Research on design scheme of urban public transportation for energy conservation

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Abstract. The transportation system promotes the development of the metropolitan area, while the number of vehicles in the transportation system is increasing, and the speed of energy consumption is also increasing. The consequences are not only the destruction of human living environment, but also many urban problems such as traffic congestion and urban environmental pollution for people living in the metropolitan area. In order to solve these problems, the article proposes a design scheme for urban public transport from the perspective of energy conservation. Through the modular design method, combined with the existing electric vehicle drive technology, the public transport is divided into two modules: the ride module and the drive module; at the same time, the existing traffic information service system is integrated to construct service system of the information guide to support the public transport scheme. The public transport design provides a possible solution to environmental pollution and traffic congestion.

1. Introduction

A metropolitan area refers to a cluster of cities with a population of more than 25 million and a population density of more than 250 people per square kilometer [1]. In terms of spatial form, it is an area consisting of the urban core and its surrounding towns, e.g. Tokyo Metropolitan Area and Paris Metropolitan Area. The urban transport network of a cluster of cities is the infrastructure that supports and ensures its development [2]. While the transportation network system promotes urban development, its growth rate of energy consumption is also accelerating [3]. Transportation accounts for more than 21% of the world's total energy consumption, while developed regions such as the European Union account for about 34% of the world's energy consumption, and the annual growth rate of 30% continues to rise [4]. The energy consumption of China's transportation network system accounts for about 8% of the total energy consumption, which is increasing with the improvement of China's urban motorization level [5, 6]. Traffic consumes a lot of energy, which has brought great damage to the environment. In addition, there are traffic congestion, environmental pollution, parking supply and demand contradictions and other issues. Yuan Jiadong, et al. [7] pointed out that light rail transit systems with a medium transport capacity play an important role in meeting the public transport demands in metropolitan areas and that developing urban public transport with light rail transit systems with a medium transport capacity serving as the backbone is an important direction for the construction of metropolitan areas in China. Zhao Ruijiang, et al. [8] pointed out that the personal rapid transit (PRT) system (a kind of driverless public transport system for individual transport), compared with the conventional public transport system, has obvious advantages. It was successfully put into operation in
Masdar City and London Heathrow Airport, setting up a good example for Guangzhou to mitigate the traffic congestion in its urban area. Zhao Ling, et al. [9] analyzed the need to develop IoT and set up a guidance system for urban traffic congestion, providing a new solution to urban traffic congestion. The light rail transit system with a medium transport capacity mentioned in the previous research has a large capacity, is suitable for operation in multiple periods, but it cannot provide passengers with comfortable, flexible, and convenient experience as private cars. The PRT system can provide passengers with comfortable, flexible, and convenient experience but it is difficult for it to finish the point-to-point distance. The public information management system proposed in the previous research is applicable to both private and public vehicles and can improve the efficiency of traffic management, but it is difficult to fundamentally solve urban traffic problems due to the national preferential policy for public transport and the limited transport and road resources. Based on the current situations, a modular concept of public transport means oriented to personal travel is proposed in the present paper to improve personal riding experience and to solve the problem of traffic congestion arising in the urban transport.

2. The influence of travel modes within the metropolitan area on urban transportation energy

2.1. Characteristics of public transport
In terms of spatial structure, Tokyo Metropolitan Area is composed of a core city, i.e. Tokyo City and surrounding towns such as Yokohama, Tama, Saitama, Tsukuba, Chiba in a circular layout. Such a layout is based on rail transit systems. In Tokyo Metropolitan Area, there are rail transit systems like the metro and railway that are rapid and have a large capacity [10]. Similarly, Paris became the core of Western European Metropolitan Area due to its developed transport systems. The urban rail transport system includes metro lines with a total length of 250 km and nearly 300 stations, covering the whole urban area. In addition, there are convenient transport systems by water, land, and air between Paris and other European cities [1]. They constitute a multi-level public transport system. According to the analysis on transport development of major metropolitan areas around the world, a multi-level public transport system usually consists of various transport modes such as rail transit, mass transit, and ground transit [11]. From the perspective of travel, public transport systems allow passengers to transfer between them. The corresponding mode of public transport organization in a metropolitan area is "trunk + shuttle"[11], and the model diagram is shown in Figure 1.

![Figure 1. “Trunk+shuttle” model](image)

2.2. The impact of travel mode on urban transportation energy
Personal travels can be classified as commuting travel and non-commuting travel. The former refers to the travel from one's residence place to employment place (or work place), usually including the travel for work, school, work-related business, etc. The latter refers to the travel except commuting travel,
usually including the travel for entertainment, shopping, visiting relatives, etc.[12] Public transport modes in metropolitan areas — "trunk + shuttle" determine that most people transfer between different modes of transport, i.e. travel of multiple modes. In the real life in metropolitan areas, the commuting travel is related to non-commuting travel, sometimes with the non-commuting travel integrated in the commuting travel. For example, many commuters integrate non-work travel in the long-distance commuting or rest. The commuting travel is relatively complex. It is necessary to analyze the process of travel by public transport in personal commuting travel. A personal commuting travel by public transport usually consists of several basic processes, i.e. from home to a public transport station, travel by public transport, and from another public transport station to work place. Depending on specific conditions, the commuter may transfer for several times and select various transport modes during the travel (see Figure 2). With the addition of the multi-mode transport from the work place to home, such travel processes constitute a commuting travel chain. At the same time, a [home]-[work place]-[home] travel chain model can be built (see Figure 3). A travel chain is a round trip composed of travel purposes arranged in a chronological order to complete one or more activities. It contains a large amount of information about time, space, mode and activity type.

**Figure 2** Analysis of multimodal travel

**Figure 3.** Travel chain model

A complex travel chain hinders the popularization of multi-mode travel, makes it difficult to shift to public transport, and increases the dependence of travel on private vehicles such as cars [13]. The multi-mode travel based on public transport is popularized because it is a green transport mode with less negative impact on the environment which can improve the overall transport operation efficiency and contribute to the sustainable development of cities. The integration of non-commuting activities to the commuting travel process makes the commuting travel chain more and more complex. In this case, personal travel requires convenient and rapid modes of transport. Mass transit systems do not have such features but private vehicles (cars) are rapid, convenient and comfortable. This leads to the contradiction of selection between private vehicles such as cars and public vehicles for travel (see Table 1). The preference is to choose private vehicles such as cars, and the increase in the use of private vehicles such as cars has made air pollution more serious. The emission of atmospheric pollutants from urban traffic based on cars is an important factor causing smog and photochemical smog pollution, and is one of the most important sources of air pollution in urban environments [14, 15]. In order to prevent pollutants from exceeding the capacity of the urban atmospheric environment, the relationship between the
influencing factors of urban transportation energy consumption should be analyzed. The intensity of travel demand directly affects the amount of traffic, which in turn affects traffic energy consumption and pollutant emissions [16, 17]; when the demand intensity of travel is constant, the intensity of energy directly affects urban traffic energy consumption and pollutants. How much is discharged. Therefore, in ensuring the existing urban travel intensity and effectively reducing the energy intensity, the pollution of urban traffic to the urban environment can be reduced. It can be understood as reducing the travel of private vehicles such as cars and optimizing the existing public transport to reduce energy consumption and reduce environmental pollution.

Table 1. Contradiction of travel choice between private transport and public transport

| Classification       | Advantages                                                                 | Disadvantages                                      |
|----------------------|-----------------------------------------------------------------------------|----------------------------------------------------|
| Private vehicles     | Comfortable, rapid, convenient, and door-to-door                            | Lead to serious environmental pollution and urban traffic congestion |
| Public vehicles      | Rapid, small pollution, conducive to sustainability of cities               | Poor travel experience and transfer required        |

3. Traffic information service system and traffic energy management system

An intelligent transportation system (ITS) is a real-time, accurate, efficient, comprehensive transport and management system functioning in a large scope and in all aspects which is established by effectively integrating and applying such advanced technologies as the information technology, data communication and transmission technology, electronic sensor technology, electronic control technology, and computer processing technology to the whole transport management system based on complete infrastructure including roads, ports, airports and communication [18]. One of its functions is to release real-time dynamic public transport travel information to the public transport travelers so that they can select their transport mode and adjust their route in a real-time manner according to the travel information.

An advanced travel information system (ATIS) is one of the key subsystems for ITS development [19]. The ATIS collects, processes, transmits and releases transport information by applying advanced communication and information technologies, and finally provides real-time dynamic transport information services for travelers (see Figure 4).

The integration of Internet, cloud computing, big data and other advanced technologies with ITS not only enhances the functions of ATIS, but also constitutes a network system for transportation energy. As for the construction of energy network, Jeremy Rifkin of the United States in the Third Industrial Revolution proposed that renewable energy should be the main energy unit, and the use of Internet technology to coordinate the control of multiple energy sources and energy storage equipment to achieve sustainable development of energy consumption [20]. For example, based on the concept and architecture of smart grid, a railway energy management system (REMS) is constructed to realize the optimal utilization of energy [21]. The combination of traffic energy network and traffic information service system not only helps the effectiveness of personal travel, but also can effectively use energy, achieve the goal of reducing energy consumption, and make the urban environment sustainable development. Therefore, the design of public transport should be closely combined with these two aspects.
4. Public transport that saves urban transportation energy

4.1. Public transport modular design method

According to point 2 of part 2 above, there is contradiction of selection between private vehicles and public transport means for personal travel. In order to get rid of this contradiction, we proposed a solution to transform the personal travel chain model into the travel chain model of the public transport means on the basis of multi-mode transfer for personal travel (see Figure 5). In terms of the concept of set, a transport mode can be described as: transport mode = {rail transport, road transport, waterway transport, air transport, ...}.

![Figure 5. Travel chain model of transport means](image)

In order to realize changes of transport modes for vehicles, the modular method is applied to the design of new public vehicle. Modular design is a method by which a series of modules is divided and built on the basis of analyzing products with the same functions but different properties and specifications within a certain range, so as to quickly form products meeting different requirements through the selection and combination of modules. In the modular design, functional modules are divided according to the following principles [23]: 1) Ensure the functional and structural independence and integrity of modules; 2) Allow easy connection and disconnection of interface elements between modules; 3) Minimize the correlation between modules. Namely, ensure weak coupling between modules and strong coupling between internal parts of modules; 4) Keep moderate granularity of disconnection; 5) Use typical components and ensure versatility, etc. According to the principles described above, modules are divided for a Tesla electric vehicle (see Figure 6). The electric vehicle falls in the road transport mode, which does not allow changes in other transport modes if its original combination mode remains unchanged. It is necessary to restructure the modules. The electric vehicle is divided into two modules under such conditions as the information and communication technology, IoT technology, unmanned driving technology, drone technology, and motor technology, i.e. a riding module and a driving module (see Figure 7).

![Figure 6. Functional modularization division of electric vehicle.](image)
Similarly, a public vehicle is divided into two modules according to the functions, namely, a riding module and a driving module. The riding module is a fixed module that only meets the need of personal travel. There are two modes available: the work and the leisure. The driving module is a module variable corresponding to the mode of transport. The driving module = \{rail driving, road driving, waterway driving, air driving, …\} (see Figure 8). The driving module can be realized by the information and communication technology, IoT technology, drone technology, unmanned driving technology, and motor technology. For example, in a road driving module, the motor is installed on the wheel to drive the vehicle directly. Based on the information and communication technology and IoT technology, the unmanned driving technology enables vehicles to reach their destination safely. In an air driving module, the information and communication technology, IoT technology, and drone technology enable people in the riding module to go to their destination conveniently and comfortably.

In the design of new public vehicle, modern advanced technologies are applied and advantages of private cars and public vehicles are integrated to make the new public vehicle rapid, comfortable and convenient as private vehicles and environmentally friendly and conducive to sustainable urban development as public vehicles. In order to ensure the normal operation of new public vehicles, there must be a new public transport service system adequate to them.

4.2 Public transportation information service system

The modular design is also used to build a service system for the new public vehicle. The service system mainly consists of four modules of data management and control center, ITS communication network, onboard terminal, and intelligent terminal (see Figure 9). Its core module is the data management and control center that uses the cloud computing technology for real-time management and analysis of
massive information data so as to coordinate and plan the data flow and directly schedule and control the new public vehicle. The information data mainly comes from the module of ITS communication network. The ITS communication network module is connected with the existing intelligent transport system, especially its subsystem ATIS, to obtain traffic information such as traffic flow, road condition, weather, temperature, traffic accidents around the clock. The new public vehicle selects the best route depending on such transport information. The onboard terminal module is a system embedded in the new public vehicle to receive commands from the data management and control center, make the route plan according to the transport information, autonomously generate the combined route of the riding module and the driving module, and enable the new public vehicle to send passengers to their destination. In addition, the new public transport vehicles can also sense each other and implement real-time information exchanges. The intelligent terminal module is an application installed on the existing terminal devices including personal computers, tablet computers, smart phones, smart bands and other handheld intelligent devices. Handheld intelligent devices are connected to the data management and control center over the wireless network and exchange information with the onboard terminal.

Figure 9. Service system architecture

Figure 10. Flow of service system operation.
The service system runs according to the process flow as follows: the user of the handheld intelligent device logs in to the server of the service system through the application, enter the origin and destination according to the prompt, and send a personal travel request to the data management and control center. According to actual transport conditions, the data management and control center analyzes the data, provides the best route and time options, generates a combined route, and issue a command to the new public vehicle closest to the traveler. During the travel, the new public vehicle dynamically adjusts the combination of the route and the riding module and driving module in a real-time manner according to the transport conditions, and finally reaches the destination safely. The operation process flow of service system is shown in Figure 10.

5. Conclusion

Urban problems such as the urban traffic congestion and transport-induced environmental pollution attract more and more attention of all the countries. Transport policies mostly give priority to the public transport. Facing the accelerated urbanization and complex personal travel chain, most people prefer convenient, rapid and comfortable private vehicles (cars), which hinders personal travel from transition to public vehicles. Based on the information and communication technology, mobile internet technology, IoT technology, and unmanned driving technology, etc., the research on conceptual design of public vehicles is done with the modular design method. The design divides a public vehicle into two parts: the riding module and the driving module. The former is a fixed module and the latter is a changing module. The vehicle runs in such a mode as to provide the best route in a real-time manner according to the analysis data of the service system and at the same time, the riding module and the driving module are combined according to the actual conditions. The new public vehicle provides convenient personal travel services, and enables people to use private vehicles (such as cars) less frequently, and thus mitigates traffic congestion and environmental pollution.

The limitation of the conceptual design of the new public vehicle lies in that it is an urban design targeted to metropolitan areas and it is difficult for the vehicle to operate in cities outside metropolitan areas. Resources like advanced technologies, abundant capital, outstanding talent in metropolitan areas make the realization of the conceptual design of new public vehicle possible. The mature application of the internet of vehicles and the unmanned driving technology is a key factor for the success in realizing the new public vehicle and a challenge for realizing the scheme. The internet technology (including the mobile internet) will improve the operation efficiency of the new public vehicle in the aspect of operation and management. As for production, the modular design provides a foundation for industrial batch production. Mass production can be done through the assembly of modules. All these conditions are the means to realize the conceptual design of the new vehicle, so as to fulfill the ultimate goal of improving the travel efficiency for public transport travelers in metropolitan areas.

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