Research on Demand Responsive Transit Route Optimization, Scheduling Models, and Solution Algorithms

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Abstract. Nowadays, urban traffic congestion is a serious issue, and the rise of demand responsive transit systems improves this problem to a certain extent. This paper delves into the route optimization, scheduling, and modeling of demand-responsive transit, exploring its seamless integration into urban transportation planning. This bus system aims to improve the efficiency of the transportation system, reduce congestion, and improve the urban environment, thus enhancing the quality of life of the residents. This study reveals the potential benefits of a demand responsive transit system in urban transportation planning, offering the possibility of increased flexibility and efficiency. Future research directions could further explore how demand responsive systems can be implemented in a targeted manner under different urban environments and demands to promote sustainable urban transport development. Considering the differences in cities, such as transportation structure, population density, and cultural characteristics, it will be crucial to develop appropriate implementation strategies. Meanwhile, combining emerging technologies, such as artificial intelligence and big data analytics, will provide strong support for further enhancement of the demand responsive transit system to better meet the travel needs of the residents and promote the development of urban transportation more sustainably. This study provides a valuable reference for urban planners and points out the direction for the improvement and development of urban transportation in the future.

Keywords: Demand Responsive Transit, Route optimization, Vehicle scheduling.

1. Introduction

Urban traffic has always been an urgent problem in contemporary urban planning and development. Traffic congestion, inconvenient public transport, and emissions negatively impact urban life, the economy, and the environment, posing a threat to sustainable urbanization.

The rise of demand-responsive transit has a direct impact on urban transportation planning, as well as on urban sustainability and residents' quality of life. Route optimization, scheduling, and resolution models are key components in achieving this goal. In the current study, route optimization aims to reduce traffic congestion and improve traffic efficiency by selecting the best route. Scheduling optimization focuses on the arrangement of bus vehicles to ensure the coverage and quality of service. At the same time, the solution model solves various traffic problems through mathematics and calculation methods, and provides support for decision-making.

In the field of transportation planning, demand-responsive bus has become a popular concept. Its core concept is to provide flexible public transport services according to passenger needs. Unlike traditional fixed-route bus systems, demand-responsive buses allow routing and vehicle scheduling to be adjusted according to actual needs. The emergence of this concept has brought a new idea for urban transportation planning, which can better meet the needs of different passenger groups and improve the flexibility and efficiency of public transportation systems [1].

There has been a lot of research and progress at home and abroad exploring how to integrate demand responsive transit systems into urban planning to promote efficient and sustainable urban transportation. These studies include case studies from different cities, policy measures, technological innovations, etc., to provide recommendations to city decision makers on how demand responsive transit system can adapt to different urban environments and needs. In the 1960s, Cole L M et al. explored possible future modes of transportation service. There is a demand-activated public transit system. The system combines the characteristics of conventional bus and taxi systems, aiming to provide convenient travel services for residents in areas with low population density, which can be said to be the epitome of DRT. In 1990, the United States enacted the relevant act, which stipulates that relevant agencies must provide flexible bus services for special passengers who cannot use regular public transportation. Since then, scholars at home and abroad have begun to study the DRT system. The research on DRT by Chinese scholars is relatively late. DRT was first introduced and implemented in Qingdao in August 2013. Subsequently, many cities such as Beijing, Jinan, and Tianjin opened DRT services.

The main purpose of this paper is to provide more comprehensive guidance for urban traffic planning through an in-depth study of route optimization, scheduling optimization, and solution models. Through research, this paper hopes to explore how to organically integrate customized public transportation systems into urban transportation planning to improve the efficiency of the transportation system, reduce congestion, improve the urban environment, and ultimately improve the quality of life of residents. This research is expected to provide strong support for urban decision makers to make urban transport systems smarter, sustainable, and adaptable to future urbanization challenges [2].

2. The development of demand-responsive public transportation and its significance

Currently, China's economy and society continue to develop rapidly, and the number of private cars continues to show a rapid growth trend. According to the Traffic Management Bureau of the Ministry of Public Security of the People's Republic of China, by the end of 2016, the number of motor vehicles in the country reached 290 million. Among them, the number of private cars reached 194 million, a 2.34-fold increase from the 2011 figure of 58.14 million. The rising number of motor vehicles exacerbates urban issues like traffic congestion, air pollution, and noise, posing significant challenges to sustainable city development. Compared with other modes of urban transportation, public transportation has outstanding comparative advantages such as large capacity, small area, small energy consumption, etc. Priority for the development of public transportation has become a must for the sustainable development of the city. In order to ensure the effective promotion of the strategy of giving priority to public transportation, the Ministry of Transportation and Communications (MOTC) issued a relevant notice on November 9, 2011, proposing that carrying out the national "public transportation metropolis" construction demonstration project is a major initiative to promote the sound and fast development of urban public transportation in China in the new period, which is of great significance and has far-reaching impact. By the end of 2014, 37 cities in China had become pilot cities for the "public transportation city" construction demonstration project [3].

At present, the conventional public transportation system is well adapted to the relatively dense urban centers, and its development is relatively stable. However, for the spreading of new urban cities, the characteristics of the residents' traveling are obviously different from those of the old cities. Due to the low travel density and dispersion of the residents in the new city, the operation of the conventional bus system is likely to cause idling and increase the operating cost, which is not conducive to the performance of the conventional bus. In the new urbanization period of China's new urban areas in the context of the flexible bus came into being. Flexible Transit is a hybrid bus system that combines the benefits of fixed-route transit (FRT) and demand-responsive transit (DRT). The system includes six main types: Variable route offset, variable point offset, demand response feeder bus service, demand response Connector bus service, stop demand response bus service, partial route change bus service, and regional route bus service.

Urban public transportation is an important part of evaluating the competitiveness and vitality of the city, and also an important guarantee for improving the livability of the city. Under the new situation and new environment, it is urgent to explore the new ideas of urban public transport development. As an innovative exploration of urban public transport travel mode, urban demand responsive transit can improve the service quality of the urban public transport system, and its development planning is the most important thing in the construction of urban public transport system in the new stage. However, the construction and development of demand responsive transit system have encountered some bottlenecks, the fundamental reason is that the theoretical research on the optimization of urban customized bus service is not deep enough, and the theoretical research cannot be effectively combined with the actual operational experience, these problems not only lead to the slow process of the innovation of the urban public transport system, but also seriously constrain the enthusiasm of the residents to travel by public transport. The research on the core issues of urban customized bus systems, such as route optimization, schedule preparation, vehicle model adaptation, etc., fully considers multiple practical constraints in theoretical research. These constraints include multiple vehicle types, random arrival time of vehicles and passengers' travel mode choice behavior. Then, by proposing related models and algorithms, we can enrich the optimization theory of urban customized bus service systems and promote its development. The proposed model and algorithm can provide some references for enriching the optimization theory of demand-responsive transit systems and promoting the rational and orderly operation and sustainable development of demand-responsive transit, which has important theoretical and practical significance.

3. Optimization of Demand Responsive Transit

3.1. Route Optimization

From an operations research perspective, the optimization problem of DRT can be described as a vehicle routing problem with simultaneous pickup and delivery (VRPSPD). This problem has been extensively studied in terms of optimization models and their solution methods. In terms of the optimization objectives of the model, there are mainly three types of optimization objectives, including the consideration of enterprise operating cost, passenger service quality, and the integrated consideration of enterprise operating cost and passenger service quality. Generally speaking, the operating cost of a company can be characterized by indicators such as minimum travel cost, minimum mileage, minimum travel time, minimum number of vehicles, etc. The quality of passenger service can be characterized by minimum unserved mileage. Passenger service quality can be measured by indicators such as a minimum number of unserved customers, maximum passenger satisfaction, and minimum response time to demand.

In terms of constraint selection for the model, the main constraints include vehicle capacity, time window, etc. As for the demand-responsive transit route optimization problem, many scholars have proposed scientific and reasonable optimization methods in their research, and the research steps are more or less the same, which can be mainly summarized into four steps. The details are shown as follows:

1) Practical investigation and analysis

The practical investigation is generally before the theoretical study of the problem. Visiting the traditional bus company provides insights into the regional demand for buses. Simultaneously, leveraging network resources to gather pertinent information and data on demand-responsive buses from websites, forums, public channels, and other sources is essential. Subsequent academic research can be tailored based on a comprehensive understanding of the actual operation of demand-responsive transit.

2) Construct an optimization model

Review relevant research in demand-responsive transit, aligning it with practical issues and collected data. Make full use of the theoretical knowledge of operations research, computers, and other related theories to construct a mathematical model that can scientifically and reasonably describe the required problem.

3) Solve the model

For the constructed mathematical optimization model, existing commercial solvers such as CPLEX, Matlab, etc. may be able to solve it directly, but they can only solve small-scale cases in a short time. Demand-responsive transit route optimization is mostly an NP-hard problem, which cannot be solved by ordinary commercial solvers in a short period of time for large-scale cases, and needs to be solved with the help of algorithms. According to the characteristics of the problem and the mathematical model design a suitable algorithm, and then in the programming software through the computer language write the algorithm to achieve the model solution.

4) Solve specific problems

After solving the model results, it is necessary to verify the reasonableness and validity of the constructed model through experiments, and further verify the validity of the proposed algorithm in the case of a reasonable and effective model. Only when the model and algorithm are reasonable and effective, the proposed model and algorithm can be applied to the actual problem.

5) Summarize

After solving the experimental results of the algorithms, the validity of the conclusions needs to be argued from different angles, and the sensitivity experiments of certain parameters can be carried out, so as to provide some reasonable management insights for the bus company. Finally, a conclusion is drawn to present shortcomings and future prospects.

3.2. Scheduling Model

Essentially, the demand-responsive transit route optimization problem is to determine a set of travel routes and intermediate stops that take into account the needs of both travelers and operators for a specific travel demand distribution and under certain regional traffic environment conditions. In view of the problems that occur in the real DRT vehicle scheduling, it is mainly elaborated from four aspects: scheduling methods, station types, time constraints, and vehicle types.

1) Scheduling Methods

According to the different scheduling methods, vehicle scheduling is divided into two categories: static scheduling and dynamic scheduling. Static scheduling mainly serves passengers who book their trips in advance. Passengers can make reservations through WeChat applets, cell phone APPs, etc., and submit travel requests to the system before the vehicle departs, and the system determines the departure route according to passenger demand. Dynamic scheduling not only meets the travel needs of reservations, but also receives real-time passenger demand during vehicle operation, and reasonably changes the vehicle route according to these needs, to achieve the purpose of serving passengers on temporary trips.

2) Station types

Bus service stops include fixed stations and variable stations. Fixed stations refer to the existence of vehicles within the area of the station, the discrete travel demand from passengers to the nearest existing station, fixed through the station regardless of whether there is a passenger demand, the vehicle must be passed. Variable station refers to the concentration of passenger demand in the service area, the collection of passenger travel information is summarized and clustered to form a number of clustering centers, which will be set up as vehicle stations, different trips generally have different stations, and the vehicle service flexibility is higher.

3) Time constraint

Time constraints generally refer to the time window in the vehicle scheduling problem, i.e., constraints on the time when the vehicle arrives at the service station. Time constraints in vehicle scheduling include hard time window constraints and soft time window constraints. A hard time window constraint means that the vehicle must serve the passengers within the passenger's desired time window. Soft time window constraints mean that a passenger can be served within the time window or can arrive at the station outside of the passenger's desired time window, and penalties are generally set and used in place of the hard time window of waiting and refusing.

4) Vehicle type

Vehicle types for vehicle dispatching are categorized into single-vehicle types and multiple-vehicle types. Single-vehicle type means that the vehicles to be dispatched are all of the same type, i.e., vehicles with the same capacity. Multi-vehicle type means that the vehicles for DRT scheduling have multiple vehicle types, each of which contains a different vehicle capacity so that the appropriate vehicle type can be selected according to the demand, making the scheduling work more efficient. [4]

3.3. Scheduling Model

DRT vehicle scheduling model solution algorithms are roughly divided into two categories: exact algorithms and heuristic algorithms. Accurate algorithms can find the optimal solution of the problem, the use of this type of algorithm requires strict constraints. With the increase in the size of the problem, it will produce a large amount of computation. Therefore, most of the existing research uses accurate algorithms to solve small-scale problems, common accurate algorithms are dynamic programming algorithms, branching and delimitation, and cutting plane method. Heuristic algorithms are often used to solve larger and more complex problems, and the solution efficiency is also better. Commonly used heuristic algorithms include local search algorithms, insertion algorithms, forbidden search algorithms, genetic algorithms, ant colony optimization algorithms, particle swarm optimization algorithms, and simulated annealing algorithms.

The DRT vehicle scheduling problem has fewer model considerations at the early stage of research, and the case size is small, mainly focusing on the exact algorithm. With the deepening of the research, the model considerations have become more comprehensive, and the scale increases, so the exact algorithm cannot solve it, and the heuristic algorithm is gradually attracting attention for its advantages of not being limited by the problem scale and fast solution speed. Due to the existence of certain differences in the objective function, constraints, etc., the solution algorithms adopted for different studies will be very different, and the size of the case also limits the selection of solution algorithms. For dynamic line optimization problems or small-scale scheduling problems, it is more suitable to use exact algorithms for solving, while heuristic algorithms are more general and more advantageous for solving large-scale problems, but the algorithms have the drawbacks of poorer solution accuracy and easily fall into the local optimum, etc. Although some computational steps in the traditional algorithms have been improved, and optimization has been carried out by combining the characteristics of two or more algorithms, only approximate optimal solutions can be obtained. The algorithm has the disadvantage of being easy to fall into local optimization.

4. Application of demand responsive transit

China's demand responsive transit system is relatively late in its development. While many developed countries have had the beginnings of demand responsive transit as early as the 1970s, China’s systme has only gradually taken off in recent years. It has not reached the stage of nationwide promotion. Compared with developed countries, most developed countries have small urban populations and more dispersed residences, which brings a major problem to the development of demand responsive transit, and the overall implementation effect is not particularly obvious. However, China is densely populated, with a large population base and diverse modes of travel, which brings opportunities for the development of demand responsive transit.

In January 2019, dynamic buses were officially launched in Huangdao District, Qingdao. Passengers only need to choose the departure location and arrival destination in the DDT App, and the platform will automatically arrange the nearest bus according to the demand. The service area of this demand responsive transit covers about 30 square kilometers, and passengers can take dynamic buses within the service area of Huangdao District to realize any station-to-station direct bus transportation, which is not only less walking and no transfer, but also shortens the time of bus travel within the service area, and expands the reachable range per unit of time.

To serve the region of Qingdao University of Science and Technology, for example, before the dynamic bus service, Qingdao University of Science and Technology, the new campus only 805 buses, students want to start from the teaching building through the public transportation to the campus, then, can only take the 805 bus to reach a limited area, if you go to the area covered by the non-805 road bus line station, you need to transfer to other bus routes. After the opening of the dynamic bus service, the new campus of Qingdao University of Science and Technology to the teaching building to the surrounding 30 square kilometers within the scope of the bus station, can be reached by dynamic bus, expanding the Qingdao University of Science and Technology students of the half-hour living circle [5].

In addition, customized buses, as a flexible public transportation system, have been applied in other aspects as well. First of all, especially in Europe and North America, this form of transportation has a history of nearly 40 years. It is mainly used in two scenarios: one is in areas of low demand and sparse distribution, where regular fixed-route buses cannot be guaranteed; the other is to provide door-to-door service for special populations, such as the disabled and the elderly. Therefore, demand responsive transit usually exists as a supplement to the regular public transportation system. Demonstration projects have been carried out in many European countries, such as Finland, the United Kingdom, Sweden, etc., of which the EU's "System of Advanced Management of Public Transport Operations (SAMPO)" program is one of the most influential. SAMPO aims to provide a higher level of public transport services according to the needs of different groups of passengers. In addition, Germany, Switzerland, Poland, and other countries also have their own relatively well-developed demand responsive transit systems in operation.

A comparative analysis of different demand responsive transit in foreign countries shows that they can be mainly divided into auxiliary buses and telephone reservation bus systems, shuttle buses, and vehicle sharing services. Auxiliary buses and telephone reservation buses mainly provide services for the elderly and the disabled, and they need to make reservations in advance by telephone and other means. Shuttle buses generally serve between two or more specific points and usually require advance reservations. Vehicle-pooling services fall somewhere between traditional transit and cabs and usually operate on fixed or semi-fixed routes. Each of these different types of demand responsive transit needs to address vehicle scheduling issues, including passenger reservation information, vehicle capacity constraints, and roadway network structure considerations to provide optimal operating routes and scheduling plans.[6]

In general, demand responsive transit has more mature experiences and applications at home and abroad, including different types of service models and solutions. In the future, with the changes in urbanization and transportation demand, demand responsive buses are expected to continue to develop and spread globally.

5. Conclusion

This paper is devoted to an in-depth study of route optimization, scheduling optimization, and solution models in order to explore how demand responsive transit systems can be smartly integrated into urban transportation planning. Demand responsive transit can significantly improve the efficiency of the transportation system, reduce congestion, improve the urban environment, and ultimately improve the quality of life of residents.

It is found that demand responsive transit, as an emerging mode of transportation service, is rapidly emerging in large and medium-sized cities in China and is showing strong applicability. This trend can be seen as a reflection of people's increasingly diverse and personalized demand for travel modes. With the improvement of living standards, more and more people are pursuing superior quality of travel services. In this context, demand responsive transit has emerged to cater more precisely to the needs of this particular group of people. This new bus service model meets the demand for high-quality travel while successfully overcoming the "last-mile" problem of traditional bus systems. This problem involves the failure of conventional buses to provide direct service when users are close to their destinations, resulting in additional walking or other modes of transportation. Demand responsive transit fills this gap more effectively through its flexible operating model and intelligent scheduling system, providing a more convenient option for travel.

It is particularly noteworthy that demand responsive transit has achieved significant operational results in several Chinese cities in recent years, demonstrating its impressive success in practice and winning the approval of users. This also lays a solid foundation for the further development of demand responsive transit in the future. With the continuous advancement of technology and the in-depth implementation of urban planning, it is believed that demand responsive buses will play an increasingly important role in the public transportation system of Chinese cities. They provide strong support for the sustainable development of cities and the quality of life of residents. Future research can further explore how to implement demand responsive transit systems in different urban environments and demands to promote the sustainable development of urban transportation.

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