. According to the different attributes of the service, the high-speed railway passenger service can be divided into transportation production demand and non-transportation production demand. According to the classification of the places where the service is provided, the high-speed railway passenger service can be divided into car service, car service and extended service demand. This study mainly analyzes the passenger service demand of high-speed railway from three aspects: station service, on-board service and extended service demand.

2.1. Station Service Requirements

The station is the basis of high-speed railway passenger transport, and the only way for passengers to travel. The station service requirements mainly include:

1) Ticketing service: mainly includes the window ticketing service and the ticketing service of the vending machine. Ticketing services mainly include ticket purchase, ticket change, ticket refund, whether the station window is sufficient, whether the passenger ticket purchase is fast and convenient.

2) Station infrastructure services: mainly including whether the security channel is convenient and safe; whether the automatic lift escalator and ticket checking channel are fast; whether the key passengers (old, young, sick, disabled, pregnant, etc.) are equipped with barrier-free facilities and special channels; whether the commercial stores in the station meet the various needs of passengers, including catering, specialty, charging facilities, mobile phone payment, entertainment facilities.

3) Passenger station information guidance service: After entering the station,

passengers need to go through the process of purchasing tickets-security check-waiting-boarding, which requires the coordination of signs, broadcasts and staff in the station. Scientific and reasonable guidance of passengers in the station, optimization of passenger station walking streamline design, and improve passenger travel satisfaction.

2.2. On-Board Service Requirements

The means of transportation for railway passenger travel is the train, and the service quality on the train will greatly affect passenger travel satisfaction. On-board service requirements mainly include:

1) Crew service demand: Crew plays a vital role in high-speed passenger service, mainly including whether the passenger service can welcome passengers, remind passengers to get on and off on time, whether the etiquette is dignified, whether the behavior is elegant, whether the hygiene in the car can be cleaned up in time, and whether the emergency can be dealt with in a timely and effective manner.

2) In-car equipment and facilities services: mainly including seat space and comfort, in-car restaurants, toilets, emergency switches and other signs are obvious. Secondly, whether it can provide wireless networks and wired charging sockets.

3) Train catering service: Train catering service is a major feature of high-speed railway passenger service. Passengers mainly focus on the quality, price and sanitary conditions of catering, and secondly, consider the taste characteristics of passengers, the differences between the North and the South, and the differences between ethnic minorities. Establishing a reasonable meal time and scientific meat and vegetable collocation is not only conducive to improving the catering efficiency of enterprises but also to improving passenger travel satisfaction.

4) Train other business services: mainly including wireless networks, television, movies, music radio, newspapers and magazines, and trolley snacks retail. These business services allow passengers to experience the same comfort as home during the ride, and can make the body and mind relax.

2.3. Extended Service Requirements

The extended service of high-speed railway passenger transport mainly includes two aspects: after-ride service and social public service. After-ride service refers to the extended service including booking service, travel planning service, transportation service, transfer service and so on, which is formulated considering the needs of passengers after taking the bus. Among them, booking services include booking hotels, booking parking spaces, booking restaurants and other services. Travel planning service refers to the travel plan provided for tourists, out-of-office and so on. Transportation service refers to the service of consigning passengers with large goods to the destination of the city. Transfer service refers to the convenient channel or guidance service provided for transferring to other trains, civil aviation or other urban transportation modes. Social public services mainly refer

to that when facing sudden natural disasters (such as freezing disasters, floods, public health disasters, etc.), railway enterprise employees need to use perfect public crisis safety awareness, master basic crisis prevention measures, and improve public satisfaction with enterprise services.

3. High-Speed Railway Passenger Service Satisfaction Model Index Establishment and Quantification

3.1. Establishment of Service Satisfaction Evaluation Index

According to the analysis results of high-speed railway passenger service demand and the psychological experience and psychological needs of passengers, the service satisfaction evaluation index is divided into three first-level indicators: station service, on-board service and extended service. The index system is shown in **Figure 1**.

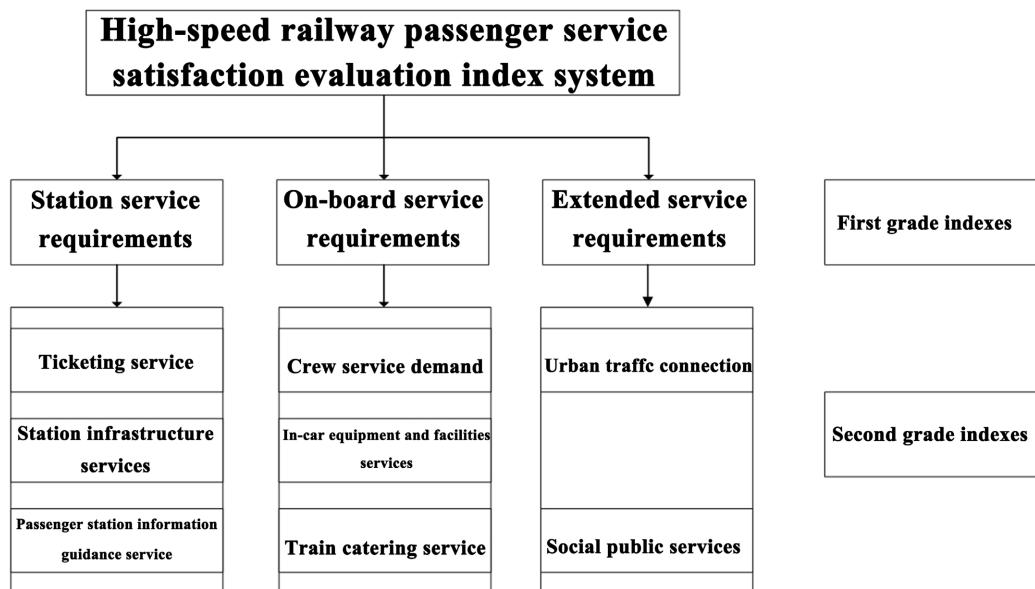


Figure 1. High-speed railway passenger service satisfaction evaluation index system.

As a first-level indicator, station service mainly includes ticket purchase service, station infrastructure service and passenger information guidance service. Among them, the ticketing service refers to the railway department providing passengers who need to travel with ticketing, change, refund, exemption and other services. At present, the main ways to provide services are online ticketing and station ticketing hall offline ticketing. If passengers purchase tickets at the station, the layout of ticketing hall and window the length of waiting time for ticketing are also important aspects related to customer satisfaction. Therefore, the convenience of ticketing service is included in the secondary sub-index of station service; in view of the station infrastructure service, we should focus on whether the design of infrastructure is humanized, whether it can provide passengers with a comfortable waiting environment, and passengers on high-speed railways may pay more at-

tention to whether the access of luggage parcels is convenient and fast, which is also an important part of customer satisfaction. Therefore, the infrastructure service of the station should be included in the secondary index of the station service; for high-speed railway stations, more attention should be paid to the work of passenger guide services. For example, by adopting advanced multimedia technology or painting significant signs in important locations, it is very convenient for passengers to find and use service facilities in the station, and guide passengers to quickly take a drop or transfer train. Whether the station staff can effectively alleviate or ease the passenger flow gathering place, whether the volunteer service in the station is in place, etc., will affect the intuitive feelings and experiences of passengers entering the station and getting on the train. Therefore, it is of great significance to put forward the information guidance service in the passenger station as the secondary index of the station service.

As a first-level indicator, in-vehicle service mainly includes in-vehicle crew service, in-vehicle facilities and equipment service, and in-vehicle catering service. Crew service mainly refers to whether high-speed railway train attendants can serve passengers with dignified etiquette and sweet smiles, and master the ability of emergencies, when passengers have an emergency situation, whether they can deal with it first time, whether the crew can guide passengers well, and whether the crew has emergency ability and first aid knowledge at a critical moment. It can be seen that the service status of the crew is one of the important factors for people to choose high-speed rail as the preferred tool for travel. Therefore, the crew service is regarded as a secondary index of on-board service. In-car facilities and equipment services mainly include in-car seat guidance signs, toilet signs, whether the car is spacious and bright, whether the seat is comfortable, whether it uses a wireless network or a charging socket, etc. These factors are related to whether the passenger's perception is good, and have reference value for improving the passenger's ride satisfaction. Therefore, in-car facilities and equipment services are used as a secondary indicator of other in-car services. For passengers, they are more concerned about the catering service, including whether the drinking water facilities are perfect, whether the catering price is reasonable, whether the catering food standards are safe and sanitary, and so on. Passengers are more concerned about the dining on the car, so the in-car catering service is taken as the third secondary indicator of the on-board service.

As a first-level indicator, extended services mainly include urban traffic connection services and social public services. Urban traffic connection service refers to the fact that different modes of transportation are often connected to each other near the railway station, which helps passengers to complete the seamless transfer of various modes of transportation. The planning and construction of high-speed rail passenger station should try to realize the intersection and docking of different modes of transportation, so that passengers can transfer quickly and conveniently through elevators, escalators or automatic walking channels without leaving the station. This way also affects passengers' satisfaction with high-speed rail travel,

so urban traffic connection service is taken as a secondary indicator of extended service. Social public services mainly include the emergency strategy and efficiency of railway passenger transport departments in the face of sudden disasters. Social public services are also of concern to the majority of passengers. The high-speed rail department should establish a crisis early warning, prevention and preparation mechanism for stations and squares, and formulate emergency plans for different events. Therefore, it is used as a secondary indicator of extended services.

3.2. Basic Operations of Vague Sets

The main purpose of Vague set model is to assist decision-making. Decision-making is defined as the process of analyzing and evaluating the methods evaluated by one or more methods and selecting the optimal scheme. In human production and life, decisions are encountered all the time. Only by adopting appropriate methods and evaluating the decision-making results can we improve the efficiency of enterprises and enhance the competitiveness of enterprises in the industry. When decision-makers make decisions, they first quickly capture decision-making information, then transform decision-making information into fuzzy values or intervals, and then establish corresponding decision-making auxiliary models. Finally, according to the decision-making results of the model, the most reasonable solution is selected.

Firstly, let X be the object space of a point fixed point, $X = \{x_1, x_2, x_3, \dots, x_n\}$, that is, any element in the set can be represented by x_i . A Vague set in the definition X is represented by a false membership function $f_{A(x)}$ and a true membership function $t_{A(x)}$, respectively. Here, $f_{A(x)}$ represents the lower bound of the negative membership degree, and $t_{A(x)}$ represents the upper bound of the negative membership degree. Each point in $t_{A(x)}$ and $f_{A(x)}$ corresponds to each real number in the range of value interval $[0, 1]$ one by one, as follows :

$$\begin{aligned} t_{A(x)} : X &\rightarrow [0, 1] \\ f_{A(x)} : X &\rightarrow [0, 1] \end{aligned}$$

where, $0 \leq t_{A(x)} + f_{A(x)} \leq 1$. $\pi_{A(x)} = 1 - t_{A(x)} - f_{A(x)}$ is the relative scale of the element x in Vague sets, which shows the uncertainty of the element x in Vague sets A .

Assuming that Vague set is A , when X is continuous, we get:

$$A = \int_x \left[t_{A(x)}, 1 - f_{A(x)} \right] / x, x \in X$$

When X is discrete, we get:

$$A = \sum_{i=1}^n \left[t_{A(x_i)}, 1 - f_{A(x_i)} \right] / x_i, x_i \in X$$

From the above definition, the membership x of A can be expressed in three dimensions, $(t_{A(x)}, f_{A(x)}, \pi_{A(x)})$, They indicate the degree of $x \in A$ support and opposition.

For example, $A = [t_{A(x)}, 1 - f_{A(x)}] = [0.3, 1 - 0.4]$, which means that the interpretation of x in Vague set A is as follows: the true membership degree of x in set A is 0.2, the false membership degree of x in set A is 0.4, and the membership degree of uncertain factors is 0.1. The result in the analogy to the voting model is: 3 votes in favor, 4 votes against, and 1 abstention.

According to the research of domestic and foreign scholars on the above theory, it is necessary to find a positive correlation strategy and a negative correlation strategy. The positive correlation strategy represents the optimal value of the attributes of the options to be selected, and the negative correlation strategy represents the lowest value of each option. The difference between the positive correlation strategy and the negative correlation strategy is analyzed and compared, and then sorted. The specific steps are as follows [15]-[18].

1) A multi-objective decision-making problem is defined. The scheme set $A = \{A_1, A_2, \dots, A_n\}$ is defined, and the corresponding scheme attribute set is $C = \{C_1, C_2, \dots, C_n\}$. Therefore, the decision matrix $T = [C_i, (t_{ij}, 1 - f_{ij})]_{nm}$ of the scheme set A in the decision attribute set C is obtained.

2) Define positive and negative correlation strategies:

Positive correlation strategy:

$$A^+ = ([t_1^+, 1 - f_1^+], [t_2^+, 1 - f_2^+], [t_3^+, 1 - f_3^+], \dots, [t_m^+, 1 - f_m^+])$$

Negative correlation strategy:

$$A^- = ([t_1^-, 1 - f_1^-], [t_2^-, 1 - f_2^-], [t_3^-, 1 - f_3^-], \dots, [t_m^-, 1 - f_m^-])$$

Where $t_j^+ - f_j^+ = \max(t_{ij} - f_{ij}), t_j^- - f_j^- = \min(t_{ij} - f_{ij})$

3) Using Vague set difference formula:

$$d(A_i, A_j) = \frac{1}{2m} \sum_{k=1}^m (|t_i - t_j| + |f_i - f_j| + |\pi_i - \pi_j|)$$

4) The closeness degree of two related indexes of Vague set is calculated, and the optimal scheme is selected according to the closeness degree.

The Vague set model used in this paper is based on the relative optimal membership. Firstly, the basic matrix is transformed into the optimal membership matrix, and then the weight of each Vague value is calculated. Finally, the expert scoring method is used to rank the results of the scheme, and the comprehensive evaluation of passenger service satisfaction is realized.

Suppose that $X = \{x_1, x_2, x_3, \dots, x_n\}$, A and B are two Vague sets on X , then the following conclusions hold:

$$A = B \Leftrightarrow \forall x_i \in X, t_A(x_i) = t_B(x_i), f_A(x_i) = f_B(x_i)$$

$$A = \sum_{i=1}^n [t_{A(x_i)}, 1 - f_{A(x_i)}] / x_i$$

$$A + B = \left\{ [t_A(x_i) + t_B(x_i) - t_A(x_i)t_B(x_i)], [1 - f_{A(x)}f_{B(x)}] \right\}$$

$$A \cdot B = \left\{ [t_A(x_i)t_B(x_i)], [1 - f_{A(x)} - f_{B(x)} + f_{A(x)}f_{B(x)}] \right\}$$

$$A \cup B = \left\{ \vee [t_A(x_i), t_B(x_i)], 1 - \wedge [f_{A(x)}, f_{B(x)}] \right\}$$

$$A \cap B = \left\{ \wedge [t_A(x_i), t_B(x_i)], 1 - \vee [f_{A(x)}, f_{B(x)}] \right\}$$

Here, “ \wedge ” denotes the minimum value and “ \vee ” denotes the maximum value.

Suppose $x_i = [t_x, 1 - f_x], x_j = [t_x, 1 - f_x]$ of Vague value, then the definition of Vague value is:

$$\begin{aligned} x_i x_j &= [t_x t_k, 1 - f_x - f_k + f_x f_k] \\ x_i + x_j &= [t_x + t_k - t_x t_k, 1 - f_x f_k] \\ kx_i &= [1 - (1 - t_x)^k, (1 - f_x)^k], k > 0 \\ x_j &= [t_x^\eta, 1 - f_x^\eta], \eta > 0 \end{aligned}$$

4. High-Speed Railway Passenger Service Satisfaction Evaluation Model Based on Vague Set

4.1. Determination of Vague Set Language Variables and Priority Membership Matrix

If we make a comprehensive evaluation of a thing with high uncertainty, it is not appropriate to use accurate values to represent the preferences of decision makers. Here, we use a term set to represent, that is, Vague set language variables, which can easily determine the relative priority of the target in order to obtain the optimal solution [19].

Therefore, the set of linguistic terms represented by Vague values is shown in **Table 1**. It should be noted that according to the actual situation, it can also be divided into different levels, such as seven or nine.

Table 1. Vague values with ten-level linguistic variables.

Order of evaluation	Value ranges	The value of typical Vague sets	Abstention value
Absolutely good	[1, 1]	[1, 1]	0
Very good	(0.9, 1)	[0.9, 0.95]	0.05
Good	(0.85, 0.9]	[0.8, 0.9]	0.1
Better	(0.7, 0.85]	[0.7, 0.85]	0.15
Medium good	(0.6, 0.8]	[0.6, 0.8]	0.2
Medium	(0.5, 0.5]	[0.5, 0.5]	0
Medium difference	(0.45, 0.6]	[0.4, 0.6]	0.2
Poor	(0.3, 0.45]	[0.3, 0.45]	0.15
difference	(0.15, 0.3]	[0.2, 0.3]	0.1
Very poor	(0, 0.15]	[0.1, 0.15]	0.05
Absolute difference	[0, 0]	[0, 0]	0

Firstly, the function $S(x)$ is used to estimate the fitness of the scheme to the decision maker, that is:

$$C(x) = t(x) - f(x)$$

where $C(x) \in [-1, 1]$.

Assume that represents the fitness of scheme A_i under the condition criterion C_j , then there is:

$$X_{ij} = t_{ij} - f_{ij} = t_{ii} + t_{jj} - 1$$

At this time, the fitness matrix of the criterion for the current scheme is $N' = [x_{ij}]_{m \times n}$.

Where $1 \leq i \leq m, 1 \leq j \leq n$.

Using Vague's own language to represent the first-order language variables. Then, the relative fitness of each target is determined, so that the main characteristics of the target are fully displayed. At this time, the calculation results can be approximated to the relative membership of Vague. The following matrix is shown:

$$M' = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix}$$

4.2. Quantification of Service Satisfaction Evaluation Index Based on Passenger Demand

Through the value of the above Vague set, the service satisfaction evaluation index is corresponding to it, that is, the passenger determines the corresponding Vague value interval by rating the index, so as to realize the quantification of the evaluation index. When conducting a questionnaire survey on passengers, if passengers believe that a service is defective or missing, it needs to be improved, indicating that passengers are not satisfied with the service; if the passenger thinks that a service is particularly good, the passenger is very satisfied; if the passenger thinks that a service is general, but it is still acceptable, indicating that the passenger is basically satisfied with the service; if a passenger thinks that a service is good, but not particularly worthy of praise, it indicates that the passenger is satisfied with the service. Accordingly, we simplify the evaluation level into four levels: very satisfied, satisfied, basically satisfied, and dissatisfied. As shown in **Table 2** below.

Table 2. Evaluation index grade and vague value corresponding table.

Index	Order of evaluation	The value of typical Vague sets
Ticketing service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
Station infrastructure services	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]

Continued

Passenger station information guidance service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
Crew service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
In-vehicle facilities and equipment services	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
In-car catering service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
Urban traffic connection service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]
Social public service	Very satisfied	(0.8, 1]
	Satisfied	(0.6, 0.8]
	Basically satisfied	(0.4, 0.6]
	Not satisfied	(0.1, 0.4]

Further, the weight of each index is determined by the method of expert ranking, that is, each index is quantified and scored by means of expert scoring, and then each index is refined according to the degree of influence on service satisfaction. Taking the content evaluated in this paper as an example, the indexes are ranked and scored. Finally, the following **Table 3** is obtained (taking station service as an example):

Table 3. Expert scoring table.

Index	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
ticketing service	w_{11}	w_{12}	w_{13}	w_{14}	w_{15}	w_{16}
Station infrastructure services	w_{21}	w_{22}	w_{23}	w_{24}	w_{25}	w_{26}
Passenger station information guidance service	w_{31}	w_{32}	w_{33}	w_{34}	w_{35}	w_{36}

The calculation method of the secondary index weight is as follows:

$$a_i = \frac{\sum_j w_{ij}}{\sum_i \sum_j w_{ij}}$$

Among them, i represents the indicators, a_i represents the weight of the second-level indicators of item i , and w_{ij} represents the scoring of item i by the j expert. Thus, the weight of the ticket service index is calculated as follows:

$$a_{\text{ticketing service}} = \frac{w_{11} + w_{12} + w_{13} + w_{14} + w_{15} + w_{16}}{\sum_3 \sum_6 w_{ij}}$$

Similarly, the ownership weight of the second-level indicators of the same level is obtained, and the weights of all first-level indicators are obtained.

4.3. Solving Algorithm of Vague Set Model

Let C_j, C_k, \dots the weight ratio of C_q is mainly $\omega_i, \omega_j, \omega_k, \dots, \omega_p$, where $\omega_i, \omega_j, \omega_k, \dots, \omega_p \in [0, 1]$, and $\omega_i + \omega_j + \omega_k + \dots + \omega_p = 1$.

The main steps are as follows:

1) Calculate the fitness of A_j satisfying each criterion:

$$\begin{aligned} \omega_{n_i=i,j,k,\dots} f_i(A_j) &= \partial[t_{ij}, t_{ij}^*] * \omega_j + \partial[t_{ik}, t_{ik}^*] * \omega_k + \dots + \partial[t_{ip}, t_{ip}^*] * \omega_p \\ &= (t_{ij} + t_{ij}^* - 1) * \omega_j + (t_{ik} + t_{ik}^* - 1) * \omega_k + \dots + (t_{ip} + t_{ip}^* - 1) * \omega_p \\ \omega_{C_s} = (A_i) &= \partial[t_{is}, t_{is}^*] = (t_{is} + t_{is}^* - 1) \end{aligned}$$

2) According to the following formula, the fitness of target A_i satisfying each criterion is calculated:

$$\begin{aligned} T_{n_i=j,k,\dots,p} e_i(A_i) &= \theta[t_{ij}, t_{ij}^*] * \omega_j + \theta[t_{ik}, t_{ik}^*] * \omega_k + \dots + \theta[t_{ip}, t_{ip}^*] * \omega_p \\ &= (t_{ij} - t_{ij}^* + 1) * \omega_j + (t_{ik} - t_{ik}^* + 1) * \omega_k + \dots + (t_{ip} - t_{ip}^* + 1) * \omega_p \\ T_{C_s} = (A_i) &= \theta[t_{is}, t_{is}^*] = (t_{is} - t_{is}^* + 1) \end{aligned}$$

3) From the above, the optimal membership of each criterion is obtained, and then the confidence interval of the current index is calculated:

$$\begin{aligned} R_{n_i=j,k,\dots,p} c_l(A_i) &= \left(\begin{aligned} &\omega_{n_i=j,k,\dots,p} c_l(A_i) - \frac{1 - T_{n_i=j,k,\dots,p} c_l(A_i)}{2} \\ &\omega_{n_i=j,k,\dots,p} c_l(A_i) + \frac{1 - T_{n_i=j,k,\dots,p} c_l(A_i)}{2} \end{aligned} \right) \\ R_{C_s}(A_i) &= \left(\begin{aligned} &R_{C_s}(A_i) - \frac{1 - T_{C_s}(A_i)}{2} \\ &W_{C_s}(A_i) + \frac{1 - T_{C_s}(A_i)}{2} \end{aligned} \right) \end{aligned}$$

where $R_{n_i=j,k,\dots,p} c_l(A_i) \in [-1, 1], R_{C_s}(A_i) \in [-1, 1], 1 \leq i \leq m$.

4) Determine the sort function to define, determine the minimum, maximum,

and intermediate:

$$R_{\min}(A_i) = \min \left(\omega_{n_1=j,k,\dots,p} C_1(A_i) - \frac{1-T_{n_1=j,k,\dots,p}(A_i)}{2}, W_{Cs}(A_i) - \frac{1-T_{Cs}(A_i)}{2} \right)$$

$$R_{\max}(A_i) = \max \left(\omega_{n_1=j,k,\dots,p} C_1(A_i) + \frac{1-T_{n_1=j,k,\dots,p}(A_i)}{2}, W_{Cs}(A_i) + \frac{1-T_{Cs}(A_i)}{2} \right)$$

$$R_{\text{center}}(A_i) = \max \left(\omega_{n_1=j,k,\dots,p} C_1(A_i), W_{Cs}(A_i) \right)$$

5) Finally, according to the decision maker's attitude towards risk, the maximum-minimum method is adopted, that is, $\max\{R_{\min}(A_i)\}$; the maximum-midway method, that is, $\max\{R_{\text{center}}(A_i)\}$ sorts each scheme to select the optimal scheme.

In summary, this method first calculates the fitness of each objective to meet the criteria according to the two ranking functions of Vague value, then defines the confidence interval of each objective to meet the criteria according to the fitness, and then defines the weighted minimum, maximum and intermediate ranking functions of the scheme according to the confidence interval. Finally, according to the different attitudes of decision makers to risks, conservative decision makers use the maximum-minimum method, aggressive decision makers use the maximum-maximum method, and neutral decision makers use the maximum-middle method to rank each scheme to select the optimal scheme.

5. Conclusions

1) Based on the analysis of high-speed railway passenger service demand, the service satisfaction evaluation index system is established, including three first-level indicators of station service, on-board service and extended service, and eight second-level indicators of ticketing service, station infrastructure service, passenger information guidance service, crew service, in-vehicle facilities and equipment service, in-vehicle catering service, urban traffic connection service and social public service.

2) Combined with the characteristics of high-speed railway passenger service, the Vague set theory and technical methods are introduced. The concept, basic operation and research status of Vague set are summarized and analyzed, and its applicability in the satisfaction evaluation of high-speed railway passenger service is illustrated.

3) A high-speed railway passenger service satisfaction evaluation model based on Vague set is established, and the algorithm of index weight and the solution method of the model are determined. The model should calculate the fitness of each objective to meet the criteria according to the two ranking functions of Vague value, then define the confidence interval of each objective to meet the criteria according to the fitness, and then define the weighted minimum, maximum and intermediate ranking functions of the scheme according to the confidence interval, so as to select the final optimal scheme.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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