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Optimization Research of the Operational Driving Organization of Guangzhou Metro onweekends Based on Optimization Method

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Abstract. By studying the passenger flow data of Guangzhou Metro Line 1, we aim to analyze the passenger flow characteristics on weekends. This involves fitting the data to obtain time-related inbound and outbound passenger flow functions. An optimization model targeting the average subway full load rate is established to improve operational efficiency. Utilizing MATLAB software for programming, we import passenger flow data into the program. This enables us to obtain the average full load rate and determine optimal train departure times during peak, off-peak, and off-peak periods. Our approach involves a detailed analysis of the passenger flow trends, considering various factors such as time of day, holidays, and special events. This comprehensive analysis allows us to adapt the train schedules to match the passenger demand more accurately. Then, under the condition that the departure interval remains consistent every hour, we determine the optimal departure interval for each stage. This ensures that trains are neither overcrowded nor underutilized. The ultimate goal is to achieve an optimized driving interval in each period, balancing efficiency and passenger comfort. By doing so, we can enhance the travel experience for commuters, reduce congestion during rush hours, and ensure a more sustainable and cost-effective operation of the metro system. Our model can also adapt to future changes in passenger flow, making the Guangzhou Metro more responsive to the needs of its users. Moreover, the model's flexibility allows for quick adjustments in case of unexpected events or sudden changes in passenger patterns. We also plan to integrate real-time data analytics for more dynamic scheduling and efficiency.

Keywords: *subway, passenger flow characteristics, optimization, driving interval.*

1. Introduction

Studying the flow characteristics of subway passengers has always attracted much attention, and many scholars have conducted statistical analysis on this. Based on existing data, they use various prediction technologies such as cluster analysis, genetic algorithm [1], neural network [2] and grayscale prediction [3] to predict the passenger flow of the subway in the future. The purpose is to dispatch subway resources more efficiently. These different theoretical methods are of great research significance.

This study uses optimization methods to adjust subway travel intervals, which not only helps improve the efficiency and transportation potential of the subway, but also improves passenger satisfaction. This work has important practical value in solving the current challenges faced by subway operators - station congestion during peak periods and waste of resources during off-peak periods.

Further, this study extends to evaluate the effectiveness of these methods in real-time management of subway systems. By analyzing historical passenger flow data and integrating it with predictive algorithms, we can forecast passenger trends and dynamically adjust service frequency. Such proactive management ensures that resources are allocated where they are needed most, significantly enhancing service reliability and passenger convenience.

Additionally, our research delves into the environmental impact of subway operations. Optimizing travel intervals not only enhances efficiency but also contributes to reduced energy consumption and lower carbon emissions. This aligns with global efforts towards sustainable urban transportation systems.

Moreover, we explore the psychological impact of crowding on passengers. Overcrowding not only leads to discomfort but can also increase stress levels and affect overall satisfaction. By optimizing travel intervals and reducing crowding, we aim to enhance the mental well-being of commuters.

In summary, the advancement in optimization methods for subway systems extends beyond mere operational efficiency. It encompasses environmental sustainability, passenger comfort, and mental well-being, paving the way for a holistic approach to urban mass transit solutions. The implications of this study are far-reaching, promising a more efficient, sustainable, and user-friendly subway system that can adapt to the evolving demands of urban life.

1.1. Analysis of passenger flow characteristics

First, organize the passenger flow data on weekends of each month in Excel and draw a chart. It is found that basically the difference in passenger flow on weekends of each month is not obvious. The following data lines all overlap, and in the morning and evening peak periods the time periods are all the same time period, as shown in Figure 1. Therefore, it was decided to sum up the passenger flow of each weekend and get the arithmetic average, and use the average passenger flow as the general passenger flow on weekends and derive the relevant passenger flow characteristics from it.

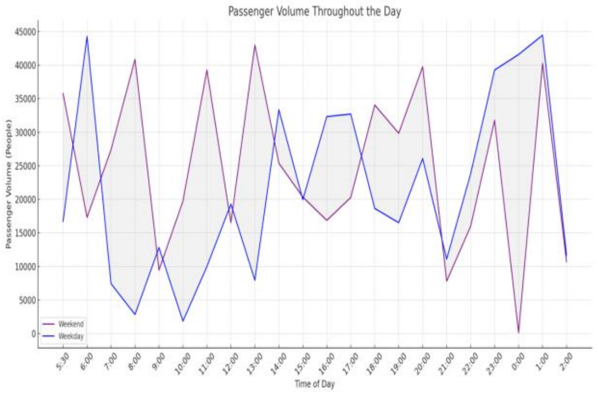

Figure 1. Comparison chart of average passenger flow on weekends and working days

Using SPSS to perform hypothesis testing on the average passenger flow data, it can be concluded that the asymptotic significance of 0.08 is greater than the significance level of 0.05. Therefore, the original hypothesis is accepted that the passenger flow distribution on weekends obeys the normal distribution, that is, the passenger flow distribution on weekends can be considered with a 95% confidence level. It follows a normal distribution with a mean of 20687.7647 and a standard deviation of 6549.95.

2. Materials and methods

2.1. Optimization method to optimize driving interval

This article uses optimization methods to establish mathematical models, reference [4].

2.2. Establishment of optimization model

The data used in this study is formatted to represent the number of people entering and exiting each station on an hourly basis. Consequently, the analysis divides the day into hourly time periods. The subway operation, as per the 1-S-1083 timetable, spans from 5:30 AM to 11:00 PM. Specifically, Guangzhou's Line 1 begins its service at Fangcun Station at 5:30 AM. In contrast, the upbound service starting from Xilang Station commences at 6:00 AM. This study focuses on optimizing the departure frequencies of the upbound line, recognizing the unique patterns and needs of this route. While the down bound line, with its symmetrically opposite route, operates under a similar framework, it features an additional time period in its schedule. By segmenting the data into these hourly blocks and paying close attention to the operational nuances of each line, the study aims to devise an optimal strategy for train departures. This approach not only enhances the precision of the optimization but also ensures that the solutions are tailored to the specific operational dynamics of the subway lines, ultimately improving the overall efficiency and effectiveness of the subway system in handling passenger traffic.

When entering the station from Fangcun Station, the number of people exiting the station at this time must be the number of people getting off the down bound subway, not the upbound subway being studied, so the number of people getting off at the first station is 0; and the number of people entering the station at the last station, Thirteenth Street, is all downward, so in the process of studying the upward route, the number of people entering the last stop can be recorded as 0. Regarding how to distinguish the number of people entering and exiting the station between upstream and downstream, this article uses the ratio of the number of stations. For example, at Qingnian Street Station, there are 15 stations heading towards No. 13 Street and 5 stations heading towards Dawn Square. Thus, the number of people entering the station is divided into the number of people going up and down according to the ratio of 15:5, while the number of people leaving the station is just the opposite, the ratio of the number of people going up and down is 5:15.

This method of allocation based on station ratios reflects a logical approach to data analysis. It helps in accurately estimating the passenger flow in each direction, which is crucial for optimizing the train schedules. The system assumes a higher likelihood of passengers heading towards the direction with a greater number of stations. This assumption is based on the understanding that passengers are more likely to travel towards a destination with multiple stops, reflecting common urban commuting patterns.

Moreover, this approach of distinguishing passenger flow direction provides a more detailed insight into the travel patterns and preferences of the commuters. By understanding the dynamics of passenger movement, the subway system can not only optimize its services but also plan for future expansions or modifications more effectively. For instance, if a particular direction consistently shows a higher passenger flow, it might indicate the need for more frequent services or additional trains in that direction.

The method of using station ratios to determine passenger flow direction is a strategic decision that enhances the accuracy of data analysis. This approach not only improves the immediate scheduling and operational efficiency but also provides valuable insights for long-term planning and development of the subway system. Driving optimization is reflected by the average full load factor. Full load rate = passenger turnover (person-kilometers)/passenger seats (capacity)-kilometers. Passenger space (capacity) kilometers is the product of the operating subway capacity and the operating kilometers; the subway capacity is the sum of the number of fixed seats in the carriage and the standing capacity quota per square meter of effective area. The subway capacity is set as the overcrowding capacity of the Line 1 subway multiplied by the limited occupancy rate. According to the driving rules provided by the subway group, the subway's overcrowding capacity is 1,820 people, with an average of 8 people per square meter. The subway's capacity is 1,440 There are an average of 6 people per square meter. Through calculation, the limited occupancy rate can be found to be 0.8.

Explanation of constant symbols: k represents the number of stages in the subway driving process; n represents the total number of stages in the subway driving process; j represents the site number of the subway stop; m represents the total number of subway stops; Y represents the Line 1 subway The excess passenger capacity; β represents the limited occupancy rate of the Line 1 subway; L_k represents the period length of the k stage (k=1,2,…,m).

Explanation of variable symbols: h_k represents the number of selectable departures in stage k; $f_i(t)$ represents the number of passengers waiting at station j at time t; $q_i(t)$ represents the number of passengers getting off at station j at time t; ΔT_k represents the th stage The departure interval of Represents the driving time between the j th station and the j+1 th station; $B_k(x_k)$ indicates the k-th stage when the number of people stranded is x_k best interests.

The number of passenger seats (capacity) kilometers per train = the number of overcrowded loads, the limited full load rate, the sum of the distances between two adjacent stations in the upstream direction: $Y \cdot \beta(\sum_{j=1}^{m-1} S_j)$, then the capacity kilometers in the kth stage = the capacity kilometers per train × the number of departures: $W = Y \cdot \beta(\sum_{j=1}^{m-1} S_j) \cdot h_k$. And the passenger turnover (person-kilometers) is the actual passenger kilometers, which is the number of passengers passing through each station and the number of passengers from station j to j+1 sum of products of station distances:

$$G_{kr} = X_{k,r}^{(1)} \cdot S_1 + \sum_{j=2}^{m-1} \left\{ \sum_{p=1}^{j} X_{k.r}^{(p)} - [\sum_{i=2}^{j} q_i(T_{k,r,i}) - q_i(T_{k,r,i} - \Delta T_k)] \right\} \cdot S_j$$

The number of passengers passing through each station refers to the total number of passengers on the subway when the subway leaves the stop. Then the average full load rate in the upstream direction of Line 1 in the kth stage: $\theta_k = (\sum_{r=1}^{h_k} G_{kr}) / W$. After obtaining the objective function, write out several necessary variables come. The number of people that the first subway train can carry at the first stop during the period is:

$$X_{k,1}^{(2)} = \min \left\{ \begin{matrix} x_{k,2} + f_2(T_{k,1,2}) - f_1(T_{k,1,2} - \Delta T_k), \\ Y \cdot \beta - \left\{ X_{k,1}^{(1)} - [q_2(T_{k,1,2}) - q_2(T_{k,1,2} - \Delta T_k)] \right\} \end{matrix} \right\}$$

Among them, $q_2(T_{k,1,2}) - q_2(T_{k,1,2} - \Delta T_k)$ refers to the people who got off the bus at the first stop.

number, and it is necessary to calculate the number of passengers that can be carried on the subway at this time, and then find the minimum value between the number of passengers and the number of passengers who will get on the subway to avoid the situation of overloading the subway.

The first subway train in the period of time can carry the number of people at the station:

$$X_{k,1}^{(j)} = \min \left\{ \begin{matrix} x_{k,j} + f_j(T_{k,1,j}) - f_1(T_{k,1,j} - \Delta T_k), \\ \beta - \left\{ \sum_{p=1}^{j-1} X_{k,1}^{(p)} - \sum_{p=1}^{j} [q_p(T_{k,1,p}) - q_p(T_{k,1,p} - \Delta T_k)] \right\} \end{matrix} \right\}$$

The number of people in the r-th subway train in the k-th time period that can carry the first stop is:

$$X_{k,r}^{(1)} = \min \left\{ x_{k,1} + f_1(T_{k,r,1}) - f_1(T_{k,r,1} - \Delta T_k), Y \cdot \beta \right\}$$

At this time, you need to pay attention to the change of time T within the function. The number of people the r-th subway can carry at the j-th station in the k-th time period is:

$$X_{k,r}^{(j)} = \min \left\{ \begin{matrix} x_{k,j} + f_j(T_{k,r,j}) - f_j(T_{k,r,j} - \Delta T_k), \\ \beta - \left\{ \sum_{p=1}^{j-1} X_{k,r}^{(p)} - \sum_{p=1}^{j} [q_p(T_{k,r,p}) - q_p(T_{k,r,p} - \Delta T_k)] \right\} \end{matrix} \right\}$$

Among them, $T_{k,r,j}$ represents the moment when the r-th subway train leaves the station in the k-th time period. The moment when subway train r leaves station j in time period k:

$$T_{k,r,n} = \sum_{p=1}^{k-1} L_p + r \cdot \Delta T_k + \sum_{p=1}^{j-1} \varepsilon_p, T_k = \frac{L_k}{h_k}$$

3. Results and discussion

According to the operation order issued by the subway group, the subway departure interval is accurate to the second. Therefore, when fitting the number of people entering and exiting each station, the independent variable used in this article is time in seconds, and the dependent variable is based on Time period accumulation of the number of people entering and exiting the station.

Use the cftool fitting function package in MATLAB to perform polynomial function fitting on the data, and find the relationship between the number of upstream passengers entering the station and time at each station. The following only takes the first station as an example to give the fitting results:

$$f_1(t) = p_1 \cdot t^6 + p_2 \cdot t^5 + p_3 \cdot t^4 + p_4 \cdot t^3 + + p_5 \cdot t^2 + p_6 \cdot t + p_7,$$

$$p_1 = 6.045 \times 10^{-24}, p_2 = -1.2 \times 10^{-18},$$

$$p_3 = 9.222 \times 10^{-14}, p_4 = -3.86 \times 10^{-9},$$

$$p_5 = 5.08 \times 10^{-5}, p_6 = 0.1561, p_7 = -262.2$$

To facilitate data calculation, it is assumed that the number of stranded people at the beginning of each stage is 0. Using the same fitting method, we can get the relationship between the number of people leaving the station and time t:

$$g_j(t) = p_1 \cdot t^6 + p_2 \cdot t^5 + p_3 \cdot t^4 + p_4 \cdot t^3 + p_5 \cdot t^2 + p_6 \cdot t + p_7,$$

And the constraint condition is $g_j(t) = 0$, that is, the number of people leaving the first site is 0.

In the process of using polynomials to fit the number of people entering and exiting the station in the upward direction, if a polynomial of degree less than six is used, it will be found that the standard error is very large, and some points in the graph are not on the fitting curve, and the accuracy of the model does not meet the requirements, and if you use polynomials of degree six or more, you will find that although the standard error will decrease, the decrease will be very small, and at this time it will also increase the complexity of the model.

In selecting a sixth-order polynomial for our analysis, we prioritized a balance between model accuracy and complexity. This decision was informed by the fact that each equation's R-square value reached an impressive 99.9%. Such a high R-square indicates that, under the hexanomial condition, the time variable is highly effective in representing the overall dynamics of the fitting function. While it's noted that both the standard error and the mean square errors are sizeable, it is crucial to consider the large scale of the data points involved. Initially, the focus is on analyzing the R-square; a value close to 1 is indicative of a good fit. Subsequently, the analysis extends to the absolute and relative errors. Their relatively small magnitudes further validate the effectiveness of the fitting function. This thorough approach in model selection and validation underscores the reliability of the study's findings, ensuring that the results are both accurate and practically significant for application in optimizing subway operations. The application of this model holds the potential to substantially enhance the efficiency and responsiveness of the subway system, by providing a robust framework for understanding and predicting passenger flow trends.

Table 1. Driving interval and full load rate before optimization

Time period	Driving interval	Average full load rate
6:00~7:00	8’18	0.191
7:00~8:00	5’14	0.345
8:00~9:00	5’14	0.347
9:00~10:00	5’14	0.318
10:00~11:00	5’14	0.302
11:00~12:00	5’14	0.299
12:00~13:00	5’14	0. 315
13:00~14:00	5’14	0.344
14:00~15:00	5’14	0.379
15:00~16:00	5’14	0.411
16:00~17:00	5’14	0.432
17:00~18:00	5’14	0.428
18:00~19:00	5’14	0.402
19:00~20:00	8’18	0.559
20:00~21:00	8’18	0.446
21:00~22:00	8’18	0.323
22:00~23:00	8’18	0.327

Table 2. Driving interval and full load rate after optimization

Time period	Driving interval	Average full load rate
6:00~7:00	10’	0.223
7:00~8:00	6’	0.408
8:00~9:00	6’	0.382
9:00~10:00	6’	0.349
10:00~11:00	6’14	0.367
11:00~12:00	6’14	0.365
12:00~13:00	6’14	0.384
13:00~14:00	6’14	0.421
14:00~15:00	6’14	0.464
15:00~16:00	6’14	0.502
16:00~17:00	5’	0.394
17:00~18:00	5’	0.392
18:00~19:00	5’	0.368
19:00~20:00	8’34	0.551
20:00~21:00	8’34	0.441
21:00~22:00	10’	0.378
22:00~23:00	10’	0.276

4. Conclusions

The optimization of subway travel intervals, as demonstrated by the increased average full load rate and reduced number of upbound trains, serves as a pivotal step towards a more responsive and efficient urban transit system. This efficiency gain is not limited to the physical aspects of the subway operation but extends into financial savings and enhanced user experience. Financially, the reduced number of operational trains directly translates into lower expenditures for the subway system. This includes savings in fuel or electricity costs, less frequent maintenance due to reduced wear and tear, and potential reductions in workforce requirements during off-peak periods. These cost savings could be strategically redirected into other areas such as infrastructure development, advanced technology integration, or staff training programs, which would further enhance the system's overall quality and efficiency. The environmental benefits of this optimization are noteworthy. Reduced emissions during off-peak hours significantly contribute to the city's environmental goals. This proactive approach in environmental stewardship reinforces the role of public transit as a sustainable option and can encourage a larger segment of the population to opt for mass transit over personal vehicles, thereby amplifying the positive environmental impact. From a passenger perspective, the optimization of travel intervals directly translates to a more reliable and comfortable commuting experience. During peak hours, the increased availability of trains helps in mitigating the issues of overcrowding, a common cause of discomfort in urban transit systems. This not only improves the daily commute for existing users but also enhances the attractiveness of the subway as a viable alternative for new users, potentially leading to a decrease in road traffic and associated problems. Moreover, the application of a dynamic, data-driven approach in scheduling reflects an advanced level of operational sophistication. By leveraging real-time data, the system can rapidly adapt to changing patterns in passenger flow, whether due to daily fluctuations or extraordinary events. This agility is particularly crucial in urban centers, where a multitude of factors can impact commuter behavior. The strategic adjustment of train schedules also has broader societal implications. By enhancing the efficiency and attractiveness of the subway system, it can play a significant role in the urban planning and development process. A reliable and efficient public transit system is a cornerstone of modern urban living, facilitating easier access to employment, education, and services, and contributing to the overall economic and social vitality of the city. The strategic optimization of subway travel intervals embodies a comprehensive approach that addresses the intricate challenges of modern urban transit. It showcases how thoughtful planning and the use of advanced data analytics can lead to significant improvements in operational efficiency, financial management, environmental sustainability, and user satisfaction. This model sets a precedent for other urban transit systems worldwide, highlighting the immense potential of embracing innovative, data-driven solutions in public transportation.

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Оңтайландыру әдісіне негізделген демалыс күндері Гуанчжоу метросының операциялық жүргізу ұйымын оңтайландыруды зерттеу

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Аңдатпа. Гуанчжоу метросының 1 желісінің жолаушылар ағынының деректерін зерттеу арқылы біз демалыс күндері жолаушылар ағынының сипаттамаларын талдауды мақсат етеміз. Бұл уақытпен байланысты кіретін және шығатын жолаушылар ағынының функцияларын алу үшін деректерді сәйкестендіруді қамтиды. Жұмыс тиімділігін арттыру үшін метроның орташа толық жүктеме жылдамдығына бағытталған оңтайландыру үлгісі орнатылған. Бағдарламалау үшін MATLAB бағдарламалық құралын пайдалана отырып, біз бағдарламаға жолаушылар ағынының деректерін импорттаймыз. Бұл бізге толық жүктеменің орташа жылдамдығын алуға және ең жоғары, жоғары емес және жоғары емес кезеңдерде пойыздардың оңтайлы жөнелту уақытын анықтауға мүмкіндік береді. Біздің көзқарасымыз күннің уақыты, мерекелер және ерекше оқиғалар сияқты әртүрлі факторларды ескере отырып, жолаушылар ағынының үрдістерін егжей-тегжейлі талдауды қамтиды. Бұл кешенді талдау жолаушылар сұранысын дәлірек сәйкестендіру үшін пойыздар кестесін бейімдеуге мүмкіндік береді. Содан кейін, кету аралығы әр сағат сайын біркелкі болып қалатын жағдайда, біз әрбір кезең үшін оңтайлы кету аралығын анықтаймыз. Бұл пойыздардың толып кетпеуін немесе толық пайдаланылмауын қамтамасыз етеді. Түпкі мақсат – тиімділік пен жолаушылар жайлылығын теңестіре отырып, әр кезеңде оңтайландырылған қозғалыс аралығына қол жеткізу. Осылайша, біз жолаушылар үшін саяхат тәжірибесін жақсарта аламыз, қарбалас уақыттарда кептелістерді азайтып, метро жүйесінің тұрақты және үнемді жұмысын қамтамасыз ете аламыз. Біздің модель жолаушылар ағынындағы болашақ өзгерістерге де бейімделе алады, бұл Гуанчжоу метросын пайдаланушылардың қажеттіліктеріне көбірек жауап береді. Сонымен қатар, модельдің икемділігі күтпеген оқиғалар немесе жолаушылар үлгісіндегі кенет өзгерістер жағдайында жылдам реттеуге мүмкіндік береді. Біз сондай-ақ динамикалық жоспарлау және тиімділік үшін нақты уақыттағы деректер талдауын біріктіруді жоспарлап отырмыз.

Негізгі сөздер: *метро, жолаушылар ағынының сипаттамалары, оңтайландыру, жүргізу аралығы.*

Исследование оптимизации организации оперативного вождения метрополитена Гуанчжоу в выходные дни на основе метода оптимизации

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Аннотация. Изучая данные о пассажиропотоке 1-й линии метро Гуанчжоу, мы стремимся проанализировать характеристики пассажиропотока в выходные дни. Это включает в себя подбор данных для получения функций входящего и исходящего пассажиропотока, связанных со временем. Модель оптимизации, ориентированная на среднюю скорость полной загрузки метрополитена, создана для повышения операционной эффективности. Используя для программирования программное обеспечение MATLAB, мы импортируем в программу данные о пассажиропотоке. Это позволяет нам получить среднюю скорость полной загрузки и определить оптимальное время отправления поездов в часы пик, внепиковое и непиковое время. Наш подход предполагает детальный анализ тенденций пассажиропотока с учетом различных факторов, таких как время суток, праздники и специальные мероприятия. Такой комплексный анализ позволяет нам более точно адаптировать расписание поездов к потребностям пассажиров. Затем, при условии, что интервал отправления остается постоянным каждый час, определяем оптимальный интервал отправления для каждого этапа. Это гарантирует, что поезда не будут ни переполнены, ни загружены недостаточно. Конечная цель — добиться оптимизации интервалов между поездками в каждый период, обеспечивая баланс между эффективностью и комфортом пассажиров. Поступая таким образом, мы сможем улучшить качество поездок для пассажиров, уменьшить заторы в часы пик и обеспечить более устойчивую и экономически эффективную работу системы метро. Наша модель также может адаптироваться к будущим изменениям пассажиропотока, что делает метро Гуанчжоу более отзывчивым к потребностям своих пользователей. Более того, гибкость модели позволяет быстро корректировать ее в случае непредвиденных событий или резких изменений в структуре пассажиропотока. Мы также планируем интегрировать анализ данных в реальном времени для более динамичного планирования и эффективности.

Ключевые слова: *метро, характеристики пассажиропотоков, оптимизация, интервал вождения*.

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