Operation Efficiency Evaluation of Online Taxi-Hailing System

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Abstract. Based on the data mining of the operation system for online taxi-hailing, combined with the requirements of taxi supervision, evaluation and statistical, the paper builds evaluation model of taxi-hailing system operation efficiency, which contains 8 indexes. The conclusion provides a basis for quantitative evaluation on the performance of the system.

Introduction
With the development of Internet and information technology, the taxi-hailing service recognised by people more and more. The construction of the intelligent system plays an important role in promoting the quality of service. Deng W J, Kuo Y F put forward the quality optimization method of importance performance analysis (IPA)\(^1\). Douglas constructed the taxi supply and demand equilibrium model through the quantitative analysis\(^2\). Yin X C put forward the way to construct taxi scheduling platform from the point of intelligent system\(^3\). But the quantitative evaluation method for taxi-hailing system is still imperfection. It is necessary to establish the method to evaluate the comprehensive operation of the taxi-hailing system. This can provide scientific method and basis for choosing and improving the taxi operation.

Analysis of Influencing Factors

Passengers Acceptance
The Passengers Acceptance shows the proportion of taxi-hailing service. It depends on the number of the taxi-hailing calling and the number of the taxi business. The higher the proportion, the stronger the passenger use the taxi-hailing service.

Service Ability of the System
The service ability of the system depends on the response of the demand, service implementation and the average of empty mileage.

Service Quality of the System
Service quality of the system determines the feeling of the taxi passengers. It is mainly reflected in four aspects: the average of waiting time, optimal selection of the route, quality-of-service constraints and the method of the payment.

Selection of Evaluation Index
According to the analysis of the influencing factors on the system operating, the paper extracts the evaluation index. At the same time, in order to guarantee the integrity and consistency of the evaluation system, normalize the quantitative index, and quantify the qualitative index\(^4\).

Rate of the Taxi-Hailing Calling
The value is the percentage of the taxi-hailing calling, expressed in \(C_t\).
In the formula (1), $S_n$ is the number of the taxi-hailing calling, $T$ is the number of the taxi business. Generally, $C_1 \leq 20\%$, to 5% range, the index normalization is shown in Table 1.

Table 1. The normalization of the rate of the taxi-hailing calling.

<table>
<thead>
<tr>
<th>Rate of the taxi-hailing calling</th>
<th>$C_1 \geq 20%$</th>
<th>$15% \leq C_1 &lt; 20%$</th>
<th>$10% \leq C_1 &lt; 15%$</th>
<th>$5% \leq C_1 &lt; 10%$</th>
<th>$C_1 &lt; 5%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalization</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Rate of the Demand Response

The value is the percentage of the demand response, expressed in $C_2$.

$$C_2 = \frac{S_d}{S_n} \times 100\%$$  \hspace{1cm} (2)

In the formula (2), $S_d$ is the number of the demand response, $S_n$ is the number of the taxi-hailing calling. Generally, $60\% \leq C_2 \leq 90\%$, to 10% range, the index normalization is shown in Table 2.

Table 2. The normalization of the rate of the demand response.

<table>
<thead>
<tr>
<th>Rate of the taxi-hailing calling</th>
<th>$C_2 \geq 90%$</th>
<th>$80% \leq C_2 &lt; 90%$</th>
<th>$70% \leq C_2 &lt; 80%$</th>
<th>$60% \leq C_2 &lt; 70%$</th>
<th>$C_2 &lt; 60%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalization</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Rate of Service Implementation

The value is the percentage of the number of service implementation, expressed in $C_3$.

$$C_3 = \frac{S_r}{S_d} \times 100\%$$  \hspace{1cm} (3)

In the formula (3), $S_r$ is the number of the service implementation, $S_d$ is the number of the demand response. Generally, $60\% \leq C_3 \leq 90\%$, to 10% range, the index normalization is shown in Table 3.

Table 3. The normalization of the rate of service implementation.

<table>
<thead>
<tr>
<th>Rate of service implementation</th>
<th>$C_3 \geq 90%$</th>
<th>$80% \leq C_3 &lt; 90%$</th>
<th>$70% \leq C_3 &lt; 80%$</th>
<th>$60% \leq C_3 &lt; 70%$</th>
<th>$C_3 &lt; 60%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalization</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Energy-Saving

The value is the percentage of the average of the empty mileage, expressed in $C_4$.

$$C_4 = \frac{m_e}{m_t} \times 100\%$$  \hspace{1cm} (4)

In the formula (4), $m_e$ is the average of empty mileage on taxi-hailing. $m_t$ is the average of empty mileage on traditional taxi. Generally, $20\% \leq C_4 \leq 60\%$, to 10% range, the index normalization is shown in Table 4.

Table 4. The normalization of the energy-saving.

<table>
<thead>
<tr>
<th>Energy-saving</th>
<th>$C_4 &lt; 20%$</th>
<th>$20% \leq C_4 &lt; 30%$</th>
<th>$30% \leq C_4 &lt; 40%$</th>
<th>$40% \leq C_4 &lt; 50%$</th>
<th>$50% \leq C_4 &lt; 60%$</th>
<th>$C_4 \geq 60%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalization</td>
<td>1</td>
<td>0.9</td>
<td>0.7</td>
<td>0.5</td>
<td>0.3</td>
<td>0.1</td>
</tr>
</tbody>
</table>
The Average of Waiting Time

The value is expressed in $C_5$. Generally, $C_5 < 5$ minutes. When $C_5 < 2$ minutes, perceptions of the service will not have obvious change. So, to 1 minute range, 5 evaluation grades are set up. The quantitative criteria and the value is shown in Table 5.

<table>
<thead>
<tr>
<th>Evaluation grades</th>
<th>$C_5 &lt; 2$</th>
<th>$2 \leq C_5 &lt; 3$</th>
<th>$3 \leq C_5 &lt; 4$</th>
<th>$4 \leq C_5 &lt; 5$</th>
<th>$C_5 \geq 5$</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantification</td>
<td>1</td>
<td>0.8</td>
<td>0.6</td>
<td>0.4</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Optimal Selection of the Route

The value is expressed in $C_6$. 3 evaluation grades are set up, expressed in $A_1 \sim A_3$. The quantitative criteria as follows and the value is shown in Table 6.

- $A_1$: Use navigation route and traffic monitoring to choose the best route;
- $A_2$: Use only navigation route to choose the route;
- $A_3$: No selection of the route.

<table>
<thead>
<tr>
<th>Evaluation grades</th>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantification</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
</tr>
</tbody>
</table>

Quality-of-Service Constraints

Quality-of-service constraints is guaranteed by credit records, evaluation mechanism and the complaints mechanism. The value is expressed in $C_7$, credit records is the most effective means, quantitative factor set to 0.4, the others is 0.3. 6 evaluation grades are set up, expressed in $A_1 \sim A_6$. The quantitative criteria as follows and the value is shown in Table 7.

- $A_1$: Use credit records, evaluation mechanism and complaints mechanism;
- $A_2$: Use credit records and another method;
- $A_3$: Use evaluation mechanism and complaints mechanism;
- $A_4$: Use credit records;
- $A_5$: Use evaluation mechanism or complaints mechanism;
- $A_6$: No quality-of-service constraints

<table>
<thead>
<tr>
<th>Evaluation grades</th>
<th>$A_1$</th>
<th>$A_2$</th>
<th>$A_3$</th>
<th>$A_4$</th>
<th>$A_5$</th>
<th>$A_6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantification</td>
<td>1</td>
<td>0.7</td>
<td>0.6</td>
<td>0.4</td>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

The Method of the Payment

In addition to cash, there are three kinds of the method of payment, Including transportation card, bank card and E-wallet. Transportation card is the most promising method by Chinese government, quantitative factor set to 0.4, the others is 0.3. 6 evaluation grades are set up, expressed in $A_1 \sim A_6$. The quantitative criteria as follows and the value is shown in Table 8.

- $A_1$: Use transportation card, bank card and E-wallet;
- $A_2$: Use transportation card and another method;
- $A_3$: Use bank card and E-wallet;
- $A_4$: Use transportation card;
- $A_5$: Use bank card or E-wallet;
- $A_6$: Only use cash.
Table 8. The quantification of the method of the payment.

<table>
<thead>
<tr>
<th>Evaluation grades</th>
<th>( A_1 )</th>
<th>( A_2 )</th>
<th>( A_3 )</th>
<th>( A_4 )</th>
<th>( A_5 )</th>
<th>( A_6 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>quantification</td>
<td>1</td>
<td>0.7</td>
<td>0.6</td>
<td>0.4</td>
<td>0.3</td>
<td>0</td>
</tr>
</tbody>
</table>

Through the research, the evaluation index system is established, including 3 first-level indicators, 8 secondary indicators, as shown in Figure 1.

The Calculation of the Weight Coefficient

The paper calculates the weight coefficient of the index system by the AHP. Establishment the model of AHP by MCE, then each of two indicators is compared and construct judgment matrix. The paper uses the scaling of 1-9 in order to make the decision quantitatively. Using matrix theory, \( \lambda \) is the matrix eigenvalue, and all of the \( a_{ij} = 1 \). When the matrix is complete congruence, \( \lambda_1 = \lambda_{\text{max}} = n \), the other eigenvalue is the 0; When the matrix is not complete congruence, \( \lambda_1 = \lambda_{\text{max}} > n \), the relation of other eigenvalue \( (\lambda_2, \lambda_3, \ldots, \lambda_n) \) is:

\[
\sum_{i=2}^{n} \lambda_i = n - \lambda_{\text{max}} \quad (5)
\]

So, the paper select \( (\lambda_2, \lambda_3, \ldots, \lambda_n) \) to metric the consistency deviation of the judgment matrix.

\[
CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (6)
\]

In order to quantification the consistency of the judgment matrix, the \( RI \) was shown in table 9.

Table 9. The number of the random index \( RI \).

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.32</td>
<td>1.41</td>
<td>1.45</td>
</tr>
</tbody>
</table>

The division of the \( CI \) and \( RI \) is called the ratio of random consistency, \( CR \)

\[
CR = \frac{CI}{RI} \quad (7)
\]

When \( CR < 0.10 \), the judgment matrix has the satisfaction consistency. \( CR > 0.10 \), we adjust matrix. Using the above steps to verify the consistency of judgment matrix, the judgment matrix A-B about the standard level relative to the object layer was shown:
The judgment matrix $B_2, B_3$ as follows. $B_1$ contains only one index, so the weight coefficient is 1.

$$W = \begin{bmatrix} 0.169 \\ 0.457 \\ 0.374 \end{bmatrix}, \quad \lambda_{\text{max}} = 3.01, CI = 0.01, RI = 0.58, CR = 0.01 < 0.10$$

Because of there is no intersect between the standard and factors, the multiplication of the weight of standard and the weight of factors is the final weight coefficient, which was shown in Table 10.

Table 10. The calculation of the weight coefficient.

<table>
<thead>
<tr>
<th>Indicators</th>
<th>Weight coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rate of the taxi-hailing calling</td>
<td>0.17</td>
</tr>
<tr>
<td>Rate of the demand response</td>
<td>0.12</td>
</tr>
<tr>
<td>Rate of service implementation</td>
<td>0.19</td>
</tr>
<tr>
<td>Energy-saving</td>
<td>0.15</td>
</tr>
<tr>
<td>the average of waiting time</td>
<td>0.13</td>
</tr>
<tr>
<td>optimal selection of the route</td>
<td>0.05</td>
</tr>
<tr>
<td>quality-of-service constraints</td>
<td>0.07</td>
</tr>
<tr>
<td>the method of the payment</td>
<td>0.12</td>
</tr>
</tbody>
</table>

Evaluation Model of Taxi-Hailing System Operation Efficiency

The paper uses the method of fuzzy comprehensive evaluation to establish the model. Establish the index collection of evaluation, $U = \{u_1, u_2, \ldots, u_n\}$ ($n$ is evaluation indicators). Judge the element in the index collection of evaluation, the relation of the element, $r_i = (r_{i1}, r_{i2}, \ldots, r_{im})$. Above all, we can establish a final judgment matrix.

$$R = (r_{ij})_{mn} = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

Finally, the evaluation method was shown in Table 11.
Table 11. The evaluation method.

<table>
<thead>
<tr>
<th>Num.</th>
<th>Indicators</th>
<th>full marks</th>
<th>score</th>
<th>Standard for evaluation</th>
</tr>
</thead>
</table>
| 1    | $C_1$ Rate of the taxi-hailing calling  | 17         |       | 17: $C_1 \geq 20$
13.6: $15\% \leq C_1 < 20$
10.2: $10\% \leq C_1 < 15$
6.8: $5\% \leq C_1 < 10$
3.4: $C_1 < 5$

| 2    | $C_2$ Rate of the demand response       | 12         |       | 12: $C_2 \geq 90$
9.6: $80\% \leq C_2 < 90$
7.2: $70\% \leq C_2 < 80$
4.8: $60\% \leq C_2 < 70$
2.4: $C_2 < 60$

| 3    | $C_3$ Rate of service implementation   | 19         |       | 19: $C_3 \geq 90$
15.2: $80\% \leq C_3 < 90$
11.4: $70\% \leq C_3 < 80$
7.6: $60\% \leq C_3 < 70$
3.8: $C_3 < 60$

| 4    | $C_4$ Energy-saving                     | 15         |       | 15: $C_4 < 20$
13.5: $20\% \leq C_4 < 30$
10.5: $30\% \leq C_4 < 40$
7.5: $40\% \leq C_4 < 50$
4.5: $50\% \leq C_4 < 60$
1.5: $C_4 \geq 60$

| 5    | $C_5$ the average of waiting time       | 13         |       | 13: $C_5 < 2$
10.4: $2 \leq C_5 < 3$
7.8: $3 \leq C_5 < 4$
5.2: $4 \leq C_5 < 5$
2.6: $C_5 \geq 5$

| 6    | $C_6$ optimal selection of the route   | 5          |       | 5: Use navigation route and traffic monitoring to choose the best route
2.5: Use only navigation route to choose the route
0: No selection of the route

| 7    | $C_7$ quality-of-service constraints   | 7          |       | 7: Use credit records, evaluation mechanism and complaints mechanism;
4.9: Use credit records and another method;
4.2: Use evaluation mechanism and complaints mechanism;
2.8: Use credit records;
2.1: Use evaluation mechanism or complaints mechanism;
0:no quality-of-service constraints
### Conclusions

The paper establishes evaluation index system, which contains 9 Indicators, and calculates the weight coefficient by AHP with the MCE. Finally, the paper establishes the method of evaluation. According normalize the quantitative index and quantify the qualitative index, the level of the operation efficiency evaluation of online taxi-hailing System can be expressed by quantization. Because of this, the level of the system is known by the leadership and the enterprise clearly. It has important meaning for energy conservation and emission reduction about taxi business.

### References


