AN EVALUATION MODEL FOR PASSenger HUB UNDER FUZZY ENVIRONMENT

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This paper aims to propose a modelling framework for service quality evaluation of passenger hub under fuzzy environment, i.e., when valuators cannot quantify all criteria accurately. The research problem is to evaluate the operation status of passenger hub that maximizes the service level, including not only quantitative index but also qualitative index. A mixed-model combined the Grey Relational Analysis (GRA) and VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) has been developed to solve the problem in a fuzzy environment where both criteria and weights could be fuzzy sets. An empirical study for evaluating service quality of three passenger hubs in different times was put forth to illustrate an application of the proposed model. The results reveal a number of interesting insights into service level evaluation, namely, this study has instructive significance in management practice.

Keywords: fuzzy environment; service quality; evaluate; combined-model

1. Introduction

A critical factor in evaluating the performance of urban traffic network is the service quality in the transport hub, which essentially contains not only quantitative index but also qualitative index. With the rapid development of urban traffic network, passenger hub is becoming a distribution centre with different transport modes and large-scale passenger flow, namely, the service level and efficiency of hub directly determine the performance of urban traffic network bring into play.

The transfer is the core service supplied by passenger hub; that is why so many existing studies focus on how to evaluate and improved its efficiency. In fact, there are three main bodies of literatures to the research presented in this paper. The first is the literature on planning program, most often applied to find the best design for hubs in a macro perspective. Demetsky et al. [1] focused on the procedures, which can be used to establish policy for station features, to provide performance measures for subsystems, and to give cost estimates. Alexandre and Wirasinghe [2] did an analysis with a special case, which performed individually for a single pier, several types of pier-satellites, and a set of remote parallel piers connected by an automated people mover (APM).

The second concerns the transfer model in a mid-scale view, which are frequently focus on the efficiency measurement, improved lines, and other things to optimal the passenger organization process. Lee and Schonefd [3] proposed optimization of various transportation modes’ slack time to enhance transfer efficiency by researching the transfer relationship of modes. Some scholars [4, 5] used simulate analysis to discuss passenger flow in hubs and found the efficiency bottleneck.

Finally, further research discussed the approaches for comprehensive service quality of hubs since they just considered one kind of equipment before [6, 7]. Yan et al. [8] developed an integer programming model to assist airport authorities to assign common use check-in counters. Raik [9] addressed operation models for workforce planning for check-in systems at airport and developed a binary linear programming formulation. As we can see, the research for hubs has become an important issue in each city [10-15].Some researchers tried to evaluate the service of the hub [16, 17]. Tsaur et al. invited fuzzy set theory into the measurement of performance [18], while one new method of measuring perceived service quality based on triangular fuzzy numbers were proposed by Chien and Tsai [19].

In fact, our mixed model can be seen as an outgrowth of these literatures. However, they did not propose comprehensive evaluation for the hubs transfer service, not to mention the method combined the
subjective and objective. Scientific evaluation has important realistic significance for transfer service quality, which could reflect the operation status directly. To bridge this research gap, this paper proposes a new comprehensive evaluation model under fuzzy environment.

The remainder of the paper is organized as follows. Section 2 proposes a mixed-model combined VIKOR and GRA under fuzzy environment, which considers as a decision matrix to carry out program optimization. Section 3 conducts case studies to test the model, and we get the final comprehensive evaluation index value and ranking order. Compared the SIV orders and service orders with the results, the applicability of the evaluation model can be proved. Section four makes concluding remarks and briefly discusses future research directions.

2. Model Formulation

2.1. GRA Methods

GRA is a grey correlation order to describe the relationship between the order of the strength, size, sequence and some other factors. Compared with the traditional multi-factor analysis (correlation, regression, etc.), the grey correlation analysis demands lower and calculate smaller, especially under the fuzzy environment, and that is why it is easy to be widely used.

GRA method was originally developed in 1982. This method is successfully applied in solving a variety of multiple attribute decision-making problems, such as the hiring decision, the restoration planning for power distribution systems, the inspection of integrated-circuit marking process, the modelling of quality function deployment, etc. GRA decides the best and ideal one by defining the similarity among each option. The option is more preferred if it has more similarity. The procedure of GRA is shown in Figure 1.

![Figure 1. Procedure of grey relational analysis](image)

Let \( X = \{x_1, x_2, \ldots, x_j, \ldots, x_n, j = 1,2,3,\ldots,n\} \) denote the set of given various alternatives. For an alternative \( x_j \), the rating of the \( i \)-th aspect is denoted by \( f_{ij} \), that is, \( f_{ij} \) is the value of \( i \)-th criterion function for the alternative \( x_j \). \( m \) is the number of criteria, \( i = 1,2,3,\ldots,m \). Then we can calculated the grey relation coefficient \( \gamma(f_{i1}, f_{ij}) \) of these alternatives at point \( i \) as follows

\[
\gamma(f_{i1}, f_{ij}) = \frac{\min_j \Delta_{ij} + \zeta \max_j \Delta_{ij}}{\Delta_{ij} + \zeta \max_j \Delta_{ij}},
\]

(1)

where \( \Delta_{ij} = |f_{i1} - f_{ij}| \), and \( \zeta \) is the resolving coefficient \( \zeta \in [0,1] \).

The grade of grey relation \( \gamma(f_{i1}, f_{ij}) \) between \( x_i \) and \( x_j \) can be calculated:

\[
\gamma(f_{i1}, f_{ij}) = \sum_{i=1}^{m} w_i \gamma(f_{i1}, f_{ij}),
\]

(2)
where $w_i$ denotes the weight of point/factor $i$, and $\sum_{i=1}^{m} w_i = 1$.

2.2. VIKOR Methods

VIKOR method tries to maximize the community benefits and minimize the negative effects in the multi-attribute decision calculation, and that is why it could be accepted by compromise solution, which is an optimization method suitable for the comprehensive evaluation calculation process.

The VIKOR method was proposed by Opricovic [20], who introduced the multicriteria ranking index based on the particular measure of “closeness” to the “ideal” solution. The basic concept of VIKOR is to define the ideal solution (positive) and negative ideal solution (negative) at first. Here, the ideal solution is the best value of the alternative criteria in the assessment while the negative ideal solution means the worst.

We use the same assumption, which mentioned in the previous section, and the VIKOR method started with the following form of $L_p$-metric:

$$L_{pj} = \left[ \sum_{i=1}^{m} \left( w_i \left( f_{ij}^* - f_{ij} \right) / \left( f_{ij} - f_{ij}^- \right) \right)^p \right]^{1/p}, \quad 1 \leq p \leq \infty; \quad j = 1, 2, ..., n. \tag{3}$$

Let $F^+$ be the ideal solution, $F^-$ be the negative ideal solution, and $F^c$ be the feasible solution which is “closest” to $F^*$. Each value $f_{ij}^* \in F^*$ is the best one in all alternatives, and $f_{ij}^- \in F^-$ is the worst one in all alternatives. We can get the compromise as an agreement established by mutual concessions (Figure 1): $\Delta f_1 = f_{i1}^* - f_{i1}^c$, $\Delta f_2 = f_{i2}^* - f_{i2}^c$.

![Figure 2. Ideal and compromise solution](image)

We will first briefly review the steps of VIKOR method as follows:

1. Determine the best $f_{ij}^*$ and the worst $f_{ij}^-$ values of all criterion functions. Assuming that $i$-th criterion function represents a benefit:

$$f_{ij}^* = \max_j f_{ij}, \quad f_{ij}^- = \min_j f_{ij}, \quad i = 1, 2, ..., m.$$  

2. Compute the values $S_j$ and $R_j$, by the relations

$$S_j = \sum_{i=1}^{m} w_i \left( f_{ij}^* - f_{ij} \right) / \left( f_{ij}^* - f_{ij}^- \right), \quad j = 1, 2, ..., n, \tag{4}$$

$$R_j = \max_i \left[ \left( f_{ij}^* - f_{ij} \right) / \left( f_{ij}^* - f_{ij}^- \right) \right], \quad j = 1, 2, ..., n, \tag{5}$$

here $w_i$ are the weights of criteria, expressing the relative importance of each criterion.

3. Compute the values $Q_j$, which are defined as
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\[ Q_j = v \left( S_j - S^* \right) / \left( S^* - S' \right) + (1-v) \left( R_j - R^* \right) / \left( R^* - R' \right), \quad j = 1, 2, \ldots, n, \]

where \( S^* = \min_j S_j, \quad S' = \max_j S_j, \quad R^* = \min_j R_j, \quad R' = \max_j R_j. \) \( v \) is the weight of the strategy of “the majority of criteria”, whereas \( (1-v) \) is the weight of the individual regret.

2.3. The Combined-Model

Based on the previous introduction of VIKOR and GRA, we will propose the mixed-model combined these methods in this section. As we have discussed before, the most important aspect in the complex decision is the vague information under our fuzzy environment. Therefore, our mixed-model employs a major technique of GRA theory to deal with the vague information as the first step.

Here, some grades of qualitative criteria will be considered as linguistic terms, which can be expressed in fuzzy numbers, as shown in Table 1. Instead of the given weight, the Buckley’s fuzzy AHP method is used to calculate them, as this method can allow fuzzy numbers for pairwise comparisons verified and satisfy fundamental consistency requirements.

### TABLE 1. Linguistic terms for the fuzzy ratings

| Very poor (VP) | (0,0,1) |
| Poor (P) | (0,1,3) |
| Medium poor (MP) | (1,3,5) |
| Fair (F) | (3,5,7) |
| Medium good (MG) | (5,7,9) |
| Good (G) | (7,9,10) |
| Very good (VG) | (9,10,10) |

A fuzzy positive reciprocal matrix \( \tilde{C} = [\tilde{c}_{ij}] \) is considered in Buckley’s fuzzy AHP method, which defines the fuzzy geometric mean of each row \( \tilde{g}_i \) and fuzzy weight \( \tilde{w}_i \) corresponding to each criterion.

It is assumed that an evaluation problem contains \( m \) possible alternatives and \( n \) criteria as before, and the formulae can be written as follows:

\[ \tilde{g}_i = (\tilde{c}_{i1}, \tilde{c}_{i2}, \ldots, \tilde{c}_{im})^{1/n}, \quad \tilde{w}_i = \tilde{g}_i \cdot (\tilde{g}_1 \times \tilde{g}_2 \times \ldots \times \tilde{g}_m)^{-1} \]

(7)

where \( \tilde{w}_i \) can be indicated by a triangular fuzzy number 2.4. \( \tilde{w}_i = (w_i^n, w_i^m) \)

A decision group has \( K \) judges and each rating (performance value) of alternatives can be calculated as follows:

\[ \tilde{f}_{ij} = \frac{1}{K} \left[ \tilde{f}_{ij}^1(+) \tilde{f}_{ij}^2(+) \ldots \tilde{f}_{ij}^K(+) \right] = \frac{1}{K} \sum_{t=1}^{K} \tilde{f}_{ij}^t \]

(8)

where \( \tilde{f}_{ij}^t \) is the fuzzy rating assigned by the \( t \)-th judge.

Then we get the fuzzy judgment matrix, which can be described as follows:

\[ \tilde{D} = \begin{bmatrix} \tilde{f}_{11} & \ldots & \tilde{f}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{f}_{m1} & \ldots & \tilde{f}_{mn} \end{bmatrix} = [\tilde{f}_{ij}]_{m \times n}, \quad \tilde{w} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_m], \]

(9)

where \( \tilde{f}_{ij} \) is the fuzzy rating of possible alternative, and \( \tilde{w}_i \) is the fuzzy weight of criterion \( \tilde{C}_i \). In order to easy to calculate the matrix, we can establish the normalized fuzzy decision matrix which denoted by \( \tilde{R} \).
\[ \tilde{R} = \left[ \tilde{r}_j \right]_{j=1}^n, \]

\[ \tilde{r}_j = \left( f_j^*, f_j^0, 0 \right) \frac{1}{r_j^*}, \text{ if } x_j \in B, \]

\[ \tilde{r}_j = \left( f_j^*, f_j^0, f_j^* \right) \frac{1}{r_j^*}, \text{ if } x_j \in C, \]

(10)

Here, \( r_j^* = \max f_j \), \( f_j^* \) is the lower bound of \( F \), \( f_j^0 \) is the median of \( F \), \( f_j^u \) is the upper bound of \( F \), and \( f_j^- \) is the minimum value of \( F \). \( B \) is the abbreviation of benefit criteria set, and \( C \) means cost criteria set, namely, \( F = B \cup C \).

After completing the performance normalization of various criteria scale, we can define the positive ideal solution \( F^* \) and negative ideal solution \( F^- \) as follows:

\[ F^* = \left[ \tilde{r}_0, \tilde{r}_20, ..., \tilde{r}_n0 \right], \quad F^- = \left[ \tilde{r}_0, \tilde{r}_20, ..., \tilde{r}_n0 \right], \]

where \( \tilde{r}_0 = \max_j(\tilde{r}_j) \), \( \tilde{r}_i = \min_i(\tilde{r}_i) \), \( i = 1, 2, ..., n \).

Then we can use the GRA method to get the grey relation coefficient \( \gamma(\tilde{r}_0^u, \tilde{r}_j) \) for each alternative as follows:

\[ \gamma(\tilde{r}_0^u, \tilde{r}_j) = \frac{\min_j \Delta_j + \zeta \max_j \Delta_j}{\Delta_j + \zeta \max_j \Delta_j} \]

(11)

where \( u = * \), \( \Delta_j = |\tilde{r}_0^u - \tilde{r}_j| \), and \( \zeta \) is the resolving coefficient \( \zeta \in [0,1] \).

At last, we must calculate the value of \( \tilde{S}_j \) and \( \tilde{R}_j \) using the method of VIKOR as follows:

\[ \tilde{S}_j = \sum_{i=1}^{n} \gamma(\tilde{r}_0^i, \tilde{r}_j), \]

\[ \tilde{R}_j = \max_i \gamma(\tilde{r}_0^i, \tilde{r}_j), \]

(12)

where \( i = 1, 2, 3, ..., n \), \( j = 1, 2, 3, ..., m \).

Values of \( \tilde{Q}_j \) can be defined as

\[ \tilde{Q}_j = v \left( \frac{\tilde{S}^* - \tilde{S}_j}{\tilde{S}^* - \tilde{S}} \right) + (1 - v) \left( \frac{\tilde{R} - \tilde{R}_j}{\tilde{R} - \tilde{R}^*} \right), \]

(13)

where \( \tilde{S}^* = \max_j \tilde{S}_j \), \( \tilde{S} = \min_j \tilde{S}_j \), \( \tilde{R}^* = \min_j \tilde{R}_j \), \( \tilde{R} = \max_j \tilde{R}_j \). \( v \) is the weight for the strategy of “the majority of criteria”, whereas \( (1 - v) \) is the weight of the individual regret.

Based on what we discussed in section 2.2, the alternatives can be ranked and our results are three ranking lists by the values \( \tilde{S} \), \( \tilde{R} \), and \( \tilde{Q} \). If an alternative \( x_j \) has the better value of \( \tilde{Q} \), which approaches to 0, it means that it is closer to the positive ideal solution and farther from the negative ideal solution. That is what we are trying to select from a set of feasible alternatives.
Noted that, our rank of \( \widetilde{Q} \) will work only when they satisfied the condition below:

\[
\widetilde{Q}^* - \widetilde{Q}^\prime \geq \frac{1}{(n-1)},
\]

(14)

here, \( \widetilde{Q}^*, \widetilde{Q}^\prime \) are the first and second values in rank of \( \widetilde{Q} \), and \( n \) is the number of alternatives.

3. Case Study

In this section, we will illustrate how the proposed model is applied to a real-world problem by using case study. As the capital of China, Beijing is the centre of National politics, culture, transport, tourism and international exchanges. What’s more, this city has the largest number of passenger hubs, that’s the reason why we choose this city as the study case. Beijing South Railway Station (BRS), Beijing Xizhimen Subway Station (BXZS) and Beijing Xuanwumen Subway Station (BXWS) are selected here as the alternatives, and note that BRS is the largest railway station in Asia. Since the number of passengers affects service quality directly, we choose the different data in both rush and common periods as the different alternatives. Then we get 6 data sets, BRS(rp), BRS(cp), BXZS (rp), BXZS (cp), BXWS (rp), and BXWS (cp).

Five intuitive criteria are listed in Table 2.

<table>
<thead>
<tr>
<th>Evaluation on criteria</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency level ((C_1))</td>
<td>Cost of processing time, can be measured by average queue length</td>
</tr>
<tr>
<td>Unobstructed level ((C_2))</td>
<td>Information display for passengers, can be measured by average stagnate time</td>
</tr>
<tr>
<td>Coordination level ((C_3))</td>
<td>Total number of passenger through</td>
</tr>
<tr>
<td>Security level ((C_4))</td>
<td>Sense of security, like service in case of fire</td>
</tr>
<tr>
<td>Comfort ((C_5))</td>
<td>Air/temperature conditioning, seat congestion</td>
</tr>
</tbody>
</table>

3.1. Alternatives Component Quantification

Although \( C_1 \), \( C_2 \) and \( C_3 \) are quantified indexes, simulation model is established to get these values. On the other side, \( C_4 \) and \( C_5 \) can be obtained by providing survey questionnaires to passengers.

3.1.1. Quantitative Index

There are many existing models to simulate the pedestrian walking behaviour, and we choose social mechanics model, which based on the Newtonian mechanics and pedestrian behaviour propensity as the simulation model here. The method of pedestrian force analysis will be used because of the characteristics of passenger flow in hubs, including high density and self-organization phenomena. The walking parameters can be reset according to different traffic environment, as shown in Figure 3.
The purpose of our simulation is to reproduce the distribution process, which is actually successive and can be divided into many successive time steps $T_i$. Since the simulation is not our focus, we will just show the simulation flow in Figure 4.

As the largest passenger transport hub in Asia, BRS integrates many modes, such as high-speed rail, subway, and some other public transport mode. The facility configuration and simulation region design scheme are shown in Figure 5.
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The model is coded in Python, and all our problem instances are solved at a PC with 3.3 GHz CPU and 4GB RAM by commercial software, Vissim 5.1. The results of the model can be seen in Table 6 and Table 3. Similarly, the simulation results of BXZS and BWXS are listed in Table 4 and Table 5.

**Figure 6. Simulation screenshot**

<table>
<thead>
<tr>
<th>TABLE 3. Simulation results of BRS¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrive number</td>
</tr>
<tr>
<td>20000(cp)</td>
</tr>
<tr>
<td>50000(rp)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 4. Simulation results of BXZS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrive number</td>
</tr>
<tr>
<td>10000(cp)</td>
</tr>
<tr>
<td>15000(rp)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE 5. Simulation results of BXWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrive number</td>
</tr>
<tr>
<td>10000(cp)</td>
</tr>
<tr>
<td>15000(rp)</td>
</tr>
</tbody>
</table>

Now we get the value of $C_1$, $C_2$ and $C_3$ as describe in Table 2.

In order to do the comparative analysis, we proposed one concept of service invalid value (SIV), which can be calculated as the sum of average lost time and stagnate time. As we all known, the service quality and efficiency can be reflect directly with the waiting time, that’s why we will compare the rank order of SIV with our mixed-model results as the authentication.

After calculate all alternatives, we can get the ranking order of the hubs’ SIV as follows: $\text{BRS(cp)} < \text{BXZS(cp)} < \text{BXWS(cp)} < \text{BRS(rp)} < \text{BXZS(rp)} < \text{BXWS(rp)}$.

Although SIV can be mirrored the average service quality of the passenger hub in an easy way, they are in the reverse order. That means the ranking order of service quality is $\text{BRS(cp)} > \text{BXZS(cp)} > \text{BXWS(cp)} > \text{BRS(rp)} > \text{BXZS(rp)} > \text{BXWS(rp)}$.

### 3.1.2. Qualitative Index

Since $C_4$ and $C_5$ are qualitative index which cannot be obtained with exact numbers, we can describe them with linguistic variables as shown in Table 1.

The Questionnaire Survey method is used to get the description of these two criteria. For the

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¹ Here, cp means common period, and rp means rush period.
questionnaires, forms were given randomly to visitors to answer in site, and were taken back to analyse data.

A total of 100 questionnaires were distributed, and 59 were returned (the return rate is 59%), of which 11 were invalid and 48 were valid.

The average fuzzy performance values of our alternatives are listed in the last two columns in Table 6. If we look at these columns and study them for a moment, some interesting insights can be seen.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Overall weights</th>
<th>BNP values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_1$</td>
<td>(0.168,0.192,0.251)</td>
<td>0.204</td>
</tr>
<tr>
<td>$C_2$</td>
<td>(0.157,0.181,0.244)</td>
<td>0.194</td>
</tr>
<tr>
<td>$C_3$</td>
<td>(0.099,0.161,0.191)</td>
<td>0.150</td>
</tr>
<tr>
<td>$C_4$</td>
<td>(0.197,0.303,0.342)</td>
<td>0.281</td>
</tr>
<tr>
<td>$C_5$</td>
<td>(0.128,0.169,0.224)</td>
<td>0.174</td>
</tr>
</tbody>
</table>

According to Eq. (9), the fuzzy normalized decision matrix can be calculated with fuzzy performance matrix $\tilde{D}$ and fuzzy weight matrix $\tilde{w}$. Then, $F^+$ and $F^-$ can be obtained using Eq. (11), and so on. The results are listed in Table 8. ($\zeta = 0.5$)
TABLE 8. The ranking results of combined methods

<table>
<thead>
<tr>
<th></th>
<th>$\tilde{S}$</th>
<th>$\tilde{R}$</th>
<th>$\tilde{Q}_{(v=1)}$</th>
<th>Rank</th>
<th>$\tilde{Q}_{(v=0.5)}$</th>
<th>Rank</th>
<th>$\tilde{Q}_{(v=0)}$</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>common period</td>
<td>BRS</td>
<td>6.3891</td>
<td>0.6831</td>
<td>0.0000</td>
<td>1</td>
<td>0.0000</td>
<td>1</td>
<td>0.0000</td>
</tr>
<tr>
<td></td>
<td>BXZS</td>
<td>5.8796</td>
<td>0.7679</td>
<td>0.3984</td>
<td>3</td>
<td>0.3330</td>
<td>2</td>
<td>0.2676</td>
</tr>
<tr>
<td></td>
<td>BXWS</td>
<td>5.6428</td>
<td>0.8443</td>
<td>0.5836</td>
<td>4</td>
<td>0.5461</td>
<td>4</td>
<td>0.5087</td>
</tr>
<tr>
<td>rush period</td>
<td>BRS</td>
<td>6.0184</td>
<td>0.8274</td>
<td>0.2899</td>
<td>2</td>
<td>0.3726</td>
<td>3</td>
<td>0.4553</td>
</tr>
<tr>
<td></td>
<td>BXZS</td>
<td>5.4831</td>
<td>0.9301</td>
<td>0.7085</td>
<td>5</td>
<td>0.7440</td>
<td>5</td>
<td>0.7794</td>
</tr>
<tr>
<td></td>
<td>BXWS</td>
<td>5.1103</td>
<td>1.0000</td>
<td>1.0000</td>
<td>6</td>
<td>1.0000</td>
<td>6</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

When $v$ value is 1, the $\tilde{Q}$ values of 6 alternatives are 0, 0.3984, 0.5836, 0.2899, 0.7085, and 1, respectively. Therefore, the ranking order of the given hubs in different periods is $\text{BRS(cp)} > \text{BRS(rp)} > \text{BXZS(cp)} > \text{BXWS(cp)} > \text{BXZS(rp)} > \text{BXWS(rp)}$.

It means during common period, the best service level of passenger transport hub is evidenced in BRS(cp). Therefore, BRS hub can provide useful suggestions to improve service quality to other hubs.

Similarly, when $v$ value changes to 0.5, it can be considered as produce ranking order of $\tilde{S}$ and $\tilde{R}$ values, while the ranking order of the given hubs is $\text{BRS(cp)} > \text{BXZS(cp)} > \text{BRS(rp)} > \text{BXWS(cp)} > \text{BXZS(rp)} > \text{BXWS(rp)}$.

Note that, no matter how value of $v$ changed, the value of $\tilde{Q}_{\text{BRS(cp)}}$ is always zero. Namely, the service quality of this alternative is the best in these hubs. At the same time, BXWS(rp) faces the totally opposite situation, which means BXWS’s service quality is the worst.

Finally, we can discuss the practicality of our model by comparing our rank order with rank of SIV and rank of questionnaire survey. They are conformed to each other. Hence, our proposed model is applicable in practice.

More importantly than all of that, these results actually provide some very useful guidance for the management of the passenger hub.

4. Conclusions

In order to optimize the public service management in the passenger transport hub, this paper proposed a mixed evaluation model that considers both qualitative index and quantitative index under the fuzzy environment. Combined with GRA and VIKOR, we formulated a comprehensive model to determine the optimal hub that minimize the total system cost and maximize the system quality.

This model was tested over a number of data sets with different alternatives, and it showed that our model could efficiently solve these instances to the true optimum. Then we analysed the importance of the criteria and conducted a series of sensitivity analysis to show how the rank order changes with parameter values. We have a number of interesting observations from these experiments. For example, no matter how $v$’s value changed, the ranking order is also kind of the same.

This research can be extended in several directions. The commercial solver, though working fine for the tested cases, may fail to solve this model for larger-scale practical problem instances. It will be worthwhile exploring more efficient customized algorithms. This study also has a potential to connect evaluation model with emergency passenger behaviour research. If further data on both operation patterns and human behaviour in passenger hub is available, this model can be applied to more realistic real-world cases, and the results may help understand and improve the service quality of public service systems for all situations.

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