A Multi-objective Optimization Modeling and Solution of Signage Layout Problem in Transport Hub

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Abstract — Aiming to solve the problem of way finding in transport hubs, this paper proposes a multi-objective optimization containing guiding distance and commercial needs. This considering with passengers’ walking distance both with hubs' incomes model, does not only solve the ineffective signage system in hubs, but also ease the current unsatisfactory situation of hubs' income. It aims to enlarge passengers' commercial needs and to increase the hubs’ incomes, which is never involved in previous studies. The model is solved by Lingo and the adaptability of multi-objective programming solving methods to practice are tested via the instance of B1 floor in Jinan west railway station. The results show that, in practical operation, according to solution of delaminating sequence method, the layout signage system can improve the ease of self-spatial orientation in hubs.

Keywords - Multi-objective program; Signage; Decision point; Lingo

I. INTRODUCTION

Transport hub brings transportation, offices, business, leisure, entertainment and other services together as a whole and shows the characteristic of complete function, large scale, complex space and so on. Wayfinding behavior occur in large space [1-2], so the wayfinding in transport hub is a long-term problem. Guiding signage, as a media or carrier of information, can help improve the wayfinding performance. A successful guiding signage system can reduce the architectural complexity of space by pass the related information [3], thus improving wayfinders' behaviors both under ordinary and emergency conditions. Signage system is the media of communication of wayfinders and the environment where they stay. Passini [4] proposes that signage system designer must aware three questions: what information to convey, convey in where and in what form. In other words, the researches related to guiding signage are divided into three categories: signage content, location and form of identification. Researches about signage location and content have become the hot topic of management and computer science. Liang Y.H. et al. [5-6] has established models with one objective by the method of system optimization and used genetic and particle swarm intelligent algorithm separately to solve the models due to signage layout can be regarded as a system optimization problem. However, the complexity and diversity of optimization objectives of signage system , resulting in one-sidedness of single objective model in solving this problem. In order to avoid that, Lin Y. et al. [7] has established a multi-objective (guide distance and induced level) model and used genetic algorithm to solve it. Therefore, based on the conclusions of above, this study focus on the current benefit of transport hub is not ideal as expected, sets up a multi-objective optimization model which considering the guide distance and transport hub's earnings. In solving aspect, this multi-objective model is relative easier as just involving in 0-1 integer programming, while Lingo, especially Lingo 10.0 which added lots of new submodels, is very suitable for dealing with this kind of programming problem. Therefore, this paper uses the multi-objective model and three solving methods to study the location and content of signage in B1 floor in Jinan west railway station in China, then take visibility index to test the applicability of the three solving methods.

II. MATERIAL AND METHODS

Service facility in transport hub is \( j \), all the \( j \) constitute the set \( F, j \in F, j = 1, 2, ..., n \)

Signage alternative location is \( i \), all the \( i \) make up the set \( S, i \in S, i = 1, 2, ..., m \)

The relationship of signage location and content can be presented by the following 0-1 variables

\[
\begin{align*}
0, & \quad \text{otherwise} \\
1, & \quad \text{layout in } i \\
0, & \quad \text{otherwise}
\end{align*}
\]

\[
\begin{align*}
1, & \quad \text{layout information about facility } j \text{ in } i \\
0, & \quad \text{don't layout information about facility } j \text{ in } i \\
\end{align*}
\]

\( w_j \) is the weight of facility \( j \), according to the using probability, facilities can be sorted into two categories: primary facility and secondary facility. Primary facilities refer to the facility all passengers must use, the weight is 1, such as security, station escalator, etc. Secondary facilities is not must, refer to passengers choose to use, such as toilet,
transport hall, restaurant, etc. The scope of secondary facilities is \( [0,1) \).

\( d_{ij} \) is the distance between alternative location \( i \) and facility \( j \). Due to all facilities occupy a certain area in the hub, so \( d_{ij} \) is the shortest linear distance between alternative layout point and facilities.

\( c_j \) is facilities' property, if \( j \) is a commercial facility, \( c_j = 1 \), otherwise, \( c_j = 0 \).

The prime function of transport hub is evacuation. In order to speed up the passenger flow, the stay in time of each passenger's should be shortest. The layout of guide signage system makes the guiding distance minimizing, which means optional layout point contains as much as possible with the nearest facilities' information. Then, considering the weight of each facility, the facility, which is nearer the optional location point, according to their importance in turn, will be take in the content of each signage. Thus, get the following objective function:

\[
\text{max } z_1 = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \frac{p_{ij} w_j}{d_{ij}}
\]

(1)

The quasi-public goods characteristic makes transport hub can't recover the investment and earn a profit just like other ordinary project in a short period of time. But as an auxiliary function, commercial facilities' instruction attracts the attention of investors and constructors gradually. Commercial facilities, located in or surrounding the transport hub, have very considerable future income. Therefore, on the premise of meet passengers' information needs in wayfinding, guide people through the commercial area as much as possible, which can not only satisfy passengers' purchase demands, also broaden the scope of shopping passengers to promote the commercial functions, to reduce the pressure of operating cost and to make recovery of the investment in short time come true. Increase the passengers' commercial demands by layout the content of guidance to commercial facilities, get the following function:

\[
\text{max } z_2 = \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} p_{ij} c_j
\]

(2)

Constraint

1) each primary facility should be guided at least once

\[
\sum_{i=1}^{m} x_{ij} p_{ij} > 0, i = 1, 2, ..., m, j = 1, 2, ..., n
\]

(3)

This is the primary constraint of location point and signage content. Each primary facility appears at least once on signage, which is the worst case to meet passengers' demand, otherwise passengers can't find out the facilities by signage system.

2) each commercial facility should be guided at least once

\[
\sum_{i=1}^{m} x_{ij} p_{ij} c_j > 0, i = 1, 2, ..., m, j = 1, 2, ..., n
\]

(4)

3) is the minimum constraint about content on signage which guiding to the commercial facilities, means each commercial facility appears at least once in signage system, which is the precondition to satisfy the minimum purchase requires of passengers.

4) Inner relationship between location point and guiding content

\[
\sum_{j=1}^{n} p_{ij} = 0, x_i = 0
\]

\[
2 \leq \sum_{j=1}^{n} p_{ij} \leq 3, x_i = 1
\]

(5)

5) is the description of inner relationship between signage location and guiding content. If point \( i \) was not selected as signage location point, it is not possible that any guiding information in this point. When point \( i \) was selected as signage location point, the signage setting in this point must contains 2 at least and 3 at most facilities' information. Guiding to how many facilities is depending on the specific situation and limitation of space and budget, which can vary from one situation to situation.

As a transport hub, Jinan west railway station is located in the west of Jinan city. It's one of the five starting station of Beijing-Shanghai high-speed railway. As a member of Jinan west railway station operation management project, we collected some basis data about Jinan railway station. So we choose B1 floor as an empirical case to test the model.

The 12 locations of service facilities and optional signage point in B1 floor of Jinan west railway station is shown in Figure 1. The color box with a number in it presents service facility and the green boxes are the locations of commercial facilities. The 36 black dots are optional signage locating point.

Figure 1. The schema of locations of service facilities and optional signage point in B1 floor of Jinan west railway station.
Added data of B1 floor of Jinan west railway station to quotation (1)-(5), getting the following multiple objective function:

$$\begin{align*}
\text{max } z_1 &= \sum_{i=1}^{36} \sum_{j=1}^{12} x_{ij} p_{ij} w_j / d_{ij} \\
\text{max } z_2 &= \sum_{i=1}^{36} \sum_{j=1}^{12} x_{ij} p_{ij} c_j
\end{align*}$$

s.t.

$$\begin{align*}
\sum_{i=1}^{36} x_{ij} p_{ij} &> 0 \\
\sum_{i=1}^{36} x_{ij} p_{ij} c_j &> 0 \\
\sum_{j=1}^{12} p_{ij} &= 0, x_i = 0 \\
2 &\leq \sum_{j=1}^{12} p_{ij} \leq 3, x_i = 1 \\
i &= 1, 2, \ldots, m
\end{align*}$$

III. RESULTS

For getting the value of $w_j$, we take out a survey in an operating transport hub, Tianjin west railway station, which has similar functions with Jinan west railway station. By investigating 357 passengers in Tianjin west railway station with a questionnaire, we collect the data each passengers using Likert method (1 is "very unimportant", 2 is "unimportant", 3 is "important", 4 is "very important") to assesses for every service facility. These are then fed into the following calculation which proposed by Dada(1997)[8]:

$$w_j = \sum_{i=1}^{36} x_{ij} f_{ij} / \sum_{i=1}^{36} f_{ij} \times 4$$

and then getting the value of $w_j$ of each service facilities in B1 floor of Jinan west railway station (see Table 1).

The value of $c_j$ can be obtain by analyzing facilities' property of B1 floor, which can be clearly seen from Figure 1. Data of $d_{ij}$ is also acquirable according the architectural drawing of B1 floor, which is shown in Appendix 1.

The multi-objective program is solved using Lingo 10.0. When getting the global optimal solution, the results of $x_i$ and $p_{ij}$ of three solutions are shown in Table 2.

In order to test the applicability and scientificity of the above three solutions, we use Visibility Index to quantify the easy of location in transport hub of each solution:

$$VI = \frac{L_S}{N^2}$$

$L_S$ is the number of visual line between service facilities, including direct visual and indirect visual via signage. $N$ is the number of facilities.

According to data in Table 2 and equation (7), the values of visibility index of the three solutions are shown in Table 3.

Based on researches related to visibility index, the range of the visibility index is $[0,1]$. Within the scope, the larger the value is, the passengers self-locating in hubs is more easier. According to Table 2 and 3, VI value reaches the top based on $x_i$ and $p_{ij}$ solved by delaminating sequence method, while the amount of signage is less than that getting from fuzzy deviation method, which cost less but can achieve a better effect.

IV. DISCUSSION

Aiming to minimum guide distance and maximum commercial need, that means the guiding distance achieving minimization and commercial facilities appearing as more as possible on the signage simultaneously. which can not only shorten times that passengers stay in the passage of transport hubs, but relieve the pressure of operation cost to improve the status of operation. In order to test the scientificity and reliability, an empirical study was carried out in Jinan west railway station. By programming in Lingo 10.0 with submodel, using ideal point method, fuzzy deviation method and delaminating sequence method, we get the location point and guiding content of each signage. In the results of ideal point method, 36 optional signage locating points were selected and each signage guiding to 2 different service facilities. In the results of fuzzy deviation method, similarly, 36 points were selected but each signage guiding to 3 different service facilities. In the results of delaminating sequence method, only 22 points were selected and each signage guiding to 2-3 facilities. Functional values can't be the criteria to evaluation the solving methods, just because the guiding facilities on the premise of budget are not the more the better, the limit should be the information on signage can just meet exactly right the passengers' demand of wayfinding around this signage's location. Moreover, even under the budget, one layout scheme, which is more cheaper but also can achieve the same effect, is a good choice obviously. So, we need to evaluate above three solutions. As the evaluation indicator, Visibility index, which is a standard to describe the ease of passengers' positioned within the hub, can not only quantize the effect of signage layout, but also can evaluate the layout schemes. According to the results, VI value is up...
to 0.54 based on $x_i$ and $p_{ij}$ solved by delaminating sequence method, which is higher than other two solutions.

<table>
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<tr>
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<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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<td>1</td>
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<th>Fuzzy deviation method</th>
<th>Delaminating sequence method</th>
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<td>$P_{ij} = 1$</td>
<td>$P_{ij} = 1$</td>
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<td>$x_3$</td>
<td>✓</td>
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<tr>
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<td>✓</td>
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</tr>
<tr>
<td>$x_{24}$</td>
<td>✓</td>
<td>$P_{2491}, P_{2410}$</td>
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</table>
Ideal point method | Fuzzy deviation method | Delaminating sequence method
---|---|---
$x_{25}$ | $P_{25,5}\cdot P_{25,11}$ | $P_{25,2}\cdot P_{25,3}\cdot P_{25,10}$ | $P_{25,4}\cdot P_{25,7}\cdot P_{25,10}$
$x_{26}$ | $P_{26,10}\cdot P_{26,11}$ | $P_{26,2}\cdot P_{26,3}\cdot P_{26,10}$ | $P_{26,4}\cdot P_{26,7}\cdot P_{26,10}$
$x_{27}$ | $P_{27,7}\cdot P_{27,12}$ | $P_{27,1}\cdot P_{27,2}\cdot P_{27,3}$ | $P_{27,4}\cdot P_{27,7}\cdot P_{27,12}$
$x_{28}$ | $P_{28,7}\cdot P_{28,12}$ | $P_{28,1}\cdot P_{28,2}\cdot P_{28,12}$ | $P_{28,2}\cdot P_{28,7}\cdot P_{28,12}$
$x_{29}$ | $P_{29,7}\cdot P_{29,12}$ | $P_{29,1}\cdot P_{29,2}\cdot P_{29,6}$ | $P_{29,3}\cdot P_{29,7}\cdot P_{29,8}$
$x_{30}$ | $P_{30,7}\cdot P_{30,12}$ | $P_{30,1}\cdot P_{30,2}\cdot P_{30,11}$ | $P_{30,3}\cdot P_{30,7}\cdot P_{30,11}$
$x_{31}$ | $P_{31,7}\cdot P_{31,12}$ | $P_{31,1}\cdot P_{31,6}\cdot P_{31,10}$ | $P_{31,3}\cdot P_{31,7}\cdot P_{31,10}$
$x_{32}$ | $P_{32,8}\cdot P_{32,12}$ | $P_{32,1}\cdot P_{32,2}\cdot P_{32,6}$ | $P_{32,7}\cdot P_{32,8}\cdot P_{32,12}$
$x_{33}$ | $P_{33,8}\cdot P_{33,12}$ | $P_{33,1}\cdot P_{33,6}\cdot P_{33,9}$ | $P_{33,3}\cdot P_{33,8}\cdot P_{33,12}$
$x_{34}$ | $P_{34,8}\cdot P_{34,12}$ | $P_{34,1}\cdot P_{34,2}\cdot P_{34,6}$ | $P_{34,3}\cdot P_{34,8}\cdot P_{34,12}$
$x_{35}$ | $P_{35,3}\cdot P_{35,8}$ | $P_{35,1}\cdot P_{35,6}\cdot P_{35,11}$ | $P_{35,3}\cdot P_{35,7}\cdot P_{35,12}$
$x_{36}$ | $P_{36,3}\cdot P_{36,8}$ | $P_{36,1}\cdot P_{36,6}\cdot P_{36,9}$ | $P_{36,3}\cdot P_{36,7}\cdot P_{36,12}$

**TABLE 3.** The values of visibility index of the three solutions based on $x_i$ and $p_{ij}$

<table>
<thead>
<tr>
<th>VI</th>
<th>Ideal point method</th>
<th>Fuzzy deviation method</th>
<th>Delaminating sequence method</th>
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</thead>
<tbody>
<tr>
<td>0.1667</td>
<td>0.3889</td>
<td>0.5417</td>
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**V. CONCLUSION**

According to the characteristics of actual deployment of signage system layout, considering the demands of hub users, managers and constructors, this paper established a multi-objective model aiming at minimizing guiding distance and maximizing commercial incomes, considering constraints of primary facilities' guiding rate, commercial facilities' guiding rate and the inner relationship between location point and signage content. Taking B1 floor in Jinan west railway station as a numerical example to certificate the model, solve the model using ideal point method, fuzzy deviation method and delaminating sequence method with Lingo10.0 software. Then, for testing the application and scientificity of these solutions, adopt Visibility Index to quantify the easy of location in transport hub under each solution. The results show that delaminating sequence method of solving this multi-objective optimization model has an obvious advantage.

This model has carried on a simple rules on guiding information load capacity of single signage just in constrains. If adding this as a variable into this model, the difficulty of solving will improve at least an order of magnitude, whereas the practical applicability and popularization degree will greatly increase. This raises further research issues.

**CONFLICT OF INTEREST**

The author confirms that this article content has no conflict of interest.

**REFERENCES**


