Research on operation optimization of Chengdu subway based on transfer station structure analysis

Haowen Li

Golden Apple Jincheng No.1 Secondary School, Chengdu, China

13875990882@163.com

Abstract. In the current case of China's rail transit as a major part of public transportation, the complexity of the line has brought more transfer stations. After the investigation and observation, the long waiting time of transfer stations is one of the biggest problems at this stage. In the investigation of the transfer station, taking Chengdu as an example, the author chose the third-line transfer station with moderate universality and complexity as the research goal, and investigated the transfer efficiency and influencing factors. After the study and discussion of the conclusion, the author decided to establish a mathematical model to optimize and improve. For the more neglected problems, the fine regulation of the transfer station structure and the train schedule. The scheduling optimization model of this paper, as a universal and simple data collection model, can be universally applied. Meanwhile, this paper gives a new perspective on the rail transit transfer optimization, with the transfer time and passenger experience as the main consideration factors.

Keywords: rail transit, transfer station optimization, operation scheduling, digital planning

1. Introduction

Nowadays, as one of the cores of the region “Sichuan and Chongqing”, Chengdu has achieved rapid and prosperous development because of its geographical location and the tendency of the national development center. And adhere to the "eastward, southern expansion, western control, northern reform, excellent [1]" Under this policy, the development area of Chengdu and the overall development level of each region are rising sharply. And based on the status quo, Chengdu rail transit era with the comprehensive development and development, is from "big city" to "metropolis" in order to ensure that Chengdu environmental protection city planning, complete the urban traffic needs, university convenience, scenic spot convenient task makes the importance of public rail transit gradually rise. In the gradual development and increase the line, the importance of transfer station and the importance of convenience is also gradually rising. In the field investigation and the feedback from the Chinese people in Chengdu on the government website, it was found that the train departure time of different lines of the transfer stations was a relatively big contradiction. People often transfer to get off, found that when they arrived at another subway station, the subway bus has just started, and for the transfer of people, they need to wait for a new longest cycle by up and down a train, the emergence of the problem seriously affected the effectiveness of the subway transfer and speed, and make the experience of the subway passengers fell sharply. These problems can be effectively and significantly improved under the structure analysis based on the transfer station, the optimization, and the change and optimization of the different time points of the shuttle bus departure time interval.

In many exploration and research on rail transit, Liu Shanwei et al. studied the optimization of the future third-line transfer time of the New South Gate, and put forward optimization measures based on Any Logic simulation analysis of equipment and facilities and traffic flow organization, which can be reduced. The conclusion that less congestion can also reduce the transfer time at other stations [1]. Based on the quantitative method of passenger flow control of urban rail transit, Jia Shuhang and others obtained the inaccurate pure experience behavior of manual transfer with low effect. Through the study of passenger flow control and flow balance of transfer station, the passenger flow control of transfer station can be further precise, reduce risks and improve the service quality [2]. Liu Xueli and others studied the too long use time and subsequent congestion of the Xiaozhai station transfer station, and proposed the method to increase the subway sign to make the passenger flow more regular and optimized to reduce the transfer time and make the experience of the transfer personnel better [3]. Zhu Haibin studied the advantages and disadvantages of the same station transfer of Zhengzhou rail transit Line 4, and put forward the online network planning, we can use the same station transfer by relying on the open site, and give the method of the open space of the transfer station hall, and draw the conclusion that the transfer of the same station is effective but there is still room for improvement and optimization [4]. Li Yi et al. studied different passenger flow walking modes under the condition of multi-line network operation of urban rail transit, and put forward six main detour and transfer modes, which gave the optimization methods and direction of future rail transfer on the basis of the existing rail transit transfer [5]. Zhu Qingbo et al. studied the bottleneck optimization problem of transfer and detention at a station in Wuhan, and proposed the method of using Anylogic to build a simulation diagram and simulation model based on the actual flow data, and concluded that the infrastructure such as security checkpoints and stairs can be improved, and the flow transportation can be optimized [6]. Li Yushu et al. studied a series of problems caused by insufficient data and insufficient detection and prediction, and put forward the data analysis and convenient prediction method of transfer from a macro perspective. In addition to simple macro changes, artificial intelligence technology can be used to get the passenger flow walking condition in real time, so as to estimate the passenger flow pressure [7]. Chai and Tian and others studied the congestion and pedestrian waiting problems at transfer stations. After the departure time of the first bus changes, the departure time elasticity changes, making passengers have less waiting time [8]. Wen-jing liu studied the rail transit transfer station physical internal and external layout, put forward the method by considering the surrounding buildings and station passenger flow situation, it can be obtained after considering various factors after considering an economic and efficient transfer method, and after similar projects to provide certain reference [9]. Wang Wei studied the optimization problem of urban rail transit transfer, put forward the difference method of personal factors of passengers, and established an optimization model starting from the demand side such as passengers [10]. Hao Cheng et al of municipal railway transfer station characteristics of the different establishment of the evaluation system, build a reliability, efficiency, comfort, economy, security as the primary index, to the existing reliability, facilities layout reliability, capacity matching 15 indicators for the secondary index of municipal railway and urban rail transit transfer station facilities configuration evaluation index system, make the transfer station data more specific and visualization [11].

In conclusion, the existing studies focus on structural changes of transfer stations and aspects of the scheduling model.On the basis of the above research, this paper focuses more on the relationship between the flow of the people and the train schedule through the structure analysis of the transfer station. The results will be the optimized experience scheme in the multi-line transfer based on the comfort of the transfer personnel. The second section of this article will talk about the Chengdu Metro Analysis of the operation status of rail transit, section 3 will describe the problem description and train operation scheduling model construction, while section 4 will explain, data collection and case analysis.

DOI: 10.54254/2753-8818/5/20230289

2. Analysis of the operation status of Chengdu Metro rail transit

It has been built on the general line 1,2,3,4,5,6,7,8 and 9,10,17,18 and Rong 2 tram. In addition, in the online network planning, the long-term plan is to build 1666km of rail lines, including 21 general lines, 8 express lines and 7 municipal railways.

Among the completed subway stations in Chengdu, there are nearly 200 single-line subway stations and more than 40 transfer stations, including six third-line transfer stations. In all types of subway stations, the existing infrastructure includes toilets and multiple exits to ensure the basic needs of passengers and walking convenience. At the same time, there are stores and convenience stores in multiple subway stations to provide convenience to passengers. At the same time, manual service desks are set up at multiple stations, and the safety protection facilities include the preparation and storage of basic fire fighting and first aid facilities. In terms of the current epidemic prevention and security checks, Chengdu Metro has set up health codes for subway stations and local railway security check channels to ensure the implementation of the epidemic prevention behavior and the guarantee of the safety of passengers.

For the departure interval problem of each line, Chengdu Metro mainly takes the line, supplemented by the peak period, and establishes the interval of the departure time.For transfer people, after to the platform, need to wait part of the time, through the commercial field of the waiting theory we can know that passengers need to reduce meaningless waiting. Any time passengers need to think their time is meaningful, that is to say, for passengers, will spend time on the way will be better than the time spent waiting in the queue. This is also another way to deal with the excessive waiting time for transfer stations. Through the study and optimization of the building structure of the transfer station, coupled with the coordination of the shuttle bus arrangement of different lines in different time periods, the problems of too long transfer waiting time and poor transfer experience can be effectively solved.

3. Problem description and construction of train operation and scheduling model

In this paper, the model considers how to minimize the transfer time when the driving schedule and the transfer time of a certain line A are optimized.

The structure optimization of the transfer station can well optimize and cooperate with the transfer time, which means that more efficient rail transit operation and better passenger experience can be realized. In addition, in order to rationalize the transfer time, the shuttle bus time needs to be divided and established more accurately. Nowadays, a common phenomenon in rail transit in China is that the departure time and waiting time are fixed, so the optimization of shuttle bus schedule can make great changes to rail transit. Through the coordination of the transfer times of different lines and the shuttle bus schedules of different lines, the waiting time of passengers can be greatly reduced, and the rail transit experience of passengers can be optimized.At the same time, the efficiency of rail transit has been further improved. The availability of a location per unit of time and the increase of passenger volume will bring higher affordable passenger value to the whole rail transit system. At the same time, studies on passenger flow can offset the cost of excessive bus frequency in a short time. With the use of the model calculation results in this paper, it can be concluded that after the appropriate adjustment of the bus time and transfer station structure optimization, the waiting time will be minimized, while the walking time is a small increase. But as discussed in this paper, walking time will not affect the passenger experience, and even optimize the evaluation of passengers for transfer.

The parameters are as follows

n: Number of transfer stations for this line, where the number of double-line transfers is n_1, The number of third-line transfers is n2

c_i: The i th double-line transfer line transfer time i=1,2,3,........， n_1

c_{1j}: In The j-th third-line transfer station, the transfer time of one of the other lines is j=1,2,3,........ ， n_2

c_{2j}: In The j-th third-line transfer station, the transfer time of one of the other lines is j=1,2,3,........ , n_2

t_{ik}^1: The other line goes up to the k shuttle bus reaches the transfer station time, 1 means the upward route, the maximum value of k is the total number of trains per day

t_{ik}^2: The other line descending line k shuttle bus reaches the transfer station moment, 2 indicates the downlink route, and the maximum value of k is the total number of trains per day

t_{1jk}^1: The other line up k bus reaches the time of the transfer station, 1 means the ascending route, the maximum value of k is the total number of trains per day

t_{1jk}^2: The other line descending bus k reaches the moment of the transfer station, 2 indicates the downlink route, and the maximum value of k is the total number of trains per day

t_{2jk}^1: The other line up k bus reaches the time of the transfer station, 1 means the ascending route, the maximum value of k is the total number of trains per day

t_{2jk}^2: The other line descending bus k reaches the moment of the transfer station, 2 indicates the downlink route, and the maximum value of k is the total number of trains per day

Determine the specific departure schedule of line A according to the basic parameters of each transfer station. The decision variables are as follows

x_{lk1}: Line A when the k th bus arrives at the l th station, 1 indicates the upside

x_{lk2}: Line A Down when the k th bus reaches the l th station, 2 indicates the downlink

The following model considers the upside direction for Line A. Then, the objective function is as follows:

$$\min \sum_{k} \sum_{l=1}^{n_1} w_{lk1} + \sum_{k} \sum_{l=1}^{n_2} \left(w_{lk1}^1 + w_{lk1}^2\right)$$

The model constraints are as follows:

$$w_{lk1} = \min_{k}\{x_{lk1} + c_{\mathrm{l}} - t_{lk'1}\}, l = 1,2, \ldots\ldots n_1, k = 1,2, \ldots\ldots.$$

$$w_{lk1} \geq 0, l = 1,2, \ldots\ldots., n_1, k = 1,2, \ldots..$$

$$w_{\mathrm{l}k1}^1 = \min_{k}\left\{x_{lk1} + c_l^1 - t_{lk'1}^1\right\}, l = 1,2, \ldots\ldots n_2, k = 1,2, \ldots\ldots.$$

$$w_{lk1}^1 \geq 0, l = 1,2, \ldots\ldots., n_2, k = 1,2, \ldots..$$

$$w_{lk1}^2 = \min_{k}\left\{x_{lk1} + c_{\mathrm{l}}^2 - t_{lk'1}^2\right\}, l = 1,2, \ldots\ldots n_2, k = 1,2, \ldots\ldots.$$

$$w_{lk1}^2 \geq 0, l = 1,2, \ldots\ldots., n_2, k = 1,2, \ldots..$$

The w in the constraint indicates the minimum waiting time for the transfer station.

4. Data collection and case analysis

The actual case studied in this paper is Chengdu Di Line 5, and the dispatching and operation line is optimized. There are 8 transfer stations on Line 5, and 7 of them are double-line transfers. As shown in Figure 2, the 7 double-line transfer stations are Huilong Station, Jincheng Avenue Station, Shenxianshu Station, Jiuxing Avenue Station, Gaoshengqiao Station, Northwest Bridge Station and North Station West Second Road. The only third-line transfer station is the TCM provincial hospital station.After field research, provincial hospital of traditional Chinese medicine, for example, TCM provincial hospital is the only three line transfer station, on the line 5 including line 5, line 4, line 2 three lines, and through the subway website, get the structure, as shown in figure 1, line 5 in a platform, line 2 and line 4 two running direction, as a platform, and the other two running direction in a platform, equal to a channel also contains a direction of two lines of the same.

DOI: 10.54254/2753-8818/5/20230289

Table 1. Summary table of information of each transfer station of Line 5.

Transfer station name	Transfer station type	Transfer line	Transfer to a walking distance of
Back to dragon station	diplonema	Line 6	65m
Jincheng Avenue Station	diplonema	Line 9	70m
Fairy tree station	diplonema	Line 7	50m
Jiuxing Avenue Station	diplonema	Line 8	80m
Gao Sheng bridge station	diplonema	Line 3	110m
Northwest bridge station	diplonema	Line 6	40m
North Station West Second Road	diplonema	Line 7	100m
Provincial Hospital of Traditional Chinese Medicine	three-way	Line 2, Line 4	120m

This paper will focus on the TCM provincial hospital station of Line 5 as an example, and the structure of the station is shown in Figure 1. The model analysis is used to solve the optimal shift operation scheduling time. First of all, the basic data survey of transferring from Line 5 to Line 2 and Line 4 at the TCM provincial hospital station is given, as shown in Table 2.

Table 2. Train Schedule of Line 2 and Line 4 at TCM Provincial Hospital Station (1 PM to 2 PM).

Line 2	Schedule of TCM Provincial Hospital Station on Line 4
1：05	1：00
1：17	1：12
1：29	1：24
1：41	1：36
1：53	1：48
	2：00

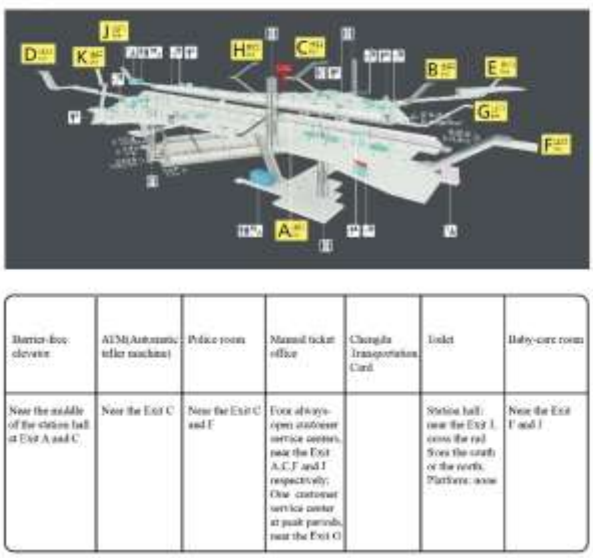

Figure 1. Structure diagram of the subway station of TCM Provincial Hospital [12].

Figure 2. Line Map of Metro Line 5 [12].

And after the field research, transfer field measurement, platform 5 to the other two lines platform time need 1min20s time, and after arriving at the platform to wait for 1min36s will have line 4 train arrived, 2min56s to wait until line 2 after the train, and for line 5, low peak bus time is 8 minutes, line 2 bus time low peak for 12 minutes, line 4 for low peak period 12 minutes.

Take the low-peak shuttle bus at 1 PM as an example, as shown in Table 3, the actual arrival time of Line 5 of TCM provincial hospitals is 01:16, the arrival time of Line 4 is 01:00, and the arrival time of Line 2 is 01:05.

Table 3. Actual Line 5, Line 4, Line 2 reached the TCM provincial hospital station time.

Provincial Hospital of Traditional Chinese Medicine	Line 5	Line 4	Line 2
	1：16	1：00	1：05
	1：24	1：12	1：17
	1：32	1：24	1：29
	1：40	1：36	1：41
	1：48	1：48	1：53
	1：56	2：00	

The feasibility of the model and the success of the results were verified by optimizing the shuttle bus time from 1:00 PM to 2:00 PM Beijing time for the low peak period. The specific verification is that the shuttle bus train schedule of Line 5 is optimized at the existing train arrival time of Line 4 and Line 2, in order to achieve the optimal waiting time, that is, the arrival time of Line 5 trains with the minimum average transfer waiting time. Because the departure interval of line 2 and line 4 is 12 minutes, so assume the departure interval of line 5 is also 12 minutes, starting from 1:00, to 1:12 every minute of average waiting time, namely the next line 2 train after line 5 arrival time difference plus the arrival of the next line 4 train arrival time difference and divided by two, calculate, get the best departure time. At the same time, because the departure interval is 12 minutes, with the best departure time of the first round, the best departure wheel time of line 5 can be launched. The specific transfer time and results are shown in Table 4.

DOI: 10.54254/2753-8818/5/20230289

Table 4. Computation results for reach time and operation process of Line 5.

Provincial Hospital of Traditional Chinese Medicine	Line 4 shuttle bus arrival time	Line 2 shuttle bus arrival time	Optimum bus arrival time for Line 5	When Line 5 arrives	Average waiting time / min
	1:00	1:05	1:00	1:00	2.5
	1:12	1:17	1:12	1:01	7.5
	1:24	1:29	1:24	1:02	6.5
	1:36	1:41	1:36	1:03	5.5
	1:48	1:53	1:48	1:04	4.5
	2:00		2:00	1:05	3.5
				1:06	8.5
				1:07	7.5
				1:08	6.5
				1:09	5.5
				1:10	4.5
				1:11	3.5
				1:12	2.5

5. Conclusion

On the basis of the predecessors, this paper has made a new attempt to optimize the experience of rail transit passengers. Using the structural adjustment of the transfer station design, combined with the optimization of the shuttle bus schedule in different time periods, to improve the transfer experience of passengers. In short, to maximize the waiting time of passengers on the platform, making passengers less aware of the cognition of time stay and psychological time waste, so that the whole transfer process provides better service, and improve the efficiency of rail transit to a certain extent. In the process of model building and example analysis, this paper establishes the transfer optimization theoretically, and puts forward the feasible optimization scheme. In the model operation, this paper concludes on how to optimize the transfer time and transfer experience while considering the optimization of the transfer station structure and the shuttle bus schedule. This conclusion can be applied in the establishment of shuttle bus schedule of transfer stations and the structure design of transfer stations. Meanwhile, this example gives a new perspective on the transfer experience of transfer stations, and contributes to the research direction of by passenger experience and the improvement of the research diversity of rail transit.

References

[1] Liu Shanwei, Zhang Yang. Functional evaluation of the tertiary transfer station based on AnyLogic simulation. Journal of Transportation Engineering and Information Technology.2021,19(01)
[2] Jia Shuhang, Lu Jianhong, Liu Mingming. Research on Quantitative Method Based on Transfer Passenger Flow Control of Urban Rail Transit. Urban fast rail transit.2021,34(05)
[3] Liu Xueli, Zan Wenbo. Analysis and Evaluation of Urban Rail Transit. Henan science and technology.2021,40(23)
[4] Haibin Zhu. Design of the Transfer Station of Zhengzhou Rail Transit Line 4. Transportation Manager World.2021,(20)
[5] Li Yi, Shi Cheng, Zou Zhijun. Analysis of Decision factors of Passenger Transfer in Urban Rail

Transit.urban communications.2021,19(02)
[6] Zhu Qingbo, Song Tingxin, Li Yan. Study on the Improvement of Rail Transit Transfer Capacity Based on Anylogic.computer simulation.2020,37(02)
[7] Li Yushu, Sun Yue, Wan Heng, Pu Qi. Evaluation Method of Passenger Flow Pressure in Transfer Channel of Urban Rail Transit Station. Research on Urban Rail Transit.2020,23(01)
[8] Chai and Tian, Chen Mengmeng, Luo Yang. Optimization of early-shift train group schedule of urban rail transit network. Qinghai Transportation Science and Technology.2020,31(01)
[9] Liu Wenjing. Selection of subway transfer station layout scheme. Tianjin Construction Technology.2019,29(06)
[10] Wang Wei. A Study on the Optimization of Urban Rail Transit Transfer. Heilongjiang Transportation Technology.2019,42(12)
[11] Hao Cheng, Yang Dan, Yin Yong. Research on Facilities Allocation Evaluation of Urban Railway and Urban Rail Transit Transfer Station.integrated transportation.2019,41(07)
[12] Chengdu Rail Transit Officer https: / / www.chengdurail.com/index_sw.html