Layout Optimization of Guidance Signs in Subway Station Based on Passenger Flow Line

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Abstract. With the continuous acceleration of urbanization, urban public traffic congestion is becoming more and more serious. In order to alleviate traffic congestion, people's demand for public transportation is increasing. Due to the increasing passenger flow in the subway station, the original guidance signs in the station often fail to play the expected role, and passengers cannot get effective guidance in the crowded passenger flow. This paper takes the maximum amount of information obtained by passengers as the objective function to establish the guidance sign layout model, and chooses a 0-1 integer programming model to solve it. Based on the distribution coefficient $p_{ij}$, the passenger flow $w_{ij}$, the weight coefficient $\delta$, and the inverse of the number of intersections $q_{ij}$, these four variables are used to comprehensively analyze the amount of guidance information of the guidance signs, and set constraints based on the number of passenger flow lines and guidance signs. Xiyuan Subway station, for example, through the site of the actual passenger flow survey, to obtain the required parameters, and finally using MATLAB programming solution, to get an effective guidance sign layout position, improve the guidance sign guide efficiency.

1. Introduction
The subway station structure is generally divided into two floors, the upper floor for the station hall, the lower floor for the platform. On station hall, there are passageways to entrances and exits, transfer corridors and elevators to the platform floor. On the platform floor, there are subway stations in different directions, toilets, and elevators leading to the station hall. It can be seen under normal circumstances, the structure of the station hall floor is much more complex than that of the platform floor, making it more difficult for passengers to find their way. Therefore, the main focus of this paper is the station hall.

Due to the neglect of the layout of guidance signs in the subway construction process in China, the poor guidance effect of guidance signs, low passenger travel efficiency, poor experience and other problems have been exposed, which has attracted the attention of domestic experts, and a series of studies have been carried out. Cao [1] proposed an optimization model based on genetic algorithm for points location selection of guidance signs and constructed an evaluation system of guidance signs, providing ideas for subsequent research on points location placement of guidance signs. Zhang [2] and Li [3] based on the perspective of human factor engineering, reasonably arranged the guidance signs of railway passenger stations according to the characteristics of passenger flow lines. Lin [4] presented guidance sign of multi-objective optimization model and used IFD - the NSGA - II algorithm to solve, which broke the previous single objective model, and used the intelligent algorithm such as genetic
algorithm. Through theoretical analysis and experimental demonstration, Zhang [5] obtained a mathematical model for the visual range of a single sign, and combined with simulation, discussed the influence of crowd pathfinding behavior from six aspects, including boundary, sign, node and arc, thus providing a new perspective for the research on the placement of guiding sign points. Zhang et al. [6] proposed a sign-guided service efficiency calculation method based on information entropy theory, aiming at maximizing the collaborative service efficiency of sign-guided labeling. This study will analyze the travel flow of passengers in the station hall, and combine with the layout model to solve more reasonable guidance sign layout points.

2. Problem description and modeling

2.1. Problem description
Within the guidance sign layout area, $X$ suitable alternative points are selected from $m$ guidance sign identification alternative points according to the set restrictions. The aim is to add guidance signs on the existing basis to strengthen the effective guidance of passengers in the distribution area.

2.2. Assumptions and modeling

2.2.1. Assumptions
1. Only the first floor of the subway station is studied as the area for the layout study of guidance signs.
2. Alternative points of guidance signs are spatial switching points of passenger flow lines, intersection points and other positions with spatial characteristics.
3. The guidance signs set for each alternative points only show the guidance information of the three surrounding intersections, and do not show the guidance information of more than three intersections;

2.2.2. Modeling
Based on the goal of maximizing the passenger guidance level, a guidance sign layout model is established.

$$\max Z = \sum_{i} \sum_{j} x_{ij} p_{ij} w_{ij}$$  \hspace{1cm} (1)

where $i$ is the identification alternative points of the passenger, $i = 1, 2, ..., m$, $j$ is the destination point of the passenger, $j = 1, 2, ..., n$, $x_{ij} = 1$ means to set a guidance sign at $i$, $x_{ij} = 0$ means not to set a guidance sign at $i$, $p_{ij}$ is the distribution coefficient. When the passenger reaches the target points $j$ and needs to pass through the alternative points $i$, $p_{ij} = 1$, otherwise $p_{ij} = 0$. $w_{ij}$ is the passenger volume, which means the passenger flow directed to the target points $j$ at the alternative points $i$. $\alpha$ is the weight coefficient, represents the balance of guiding passenger flow and guiding distance when guiding signs are set. In this paper, $\alpha = 1.5$.

2.3. The constraint
It is assumed that $X$ guidance signs are set at alternative points (The total number has been determined according to the spatial layout, passenger flow, number of alternative points.). The constraint conditions are as follows:

$$\sum_{i} x_{i} = X, i = 1, 2, ..., m$$  \hspace{1cm} (2)

where $0 < X < m$, and $X$ is an integer. When $x_{i} = 1$, The necessary conditions must be met when the guide signs are set at $i$ : the guide signs set at $i$ should guide at least one passenger to travel.

All passenger flow in the location area must be guided by the guide sign at least once. The constraints conditions are as follows:
\[
\sum_{i} x_i \geq 1, i = 1, 2, ..., m
\]  
(3)

where \( r \) is the passenger flow entering the location area, and \( i \) is the set of guide identification alternative points of the \( r \)-th passenger flow entering the location area in different directions.

The flow of passengers arriving at all target points has been directed at least once by the guide signs. The constraints conditions are as follows:

\[
\sum_{j} y_j \geq 1, i = 1, 2, ..., m
\]  
(4)

where \( j \) is the set of alternative points that must be passed when reaching the target point \( j \).

3. **Introduction to matlab intlinprog function**

First of all, MATLAB solves the problem that the objective function is the minimum value, but if our objective function is to seek the maximum value, we can multiply each item in the objective function by -1 to convert the maximum value problem into the minimum value. Its standard form is as follows:

\[
\begin{align*}
\text{min} & \quad f^T x \\
\text{st} & \quad A \cdot X \leq b \\
& \quad A_{eq} \cdot X = b_{eq} \\
& \quad lb \leq X \leq ub
\end{align*}
\]  
(5)

\[
[x, fval, exitflag]=\text{intlinprog}(f, \text{intcon}, A, b, A_{eq}, b_{eq}, lb, ub);
\]

Where \( x \) is the value of the variable, \( fval \) is the optimal value of the objective function, \( \text{exitflag} \) is the flag for function exit, \( f \) is the coefficient matrix of each variable in the objective function, \( \text{intcon} \) is an integer constraint variable, \( A \) is the coefficient matrix on the left side of the inequality constraint, \( B \) is the coefficient matrix on the right side of the inequality constraint, \( A_{eq} \) is the coefficient matrix on the left side of the equality constraint, \( B_{eq} \) is the coefficient matrix on the right side of the equation constraint, \( lb \) is the lower limit interval of each variable respectively, \( ub \) is the upper limit of each variable respectively.

4. **Guidance sign layout case**

Xiyuan Station is a transfer station, connecting Beijing Metro Line 4 and Line 16. The station is located on the west side of Wanquanhui Expressway, near the Xiyuan bus hub in the north, and on The Summer Palace Road, adjacent to Old Summer Palace, Summer Palace and other important attractions. During our survey, we found that there were a large number of passengers transferring to buses at Xiyuan Station, and there was no information about bus transfers in the information of the exit guidance signs, and the continuity of the signs was poor, and the layout was not reasonable.

4.1. **Passenger flow line and passenger volume Xiyuan Station of Line 4**

As shown in Figure 1, a field survey was conducted at Xiyuan Station of Beijing Metro Line 4, and the passenger flow lines and passenger volume in the station were obtained. There were 3 starting points, 11 target points, and 19 alternative points. All alternative points except alternative points 7 and 8 are passenger flow intersection points or spatial transfer points. As the transfer channel distance between alternative points 5 to 9 and alternative points 6 to 13 is too long, according to the “Urban Rail Transit Passenger Service Sign” [7]. It is recommended that two alternative points 7 and 8 should be set to meet the continuity requirements of the guidance sign. The specific parameters are shown TABLE 1.
Figure 1. Passenger flow Lines and Passenger volume Chart of Xiyuan Station of Metro Line 4

TABLE 1. Calculating table of objective function parameters of Xiyuan Station of Metro Line 4

| Alternative points i | x_i Target points j | P_{ij} | w_{ij} | Q_{ij} |
|----------------------|---------------------|--------|--------|--------|
| 1                    | x_1 1—11            | p_{11}(1) | 104,72,100,93,91,105,261,237,221,12 59,291 | 1/4,1/4,1/3,1/3,1/4,1/4,1/5,1/6,1/5,1/4 |
| 2                    | x_2 1—11            | p_{21}(1) | 31,28,35,24,27,27,105,92,68,108,101 | 1/3,1/4,1/4,1/4,1/5,1/5,1/6,1/6,1/7,1/7,1 |
| 3                    | x_3 1—11            | p_{31}(1) | 60,37,53,59,54,64,143,128,90,135,17,6 | 1/5,1/5,1/5,1/5,1/5,1/5,1/6,1/7,1/7,1/7,1 |
| 4                    | x_4 7—11            | p_{47}(1) | 261,237,221,259,291 | 1/3,1/4,1/5,1/4,1/3 |
| 5                    | x_5 7—9             | p_{59}(1) | 261,237,105 | 1/2,1/3,1/4 |
| 6                    | x_6 9—11            | p_{69}(1) | 116,259,291 | 1/2,1/3,1/4 |
| 7                    | x_7 7—9             | p_{79}(1) | 261,237,105 | 1/2,1/3,1/4 |
| 8                    | x_8 9—11            | p_{89}(1) | 116,259,291 | 1/2,1/3,1/4 |
| 9                    | x_9 7—9             | p_{97}(1) | 261,237,105 | 1/2,1/3,1/4 |
| 10                   | x_{10} 8—9          | p_{108}(1) | 237,105 | 1,1/2 |
| 11                   | x_{11} 9            | p_{119}(1) | 105 | 1 |
| 12                   | x_{12} 9—10         | p_{129}(1) | 116,259 | 1/2,1 |
| 13                   | x_{13} 9—11         | p_{139}(1) | 116,259,291 | 1/3,1/2,1 |
| 14                   | x_{14} 1—6          | p_{146}(1) | 104,72,100,93,91,105 | 1/3,1/3,1/2,1/2,1/3,1/3 |
| 15                   | x_{15} 1—2          | p_{152}(1) | 104,72 | 1/2,1/2 |
| 16                   | x_{16} 1—2          | p_{162}(1) | 104,72 | 1 |
| 17                   | x_{17} 5—6          | p_{175}(1) | 91,105 | 1/2,1/2 |
| 18                   | x_{17} 5—6          | p_{185}(1) | 91,105 | 1 |
| 19                   | x_{19} 3—4          | p_{193}(1) | 100,93 | 1 |
The number of guidance sign $X$ is defined as 10. According to the passenger flow at each starting points, it shall be guided at least once by the guidance sign:

$$x_1 + x_4 + x_{10} \geq 1,$$  \hspace{1cm} (6)

$$x_1 + x_2 + x_4 \geq 1,$$ \hspace{1cm} (7)

$$x_1 + x_3 + x_{14} \geq 1.$$ \hspace{1cm} (8)

The flow of passengers arriving at the target points has been guided by the guidance sign at least once:

$$x_1 + x_2 + x_3 + x_{14} + x_{15} + x_{16} \geq 1,$$ \hspace{1cm} (9)

$$x_1 + x_2 + x_3 + x_{14} + x_{19} \geq 1,$$ \hspace{1cm} (10)

$$x_1 + x_2 + x_5 + x_{14} + x_{17} + x_{18} \geq 1,$$ \hspace{1cm} (11)

$$x_1 + x_2 + x_3 + x_5 + x_7 + x_8 \geq 1,$$ \hspace{1cm} (12)

$$x_1 + x_2 + x_3 + x_4 + x_7 + x_9 + x_{10} \geq 1,$$ \hspace{1cm} (13)

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_{10} + x_{11} + x_{12} + x_{13} \geq 1,$$ \hspace{1cm} (14)

$$x_1 + x_2 + x_5 + x_6 + x_7 + x_8 + x_{12} + x_{13} \geq 1,$$ \hspace{1cm} (15)

$$x_1 + x_2 + x_3 + x_4 + x_6 + x_8 + x_{13} \geq 1.$$ \hspace{1cm} (16)

MATLAB operation results show that the optimal sequence is 1 001, 111, 111, 011, 000, 000, and the maximum induced information is 51030. Therefore, in Xiyuan station of Beijing subway line 4, the guidance signs should be set at 1, 4, 5, 6, 7, 8, 9, 10, 12, 13. It can be seen from Figure 1 that passengers in Xiyuan Station of Beijing Metro Line 4 have a large transfer volume and a high transfer demand at the nine alternative guidance signs in 4, 5, 6, 7, 8, 9, 10, 12, 13. Therefore, it is necessary to set the guidance signs of intra-station transfer at these points. At the alternative points 1, the intersection points of transfer and outbound passenger flow, passengers have a high demand for outbound guidance. Therefore, it is necessary to set up the guidance signs of transfer station and out-station at this points, so that passengers can complete their travel behaviors efficiently.

### 4.2. Passenger flow lines and passenger volume in Xiyuan Station of Line 16

As shown in Figure 2, a field survey was conducted at Xiyuan Station of Beijing Metro Line 16, and the passenger flow lines and passenger volume in the station were obtained. There were 5 starting points, 9 target points, and 25 alternative points. All alternative points except alternative points 10, 11, 18, 20 and 24 are passenger flow intersection points or spatial switching points, because the transfer channel distance between alternative points 6 and 19, alternative points 19 to 21, alternative points 9 to 25, alternative points 7 to 12 and alternative points 8 to 14 is too long. According to the suggestion of "Urban Rail Transit Passenger Service Sign", alternative points 10, 11, 18, 20 and 24 should be set up to meet the continuity requirements of the guide sign. The specific parameters are shown in TABLE 2.
Figure 2: Passenger flow Lines and Passenger volume Chart of Xiyuan Station of Metro Line 16

| Alternative points | \( x_i \) | Target points | \( p_{ij} \) | Target point | \( w_{ij} \) | \( q_t \) |
|--------------------|--------|--------------|--------|-------------|--------|------|
| 1                  | \( x_1 \) | 1—9          | 85,212,188,125,108,127,109,10,18 | 1/5,1/6,1/6,1/6,1/6,1/6,1/9,1/9 |
| 2                  | \( x_2 \) | 1—9          | 105,212,221,105,93,109,100,47,64 | 1/5,1/6,1/5,1/5,1/8,1/7,1/7 |
| 3                  | \( x_3 \) | 1—9          | 57,20,74,56,82,68,84,77 | 1/6,1/7,1/7,1/6,1/6,1/6,1/6,1/6 |
| 4                  | \( x_4 \) | 1—9          | 122,211,212,62,58,75,64,91,109 | 1/5,1/6,1/6,1/7,1/7,1/10,1/10,1/5,1/5 |
| 5                  | \( x_5 \) | 1—9          | 72,196,193,29,30,35,32,131,141 | 1/5,1/6,1/6,1/9,1/9,1/12,1/2,1/3,1/3 |
| 6                  | \( x_6 \) | 4—7          | 125,108,127,109 | 1/2,1/2,1/5,1/5 |
| 7                  | \( x_7 \) | 1—9          | 190,424,409,105,93,109,10,18 | 1/4,1/5,1/5,1/4,1/7,1/7,1/8,1/8 |
| 8                  | \( x_8 \) | 1—9          | 194,407,405,29,30,35,32,131,109 | 1/4,1/5,1/6,1/8,1/8,1/11,1/11,1/4,1/4 |
| 9                  | \( x_9 \) | 8—9          | 131,134 | 1/2,1/2 |
| 10                 | \( x_{10} \) | 1—3          | 190,424,409 | 1/3,1/4,1/4 |
| 11                 | \( x_{11} \) | 1—3          | 194,407,405 | 1/3,1/4,1/4 |
| 12                 | \( x_{12} \) | 1—3          | 190,424,409 | 1/3,1/4,1/4 |
| 13                 | \( x_{13} \) | 1—3          | 384,831,814 | 1/2,1/3,1/3 |
| 14                 | \( x_{14} \) | 1—3          | 194,407,405 | 1/3,1/4,1/4 |
| 15                 | \( x_{15} \) | 2            | 831 | 1 |
| 16                 | \( x_{16} \) | 1—3          | 194,407,405 | 1/1,2,1/2 |
| 17                 | \( x_{17} \) | 3            | 814 | 1 |
| 18                 | \( x_{18} \) | 4—7          | 125,108,127,109 | 1/1,1/4,1/4 |
| 19                 | \( x_{19} \) | 4—7          | 125,108,127,109 | 1/1,1/4,1/4 |
| 20                 | \( x_{20} \) | 6—7          | 127,109 | 1/3,1/3 |
| 21                 | \( x_{21} \) | 6—7          | 127,109 | 1/3,1/3 |
| 22                 | \( x_{22} \) | 6—7          | 127,109 | 1/2,1/2 |
| 23                 | \( x_{23} \) | 6—7          | 127,109 | 1 |
| 24                 | \( x_{24} \) | 8—9          | 131,134 | 1 |
| 25                 | \( x_{25} \) | 8—9          | 131,134 | 1,1 |

The number of guidance sign \( X \) is defined as 16.

According to the passenger flow at each starting points, it shall be guided at least once by the guidance sign:
The flow of passengers arriving at the target points has been guided by the guidance sign at least once:

\[ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_{10} + x_1 + x_{12} + x_{13} + x_{14} + x_{16} \geq 1, \]  
\[ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{16} \geq 1, \]  
\[ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} + x_{15} + x_{17} \geq 1, \]  
\[ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_{10} + x_{18} + x_{20} + x_{23} + x_{23} \geq 1, \]  
\[ x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_{18} + x_{19} + x_{20} + x_{21} + x_{22} + x_{23} \geq 1. \]  

MATLAB operation results show that the optimal sequence is 0 100 001 101 111 111 111 000 011, and the maximum amount of induced information is 121660. Therefore, at Xiyuan Station of Beijing Metro Line 16, the guidance signs that need to be set are 2, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 24, 25. Combined with Figure 4, it can be seen that for the passengers in the Xiyuan Station of Beijing Metro Line 16 at 7, 8, 10, 11, 12, 13, 14, 15, 16, 17 these ten guidance signs alternate passenger volume larger, higher demand for guidance required by passengers. Therefore, it is necessary to focus on setting up guidance signs for transfer station at these points. On the other hand, the outbound passenger volume at the five alternative points of guidance signs 2, 18, 19, 24, 25 is relatively large, and the outbound demand of passengers is higher. Therefore, it is necessary to focus on setting guidance signs for exiting the station at these points to enable passengers to efficiently complete the exit behavior.

5. Conclusion
In this paper, optimization modeling is carried out on how to select the location of guidance signs in subway stations and how to improve the guiding effect of guidance signs. The layout study is carried out with the goal of maximizing the guidance level, and the transformation from qualitative analysis to quantitative analysis is realized. The complex systematic decision problem of pedestrian guidance sign layout is transformed into a mathematical model for processing. Finally, on the basis of theory and practice, the case analysis was carried out through Xiyuan Station of Beijing Subway, and the targeted positioning of guidance signs was optimized to improve the guidance effect of guidance signs, passenger travel efficiency and station organization and operation efficiency.

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