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# Directional Signage Location Optimization of Subway Station Based on Big Data

**QUN TU, ZHENJI ZHANG, AND QIANQIAN ZHANG**
School of Economics and Management, Beijing Jiaotong University, Beijing 100044, China
Corresponding author: Zhenji Zhang (zhjzhang@bjtu.edu.cn)

**ABSTRACT** The imperfection of the guide signs in the subway will lead to many difficulties for passengers, which directly affects the operation efficiency of subway stations. In this paper, we use big data to analyze the problem of signages in Beijing subway, and propose the optimization model of signages in subway stations based on particle swarm optimization algorithm. The experimental results of Dongzhimen subway station in Beijing show that the model has strong robustness in optimization, and the global best position can be found 100%.

**INDEX TERMS** PSO algorithm, signage location optimization, subway station, big data.

## I. INTRODUCTION

Signage system is essential for the guidance of the route, especially for people gathering space, such as stadiums, transit hub, shopping malls and so on. Well-designed signage system helps a lot in wayfinding process and information provision [1]. Even through, in recent years, with the advent of smart phones, pedestrians use the capabilities of these devices to locate themselves and find the best route to their destination outdoors. However, the low accuracy and outdated plane maps of indoor positioning technology reduce the indoor navigation effectiveness. Therefore, maps and signage systems continue to play an important role in helping pedestrians reach their destination [2].

Because of the large passenger flow and the strong mobility of the personnel in the subway station, people rely more on the signages to guide them correctly and effectively to their destination. Therefore, there is a higher requirement on the rationality, standardization and scientific on the planning and design of subway signage [8]. An effective signage system can guide passengers to complete ticket purchasing, ticket checking, waiting, taking, transferring and leaving stations orderly and smoothly, as a result, improve the operation of subway [32].

Improving the efficiency of signage system has always been a challenge for designers, planners and construction managers. This is because the design of signage system should consider the complexity of building structure and geometric structure, as well as the fluctuation of a large number of pedestrians, and the diversity of pedestrian needs. Therefore, it is difficult to predict the potential optimal location of a particular signage [3]. At present, the design of signage system is accomplished through general guidance, professional knowledge or on-site evaluation. The theoretical visibility of the sign is considered by means of repeated tests, and the on-site inspection is carried out to complete this work [4].

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At present, most of the research on signage system focus on the design and visibility of the identification system. In this paper, a data-driven and mathematical modeling method is proposed to study the signage system of subway.

Firstly, some statistical information was found by data mining to point out the signage problems of Beijing subway system. Secondly, this paper provides an optimization model of signage system according to the characteristics of streamline in subway stations. Finally, the particle swarm optimization (PSO) algorithm is used to solve the model.

## II. RELATED WORK

### A. DIRECTIONAL SIGNAGE

According to a guidance document issued by the Japanese government [5], there are four types of signage: information signage, directional signage, identification signage and safety regulatory signage. Directional signage is used to display the location of facilities and services, as a result to improve the orientation of public space. The inefficiency of the signage system (such as the gap in the continuity of the signage or the inefficient placement of the signage) will lead to inefficiency in finding the way or the loss of pedestrians in public places [6]. In particular, in emergencies, poor directional systems may pose a potential risk to people in extreme stress [7]. On the other hand, an efficient routing system can provide travelers with a good experience and increase their chances of revisiting [8]. Therefore, the effectiveness of directional signage is particularly important for public places.

In terms of subway stations, signages directly affect the smoothness and effectiveness of passenger travel. The reasonable setting of directional signages has a significant impact on the safety and convenience of passengers in the subway [28]–[31].

### B. OPTIMIZATION OF SIGNAGES IN SUBWAY

Wakide Ichiro took Yokohama Metro Station as an example, summarizes the traffic flow in the hub station, which is conducive to the installation of such standardized and easy-to-understand directional signages throughout the station [9]. Zeng designed and established a method for evaluating the performance of the subway signage system to find out the shortcomings and limitations of the existing signage system in subway stations, and to prepare for further optimization and improvement of the subway signage system [10].

Furubayashi *et al.* developed a system based on the directional signages of railway station to verify whether the information provided by such signs is complete. In addition, the method proposed by them can identify whether the signages displayed contradictory information [11]. Puttipakorn and Upala researched the relationship between passengers' efficiency exiting the station and the graphic design (information, elements, layout) of signages in Bangkok Metro Station [12]. Jeon and Hong conducted an evacuation experiment in a damaged visibility environment in a metro station by inviting 103 research subjects to study the changes of human behavior caused by phosphorescent guided signages, and obtained the experimental results that phosphorescent guided signages in a metro station are more convenient for finding evacuation paths [13].

### C. BIG DATA AND SIGNAGE OPTIMIZATION

In general, there are not many studies on the combination of big data and the optimization of signage system. Xie *et al.* used a variety of data sources, such as economics, population, house price, traffic and social network as modelling factors, to present a location recommendation algorithm for electronic signages. Experiments show that the method has high accuracy and recall [14].

Bauer *et al*. focused on the attraction of electronic signage content to customers, a recommendation algorithm for electronic content recommendation of retailers is proposed based on the sales data of retailers [15]. Abraham and Kennedy proposed an intelligent transformation scheme of digital signage system, which makes the digital signage system more interactive with the audience. The flexibility and enhancement of digital signage system can be realized by providing optimized information and attractive appearance multimedia content. In this study, real-time computer vision algorithm is applied to the electronic signage board, and different contents are displayed on the electronic signage board according to the observer's gender and other demographic characteristics [19].

### D. MATHEMATIC MODELLING AND SIGNAGE OPTIMIZATION

A binary linear programming method is proposed to help better allocate the location of directional signages for airport terminal buildings, and a quantitative measurement method called visibility index is used to evaluate the difficulty of finding a way by the signage system. The model can be applied to improve the design of the directional system in various enclosed environments such as airport terminal, multi-function railway station and shopping mall [16]. Based on geographic analysis, a mathematical model for optimizing guiding signs in scenic spots is proposed by Ruan *et al.* The model analyses the spatial distribution of the roads and junctions in scenic area, then choose the signage location according to the grade of roads and scenic spots [17].

Filippidis *et al*. combined the improved building information model with computer virtual reality technology to construct a virtual display environment to evaluate the visibility of the signages. Duszek divided the directional signages in subway station into four categories according to the importance of different signages: I, II, III and IV. They improved the signage location model performance by optimization modelling, AHA analytic hierarchy process and non-inferior classification genetic algorithm [18].

### E. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a swarm intelligence algorithm proposed by Kennedy and Eberhart in 1995, inspired by the foraging behavior of birds and fish and the swarm theory. Particles in the population search in the feasible space determined by specific problems, and the search direction is determined by the current speed (size and direction), the optimal position experienced by the particles themselves, the global optimal position experienced by the population and the random disturbance [21]. Shi and Eberhart think that particle swarm optimization needs to trade-off between global search and local search, and different problems have different trade-offs. Therefore, the inertia weight of normal, linear or nonlinear functions is introduced into the updating formula of particle swarm optimization, and a standard particle swarm optimization algorithm is proposed [22], [23].

Al Kazemi thinks that traditional particle swarm optimization wastes a lot of computing work by combining local and global search, and every particle in it will continue to move in the same direction until the global optimal position changes [23]. Therefore, the multi-phase particle swarm optimization algorithm (MPPSO) is proposed, in which, particle swarm is divided into multiple groups to increase population diversity and space exploration, and different phases (the direction of particle movement changes), moving to the improved position of fitness [24].

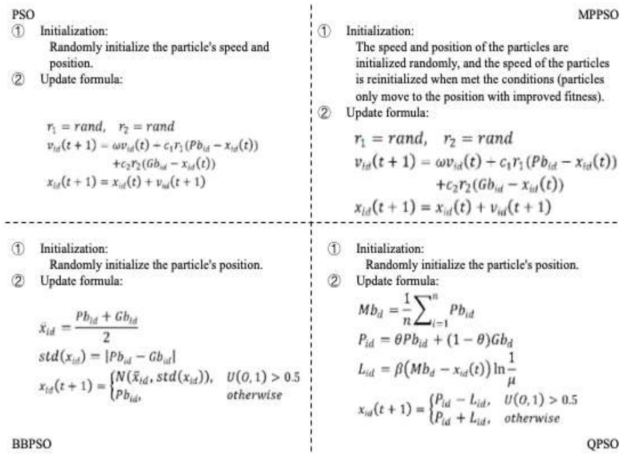


**FIGURE 1.** Comparison of four main variants of PSO.

Kennedy thinks that the formula of particle swarm optimization algorithm is very simple and even can easily describe the working principle of the algorithm orally, but it is difficult to remember how the particles oscillate around the changing center, how they affect each other, how various parameters affect the tracks of the particles and how the topology of the group affects its performance, etc., so he proposes the Bare-Bones particle swarm optimization algorithm (BBPSO) [25].

Inspired by the analysis of PSO convergence, Sun, Feng and Xu studied the movement of a single particle in the PSO system in the quantum multi-dimensional space, established the quantum delta potential well model, and proposed the quantum-behaved particle swarm optimization algorithm (QPSO) [26]–[28]. The differences among the four main variants of PSO are shown in Fig. 1.

## III. ANALYSIS OF THE SIGNAGE PROBLEM OF BEIJING SUBWAY STATION BY BIG DATA

In order to study the validity of the signage system in Beijing subway station, we adopt the data-driven method to extract the statistical data which can reflect the validity of the Metro identification system from the massive origin and destination (OD) data and the complaint data from passengers.

In this study, the data of smart cards for a week from October 27, 2017 to November 3, 2017 at various subway stations in Beijing were used. The original data field of smart card includes: card number, card category, inbound time, outbound time, site name, line name, consumption amount, etc. It includes 39,568,245 records, including 20 lines and 358 stations of Beijing subway. At the same time, a total of 22,498 complaint records from January 1, 2018 to December 31, 2018 were also used for research.

### *A. ANALYSIS OF IN AND OUT AT THE SAME STATION*

According to statistics, 139,887 passengers entered and left at the same station 142,558 times between October 27, 2017 and November 3, 2017. Among them, 61.2% were short-term

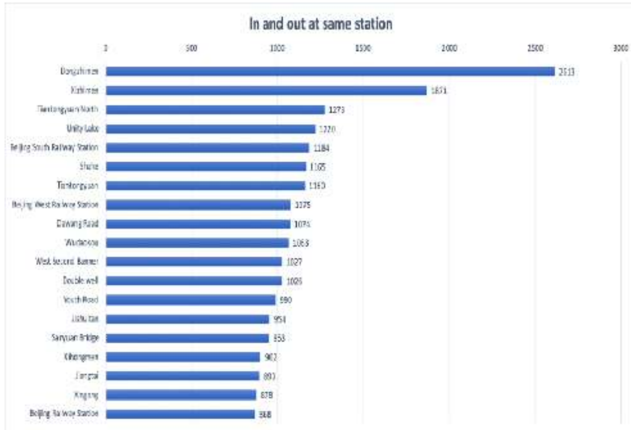


**FIGURE 2.** Ranking of number of person-times in and out at same station happened in 7 days.

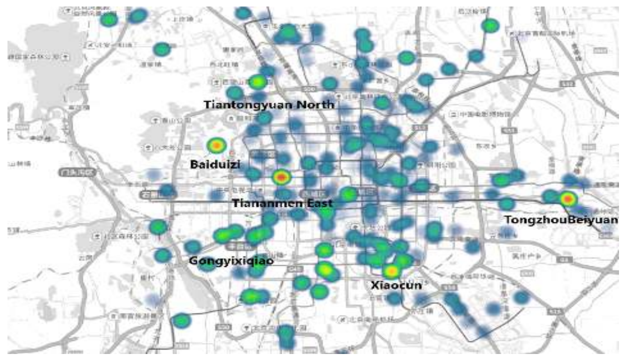


**FIGURE 3.** The proportion of in and out happened at the same station in 7 days.

passengers (within 10 minutes), and 94% were passengers who took the subway once in 7 days.

According to Zhang *et al.*'s research, the possible reasons for entering and leaving the same station include the subway staff behavior, personal emergencies, malicious illegal ticket packages, stealing and begging behavior, and incorrect road-finding [33]. However, a large number of passengers with low frequencies have short-term in-and-out behavior at the same station, which can be considered to be related to the poor routing caused by the problem of subway signages [34].

Fig. 2 shows the ranking of number of person-times in and out at same station happened in the 7 days, and Fig. 3 shows the highest proportion station of that situation happened. According to the two figures, we can easily find that Dongzhimen subway station has both the high frequency and high proportion of in and out at the same station.

### *B. ANALYSIS BETWEEN FREQUENT AND TEMPORARY PASSENGERS*

In order to further study the impact of the signage system on the travel time of Beijing subway, this paper selected five routes with the fixed origin and destination stations

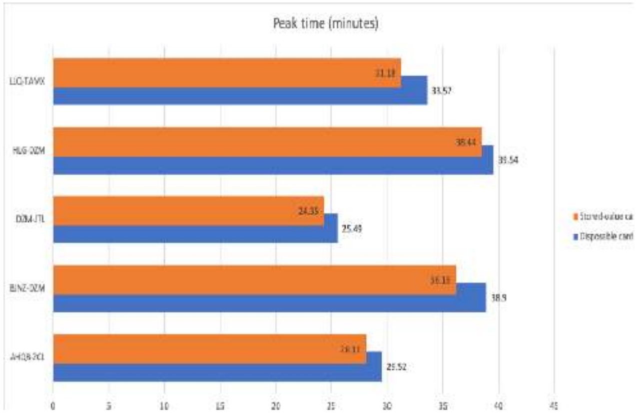


**FIGURE 4.** **Comparison of average travel time at peak time between stored-value card holder and disposable card holder.**

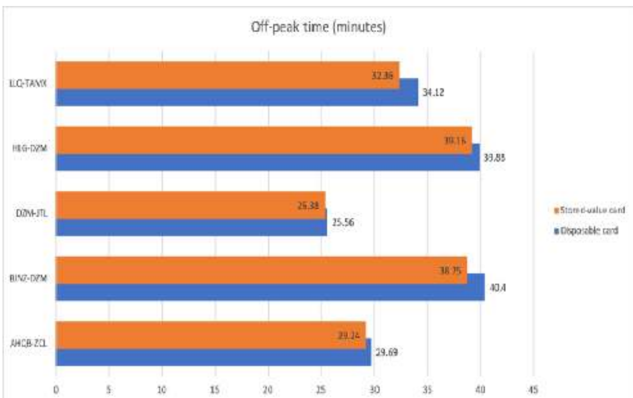


**FIGURE 5.** **Comparison of average travel time at peak time between stored-value card holder and disposable card holder.**

to compare the time spent by passengers with stored value cards and temporary cards in the same period of time. These five lines are Liuliqiao station to Tiananmen West station (LLQ-TAMX), Huilongguan station to Dongzhimen station (HLG-DZM), Dongzhimen station to Jintai Road station (DZM-JTL), Beijing South Railway station to Dongzhimen station (BJNZ-DZM), Anhe Bridge North station Zhichun Road station (AHQB-ZCL).

Fig. 4 shows the comparison of average travel time of the 5 routes by passengers with stored value cards and temporary cards at the peak time (from 7am-10am and from 17pm-20pm everyday) in 7 days. Fig. 5 describes the comparison at the off-peak time in 7 days. By comparative analysis, it can be easily found that, travel time by passengers with stored value card is shorter than travel time by passengers who use temporary cards. The results show that for passengers taking these five routes, people who need guide signages to find their way spend more time than those who are familiar with the routes.

Another finding is that, in some cases, the travel time at off-peak time is longer than the peak time. This is mainly due to the increase in the number of trains during rush hours.

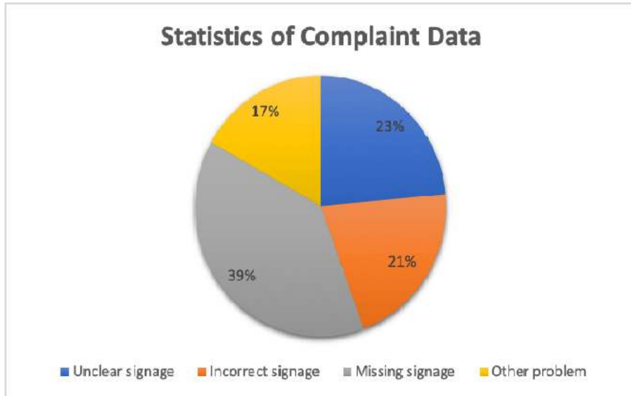


**FIGURE 6.** **Statistical analysis of complaint data by passengers in a year.**

### *C. ANALYSIS OF PASSENGER COMPLAINTS DATA*

In order to verify our analysis of signage problems of Beijing subway station above, we analyzed the complaint data of Beijing subway. These complaint data are fed back by citizens through the subway complaint hotline. We have obtained 22,498 records from January 1, 2018 to December 31, 2018.

There are in total 225 records about signage problems, consists of 4 categories including unclear signage, incorrect signage, missing signage and other problems. Fig. 6 indicates the statistical analysis of complaint data, in which the feedback on the missing signage accounts for 39% of the total, followed by unclear signage, incorrect signage and other problems.

## IV. SIGNAGE POSITION OPTIMIZATION MODEL

### *A. ANALYSIS OF PASSENGER STREAMLINE*

In the process of passenger's behavior such as entering, transferring and leaving the station, some fixed moving routes will be formed, which we call passenger streamlines. Passengers can reach their destination smoothly only when they follow the signages to complete the streamline from arrival to departure. Therefore, the analysis of passenger streamlines is the basis of signage position optimization. According to the composition of passenger flow, passenger streamline can be divided into three parts: inbound streamline, outbound streamline and transfer streamline.

#### 1) INBOUND STREAMLINE

Passengers who enter the subway from the ground entrance will purchase tickets, conduct security checks, swipe cards or scan the passenger code, and then go to the waiting area to wait and take the train. This series of processes need the guidance of the directional signage. The inbound flow line is shown as Fig. 7.

#### 2) OUTBOUND STREAMLINE

After the subway arrives at the station, some passengers who do not need to transfer get off the train and go through the exit directly. Then, according to their destinations, they choose the

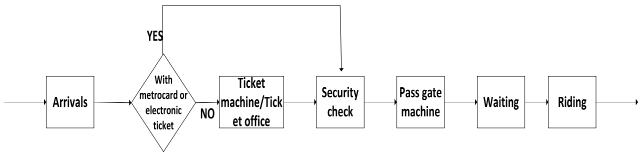


**FIGURE 7.** Inbound flow line in subway stations.

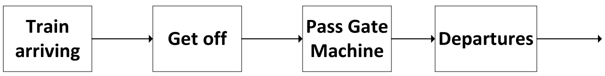


**FIGURE 8.** Outbound flow line in subway stations.

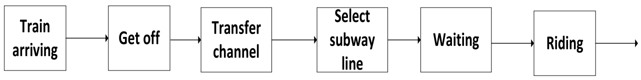


**FIGURE 9.** Transfer flow line in subway stations.

route to leave the station. The outbound flow line is shown in Fig. 8.

### 3) TRANSFER STREAMLINE

After the train arrives at the station, some passengers need to choose another route at the transfer station to reach their destination. The transfer flow is shown in Fig. 9.

## *B. SIGNAGE POSITION OPTIMIZATION MODEL*

The key point to signage position optimization is to select the optimal location of the signages, which is essentially a complex decision-making point selection optimization problem. It means to select the most suitable and optimal points from multiple alternative locations, so that the signages provide correct and sufficient information for passengers to help them finish way-finding process. Therefore, this problem can be solved by establishing an optimal mathematical model of the location of signages. The location where passengers stop and make decisions is called decision point [58]. Whether or not to set a guide sign at a decision point belongs to a 0-1 programming problem, and which decision point to set a signage belongs to the optimization problem.

### 1) PROBLEM DESCRIPTION

The conceptual model for optimizing the location of directional signages is shown in the Fig. 10.

Directional signages of urban subway stations are laid on the basis of passenger streamlines, guiding passengers to make decisions at the nodes and arriving at destination smoothly according to the established streamlines. The mathematical model for optimizing the location of directional signages is described as follows: assuming that there are $m$

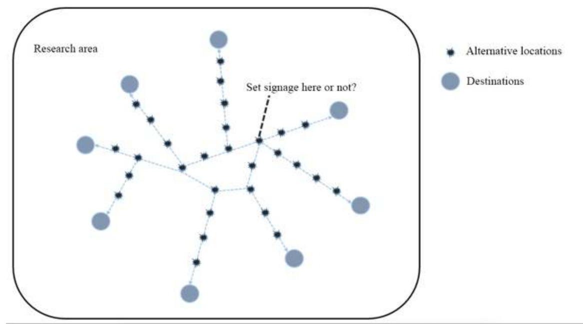


**FIGURE 10.** The conceptual model for optimizing the location of directional signages.

alternative locations for guiding signs (the set of m alternative locations for guiding signages), $p$ locations meeting the restriction requirements are selected from $m$ alternative locations according to certain constraints. A 0-1 function can be used to represent the decision-making of locations (1), as shown at the bottom of this page.

In formula $j$ represents alternative position, $j = 1, 2, \ldots m$.

### 2) OPTIMIZING CONSTRAINT CONDITIONS

Assuming that signages are set at passenger crossings, entrances and exits, stairways, elevators, corners etc., therefore alternative locations are a set of such locations;

The distance between two signages should not be too far. It is assumed that the signage set at each alternative point only displays guidance information within three nodes around the location, and does not display guidance information beyond three nodes.

It is assumed that one level in the station will be taken as the research area.

### 3) ESTABLISHMENT OF OPTIMIZATION MODEL

Objectives function: The optimization model of directional signage distribution with the objective of maximizing the amount of induced information in the research area is established. The optimal objective function is as follows:

$$\max z = \sum_{j=1}^{m} \sum_{i=1}^{n} \frac{f(j) p_{ji} w_{ji}^{a}}{d_{ji}} \tag{2}$$

In this formula, $j$ represents the alternative location of the signage setting, decision point, $j = 1, 2, \ldots m$;

$i$ represents passenger's destination, $i = 1, 2, \ldots n$;

$f(j)$ represents 0-1 function, as shown in formula (1), when the signage is set at the alternative point $j$, $f(j) = 1$; when the signage is not set at the alternative point $j$, $f(j) = 0$;

$p_{ji}$ represents guidance coefficient, assuming that the passenger can accept the guidance service of the signage of

$$f(j) = \begin{cases} 1, & \text{lay out the guiding signs in alternative location } j \\ 0, & \text{not arrange the guiding sings in alternative location } j \end{cases} \tag{1}$$

point $j$ when he going to the destination location $i$, $p_{ji} = 1$; otherwise, $p_{ji} = 0$;

$w_{ji}$ represents passenger flow, which indicates the passenger flow guided by the signage set at point j when the passenger going the destination location $i$. When other conditions remain unchanged, the larger the passenger flow and the more passengers guided, the greater the amount of guidance information, the higher the effect of signage setting;

$a$ represents the weight coefficient, usually a selected constant, represents the balance and weight relationship between the induced passenger flow and the induced distance of the guide sign. When the weight of induced passenger flow is bigger, the value $a$ will be bigger; when the weight of induced distance is bigger, the value $a$ can be slightly smaller, and vice versa; this study takes $a = 1.5$;

$a_{ji}$ represents the number of intersections that passengers can pass through in the process of traveling from the signage of point $j$ to the target location $i$.

From the above optimization model, we can find that there is a positive correlation between the guided passenger flow and the guidance information. That is to say, the more passenger flow guided by the signage, the more effective of the signage. When passengers travel from the signage setting point to the target location, the less intersections they pass and the shorter distance they are from the target location, the more information they received, which indicates that the more effective the signages.

- Constraints:

Assuming that there are p suitable layout points for setting guide signs, the constraint of the number of guide signs is as follows:

$$\sum\nolimits_{j=1}^{m} f(j) = p, \quad j = 1, 2, \ldots, m \tag{3}$$

where $m$ represents number of alternative positions of guide signs;

$p$ represents the number of proper deployment points for guiding signs, $1 < p < m$ and $p$ is an integer.

Assuming that all passenger flows have been guided at least once, the constraint is as follows:

$$\sum_{r}^{Ir} f(j) > 0 \tag{4}$$

where $r$ represents the actual passenger flow into the subway;

$I_r$ represents the collection of alternative points of guide signs that passengers r must pass after entering the subway.

Assuming that each target location has been displayed at least once by the guidance sign, the constraint is as follows:

$$\sum_{i}^{Ii} f(j) > 0 \tag{5}$$

where $i$ represents the actual passenger flow into the subway;

$I_i$ represents the collection of alternative points of guide signs that passengers r must pass after entering the subway.

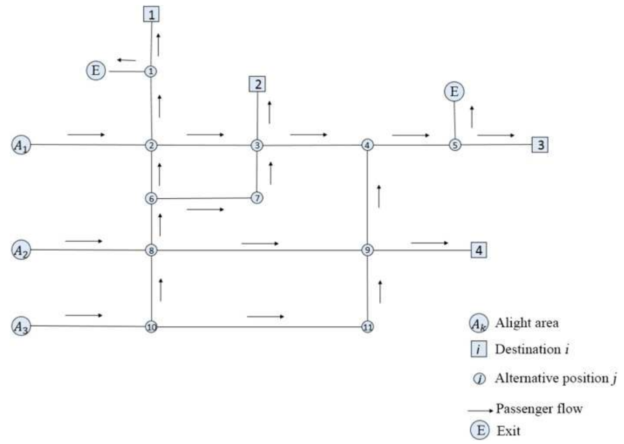


**FIGURE 11. The passenger flow line on the second underground floor of Dongzhimen station.**

Based on the above discussion, the optimal mathematical model is as follows:

$$\max z = \sum_{j=1}^{m} \sum_{i=1}^{n} \frac{f(j) p_{ji} w_{ji}^{a}}{d_{ji}}$$

$$s.t. \begin{cases} \sum_{j=1}^{m} f(j) = p, \quad j = 1, 2, \ldots, m; \\ \sum_{r}^{I_r} f(j) > 0; \\ \sum_{i}^{I_i} f(j) > 0. \end{cases} \tag{6}$$

## V. EXPERIMENT

### A. CALCULATION EXAMPLE DESIGN

#### 1) DETERMINE ALTERNATIVE LOCATIONS, TARGET LOCATIONS AND PASSENGER FLOW

This paper mainly studies the selection of the signage positions of Dongzhimen subway station in Beijing. The passenger flow line on the second underground floor of Dongzhimen station is shown in the Fig. 11.

In order to facilitate the description of passengers' transfer and exit behaviors after getting off, the places where passengers get off the Metro Line 2 are divided into three areas, namely A1, A2 and A3. Target locations 1, 2 and 3 represent the entrance hall for passengers to change to Metro Line 13, airport line and bus station after getting off, and target location 4 represents the exit.

The intersection and decision-making point of passenger flow line in the transfer area of the underground second floor of Dongzhimen metro station are selected as the alternative location for the distribution of guide signs $j(j = 1, 2, \ldots, 11)$, and the parameters in the optimization model can be obtained. The calculation table is shown in Table 1:

**TABLE 1.** The calculation table.

| $j$ | $f(j)$ | $i$ | $w_{ji}$ | $d_{ji}$ |
|---|---|---|---|---|
| 1 | $f(1)$ | 1 | 135 | 1 |
| 2 | $f(2)$ | 1,2,3 | 375,247,157 | 1,1,2 |
| 3 | $f(3)$ | 2,3 | 282,157 | 1,1 |
| 4 | $f(4)$ | 3 | 273 | 1 |
| 5 | $f(5)$ | 3 | 156 | 1 |
| 6 | $f(6)$ | 1,2,3 | 238,192,157 | 1,2,3 |
| 7 | $f(7)$ | 2,3 | 35,157 | 1,2 |
| 8 | $f(8)$ | 1,2,3,4 | 242,105,51,8 | 2,3,2,1 |
| 9 | $f(9)$ | 3,4 | 116,8 | 1,1 |
| 10 | $f(10)$ | 1,2,3,4 | 261,188,65,73 | 3,4,3,2 |
| 11 | $f(11)$ | 3,4 | 65,8 | 2,1 |

### 2) ESTABLISH OBJECTIVE FUNCTION

Establish the optimization objective function relationship, according to (7):

$$\max z = \sum_{j=1}^{11} \sum_{i=1}^{4} \frac{f(j) p_{ji} w_{ji}^{1.5}}{d_{ji}} \tag{7}$$

Based on (7) and Table 1, the optimization objective function can be obtained as follows:

$$\begin{aligned}\max z = &\frac{f(1)\times 135^{1.5}}{1} + \frac{f(2)\times 375^{1.5}}{1} + \frac{f(2)\times 247^{1.5}}{1} \\ &+ \frac{f(2)\times 157^{1.5}}{2} + \frac{f(3)\times 282^{1.5}}{1} \\ &+ \frac{f(3)\times 157^{1.5}}{1} + \frac{f(4)\times 273^{1.5}}{1} + \frac{f(5)\times 156^{1.5}}{1} \\ &+ \frac{f(6)\times 238^{1.5}}{1} \\ &+ \frac{f(6)\times 192^{1.5}}{2} + \frac{f(6)\times 157^{1.5}}{3} + \frac{f(7)\times 35^{1.5}}{1} \\ &+ \frac{f(7)\times 157^{1.5}}{2} \\ &+ \frac{f(8)\times 242^{1.5}}{2} + \frac{f(8)\times 105^{1.5}}{3} + \frac{f(8)\times 51^{1.5}}{2} \\ &+ \frac{f(8)\times 8^{1.5}}{1} \\ &+ \frac{f(9)\times 116^{1.5}}{1} + \frac{f(9)\times 8^{1.5}}{1} + \frac{f(10)\times 261^{1.5}}{3} \\ &+ \frac{f(10)\times 188^{1.5}}{4} \\ &+ \frac{f(10)\times 65^{1.5}}{3} + \frac{f(10)\times 73^{1.5}}{2} + \frac{f(11)\times 65^{1.5}}{2} \\ &+ \frac{f(11)\times 8^{1.5}}{1}\end{aligned} \tag{8}$$

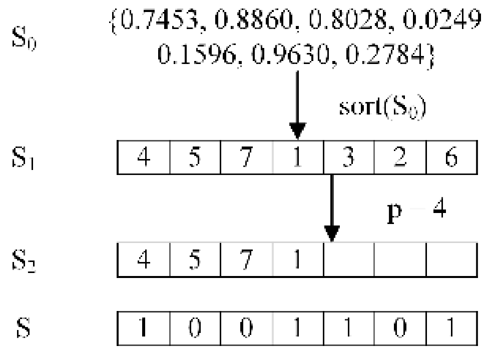


**FIGURE 12.** Coding system of signage optimization of subway stations.

### 3) DETERMINE CONSTRAINTS

- According to (9), set the number of guidance signs as 6.

$$\sum_{j=1}^{11} f(j) = 6 \tag{9}$$

- According to the constraint of (4), all passenger flows have to be guided at least once. The constraints of the passenger flow of start points A1, A2 and A3 can be obtained as follows:

$$A_1 : f(1) + f(2) + f(3) > 0 \tag{10}$$

$$A_2 : f(6) + f(8) + f(9) > 0 \tag{11}$$

$$A_3 : f(8) + f(10) + f(11) > 0 \tag{12}$$

- According to the constraint conditions of formula (5), each target location has been displayed at least once. The constraints for the passenger flow of the target location 1, 2, 3 and 4 are as follows:

Target location 1:

$$f(1) + f(2) + f(6) + f(8) + f(10) > 0 \tag{13}$$

Target location 2:

$$f(2) + f(3) + f(6) + f(7) + f(8) + f(10) > 0 \tag{14}$$

Target location 3:

$$\begin{aligned} f(2) + f(3) + f(4) + f(5) + f(6) + f(7) + f(8) \\ + f(9) + f(10) + f(11) > 0 \end{aligned} \tag{15}$$

Target location 4:

$$f(8) + f(10) + f(11) > 0 \tag{16}$$

### *B. CODING SYSTEM*

There are a lot of researchers worked on the PSO, and they improved it by proposing a variety of main variants. However, the main process of these variants keeps the same as the original PSO. Therefore, Matlab pseudo code of the main variants of PSO algorithm is as follows.

In this paper, the real number coding system is used to deal with the subway signage optimization problem. Each element in the coding system takes a value in the open interval (0,1),

Step 0: Initialize parameters, such as population number $Ns$ and maximum number of iterations $ite\_max$。
Step 1: Initialize particle speed and position according to different variants of PSO algorithm (see Fig. 1), and calculate the fitness.
Step 2: Initialize the historical optimal position of an individual $Pb$.
Step 3: Initialize the historical global optimal position of population $Gb$.
Step 4: Start iterative evolution of population.
for $ite = 1 : ite\_max$
4.1 Determine whether the particle speed needs to be reinitialized according to the variant (see Figure 1).
4.2 Start individual evolution
for $i = 1 : Ns$
step 4.2.1: Update particle speed and position according to different variants of PSO (see Figure 1).
step 4.2.2: Constrain the particle position according to the actual problem and judge whether the current position is feasible. If it is infeasible, the probability of the corresponding sub dimension is updated to random position, the historical optimal position of the individual, the historical global optimal position of the population or the constrained boundary value according to the reference [7].
step 4.2.3: Calculate the fitness $f_i$ of current individual $i$.
step 4.2.4: Update the historical optimal position of current individual $Pb_i$.
if $f_i < Pb_i$(For minimum. If it is to find the maximum value (for example, the calculation example in this paper), the condition is modified to $f_i > Pb_i$)
$Pb_i = f_i$
end
end
Step 4.3 Update the historical global optimal position of the population $Gb$.
$Gb = \min(Pb)$ (For minimum. If it is to find the maximum value (for example, the calculation example in this paper), then $Gb = \max(Pb)$)
end

which is used to represent the priority of the selected alternative location. The smaller the value, the more priority it will be selected. Fig. 12 shows an example of the coding system of signage optimization problem of subway stations. $S_0$ in the figure represents the 7 instances of alternative position, which means the positions of the individuals in the particle swarm. By sorting $S_0$, we can get the priority of the alternative locations $S_1$. Furthermore, the selected positions are $S_2$ (4, 5, 7, 1) which are the first four positions of $S_1$, since the number of signages $p$ is set as 4 in this example. After further decoding, the sign positions were selected corresponding to the location index in $S_2$, and the solution of the subway signage optimization problem $S$ was obtained.

**TABLE 2. Calculation statistics of four main variants of PSO algorithms in subway signage optimization.**

| Algorithm Name | Global Best | | | |
|---|---|---|---|---|
| | Min | Max | Mean | Std |
| PSO | 33980.67 | 33980.67 | 33980.67 | 0 |
| MPPSO | 33980.67 | 33980.67 | 33980.67 | 0 |
| BBPSO | 33980.67 | 33980.67 | 33980.67 | 0 |
| QPSO | 33980.67 | 33980.67 | 33980.67 | 0 |

### C. PARAMETER SETTING

In order to facilitate the comparison of optimization performance, the number of population and the maximum number of iterations of the four PSO algorithms are set to the same value, respectively, $Ns = 50$ and $ite\_max = 100$. The other parameters of PSO algorithm are set as $c_1 = 2.8$, $c_2 = 1.3$ and $\omega = 0.7298$. The other parameters of MPPSO algorithm are set as $ph = 2$, $pcf = 5$, $g = 2$, $sllu = \left[1, \ min(10, \ Nd)\right]$ (where $Nd$ is the dimension of the problem, which is the number of alternative positions in the example) and $VC = 10$. BBPSO algorithm has no other parameters. The other parameters of QPSO algorithm are set as $\beta_{max} = 1$ and $\beta_{min} = 0.5$.

### D. EXPERIMENTAL RESULTS

In this experiment, the four main variants PSO, MPPSO, BBPSO and QPSO, are all programmed by MATLAB. All experiments are simulated by MATLAB R2019b in the laptop with Intel Core i7-8550u CPU and 64-bit Windows 10 home edition operating system. All algorithms run independently 30 times.

For the effect of the four PSO algorithms, in the 30 independent operations of the subway signage optimization problem, the convergence is shown in Fig. 13, the statistical analysis is shown in Fig. 14, and the calculation statistics are shown in Table 2.

Fig. 13 shows that, in the 30 independent operations of subway signage optimization, all the four PSO algorithms can converge rapidly, basically before the 20 iterations of the population evolution. It can be seen from Fig. 14, Table 2 and Table 3 that all of them have strong robustness in optimization, and the global best position can be found 100%, that is to say, the optimal solution of the subway signage optimization problem can be obtained; it can be seen from Fig. 12 and Table 2 that the robustness of operation time is also very good, the standard error of operation time is within 0.02 second, and the average time of an independent operation is less than 1 second. The average running time of QPSO algorithm the

 

**TABLE 3.** Calculation statistics of four main variants of PSO algorithms in subway signage optimization.

| Algorithm Name | Running Time (s) | | | |
|---|---|---|---|---|
| | Min | Max | Mean | Std |
| PSO | 0.18 | 0.26 | 0.19 | 0.01 |
| MPPSO | 0.50 | 0.62 | 0.51 | 0.02 |
| BBPSO | 0.26 | 0.39 | 0.27 | 0.02 |
| QPSO | 0.11 | 0.20 | 0.13 | 0.02 |

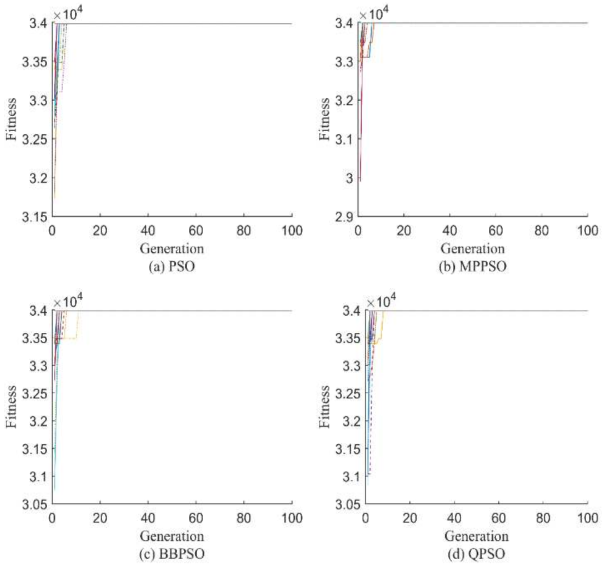


**FIGURE 13.** The convergence of four main variants of PSO algorithm in subway signage optimization.

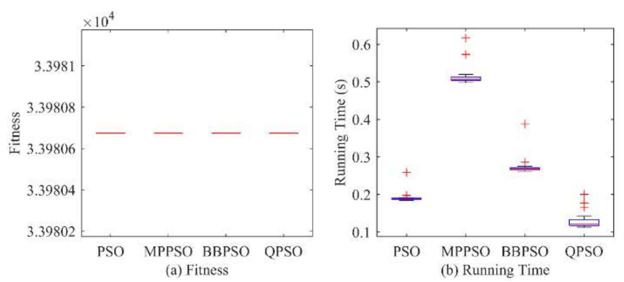


**FIGURE 14.** Statistical analysis of four main variants of PSO algorithm in subway signage optimization.

shortest with 0.13 second, followed by PSO and BBPSO. The MPPSO algorithm runs the longest with 0.51 second, which is 2-4 times that of other algorithms. Therefore, the main four variants of PSO algorithm have a good solution effect in the example of subway signage optimization problem.

Select one of the optimal solutions obtained by one of the algorithms in a certain independence, that is, the example of the optimal solution of the subway signage optimization, as $S_0$ shown in Fig. 13. After decoding through the coding system, we can get the optimal scheme of the subway signage

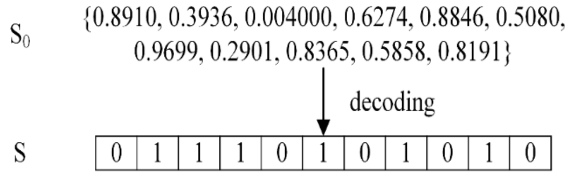


**FIGURE 15.** Example of the optimal solution of the subway signage optimization.

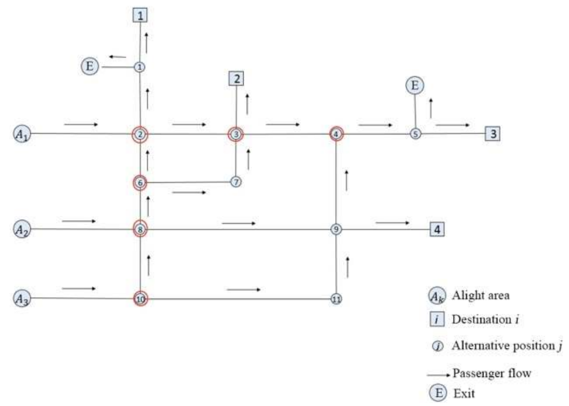


**FIGURE 16.** Optimization scheme of signages for example of subway signage optimization.

optimization problem, as $S$ shown in Fig. 15. Therefore, among the 11 alternative positions, signages should be set at number 2, 3, 4, 6, 8, and 10, as shown in Fig. 16. According to this scheme, the maximum adaptability of 33980.67 can be obtained.

## VI. CONCLUSION

By analyzing the OD data of Beijing subway, this paper draws the conclusion that the signages in Beijing subway stations are inefficient, and verifies it with the passenger complaint data. Therefore, this paper uses the optimization method to build the mathematical model of the location optimization problem of signages in subway stations, and uses the particle swarm optimization algorithm to solve it. Finally, the experimental results of Dongzhimen subway station in Beijing show that the method in this paper has a good solution to the problem of location optimization of signage in subway stations.

## REFERENCES

[1] Z. A. Bohari, S. Bachok, and M. M. Osman, "Improving the quality of public transportation system: Application of simulation model for passenger movement," *Procedia Social Behav. Sci.*, vol. 153, pp. 542–552, Oct. 2014.
[2] O. Neurath, *International Picture Language: The First Rules of Isotype*, 1st ed. London, U.K: Kegan Paul, Trench, Trubner, 1936, pp. 20–21.
[3] S. J. Buechner, J. Wiener, and C. Hölscher, "Methodological triangulation to assess sign placement," in *Proc. Symp. Eye Tracking Res. Appl. (ETRA)*, Santa Barbara, CA, USA, 2012, pp. 185–188.
[4] J. Van Den Berg, M. Lin, and D. Manocha, "Reciprocal velocity obstacles for real-time multi-agent navigation," in *Proc. IEEE Int. Conf. Robot. Autom.*, Piscataway, NJ, USA, May 2008, pp. 1928–1935.
[5] A. Motamedi, Z. Wang, N. Yabuki, T. Fukuda, and T. Michikawa, "Signage visibility analysis and optimization system using BIM-enabled virtual reality (VR) environments," *Adv. Eng. Informat.*, vol. 32, pp. 248–262, Apr. 2017.

[6] L. Filippidis, P. Lawrence, E. Galea, and D. Blackshields, "Simulating the Interaction of Occupants with Signage Systems," in *Proc. 9th Int. Symp.*, vol. 9, 2008, pp. 389–400.

[7] L. Li and W. Li, "Naive Bayesian automatic classification of railway service complaint text based on eigenvalue extraction," *Tehni ki Vjesnik*, vol. 26, no. 3, pp. 778–785, 2019.

[8] E. Cubukcu, "Investigating wayfinding using virtual environments," Ph.D. dissertation, Dept. Elect. Eng., The Ohio State Univ., Columbus, OH, USA, 2003.

[9] I. Wakide, "Standardized guide signs at Yokohama station," in *Proc. Japanese Railway Eng.*, Tokyo, Japan, Jun. 2005, p. 45.

[10] Q. Zeng, "Performance Evaluation of Signage System in Subway Stations," Ph.D. dissertation, Dept. Elect. Eng., Concordia Univ., Montreal, QC, Canada, 2011.

[11] S. Furubayashi, N. N. Yabuki, and T. Fukuda, "A data model for checking directional signage at railway stations," in *Proc. Int. Conf. Civil Building Eng. Inform.*, Tokyo, Japan, 2013, pp. 7–8.

[12] P. Puttipakorn and P. Upala, "Environmental graphic design and the travelers–perception on the exit patterns of subway stations in bangkok," *Environ.-Behav. Proc. J.*, vol. 2, no. 5, , pp. 369–380, Mar. 2017.

[13] G.-Y. Jeon and W.-H. Hong, "An experimental study on how phosphorescent guidance equipment influences on evacuation in impaired visibility," *J. Loss Prevention Process Industries*, vol. 22, no. 6, pp. 934–942, Nov. 2009.

[14] X. Xie, X. Zhang, J. Fu, D. Jiang, C. Yu, and M. Jin, "Location recommendation of digital signage based on multi–source information fusion," *Sustainability*, vol. 10, no. 7, p. 2357, Jul. 2018.

[15] C. Bauer, M. Garaus, C. Strauss, and U. Wagner, "Research directions for digital signage systems in retail," *Procedia Comput. Sci.*, vol. 141, pp. 503–506, Jan. 2018.

[16] M. L. Tam, "An optimization model for wayfinding problems in terminal building," *J. Air Transp. Manage.*, vol. 17, no. 2, pp. 74–79, Mar. 2011.

[17] L. Ruan, Y. Long, L. Zhang, and X. L. Wu, "A geographic analysis of optimal signage location selection in scenic area," *Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci.*, vols. XLI–B2, pp. 477–481, Jun. 2016.

[18] R. Duszek, "The Warsaw subway signage system," *Inf. Des. J.*, vol. 12, no. 3, pp. 181–186, Jan. 2004.

[19] R. E. Abraham and M. Robert Kennedy, "Intelligent digital signage system based on gender identification," in *Intelligent Embedded Systems*. Singapore: Springer, 2018, pp. 251–262.

[20] R. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *Proc. 6th Int. Symp. Micro Mach. Hum. Sci.*, Nagoya, Japan, Nov. 2002, 1995, pp. 39–43

[21] Y. Y. Shi and R. Eberhart, "A modified particle swarm optimize," in *Proc. IEEE World Congr. Comput. Intell.*, Anchorage, Ak, USA, May 1998, pp. 69–73.

[22] Y. Shi and R. Eberhart, "Empirical study of particle swarm optimization," in *Proc. Congr. Evol. Comput. (CEC)*, Washington, DC, USA, Jan. 2003, pp. 1945–1950.

[23] B. Al-kazemi and C. Mohan, "Multi-phase generalization of the particle swarm optimization algorithm," in *Proc. Congr. Evol. Comput. (CEC)*, Honolulu, HI, USA, Jun. 2003. pp. 489–494.

[24] J. Kennedy, "Bare bones particle swarms," in *Proc. IEEE Swarm Intell. Symp. (SIS)*, Indianapolis, IN, USA, Mar. 2004, pp. 80–87.

[25] J. Sun, B. Feng, and W. Xu, "Particle swarm optimization with particles having quantum behavior," in *Proc. Congr. Evol. Comput.*, Portland, OR, USA, Sep. 2004, pp. 325–331.

[26] J. Sun, W. Xu, and B. Feng, "A global search strategy of quantum-behaved particle swarm optimization," in *Proc. IEEE Conf. Intell. Syst.*, Singapore, Jul. 2005, pp. 111–116.

[27] J. Sun, W. Xu, and B. Feng, "Adaptive parameter control for quantum-behaved particle swarm optimization on individual level," in *Proc. IEEE Int. Conf. Syst., Man Cybern.*, Waikoloa, HI, USA, Jan. 2006, pp. 3049–3054.

[28] D. Gong, S. Liu, M. Tang, L. Ren, J. Liu, and X. Liu, "Revenue sharing or profit sharing? An internet production perspective," *Adv. Prod. Eng. Manage.*, vol. 13, no. 1, pp. 81–92, Mar. 2018.

[29] D. Gong, M. Tang, S. Liu, G. Xue, and L. Wang, "Achieving sustainable transport through resource scheduling: A case study for electric vehicle charging stations," *Adv. Prod. Eng. Manage.*, vol. 14, no. 1, pp. 65–79, Mar. 2019.

[30] S. Liu and D. Gong, "Modelling and simulation on recycling of electric vehicle batteries–using agent approach," *Int. J. Simul. Model.*, vol. 13, no. 1, pp. 79–92, Mar. 2014.

[31] D. Gong, S. Liu, and X. Lu, "Modelling the impacts of resource sharing on supply chain efficiency," *Int. J. Simul. Model.*, vol. 14, no. 4, pp. 744–755, Dec. 2015.

[32] D. Zhang, J. Sui, and Y. Gong, "Large scale software test data generation based on collective constraint and weighted combination method," *Tehniki Vjesnik*, vol. 24, no. 4, pp. 1041–1050, Aug. 2017.

[33] D. Zhang, "High-speed train control system big data analysis based on the fuzzy RDF model and uncertain reasoning," *Int J. Comput. Commun.*, vol. 12, no. 4, pp. 577–591, Jun. 2017.

[34] Q. Zhang, S. Liu, D. Gong, and Q. Tu, "A latent-Dirichlet-allocation based extension for domain ontology of enterprise–technological innovation," *Int. J. Comput. Commun.*, vol. 14, no. 1, pp. 107–123, Feb. 2019.


**QUN TU** received the M.S. degree from Loughborough University, U.K. He is currently pursuing the Ph.D. degree in management science with Beijing Jiaotong University. His current research interests include big data analysis on subway and face recognition.

**ZHENJI ZHANG** received the Ph.D. degree in management from Moscow State University, Moscow, Russia. He is currently a Professor of management science with Beijing Jiaotong University. His current research involves in logistics management and information management.

**QIANQIAN ZHANG** received the M.S. degree in information and knowledge management from Loughborough University, U.K. She is currently pursuing the Ph.D. degree in management science with Beijing Jiaotong University. Her current research interests include data mining and analysis, intelligent transportation, and enterprises technological innovation.