Research on smart mobility in public transportation and solutions for mobility

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Abstracts. As an important part of modern urban transportation system, smart mobility and public transportation are directly related to people's travel convenience, transportation efficiency and sustainable urban development. With the continuous progress of science and technology, smart mobility solutions play an increasingly important role in the field of smart travel and public transportation. As an important support of urban transportation system, public transportation is of great significance in reducing traffic congestion, improving air quality and saving energy. However, traditional public transportation systems often face problems such as irrational route design, improper scheduling, and untimely information transfer. Therefore, the introduction of smart mobility solutions, such as intelligent scheduling systems and passenger information services, will bring new improvement and development opportunities for public transportation. The research significance of this thesis is to conduct an in-depth study on smart mobility solutions in the field of smart mobility and public transportation, so as to explore how to promote the upgrading and improvement of the transportation system at the technical, managerial and policy levels. This paper will focus on the integration of smart mobility and public transportation, exploring the synergies between the two to achieve a more efficient, environmentally friendly and convenient way of traveling.

Keywords: smart mobility; public transportation; smart mobility solutions; transportation systems; smart navigation.

1. Introduction

1.1 Evolution of the Smart Mobility and Public Transportation Sector

As an important part of the urban transportation field, the development of smart travel and public transportation has gone through several stages. At first, urban transportation mainly relied on traditional public transportation systems, such as subways and buses, etc. Although these means of transportation can meet people's basic travel needs, they gradually show their limitations in the face of urbanization and traffic congestion [1]. With the continuous development of information technology and communication technology, the concept of smart travel has emerged. Intelligent travel through intelligent, digital means to optimize the management of the transportation system, to provide users with more convenient and efficient travel services. The emergence of intelligent navigation systems enables drivers to avoid congested roads based on real-time traffic information, saving time and fuel [2]. Travel planning software, on the other hand, can provide users with personalized travel solutions based on their travel needs and preferences, including a combination of modes such as walking, public transportation and shared travel. These smart travel solutions not only improve travel efficiency, but also bring new challenges and opportunities for urban traffic management [3].

1.2 Research on the Integration of Smart Mobility and Public Transportation

The research on the integration of smart mobility and public transportation is one of the important research directions in the current transportation field. Converging smart travel and public transportation means effectively integrating individual travel needs with public transportation systems to form a smarter and more efficient transportation network. Such integration can bring many advantages, such as reducing traffic congestion, increasing the utilization rate of public transportation, and reducing tailpipe emissions, which is of positive significance for improving urban traffic conditions and promoting sustainable urban development [4].

In terms of convergence research, on the one hand, attention needs to be paid to how to optimize the service quality of public transport through smart mobility solutions. For example, using intelligent dispatching systems and big data analysis, the operation of public transportation can be monitored and adjusted in real time in order to improve the punctuality and operational efficiency of public transportation vehicles [5]. On the other hand, integration also needs to consider how to provide better support for smart mobility through the public transportation network. For example, smart navigation terminals can be set up at public transportation stations to make it easier for passengers to find the optimal ride options and encourage more people to choose public transportation for their trips. There are also a number of technical and management challenges that need to be addressed when studying convergence options. For example, how to handle the large amount of traffic data, how to protect user privacy, and how to establish an information sharing mechanism between smart travel and public transportation. Meanwhile, support at the policy level is also crucial, and relevant departments need to introduce policies and measures to encourage the integration of smart mobility and public transportation, so as to promote the actual implementation of the integration [6].

Overall, the research on the integration of smart travel and public transportation has important theoretical and practical value. Through in-depth exploration and research, it can provide useful insights and guidance for building a smarter and more efficient urban transportation system [7].

1.3 Intelligent Transportation Dispatch and Passenger Services

Intelligent dispatching system is one of the most important solutions in the field of public transportation. Through the use of real-time data acquisition and processing technology, the location and operation of public transportation vehicles are monitored and dispatched. These systems can help transportation managers understand the operating conditions of public transportation in real time, improve vehicle punctuality and operating efficiency, and at the same time reduce passenger waiting time and congestion [8]. Passenger information services are designed to provide public transportation users with accurate and timely ridership information to improve user experience and meet travel demand. These information services can include vehicle arrival time forecasts, real-time route inquiries, transfer suggestions, and more. Through smartphone applications or station information terminals, passengers can easily access the information they need and plan their trips in advance, thus increasing their willingness to use public transportation [9].

2. Overview of relevant theoretical foundations and evaluation models for smart mobility

In order to realize the sustainable development of smart mobility and public transportation, two progressive levels of research are needed, namely, the evaluation of the sustainability of smart mobility and the development strategy of public transportation. The research is mainly accomplished through the combination of various multi-attribute decision-making models and the combination of qualitative and quantitative analysis.

2.1 Theoretical basis for sustainability assessment and development strategy analysis

The scientific definition of sustainability evaluation lies in the understanding of the main elements within the sustainability framework, and the interpretation of "sustainability" is derived from the expression of a number of interrelated multidimensional structures. For example, the Brundtland Commission pointed out that sustainability includes the two dimensions of environment and economic development, as shown in figure 1, and that the interdependence inherent in the three dimensions of the definition of sustainability indicates that sustainability evaluation must take into account three dimensions of sustainability: economic sustainability, environmental sustainability and social sustainability[10]. In recent years, with the gradual deepening of the academic community's theoretical research on sustainability evaluation, it has been found that the sustainability of smart travel and transportation is also profoundly affected by the technological dimension, i.e., the level of technology will have an impact on the traditional three-dimensional sustainability performance [11].

Figure 1. Schematic representation of sustainable development

2.2 Smart travel matching algorithm based on improved curve fitting

Map matching in smart travel refers to the process of matching the latitude and longitude sampling sequences of driving trajectories with the digital map road network, and there are two key problems to be solved by map matching: one is horizontal matching, i.e., determining the matching road of the GPS positioning point; the other is longitudinal matching, because the road in reality has a certain width, and the longitudinal matching is to determine the specific projection position of the GPS positioning point on the matching road. Since the specific position of the projection point on the road is not closely related to the content of this study, longitudinal matching is not considered in this study. At present, for horizontal matching, i.e., how to correctly identify the road where the current vehicle is running, dozens of matching algorithms have been proposed by domestic and foreign researchers and scholars[12].

In this paper, the specific position of GPS points on the road accuracy requirements are not high, and hope that the map matching algorithm is easy to operate, high efficiency, comprehensive consideration of the advantages and disadvantages of various matching algorithms, and ultimately determined to use geometric matching algorithm. The following mainly introduces the map matching algorithm based on curve fitting in the geometric matching algorithm, which mainly utilizes the phase beauty between the trajectory points to match the single GPS loci. The principle is as follows (2-1).

$$B=\begin{bmatrix} b_0 \\ b_1 \\ \vdots \\ b_m \end{bmatrix}, Y=\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix}, X=\begin{bmatrix} 1 & x_1 & x_1^2 & \cdots & x_1^m \\ 1 & x_2 & x_2^2 & \cdots & x_2^m \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & x_n & x_n^2 & \cdots & x_n^m \end{bmatrix} \tag{1}$$

Assuming $X^T X=A$, $X^T Y=C$, equation (2-I) simplifies to AB=C. Since roads in electronic maps are approximated with straight line segments (curved roads are also combinations of many straight line segments) and vehicles are always traveling on roads, based on these two premises, the trajectory of the observation point can be approximated by fitting a straight line Y = AX +B. Considering the possible shortest length of the road segment and the computational difficulty of the algorithm, five observation and positioning points are selected to fit the curve, and the planar coordinates of the current point and the first four GPS positioning points adjacent to the current point, then the coefficient matrix B can be obtained, and the formula is shown in (2-2) below [13].

$$B=A^{-1}C=\begin{bmatrix} k_0 \\ b \end{bmatrix}=\frac{1}{5\sum_{i=1}^{5}x_i^2-\left(\sum_{i=1}^{5}x_i\right)^2}\begin{bmatrix} \sum_{i=1}^{5}x_i^2\sum_{i=1}^{5}y_i-\sum_{i=1}^{n}x_i\sum_{i=1}^{5}x_iy_i \\ -\sum_{i=1}^{5}x_i\sum_{i=1}^{5}y_i+5\sum_{i=1}^{5}x_iy_i \end{bmatrix} \tag{2}$$

Therefore, the formula (2-3) for the slope of the fitted curve K_0 can be derived as follows.

$$K_0 = \frac{-\sum_{i=1}^{5} x_i \sum_{i=1}^{5} y_i + 5\sum_{i=1}^{5} x_i y_i}{5\sum_{i=1}^{5} x_i^2 - \left(\sum_{i=1}^{5} x_i\right)^2} \tag{3}$$

The map matching algorithm based on curve fitting is a good solution to the problem of mis-matching of GPS location points at intersections. In this paper, the research road network is stored based on the form of "point and line". Point elements are divided into nodes and intersections, nodes are point elements connecting only two line segments, and intersections are point elements connecting more than two line segments; line elements are defined as road segments, and urban roads are divided into road segments by nodes and intersections, and many road segments are used to approximate the special curved roads, so as to transform the road network into a vector map, which is shown in Figure 2.

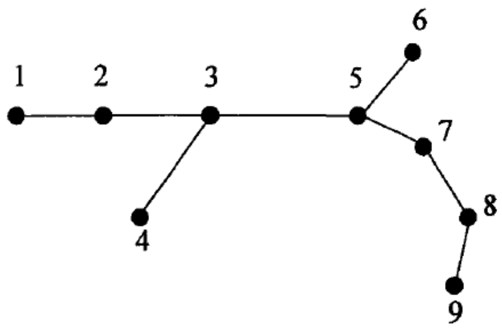

Figure 2. Schematic diagram of vector road network map elements

3. Dynamic definition of optimal routes

The dynamic definition of the optimal route refers to the real-time calculation of the most suitable travel route under the current traffic conditions based on real-time traffic information and the user's personalized travel needs. This dynamic definition takes into account the real-time changes in the traffic network as well as the user's travel time, origin and destination, thus providing the user with more intelligent and personalized travel suggestions. The following key research aspects are involved in studying the dynamic definition of optimal routes [14].

3.1 Collection and processing of real-time traffic information

Real-time traffic information is a key data source for calculating the optimal route. Researchers need to collect various types of traffic data, such as road speed, traffic flow, traffic accidents and other information, and use big data processing technology to analyze and process these data in real time. This can get a comprehensive and accurate description of the current traffic situation and provide support for the subsequent calculation of the optimal route. The map has a zigzag roadway course, which is composed of multiple roadway segments. Each road section is connected by a straight line of nodes at its two ends [15]. Taking Fig. 3 as an example, the nodes and road sections on the picture are numbered as shown in Fig. 4.

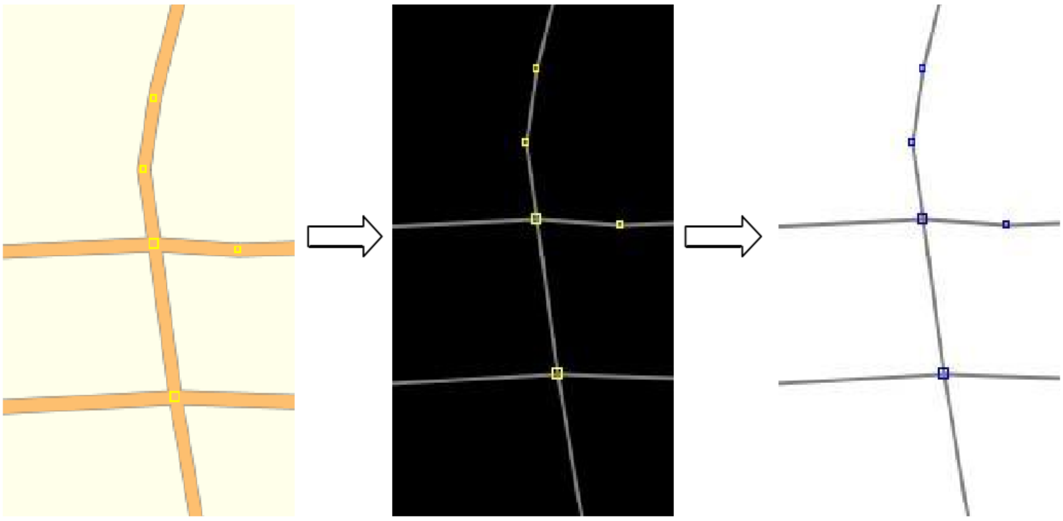

Figure 3. Map processing

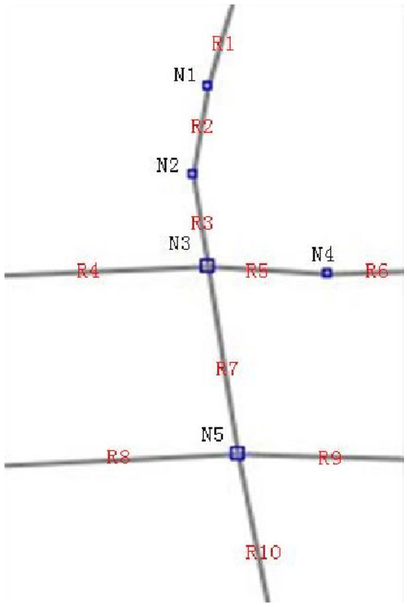

Figure 4. Map segments after labeling

There are five nodes: N1, N2, N3, N4 and N5 and 10 road segments: R1-R10.They are stored in the node table and road segment table respectively. According to whether it is an intersection node or not, we can classify the nodes into two categories. And whether it is an intersection node or not can be judged according to the number of road sections connected by the node. When the number of road sections connected by a node is greater than 2, then this node is in the intersection position. For example, node N3, connects four road sections:R3, R4, R5 and R7, we judge that node N3 is an intersection node. While node N1, connects two road sections: R1 and R2, we judge that node N1 is not an intersection node. In Fig. 4, the intersection nodes are N3 and N5, and the non-intersection nodes are N1,N2 and N4.

To plan an optimal path, first determine the optimality criterion and then set the weights for each road segment. If the optimal criterion for path planning is the shortest distance traveled, then the weights are set to the static length of the road section. If the optimal criterion for path planning is the shortest travel time, it is necessary to take into account the factors affecting the efficiency of vehicle travel, set up the weights that can accurately represent the travel time of each road section, and then plan the path with the shortest total weights, i.e., the shortest total travel time [16].

3.2 Dynamic path planning algorithm

Dynamic path planning algorithm is the core technology to realize the dynamic definition of the optimal route. The algorithm needs to comprehensively consider real-time traffic information and users' personalized travel needs to find the optimal travel path under the current traffic conditions. This involves complex data analysis and computation, including graph theory algorithms, shortest path algorithms, traffic prediction, and so on. Currently, some intelligent navigation systems have adopted dynamic path planning-based approaches to provide users with real-time route navigation suggestions [17].

Vehicles passing through the intersection, if the parking queue waiting, waiting for the vehicle before slowing down, waiting for the process of the vehicle is stationary, restart the vehicle from a standstill gradually change to normal speed, this process is caused by the time delay is called the intersection delay. Intersection delay is a statistical concept [18]. The factors that affect the intersection delay of a roadway are the capacity of the roadway, the average vehicle queue length, and the vehicle reach rate. These factors are statistically analyzed after roadway collection. Since intersection delay is a statistical concept, the value of intersection delay is also a statistical value.

The inputs to the intersection delay are parameters such as capacity, average queue length, and vehicle attainment. These parameters are statistically analyzed and used to characterize the population after actual observation. Intersection delays are surveyed by specialized road authorities, and the point-sample method is widely used in various countries. The main idea of the point sample method is that several observers and a timekeeper stand at the intersection to record the number of vehicles stopping and passing on the approach road at certain time intervals, and then calculate the average vehicle delay according to the number of vehicles and time intervals. The weighted values from node 1 to node n are:

$$W = \sum_{i=1}^{n-1} w(v_i, v_{i+1}) \tag{4}$$

The shortest path algorithm is the algorithm used to solve the shortest path from the start point to the end point in the network topology graph, which can also be referred to as the path algorithm. The main idea of Djkstra's algorithm is to expand the nodes in the network to the peripheral nodes centered on the start point. The length of the path increases with the number of expanded nodes, and eventually, a topological path tree is constructed. The root node of the tree is the starting point, and its paths to all other nodes in the network can be derived from the paths of the nodes in the tree back to the root node, as shown in Figure 5.

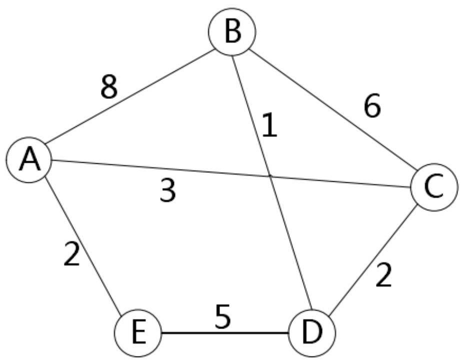

Figure 5. Example of Dikstra's algorithm

3.3 Realization of intelligent support and real-time control of transportation systems

Achieving the dynamic definition of the optimal route also requires the intelligent support of the transportation system. The path derived according to the above steps is the driving path planned based on the road traffic status at the departure moment. In the process of vehicle driving, the traffic network driving conditions change constantly, and a section of the previously planned path may be congested. Therefore, the system needs to dynamically update the real-time information of the traffic network in the process of vehicle traveling to guide the driver on the path. In Figure 6, there is a clear "morning peak" from 6:00 a.m. to 11:00 a.m., which is due to the obvious increase of vehicles during working hours.

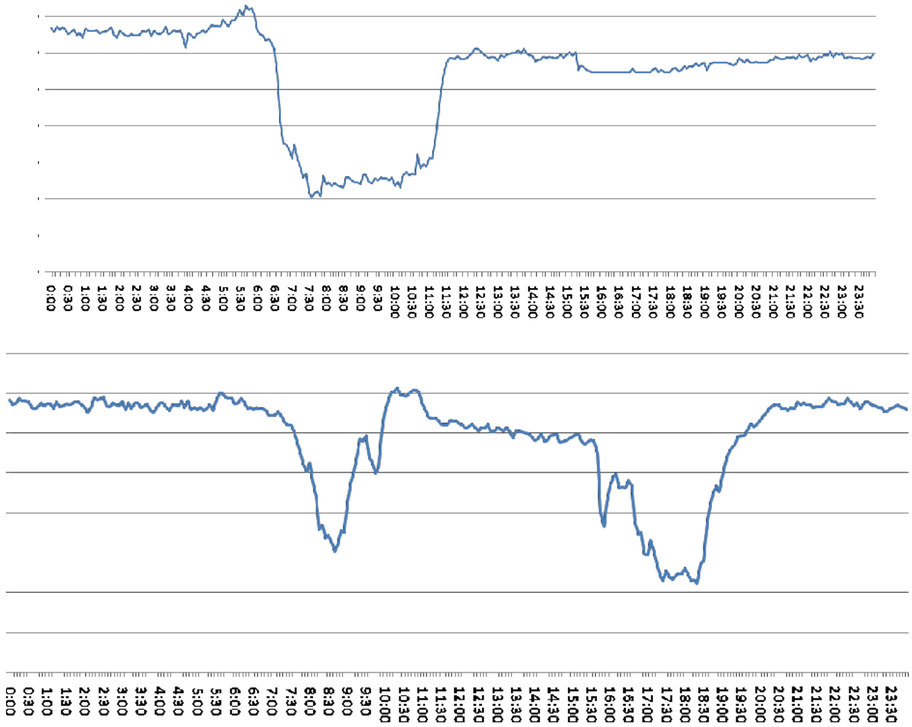

Figure 6. Map of highway travel speed thresholds

4. Conclusion

The design process of the real-time path planning system includes obtaining map data, extracting road node information and processing it, setting road segment weights according to real-time traffic information, inputting the starting point and then being able to apply path algorithms for path searching, dynamic updating of the real-time road information, resetting the road segment weights and pathfinding during driving, and other parts. The real-time path planning system is tested and compared with the shortest distance path search and traditional shortest time path search in simulation. The data used for the system testing is the real road traffic data of a city in China, and it is also tested and compared with the shortest distance path search and traditional shortest time path search. The results demonstrate the travel time advantage of the paths planned by the real-time path planning system.

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