The optimization of conventional transit network based on improved genetic algorithm

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Abstract. To deal with problems such as ill-structured conventional transit network and low operational efficiency, this paper presents a method to use transit scheduling value and passenger transit travel time as an optimal objective function to build an optimization model, as an effort to optimize conventional transit network. It aims to improve traditional genetic algorithm, which combines the simulated annealing algorithm with the elitist strategy, and adopts the Python programming to solve the optimization model. The results show that the optimization model can output an optimal transit network and an appropriate scheduling scheme, proving that it is reasonable and feasible to use the improved genetic algorithm in the optimization of transit network.

1. Introduction

With the expansion of city scale, the distance of suburban travel and the difficulty of residents' travel is increasing, and urban traffic congestion is becoming more and more serious. The acceptance of suburban traffic is faced with many challenges, such as poor service level and low passenger flow partaking rate. Therefore, the reasonable construction of conventional transit network layout has been the focus of the researchers native and abroad.

Nikolić M et al. [1] optimize the transit network with the quality of transit service and transfer time. Murawski L et al. [2] propose a transit network optimization scheme aiming at maximizing accessibility. Gutiérrez-Jarpa G et al. [3] establish a spatial-temporal coordination model to optimize transit network layout, taking passenger travel costs and transit schedules as optimization parameters. Jie Yuan-peng et al. [4] take the overall travel efficiency of passengers as the optimization target and construct transit network optimization model, which reduces the average travel time of passengers and improves the overall travel efficiency. Quadrifoglio L et al. [5] establish an off-line optimization model and mix integer programming model for the transit line scheduling problem. Then they propose the insertion heuristic algorithm to solve these models. Tang Sheng-an et al. [6] establish a grey neural network system prediction model to solve the transfer problem of transit hubs, and improve the model by genetic algorithm. Aiming at the optimization model of public transport network, the existing researches mostly use the corresponding genetic algorithm to solve the model, and get the optimal solution [7-9]. Therefore, considering that the traditional genetic algorithm is prone to fall into the local optimal problem, this paper improves the algorithm. The optimization objective is to optimize transit scheduling value and passenger travel time. Finally, an example is given to verify the feasibility of the algorithm.
2. Problem description and model establishment

2.1. Problem description
Most of the existing urban public transports are rail transit and conventional bus interconnecting each other. Residents are more inclined to choose rail transit because of its high-level service. However, the rail transit lines are fixed, it is impossible to cover the residents' travel beyond the radiation range of the lines. Therefore, this paper considers building a conventional transit network optimization model with optimal transit scheduling and minimizing travel time to meet the needs of residents in urban conventional transit transfer.

2.2. Model assumptions
In the present study, the basic assumptions of constructing the conventional transit network optimization model are as follows [10-13].
- The passenger flow and its distribution between stations are constant and known;
- Each transit line is unique, all transit operation vehicles are of the same model, operating vehicle speed and load rate are constant and known. The transit station spacing is known;
- Transits are scheduled in strict accordance with the operation schedule, and there are no traffic jams or accidents on the way;
- The effects of fare, site size and site type are not considered.

2.3. Model establishment

2.3.1. Conventional transit scheduling value. Transit scheduling refers to the optimization of departure frequency and maximization of operation efficiency under the condition of meeting the passenger flow demand of the station. Consequently, the optimal transit scheduling value is expressed by the departure frequency. The formula of transit scheduling value is as in equation (1).

$$F_r = \frac{L_r}{V} + \sum_{i \in N} \lambda_i \times Q_{od} \times \tau_{average}$$  \hspace{1cm} (1)

Where \(F_r\) is the transit scheduling value on transit line \(r\); \(L_r\) is the actual distance (km) on transit line \(r\); \(Q_{od}\) is the number of passengers from transit station \(o\) to transit station \(d\); \(V\) is the average running speed of conventional transit, 40 km/h; \(\lambda_i\) is the judgment item, when there are passengers getting on and off at the transit station, \(\lambda_i = 1\); otherwise, \(\lambda_i = 0\); \(\tau_{average}\) is the average delay time of passengers getting on and off the transit, 0.134min; \(B_{r,max}\) is the maximum number of vehicles supplied by line \(r\), 15 vehicles.

2.3.2. Passenger transit travel time. Transit travel time includes transit travel time and transfer time. In the optimization of transit network, the interests of passengers should be fully considered to ensure the lower transfer rate and transfer time. We formulate the transit travel time as follows equation (2).

$$T_r = \sum_{r \in R} \left( \frac{1}{2F_r} \right) \sum_{o \in N} \sum_{d \in N} Q_{od} \delta_{od} + \sum_{r \in R} \sum_{o \in N} \sum_{d \in N} \frac{L_{od}}{V} Q_{od} \delta_{od}$$  \hspace{1cm} (2)

Where \(N\) is a collection of transit stations; \(R\) is the initial transit line set; \(\delta_{od}\) is the judgment item, when the transit station \(o\) is connected to the transit station \(d\) on line \(r\), \(\delta_{od} = 1\), when the transit station \(o\) is not connected to the transit station \(d\) on line \(r\), \(\delta_{od} = 0\); \(L_{od}\) is the distance between the transit station \(o\) and the transit station \(d\) (km); transit capacity, 50 people per car.
2.3.3. Constraint condition

- Line nonlinear coefficient

\[ \rho = L/d \leq 1.4 \]  \hspace{1cm} (3)

Where \( \rho \) is the transit line nonlinear coefficient; \( L \) is the actual space distance between the first and last stations of the transit line; \( d \) is the space straight line distance of the transit line.

- Length of line

\[ L_{\text{min}} \leq L \leq L_{\text{max}} = VT_{\text{max}}/60 \]  \hspace{1cm} (4)

Where \( L \) is the length of conventional transit line; \( V \) is the mean travel velocity of conventional transit; \( T_{\text{max}} \) is the single-trip time for 95% of urban passengers. The limitation of transit length, 2~10 km.

2.3.4. Objective function

\[
\min Z = F_r \times T_c = \frac{\frac{L}{V} + \sum_{i \in N} \lambda_i \times Q_{od} \times t_{average}}{B_{r,\text{max}}} \times \left( \sum_{r \in R} \frac{1}{2F_r} \sum_{o \in N} \sum_{d \in N} Q_{od} \delta_{ad} + \sum_{r \in R} \sum_{o \in N} \sum_{d \in N} \frac{L_{od}}{V} Q_{od} \delta_{od} \right)
\]  \hspace{1cm} (5)

s.t. \[ \sum_{i \in N} \lambda_i = 1 \]  \hspace{1cm} (6)

\[ \sum_{o \in N} \sum_{d \in N} \delta_{od} = 1 \]  \hspace{1cm} (7)

\[ \rho = L/d \leq 1.4 \]  \hspace{1cm} (8)

\[ L_{\text{min}} \leq L \leq L_{\text{max}} = VT_{\text{max}}/60 \]  \hspace{1cm} (9)

3. Algorithm designing

The optimization model in this study is a nonlinear multi-objective programming problem, which cannot be solved by deterministic analytic method. This model can be solved by genetic algorithm, but there are some shortcomings, as described in the introduction. So the traditional genetic algorithm is improved as follows.

3.1. Chromosome coding

According to the coding characteristics of genetic algorithm in this paper, each transit line is digitally numbered in decimal system. The number of each transit line is grouped into one substring, and then many substrings form the whole transit line network. An example of a whole transit line network as follows.

The transit lines: route1 (1 3 4 11 14), route2 (7 6 3 4), route3 (8 9 10 5 11), route4 (12 8 7 1), thus a string (134 11 14 7 6 4 8 9 5 11 8 7 1) is formed, indicating that the transit network has four lines. Since a chromosome can only represent one solution vector, this method is unique and the solution vector is unique.

3.2. Preliminary population building

The existing transit lines in the research area are coded and treated as preliminary individuals. If the individual size of the population is \( N \), the preliminary individual will be duplicated \( N \) times, and then \( N \) identical individuals will be obtained to form the preliminary population required by this model.

3.3. Establishment of fitness function

Due to the genetic algorithm mainly uses internal information to search, the fitness function determines the convergence rate of the genetic algorithm and the selection of the optimal solution. Moreover, fitness function is the main component of genetic algorithm, and its complexity is the same,
so the design of fitness function should be as simple as possible to minimize the computing time.  

Based on an expression method in reference [4], the reciprocal of the objective function value of the optimization model is used as the fitness function to calculate the fitness value of individuals in the population. Assuming that the fitness value of the \( n \)th individual in the population is \( m \), then \( m \) is the reciprocal of the total travel time consumption of all passengers on the transit line shown by the \( n \)th individual.

### 3.4. Selection

Genetic algorithm is prone to produce local optimal solution. In order to remedy this defect, simulated annealing algorithm is introduced in this study. The simulated annealing algorithm mainly uses Metropolis criterion to determine the state transfer probability \( P_i \) of the current solution \( a \) to the new solution \( b \). The specific formula is as in equation (10).

\[
P_i(a \Rightarrow b) = \begin{cases} 1 & f(b) < f(a) \\ \exp(-\frac{f(b)-f(a)}{T}) & f(b) \geq f(a) \\ \end{cases}
\]  

(10)

Where \( f(a) \) is the fitness value before the cross-mutation of an individual in a population; \( f(b) \) is the fitness value of the individual after cross-mutation; \( T \) is the current temperature, and \( T \) decays at a cooling rate as evolution progresses. The current temperature \( T(t) \) is as in equation(11).

\[
T(t) = T_0/(1+t)
\]

(11)

Where \( T_0 \) is the preliminary temperature; \( t \) is the number of iterations.

In this paper, simulated annealing algorithm and elite strategy are used to carry out selection operation, which can effectively avoid the destruction of excellent individuals and protect the diversity of individuals in the population [14].

### 3.5. Crossover and mutation

In the paired population selected by the matching pool, crossover individual pairs are randomly generated according to a certain crossover probability \( P_m \). Then a crosspoint is randomly selected in individual coding. Finally, the chromosome behind it is exchanged to generate two new individuals. That is, the number of chromosomes is \( N_{pop-size} \), and the average number of chromosomes crossing each time in the population is \( P_m \cdot N_{pop-size} \).

The diversity of the target population is maintained by determining the mutation probability \( P_n \), which indicates that \( P_m \cdot N_{pop-size} \) chromosomes are mutated in each evolution. At the same time, combining the self-adjusting strategy between crossover and mutation operators, the individuals in the population have great differences, which not only improves the convergence speed of the algorithm, but also makes the algorithm better jump out of the local optimal solution.

### 4. Case analysis

In the present study, 15 transit stations and 26 transit station connecting sections in a certain area are taken as research objects, and transit stations are numbered 1-15. Among them, there are 4 pairs of transit stations at the beginning and the end, which are 1-13, 3-15, 7-11 and 1-15 respectively. The layout of transit network in the study area is shown in Figure 1. OD data of peak time between transit stations are shown in Table 1, and the shortest distance between transit stations is determined according to reference [15].
Figure 1. Conventional transit network layout in the study area

Table 1. OD data during peak period of station

| sites | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|-------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1     | 0  | 67 | 24 | 51 | 20 | 98 | 72 | 102| 95 | 161| 76 | 104| 119| 176| 34 |
| 2     | 60 | 0  | 10 | 79 | 8  | 30 | 33 | 96 | 15 | 23 | 19 | 48 | 10 | 29 | 33 |
| 3     | 31 | 8  | 0  | 62 | 15 | 3  | 165| 21 | 9  | 5  | 64 | 18 | 53 | 69 | 9  |
| 4     | 175| 41 | 71 | 0  | 126| 18 | 267| 45 | 198| 33 | 81 | 79 | 123| 64 | 17 |
| 5     | 25 | 7  | 59 | 23 | 0  | 71 | 137| 145| 84 | 55 | 114| 134| 179| 120| 206|
| 6     | 52 | 12 | 69 | 24 | 11 | 0  | 51 | 50 | 39 | 211| 27 | 52 | 31 | 91 | 257|
| 7     | 32 | 3  | 20 | 36 | 260| 277| 0  | 22 | 69 | 9  | 27 | 52 | 36 | 13 | 120|
| 8     | 52 | 11 | 52 | 157| 26 | 136| 32 | 0  | 32 | 7  | 15 | 35 | 47 | 17 | 10 |
| 9     | 54 | 75 | 50 | 192| 5  | 72 | 56 | 32 | 0  | 277| 26 | 378| 98 | 115| 85 |
| 10    | 101| 23 | 34 | 65 | 7  | 229| 32 | 41 | 69 | 0  | 29 | 22 | 63 | 12 | 17 |
| 11    | 12 | 42 | 24 | 164| 157| 45 | 24 | 17 | 147| 45 | 0  | 29 | 30 | 23 | 19 |
| 12    | 55 | 2  | 63 | 11 | 163| 141| 31 | 52 | 24 | 34 | 10 | 0  | 19 | 30 | 88 |
| 13    | 10 | 70 | 2  | 29 | 32 | 207| 42 | 32 | 233| 41 | 12 | 7  | 0  | 78 | 90 |
| 14    | 56 | 25 | 72 | 73 | 61 | 120| 101| 42 | 135| 11 | 23 | 6  | 22 | 0  | 35 |
| 15    | 86 | 26 | 153| 21 | 12 | 266| 30 | 20 | 40 | 42 | 42 | 141| 35 | 43 | 0  |

This study improves the classical genetic algorithm, uses Python programming software to solve the model, and calculates the optimal routing and departure frequencies of the transit network, as shown in Table 2.

Table 2. Results of optimized conventional transit network

| Transit terminals | Transit lines | Transit scheduling value(min) |
|-------------------|---------------|------------------------------|
| 1-13              | 1-2-3-6-8-13  | 6.3                          |
| 3-15              | 3-2-4-9-10-11-14-15 | 4.7                      |
| 7-11              | 7-6-5-4-10-11  | 3.9                          |
| 1-15              | 1-2-4-10-14-15 | 9.1                          |

5. Conclusion

Aiming at the optimization of conventional transit network, this paper establishes the optimization model of the transit network with the transit scheduling value and passenger transit travel time as the objective, and uses the improved genetic algorithm combined with simulated annealing algorithm and elite strategy to obtain the optimal solution of the model. At last, the feasibility and rationality of the algorithm are verified by a case. Since there are many factors influencing transit operation, the algorithm will be further improved in the future.
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