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URBAN RAIL TRANSIT PASSENGER SERVICE QUALITY EVALUATION BASED ON THE KANO–ENTROPY–TOPSIS MODEL: THE CHINA CASE

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Abstract. In order to evaluate the URTPSQ (Urban Rail Transit Passenger Service Quality) comprehensively, find the shortage of URTPSQ, find out the difference between the actual service situation and the passenger's expectation and demand, and provide passengers with better travel services, a passenger-oriented KANO–Entropy–TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) method is proposed and applied in this paper. Firstly, a KANO model is applied to select the service quality indicators from the 24 URTPSQ evaluation sub-indicators, according to the selection results, the KANO service quality indicators of URTPSQ are constructed. Then the sensitivity of the KANO service quality indicators based on the KANO model are calculated and ranked, the PS (Passenger Satisfaction) of each KANO service quality indicator by using the Entropy–TOPSIS method is calculated and ranked. Based on the difference between the sensitivity degree rank and the satisfaction degree rank of each KANO service quality indicator, determine the service quality KANO indicators of the URTPSQ that need to be improved significantly. A case study is conducted by taking the Chengdu subway system in China as a background. The results show that the Chengdu subway operation enterprises should pay attention to the must-be demand first, then the one-dimensional demand, finally the attractive demand. The three indicators, including transfer on the same floor in the station, service quality of staffs of urban rail transit enterprises, and cleanness in the station and passenger coach, need to be improved urgently. For the managers and operators of urban rail transit system, the passengers' must-be demand should be satisfied first if the KANO model is applied to evaluate the service. The indicators with highest sensitivity degree and lowest TOPSIS value should be improved based on the KANO–Entropy–TOPSIS model.

Keywords: urban rail transit, passenger service quality, KANO–Entropy–TOPSIS, sensitivity degree, satisfaction degree, passenger-oriented.

Notations

AHP – analytic hierarchy process;
EWM – entropy weighting method;
FAHP – fuzzy AHP;
MCDM – multi-criteria decision-making;
PS – passenger satisfaction;
SERVQUAL – service quality;
TOPSIS – technique for order of preference by similarity to ideal solution;
TTEECIC – Traffic and Transportation Engineering Experiment and Comprehensive Innovation Center (China);
URTPSQ – urban rail transit passenger service quality.

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Introduction

Over the last decade, urban rail transit system (including subway system, light rail system, suburban railway, monorail system, tram system and magnetic levitation system) development has been booming in China. An urban rail transit system undertakes tasks of a large number of passengers' daily traveling in the city; the reliable and energy-efficient public passenger transport mode has come to be regarded as the best transportation system to alleviate road congestion, thus it plays an increasingly important role in many large Chinese cities (Kang *et al.* 2015; Sun *et al.* 2016).

Urban rail transit is a typical service industry (Shen *et al.* 2016). Through on-the-spot investigation and comprehensive evaluation of the URTPSQ, the shortage of urban rail transit passenger service and the gap between actual service and passengers' perceptions and expectations can be found, so as to provide passengers with more personalized travel services. URTPSQ should be evaluated periodically by service providers to designate the effectiveness of the services (Feng *et al.* 2019). The URTPSQ evaluation process should contain not only main activities and forecasted demand, but also unsatisfied service needs and interests of stakeholders (Hassan *et al.* 2013; Aydin 2017). In addition, the evaluation processes should contain an evaluation of many factors related to URTPSQ in customer satisfaction assessments (Awasthi *et al.* 2011; Aydin 2017).

In this paper a passenger-oriented model, called KANO–Entropy–TOPSIS, is proposed to evaluate the URTPSQ in China. The contributions of this study are:

- the URTPSQ evaluation indicators system is established based on MOPES 2.0 (CTA URTPC 2011). The evaluation indicators system includes 8 indicators and 24 sub-indicators;
- the KANO model is used to select the service quality indicators from the 24 URTPSQ evaluation sub-indicators, because not all 24 sub-indicators belong to the service quality indicators. According to the selection results, the KANO service quality indicators of URTPSQ are constructed;
- the sensitivity of the KANO service quality indicators based on the KANO model are calculated and ranked, then the PS of each KANO service quality indicator by using the Entropy–TOPSIS method (Huang *et al.* 2018a, 2018b) is calculated and ranked;
- based on the difference between the sensitivity degree rank and the satisfaction degree rank of each KANO service quality indicator, determine the service quality KANO indicators of URTPSQ that need to be improved significantly.

Based on the final analysis of this paper, we try to overcome the shortage of urban rail transit passenger service, improve the gap between actual service and passengers' perceptions and expectations, and provide passengers with more personalized travel services, which is significant to the health development of urban rail transit system.

The rest of the paper is organized as follows. Section 1 is devoted to the literature review. In section 2, the URTPSQ evaluation indicators system based on MOPES 2.0 is established. Section 3 is devoted to the description of the KANO–Entropy–TOPSIS method. In section 4, a case study is conducted by taking the Chengdu subway system in China as a background. The evaluation analysis results are presented and the related suggestions for Chinese government departments and Chengdu subway operation enterprises are given. In last section, the major conclusions and an outline of future research tasks are presented.

1. Literature review

There are a lot of theoretical researches having been devoted to URTPSQ. In general, these papers can be divided into two categories:

- the papers were devoted to analyse the operational effects of urban rail transit systems;
- aimed at the application of evaluation approaches of URTPSQ.

Next the two categories of previous literatures are introduced, and the approach applied in this paper is presented.

1.1. Analysing the operational effects of urban rail transit systems

Garrett (2004) concluded that the traffic congestion was reduced in several American cities after light rail transit lines were developed.

Baum-Snow and Kahn (2005) concluded that the average travel time was reduced in the areas that were located near rail transit lines.

Vuk (2005) carried out an analysis to determine the effect of the metro line of the city of Copenhagen on traffic; the author concluded that metro positively affects the traffic between 13…18%.

Nelson *et al.* (2007) noted that Washington DC's rail transit services provided benefits in terms of traffic congestion reduction.

Litman (2007) concluded that enhancing rail transit's service quality reduced the delay or number of automobile/bus trips, which effected all users. The author also mentioned that high service quality in rail transit encouraged users to drive less and walk if they live in a more automobile dependent area.

Similarly, Diana (2012) investigated the satisfaction of users who travel with different urban areas' rail transit lines, the author observed that smaller towns' rail transit line users have higher satisfaction in terms of service quality than metropolitan cities' rail transit line users.

Nathanail (2008) evaluated the performance of Hellenic railways based on 22 criteria, which included six main factors: itinerary accuracy, system safety, cleanness, passenger comfort, servicing and passenger information. They concluded that the rail transit system performed the best on the itinerary accuracy and system safety.

Brons *et al.* (2009) determined how significant the "access-to-the-station" is to users in their total satisfaction, and the balance between features of the rail transit services. They found that in several parts of the rail transit network, improving and increasing access services to the railway stations could substitute for improving and increasing the services provided, and this may attract users who use other types of transportation modes.

In conclusion, these literatures mentioned above studied the operational effects of urban rail transit system; these effects include traffic congestion reduction, travel time deduction, itinerary accuracy improvement, system safety improvement and so on. Most of these papers are government-oriented, operators-oriented and passengers-oriented, less literatures are from the URTPSQ evaluation comprehensively perspective, less discussion about the shortage of URTPSQ or the difference between the actual service situation and the passenger's expectation and demand.

1.2. Application of evaluation approaches of URTPSQ

De Oña *et al.* (2015a, 2015b, 2016) calculated the indicators numbers on the basis of data collected from surveys during the years of 2007 and 2013, in which they considered both perceptions of users and importance rates to determine the service quality levels.

Semchugova *et al.* (2017) thought the trip time was the most important factor when assessing the passenger service quality by consumers. They established evaluation methods of the use and application of such quality indicators as regularity and reliability of transport. Evaluate the service quality level needs to consider multiple factors to get accurate results. MCDM methods are efficient approaches for this purpose.

Another advantage of MCDM procedures is that they are flexible to be combined with mathematical modelling techniques. For instance, Awasthi *et al.* (2011) applied the SERVQUAL–TOPSIS approach to evaluate the service quality of Montreal metro lines.

Aydin *et al.* (2015) evaluated the service quality level of rail transit of Istanbul considering one year survey data, they proposed a combined framework of statistical analysis, FAHP, trapezoidal fuzzy sets and Choquet integral to evaluate service quality levels.

Eboli *et al.* (2016) established a multilevel fuzzy synthetic evaluation model to evaluate the railway service quality based on the fuzzy theory. An evaluation indicator system with three grades evaluation indicators was established, and their weights were determined on the basis of opinions expressed by interviewed passengers.

Aydin (2017) proposed a service quality evaluation outline to measure rail transit lines' performances via PS surveys in Istanbul in 2012–2014. The proposed approach combines statistical analysis, fuzzy trapezoidal numbers and TOPSIS to evaluate service quality levels for multi periods.

Štefancová *et al.* (2017) focused on the new approach in designing the preparation of processes and services in accordance with customer's needs. A new software solution was created for the achievement of the complexity of the preparation, effective implementation and timely indication of any diversions from quality in railway transport. The principles of the dynamic quality modelling and total service management were used as an important support for new software in railway transport operation.

Nedeliaková *et al.* (2014) proposed a two parts approach to identify the level of railway transport service quality, the first part was characterized by calculating the complex indicator of quality for the corresponding process of the provision of service, the second part was focused on a customer, employee and supplier oriented approach in terms of compliance with principles applicable to railway transport.

In conclusion, when evaluating the URTPSQ, most of the papers applied questionnaire investigation and operational data collection to obtain the initial data, then use the MCDM to evaluate the URTPSQ. The most common used MCDM approaches including SERVQUAL, TOPSIS, FAHP, or combined approaches. Some qualitative methods, e.g., AHP and FAHP, rely on the background and experience of researchers (or experts), which means, the final evaluation results are influenced by the experts.

KANO–Entropy–TOPSIS applied in this paper belongs to a passenger-oriented and quantitative URTPSQ model, which aims at overcoming the shortage of urban rail transit passenger service, improving the gap between actual service and passengers' perceptions and expectations, and providing passengers with more personalized travel services. The initial data of all URTPSQ evaluation indicators are obtained from on-the-spot questionnaire investigation based on KANO; based on initial data, the KANO service quality indicators are determined quantitatively; the sensitivity of each KANO service quality indicator is calculated and ranked quantitatively, the PS of each KANO service quality indicator by using the Entropy–TOPSIS method is calculated and ranked quantitatively.

EWM (Huang *et al.* 2016, 2017; Huang, Shuai 2017) belongs to an objective and quantitative weighting method. The initial data input of EWM in this paper is from on-the-spot questionnaire investigation. Hence, the weighting results are more accurate and objective because EWM is not influenced by experience or knowledge from the evaluators or experts.

TOPSIS (Huang *et al.* 2018a, 2018b) attempts to choose alternatives that should simultaneously have the closest distance from the positive ideal solution and the farthest distance from the negative ideal solution, it belongs to an objective and quantitative rank approach, which means, the final difference value between the sensitivity degree rank and the satisfaction degree rank of each KANO service quality indicator obtained by Entropy–TOPSIS method is more accurate, objective, and less influence by experience or knowledge from the evaluators or experts than other MCDM approaches, such as AHP and FAHP.

2. The URTPSQ evaluation indicators: inputs

In 2012, the State Council of the People's Republic of China enacted the manual: *Guiding Opinions on Priority Urban Development of Public Transport by the State Council of the People's Republic of China* (SC PRC 2012). The manual requires that all urban rail transit enterprises in China should find out suitable approaches, evaluation indicators and criteria on the operation performance evaluation and service quality evaluation. The URTPSQ has already become a basic national policy. After that, the Urban Rail Transit Professional Committee of the China Transportation Association organized and published the urban rail transit performance and service evaluation indicators system standard, called MOPES 2.0 (CTA URTPC 2011), which contains 8 broad indicators including networks, stations, passenger volume, train operation, service, safety, energy consumption, operation and management cost, and a total of 117 sub-indicators. MOPES 2.0 can provide all possible indicators for the urban transit systems in China, e.g., a single line urban transit system, non-network system, fixed-scale urban rail transit network, passenger service quality etc., hence, we need to select the related sub-indicators from the 117 sub-indicators to establish the URTPSQ evaluation indicators system according to practical problem demand or under the help of experts, evaluators or the urban rail transit operators. For example, in order to establish the urban transit non-network system performance evaluation indicators system, Huang *et al.* (2016) selected 6 indicators and 30 sub-indicators from MOPES 2.0 under the help of the urban rail transit operators. In this paper, the URTPSQ evaluation indicators system is established with the help of the urban rail transit operators and experts.

In China, passengers choosing the urban rail transit system to travel will generally go through the following processes: enter the station, security checks, ticketing, waiting for train, riding, transferring, exit the station. After analysing the processes as well as the MOPES 2.0, the URTPSQ evaluation indicators from the passengers' perspective can be established: URTPSQ evaluation indicators are set by focusing on assessing passengers' subjective feelings on the advantages and disadvantages of passenger transport service provided by urban rail transit, there are 6 indicators including environment in the station and passenger coach, passenger guiding information, service, passenger transfer, facilities and equipment in MOPES 2.0 that satisfied the URTPSQ requirements mentioned above. The 6 indicators can be separated into 24 sub-indicators in total. In this paper, we use i (i = 1, 2, 3, …, 24) to represent each sub-indicator:

- ***environment in the station and passenger coach***, includes the cleanness in the station and passenger coach (i = 1), the temperature in the station and passenger coach (i = 2), the light intensity in the station and passenger coach (i = 3), the air quality in the station and passenger coach (i = 4), the interior decoration in the station and passenger coach (i = 5);
- ***passenger guiding information***, includes passenger guiding signs of station entrance (i = 6), passenger guiding information signs in the station and passenger coach (i = 7), safety warning signs in the station and passenger coach (i = 8);
- ***service***, includes the punctuality of the train (i = 9), the operation stationary of the train (i = 10), time-interval of train departure (i = 11), security in the station and passenger coach (i = 12), the clear and timely of broadcast (including clear and timely of broadcasts in general and in disturbances situations, and broadcast languages, etc.) (i = 13), service quality of staffs of urban rail transit enterprises (i = 14), complaint handling satisfaction of urban rail transit enterprises (i = 15), innovation and learning ability of staffs of urban rail transit enterprises (i = 16);
- ***passenger transfer***, includes the transfer time (i = 17), the transfer distance (i = 18), transfer on the same floor in the station (i = 19);
- ***facilities and equipment***, includes the working condition of vending machines (i = 20), the working condition of escalator and stair (i = 21), the working condition of safety gates (i = 22), the working condition of automatic check-in gates (i = 23), the availability of disability facilities (i = 24).

Under the help of the urban rail transit operators and the members of TTEECIC, the KANO based passenger questionnaire investigation in the stations is carried out. The initial data of the 24 sub-indicators is collected and counted, and the final results are used as the inputs in order to obtain the final URTPSQ evaluation results. Next, the KANO–Entropy–TOPSIS method applied in this paper is described in detail.

3. The KANO–Entropy–TOPSIS method

There are two steps of the KANO–Entropy–TOPSIS method when applied to evaluate the URTPSQ:

- using the KANO model to select service quality indicators;
- using the Entropy–TOPSIS method to calculate satisfaction degree of KANO service quality indicators.

3.1. Using the KANO model to select service quality indicators

The KANO model was introduced by Kano *et al.* (1984), who developed a two-dimensional model to find out passenger requirements and their impact on PS. The KANO model enables one to explore the components of service quality of an urban rail transit that affect PS. Furthermore, the role of these service characteristics on a passenger's perception of quality. The KANO model divides passenger requirements into six attributes (Kwong *et al.* 2011; Wang 2013; He *et al.* 2017), shown in Figure 1, each category affects PS in a different way. KANO attributes are briefly explained as follows:

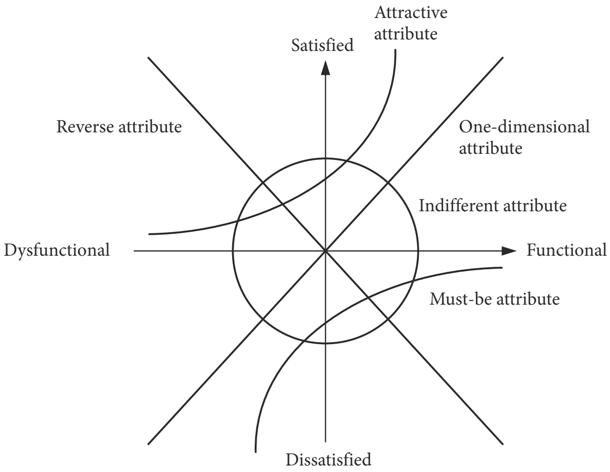

Figure 1. KANO model (He *et al.* 2017)

- ***attractive*** (A): the functional presence of the attribute results high level of PS while the absence would not affect PS;
- ***one-dimensional*** (O): the functional presence of the attribute generates PS while the absence would result in non-satisfaction;
- ***must-be*** (M): passengers take the presence of the attribute for granted, insufficiency of the attribute would result in extreme non-satisfaction, but the sufficiency would not increase satisfaction level;
- ***indifferent*** (I): the attribute, whether present or not, would not affect PS;
- ***reverse*** (R): The presence of the attribute would generate non-satisfaction, the absence of the attribute would increase the satisfaction;
- ***questionable*** (Q): this outcome indicates that either the responses do not make any logical sense, or the question was phrased incorrectly.

For each sub-indicator i in the URTPSQ evaluation indicators system, the functional and dysfunctional passenger questionnaire is applied to collect the passengers' evaluation and demand. The functional questionnaire reflects the passenger's evaluation and demand when the urban rail transit passenger service meets the sub-indicator. The dysfunctional questionnaire reflects the passenger's evaluation and demand when the urban rail transit passenger service does not meet the sub-indicator. The form of the questionnaire is shown in Table 1, because of the huge scale of the total questionnaire, here we use one sub-indicator, cleanness in the station and passenger coach (i = 1) as an example, all sub-indicators' questionnaire form should follow the Table 1.

After obtaining the functional and dysfunctional questionnaires of all sub-indicators, the KANO attributes of all sub-indicators mentioned above should be counted and calculated by using the 5 by 5 evaluation table as conducting instrument (Kano *et al.* 1984), which is shown in Table 2.

The final KANO attributes of passenger requirements are evaluated according to response frequencies of each sub-indicator i, the highest frequency represents the dominant passenger view (He *et al.* 2017). The formulas are shown as follows:

$$K_A^i = \frac{N_A^i}{N_A^i + N_O^i + N_M^i + N_I^i}, \ \forall i; \tag{1}$$

$$K_O^i = \frac{N_O^i}{N_A^i + N_O^i + N_M^i + N_I^i}, \ \forall i; \tag{2}$$

$$K_M^i = \frac{N_M^i}{N_A^i + N_O^i + N_M^i + N_I^i}, \ \forall i; \tag{3}$$

$$K_I^i = \frac{N_I^i}{N_A^i + N_O^i + N_M^i + N_I^i}, \ \forall i, \tag{4}$$

where: K_A^i, K_O^i, K_M^i, K_I^i are the response frequencies of attractive (A), one-dimensional (O), must-be (M) and indifferent (I); N_A^i, N_O^i, N_M^i, N_I^i are the response statistics number of attractive (A), one-dimensional (O), must-be (M) and indifferent (I) according to the KANO questionnaires.

Table 1. KANO questionnaire for each sub-indicator – by taking (i = 1) as an example

Please mark √ in the box under the option that you agree with	Like	Must-be	Neutral	Live-with	Dislike
Functional: the cleanness in the station and passenger coach is good					
Dysfunctional: the cleanness in the station and passenger coach is terrible					

Table 2. KANO evaluation table (He *et al.* 2017)

Functional	Dysfunctional				
	Like	Must-be	Neutral	Live-with	Dislike
Like	Q	A	A	A	O
Must-be	R	I	I	I	M
Neutral	R	I	I	I	M
Live-with	R	I	I	I	M
Dislike	R	R	R	R	Q

Notes: A – attractive; O – one-dimensional; M – must-be; I – indifferent; R – reverse; Q – questionable.

After obtaining the KANO attribute of each sub-indicator i of URTPSQ, the sub-indicators with KANO attributes of indifferent (I), reverse (R) and questionable (Q) should be removed, because the three sub-indicators have no effect on the improvement of passenger service quality. Only the sub-indicators with KANO attributes of attractive (A), one-dimensional (O) and must-be (M) should be remained, the remained sub-indicators form the KANO service quality indicators of URTPSQ. For each KANO service quality indicator $j \left(j = 1, 2, 3, ..., J\right)$ with KANO attribute $k \left(k \in \left\{A, O, M\right\}\right)$, using the sensitivity degree d_j^k to analyse each KANO service quality indicator:

- firstly, calculate the satisfaction level SI_j^k of each service quality indicator j;
- secondly, calculate the dissatisfaction level DSI_j^k of each service quality indicator j;
- finally, calculate the sensitivity degree d_j^k:

$$SI_j^k = \frac{N_A^j + N_O^j}{N_A^j + N_O^j + N_M^j + N_I^j}, \ \forall j, k; \tag{5}$$

$$DSI_j^k = -\frac{N_M^j + N_O^j}{N_A^j + N_O^j + N_M^j + N_I^j}, \ \forall j, k; \tag{6}$$

$$d_j^k = \sqrt{\left(SI_j^k\right)^2 + \left(DSI_j^k\right)^2}, \ \forall j, k, \tag{7}$$

where: N_A^j, N_O^j, N_M^j, N_I^j are the response statistics number of attractive (A), one-dimensional (O), must-be (M) and indifferent (I) according to the KANO questionnaires. After that, rank each KANO service quality indicator j $\left(j = 1, 2, 3, ..., J\right)$ with KANO attribute $k\left(k \in \left\{A, O, M\right\}\right)$, $rank\left(d_j^k\right)$ is applied to represent the rank value of each KANO service quality indicator. The higher rank value is, the higher sensitivity of the KANO service quality indicator has, which means the urban rail transit operation department should pay more attentions to improve the KANO service quality indicator.

3.2. Using Entropy–TOPSIS method to calculate the satisfaction degree of KANO service quality indicators

Next the actual PS degree of each KANO service quality indicator should be obtained. After analysing the PS degree and the sensitivity degree d_j^k of service quality indicator comprehensively, the KANO service quality indicators need to be improved in urban rail transit service can be determined. A KANO service quality indicators satisfaction questionnaire is designed to obtain the initial data, the survey respondents are passengers. For each KANO service quality indicator j, using 1…9 to score the satisfaction degree, higher score value means the passengers are more satisfied with this service quality indicator. Then the EWM is used to calculate the weight of each KANO service quality indicator, TOPSIS method is used to obtain the satisfaction degree rank of each KANO service quality indicator.

The EWM is based on Shannon entropy, originally developed by Shannon (Shannon, Weaver 1971). Shannon entropy is a concept, which is proposed as a measure of uncertainty in information, formulated in terms of probability theory. The concept of entropy is well suited to measure the relative intensities of contrast criteria in order to represent the average intrinsic information transmitted for decision-making (Zeleny 1976). The method was applied to describe the thermodynamics information systems by Shannon (2001). The uncertainty of signals in communication processes is called information entropy; the lower the information entropy is, the higher the weight is. For each KANO service quality indicator $j\left(j = 1, 2, 3, ..., J\right)$ with $k\left(k \in \left\{A, O, M\right\}\right)$, the passenger $s\left(s = 1, 2, 3, ..., S\right)$ provides effective evaluation value $u_{j,s}^k$ $\left(u_{j,s}^k \in \left[1, 9\right]\right)$, then information decision matrix $U^k = \left[u_{j,s}^k\right]_{J\times S}$ can be established:

$$U^k = \left[u_{j,s}^k\right]_{J\times S} = \begin{bmatrix} u_{1,1}^k & u_{2,1}^k & \cdots & u_{J-1,1}^k & u_{J,1}^k \\ u_{1,2}^k & u_{2,2}^k & \cdots & u_{J-1,2}^k & u_{J,2}^k \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ u_{1,S}^k & u_{2,S}^k & \cdots & u_{J-1,S}^k & u_{J,S}^k \end{bmatrix}, \forall k. \tag{8}$$

Standardized the information decision matrix according to Equation (9) (when the indicators are benefit-type) and Equation (10) (when the indicators are cost-type), the standard information matrix $\bar{U}^k = \left[\bar{u}_{j,s}^k\right]_{J\times S}$ can be obtained:

$$\bar{u}_{j,s}^k = \frac{u_{j,s}^k - \min u_{j,s}^k}{\max u_{j,s}^k - \min u_{j,s}^k}, \ \forall j, s, k; \tag{9}$$

$$\bar{u}_{j,s}^k = \frac{\max u_{j,s}^k - u_{j,s}^k}{\max u_{j,s}^k - \min u_{j,s}^k}, \ \forall j, s, k, \tag{10}$$

where: $\min u_{j,s}^k$ is the minimum value of $u_{j,s}^k$; $\max u_{j,s}^k$ is the maximum value of $u_{j,s}^k$; $\min u_{j,s}^k \neq \max u_{j,s}^k$.

Then the probability of each $u_{j,s}^k$ is calculated:

$$p_{j,s}^k = \frac{\bar{u}_{j,s}^k}{\sum_{s=1}^{S} \bar{u}_{j,s}^k}, \forall j, s, k. \tag{11}$$

The information entropy for each indicator is defined as:

$$H_j^k = -\frac{1}{\ln S} \cdot \sum_{s=1}^{S}\left(p_{j,s}^k \cdot \ln p_{j,s}^k\right), \forall j, k, \tag{12}$$

and the weight obtained from information entropy is expressed as follows:

$$\varpi_j^k = \frac{1 - H_j^k}{\sum_{j=1}^{J}\left(1 - H_j^k\right)}, \forall j, k, \tag{13}$$

where: $\varpi_j^k \in \left[0, 1\right]$, and $\sum_{j=1}^{J} \varpi_j^k = 1$.

Next the TOPSIS method is used to obtain the satisfaction degree rank of each KANO service quality indicator. As a tool for decision analysis, TOPSIS attempts to choose alternative that should simultaneously have the closest distance from the positive ideal solution and the farthest distance from the negative ideal solution, which has been widely applied in the past decades with satisfactory results (Kuo 2017; Walczak, Rutkowska 2017). TOPSIS belongs to an objective and quantitative rank approach, the final difference value between the sensitivity degree rank and the satisfaction degree rank of each KANO service quality indicator obtained by Entropy–TOPSIS method is more accurate, objective, and not influenced by experience or knowledge from the evaluators or experts. The procedure of TOPSIS consists of the following six steps:

- normalize the decision matrix;
- compute the weighted normalized decision matrix;
- determine the *positive ideal solution* and the *negative ideal solution*;
- calculate the separations of an alternative from the *positive ideal solution* and the *negative ideal solution*;
- calculate the rank indicator;
- arrange the rank indicator in a descending order to obtain the best alternative.

Calculate weighted matrix $R^k = \left[r_{j,s}^k \right]_{J \times S}$ according to Equation (8) and Equation (13):

$$r_{j,s}^k = \varpi_j^k \cdot u_{j,s}^k, \ \forall j,s,k. \quad (14)$$

For each KANO service quality indicator, calculate *positive ideal solution* $\left(T_s^k\right)^+$ and *negative ideal solution* $\left(T_s^k\right)^-$:

$$\left(T_s^k\right)^+ = \max\left(r_{j,1}^k, r_{j,2}^k, r_{j,3}^k, \ldots, r_{j,s}^k\right), \ \forall j,k; \quad (15)$$

$$\left(T_s^k\right)^- = \min\left(r_{j,1}^k, r_{j,2}^k, r_{j,3}^k, \ldots, r_{j,s}^k\right), \ \forall j,k. \quad (16)$$

For each KANO service quality indicator, calculate the Euclidean distance with $\left(T_s^k\right)^+$ and $\left(T_s^k\right)^-$:

$$\left(sep_j^k\right)^+ = \sqrt{\sum_{s=1}^{S} \left(\left(T_s^k\right)^+ - r_{j,s}^k \right)^2}, \ \forall j,k; \quad (17)$$

$$\left(sep_j^k\right)^- = \sqrt{\sum_{s=1}^{S} \left(\left(T_s^k\right)^- - r_{j,s}^k \right)^2}, \ \forall j,k. \quad (18)$$

Finally, calculate the comprehensive satisfaction degree C_j^k:

$$C_j^k = \frac{\left(sep_j^k\right)^-}{\left(sep_j^k\right)^+ + \left(sep_j^k\right)^-}, \ \forall j,k, \ C_j^k \in [0,1]. \quad (19)$$

The higher comprehensive satisfaction degree C_j^k means the higher TOPSIS score rank $rank\left(C_j^k\right)$, shows the KANO service quality indicator satisfies passenger's demand, and the service quality of the indicator is better. The difference θ_j^k between the rank value of sensitivity degree $rank\left(d_j^k\right)$ and the rank value of PS degree $rank\left(C_j^k\right)$ is used to analyse the KANO service quality indicator, the smaller value of θ_j^k means this service quality indicator need to be improved as soon as possible:

$$\theta_j^k = rank\left(d_j^k\right) - rank\left(C_j^k\right), \ \forall j,k. \quad (20)$$

4. Case study

Now a case study is conducted by taking the Chengdu subway system in China as a background. The layout of the network is shown in Figure 2 (2 June 2017). The average daily passenger flow of the Chengdu subway system in 2017 has reached 2.1425 million.

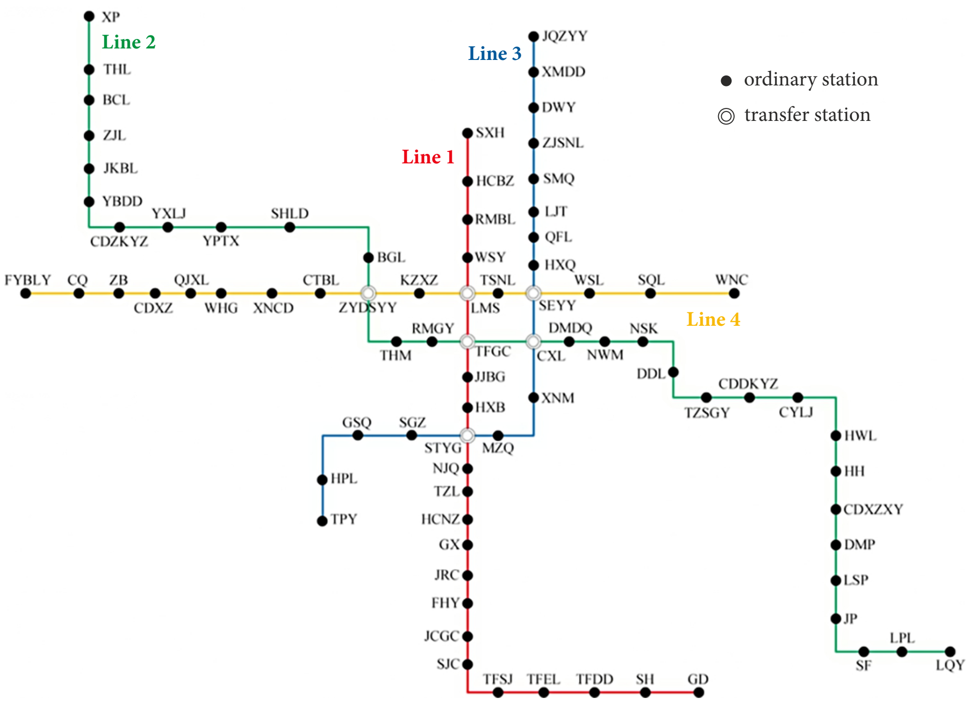

Figure 2. The layout of the network of Chengdu subway system (2 June 2017) (Huang *et al.* 2018b)

We carried out the KANO questionnaire investigation in the 6 transfer stations (Chengdu University of TCM and Sichuan Provincial People's Hospital: ZYDSYY; Luomashi: LMS; Second Municipal Hospital: TFGC; Tianfu Square: TFGC; Chunxi Road: CXL; the Provincial Stadium: SEYY) in 15 June 2017. With the help of the urban rail transit operators and the members of the TTEECIC, the investigators issued 200 questionnaires in each station, and obtained a total of 979 valid questionnaires. After that, the results are counted and calculated by the members of TTEECIC. The results of the KANO attributes are shown in Table 3 (according to Equations (1)–(4)).

After analysing the KANO attributes of the 24 sub-indicators, the following conclusions can be found: there are 5 sub-indicators belong to attractive (A); 6 sub-indicators belong to one-dimensional (O); 9 sub-indicators belong to must-be (M); 4 sub-indicators belong to indifferent (I); there is no sub-indicator belongs to reverse (R) or questionable (Q). After removing the four Indifferent sub-indicators, the Chengdu subway KANO service quality evaluation system is formed, the KANO service quality indicators of URTPSQ are shown as follows:

- ***attractive*** (A): the interior decoration in the station and passenger coach (j = 1), time-interval of train departure (j = 2), complaint handling satisfaction of urban rail transit enterprises (j = 3), transfer on the same floor in the station (j = 4), the availability of disability facilities (j = 5);
- ***one-dimensional*** (O): the temperature in the station and passenger coach (j = 1), the light intensity in the station and passenger coach (j = 2), the air quality in the station and passenger coach (j = 3), service quality of staffs of urban rail transit enterprises (j = 4), transfer time (j = 5), the transfer distance (j = 6);
- ***must-be*** (M): the cleanness in the station and passenger coach (j = 1), passenger guiding signs of station entrance (j = 2), passenger guiding information signs in the station and passenger coach (j = 3), safety warning signs in the station and passenger coach (j = 4), security in the station and passenger coach (j = 5), the working condition of vending machines (j = 6), the working condition of escalator and stair (j = 7), the working condition of safety gates (j = 8), the working condition of automatic check-in gates (j = 9).

Then the satisfaction level SI_j^k, the dissatisfaction level DSI_j^k and the sensitivity d_j^k of each KANO service quality indicator are calculated, the results are shown in Table 4.

After analysing the results presented in Table 4, the following conclusions can be obtained:

- the must-be (M) KANO service quality indicators of Chengdu subway passenger service are the most sensitive, because the sensitivity degree d_j^k of all ser-

Table 3. The results of the KANO attributes of Chengdu subway system

Indicator	Sub-indicator	K_A^i [%]	K_O^i [%]	K_M^i [%]	K_I^i [%]	KANO attribute
Environment in the station and passenger coach	i = 1	3.6	40.7	47.9	7.8	M
	i = 2	23.3	35.5	25.4	15.8	O
	i = 3	20.2	37.1	31.1	11.6	O
	i = 4	30.8	40.9	10.1	18.2	O
	i = 5	35.6	21.7	21.5	21.2	A
Passenger guiding information	i = 6	21.0	38.5	39.9	0.6	M
	i = 7	26.6	31.9	37.0	4.5	M
	i = 8	13.3	36.1	49.7	0.9	M
Service	i = 9	10.5	10.9	23.5	55.1	I
	i = 10	16.3	10.2	31.9	41.6	I
	i = 11	40.8	14.9	19.8	24.5	A
	i = 12	20.8	33.1	39.7	6.4	M
	i = 13	9.5	9.5	10.1	70.9	I
	i = 14	21.7	36.6	31.4	10.3	O
	i = 15	46.0	11.8	12.2	30.0	A
	i = 16	33.0	0.0	0.0	67.0	I
Passenger transfer	i = 17	24.3	34.1	31.1	10.5	O
	i = 18	23.3	36.5	30.1	10.1	O
	i = 19	49.8	20.2	9.8	20.2	A
Facilities and equipment	i = 20	21.9	33.4	44.7	0.0	M
	i = 21	20.1	34.1	40.9	4.9	M
	i = 22	17.4	31.1	50.9	0.6	M
	i = 23	39.9	10.8	25.6	23.7	A
	i = 24	19.1	29.6	51.3	0.0	M

Notes: A – attractive; O – one-dimensional; M – must-be; I – indifferent; R – reverse; Q – questionable.

Table 4. Satisfaction level, dissatisfaction level, sensitivity of indicator and its ranks of KANO service quality indicators

KANO attribute	indicator	SI_j^k	DSI_j^k	d_j^k	$rank\left(d_j^k\right)$
Attractive (A)	j = 1	0.573	−0.432	0.718	2
	j = 2	0.557	−0.347	0.656	3
	j = 3	0.578	−0.240	0.626	4
	j = 4	0.700	−0.300	0.762	1
	j = 5	0.507	−0.364	0.624	5
One-dimensional (O)	j = 1	0.588	−0.609	0.847	6
	j = 2	0.573	−0.682	0.891	3
	j = 3	0.717	−0.510	0.880	5
	j = 4	0.583	−0.680	0.896	1
	j = 5	0.584	−0.652	0.875	4
	j = 6	0.598	−0.666	0.895	2
Must-be (M)	j = 1	0.443	−0.886	0.991	1
	j = 2	0.595	−0.784	0.984	3
	j = 3	0.585	−0.689	0.904	9
	j = 4	0.494	−0.858	0.990	2
	j = 5	0.539	−0.728	0.906	8
	j = 6	0.553	−0.781	0.957	4
	j = 7	0.542	−0.750	0.925	7
	j = 8	0.485	−0.820	0.953	5
	j = 9	0.487	−0.809	0.944	6

vice quality indicators are more than 0.9. The most sensitive service quality indicator is the cleanness in the station and passenger coach (j = 1). The most insensitive service quality indicator is passenger guiding information signs in the station and passenger coach (j = 3);

- the one-dimensional (O) KANO service quality indicators of Chengdu subway passenger service are the secondary sensitive, because the sensitivity degree d_j^k of all service quality indicators are 0.8…0.9. The most sensitive service quality indicator is service quality of staffs of urban rail transit enterprises (j = 4), and the most insensitive service quality indicator is the temperature in the station and passenger coach (j = 1);
- the attractive (A) KANO service quality indicators of Chengdu subway passenger service are the most insensitive, because the sensitivity degree d_j^k of all service quality indicators are 0.6…0.8. The most sensitive service quality indicator is the transfer on the same floor in the station (j = 4), and the most insensitive service quality indicator is the availability of disability facilities (j = 5);
- Chengdu subway operation enterprise should firstly pay attention to the passengers' must-be (M) demand, improve the service quality that enterprise is obliged to do, and ensure the issue raised by passengers to be valued and resolved. After that, Chengdu subway operation enterprise should try their best to satisfy the one-dimensional (O) demand of passengers, because one-dimensional (O) service quality is a competitive factor for Chengdu subway operation enterprise, which guiding passengers to strengthen good impression on Chengdu subway and making passengers satisfied. Finally, try to meet the attractive (A) demand of the passengers and establish the most loyal passenger group for the Chengdu subway.

After that, a KANO service quality indicators satisfaction questionnaire is designed to obtain the initial data. The survey respondents are passengers. For each KANO service quality indicator j, use 1…9 to score the satisfaction degree. In addition, we carried out the questionnaire investigation in the 6 transfer stations (Chengdu University of TCM and Sichuan Provincial People's Hospital: ZYDSYY; Luomashi: LMS; Second Municipal Hospital: TFGC; Tianfu Square: TFGC; Chunxi Road: CXL; the Provincial Stadium: SEYY) in 20 June 2017. Under the help of the urban rail transit operators and the members of TTEECIC, the investigators issued 200 questionnaires in each station, and obtained a total of 921 valid questionnaires. After that, the results are counted and calculated by the members of TTEECIC. The weight of each KANO service quality indicator, TOPSIS calculation value and its rank, the difference θ_j^k between the rank value of sensitivity degree $rank\left(d_j^k\right)$ and the rank value of PS degree $rank\left(C_j^k\right)$ are shown in Table 5 (for attractive (A)), Table 6 (for one-dimensional (O)) and Table 7 (for must-be (M)).

Table 5. The weight, TOPSIS calculation value and its rank, θ_j^k of each attractive (A) KANO service quality indicator

Indicator	Weight	TOPSIS value	$rank\left(C_j^k\right)$	$rank\left(d_j^k\right)$	θ_j^k
j = 1	0.197	0.681	1	2	1
j = 2	0.058	0.169	4	3	–1
j = 3	0.209	0.257	2	4	2
j = 4	0.318	0.057	5	1	–4
j = 5	0.218	0.250	3	5	2

Table 6. The weight, TOPSIS value and its rank, θ_j^k of each one-dimensional (O) KANO service quality indicator

Indicator	Weight	TOPSIS value	$rank\left(C_j^k\right)$	$rank\left(d_j^k\right)$	θ_j^k
j = 1	0.138	0.347	3	6	3
j = 2	0.097	0.268	4	3	–1
j = 3	0.124	0.578	1	5	4
j = 4	0.176	0.158	6	1	–5
j = 5	0.198	0.236	5	4	–1
j = 6	0.267	0.387	2	2	0

Table 7. The weight, TOPSIS calculation value and its rank, θ_j^k of each must-be (M) KANO service quality indicator

Indicator	Weight	TOPSIS value	$rank\left(C_j^k\right)$	$rank\left(d_j^k\right)$	θ_j^k
j = 1	0.199	0.044	7	1	–6
j = 2	0.096	0.851	2	3	1
j = 3	0.057	0.368	6	9	3
j = 4	0.201	0.527	5	2	–3
j = 5	0.157	0.637	3	8	5
j = 6	0.068	0.038	8	4	–4
j = 7	0.012	0.582	4	7	3
j = 8	0.185	0.982	1	5	4
j = 9	0.025	0.027	9	6	–3

The calculation results in Table 5 show that:

- the weight of transfer on the same floor in the station (j = 4) is the largest, indicating that this indicator is the most important among the attractive (A) KANO demand indicator system. The weight of time-interval of train departure (j = 2) is the smallest, indicating that this indicator is the most unimportant among the attractive (A) KANO demand indicator system;
- the results of TOPSIS calculation show that passengers are most satisfied with the interior decoration in the station and passenger coach (j = 1), because the TOPSIS value of this indicator is the highest. Chengdu subway has done a great deal of works in the interior decoration in the station and passenger coach, such as the panda ambassador artistic theme wall in Panda Avenue Station Hall and the red arch image in Hongpailou Station, which has a strong

urban style and a high degree of recognition. The most dissatisfied one is transfer on the same floor in the station (j = 4), because the TOPSIS value of this indicator is the smallest;
- transfer on the same floor in the station (j = 4) has the smallest θ_j^k, the sensitivity degree of this indicator is the highest but the TOPSIS value is the lowest, which means it is the indicator need to be improved as soon as possible. Passengers are satisfied with two indicators, complaint handling satisfaction (j = 3) and the availability of disability facilities (j = 5), the θ_j^k of the two indicators is 2, furthermore, the sensitivity degrees are low, hence the two indicators are the final consideration to improve. Chengdu subway operation enterprises should pay more attentions to the improvement of indicators with highest sensitivity degree and lowest TOPSIS value.

The calculation results in Table 6 show that:
- the weight of the transfer distance (j = 6) is the largest, indicating that this indicator is the most important among the one-dimensional (O) KANO demand indicator system. The weight of the light intensity in the station and passenger coach (j = 2) is the smallest, indicating that this indicator is the most unimportant in the one-dimensional (O) KANO demand indicator system;
- the calculation results of TOPSIS show that passengers are most satisfied with the air quality in the station and passenger coach (j = 3), because the TOPSIS value of this indicator is the highest. The most dissatisfied indicator is service quality of staffs of urban rail transit enterprises (j = 4), because the TOPSIS value of this indicator is the smallest;
- service quality of staffs of urban rail transit enterprises (j = 4) has the smallest θ_j^k, the sensitivity degree of this indicator is the highest but the TOPSIS value is the lowest, this is the indicator need to be improved as soon as possible. Passengers are satisfied with the air quality in the station and passenger coach (j = 3), and the sensitivity degree of the indicator is low, hence the indicator is the final consideration to improve. Chengdu subway operation enterprises should pay more attentions to the improvement of indicators with highest sensitivity degree and lowest TOPSIS value.

The calculation results in Table 7 show that:
- the weight of safety warning signs in the station and passenger coach (j = 4) is the largest, indicating that this indicator is the most important among the must-be (M) KANO demand indicator system. The weight of the working condition of escalator and stair (j = 7) is the smallest, indicating that this indicator is the most unimportant in the must-be (M) KANO demand indicator system;
- the calculation results of TOPSIS show that passengers are most satisfied with the working condition of the safety gates (j = 8), because the TOPSIS value of this indicator is the highest. The most dissatisfied indicator is the working condition of automatic check-in gates (j = 9), because the TOPSIS value of this indicator is the smallest;
- the cleanness in the station and passenger coach (j = 1) has the smallest θ_j^k, the sensitivity degree of this indicator is the highest but the TOPSIS value is the lowest, this is the indicator that need to be improved as soon as possible. Passengers are satisfied with the security in the station and passenger coach (j = 5), and the sensitivity degree of the indicator is low, hence the indicator is the final consideration to improve. Chengdu subway operation enterprises should pay more attentions to the improvement of indicators with highest sensitivity degree and lowest TOPSIS value.

Conclusions

According to the field research and comprehensive evaluation of the URTPSQ, we can find the shortage of urban rail transit passenger service, find out the difference between the actual service situation and the passenger's expectation and demand, and provide passengers with better travel services. In this paper, a KANO–Entropy–TOPSIS model is proposed to solve the problem. Firstly, KANO model can select the service quality indicators from the 24 URTPSQ evaluation sub-indicators, according to the selection results the KANO service quality indicators of URTPSQ can be constructed. Then the sensitivity of KANO service quality indicators based on KANO model is calculated and ranked, the PS of each KANO service quality indicator by using Entropy–TOPSIS method is calculated and ranked. Based on the difference between the sensitivity degree rank and the satisfaction degree rank of each KANO service quality indicator, determine the service quality KANO indicators of URTPSQ that need to be improved significantly.

A case study is conducted by taking the Chengdu subway system in China as a background, the calculation results show that:
- Chengdu subway operation enterprise should firstly pay attention to the passengers' must-be (M) demand, improve the service quality that enterprise is obliged to do, and ensure the issue raised by passengers to be valued and resolved. After that, Chengdu subway operation enterprise should try their best to satisfy the one-dimensional (O) demand of passengers, because one-dimensional (O) service quality is a competitive factor for Chengdu subway operation enterprise, which guiding passengers to strengthen good impression on Chengdu subway and making passengers satisfied. Finally, try to meet the attractive (A) demand of the passengers and establish the most loyal passenger group for the Chengdu subway;
- transfer on the same floor in the station need to be improved as soon as possible. Passengers are satisfied with two indicators, complaint handling satis-

faction and the availability of disability facilities, the two indicators are the final consideration to improve;
- service quality of staffs need to be improved as soon as possible. Passengers are satisfied with the air quality in the station and passenger coach, the indicator is the final consideration to improve;
- the cleanness in the station and passenger coach need to be improved as soon as possible. Passengers are satisfied with the security in the station and passenger coach, the indicator is the final consideration to improve.

For the managers and operators of urban rail transit system, the passengers' must-be (M) demand should be satisfied first if the KANO model is applied to evaluate the service. The indicators with highest sensitivity degree and lowest TOPSIS value should be improved based on the KANO–Entropy–TOPSIS model. Next, the relevant policies, traffic situation, etc., which may have an influence when evaluating urban rail transit passenger demand satisfaction, hence these issues can be discussed in the further. In addition, the KANO–Entropy–TOPSIS proposed in this paper is also can be used to evaluate the service level in other industries, e.g., aviation industry, railway industry.

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