ISSN: 2710-0588

Optimization Study of Urban Intelligent Green Mobility Chain Based on Dual-Carbon Background

-- Taking Bengbu City in Anhui Province as an Example

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Abstract

In recent years, with the rapid development of the economy, the pollution caused by the problem has aroused widespread concern in society, in the country put forward the "carbon peak", "carbon neutral" in the context of the transportation industry as a large carbon emissions, how to effectively solve the carbon emissions is also an important issue in the process of realizing the goal of "carbon emission", and then the urban residents travel chain carbon emissions also need to be solved. How to effectively solve the carbon emission is also an important issue in the process of realizing this goal, and then the carbon emission problem of urban residents' travel chain also needs to be solved urgently. Based on the MaaS (Mobility as a Service) system, the authors propose a new optimization model to build a multi-modal transportation intelligent travel chain to and travel route recommendation. Through the establishment of a new path planning system, to achieve the result of travel costs, time, carbon emissions system optimal, and travel system simulation simulation, for the realization of energy saving and emission reduction, the realization of low-carbon travel has a certain degree of help.

Keywords

Carbon Dafeng, MaaS system, smart travel chain, travel cost, energy saving and emission reduction.

1. Overview

1.1. Background of the study

With the sustained development of the global economy, energy demand has shown a rapid rise, in which fossil energy consumption occupies a dominant position. Along with this, global carbon dioxide emissions have shown significant growth. Since the industrialization process accelerated, China's carbon emissions to maintain a sustained growth trend. According to the statistics of the International Energy Agency (IEA), the contribution rate of carbon emissions from the global transportation sector has reached 24.8%, becoming the second largest source of emissions after energy production. Specific to the sectoral emission mapping, road transportation dominates the sectoral emission structure with a 77.5% share, followed by maritime transportation (10.7%) and civil aviation (11.2%), while railroad transportation accounts for only 0.2%.

1.2. Low-carbon transportation

Low-carbon transportation refers to the reduction of carbon emissions in the transportation process through measures such as improving energy efficiency, promoting clean energy and energy-saving technologies, and optimizing the transportation structure in the field of transportation, so as to realize the low-carbon and green development of the transportation

ISSN: 2710-0588

industry. It includes not only the decarbonization of the means of transport itself, such as the promotion of the use of new energy vehicles, but also the optimization of transport modes, such as the priority development of public transport and the encouragement of green travel modes such as cycling and walking. The development of low-carbon transportation is of great significance in addressing climate change, protecting the environment, saving energy and promoting sustainable economic and social development. Firstly, transportation is one of the major areas of carbon emissions, and the development of low-carbon transportation can help reduce greenhouse gas emissions and mitigate global warming. Secondly, low-carbon transportation can promote the optimization and upgrading of the energy structure, reduce the dependence on fossil energy and improve the efficiency of energy use. Furthermore, low-carbon transportation can also promote the innovation and development of the transportation industry, drive the formation and development of related industrial chains, and provide new impetus for economic growth.

1.3. MaaS System Overview

MaaS (Mobility as a Service) is a new type of transportation system that integrates various modes of transportation on a single platform to provide users with a seamless travel experience. Transportation-related services are accessed and managed through an electronic interactive interface to meet consumers' travel requirements. It aims to deeply understand the public's travel needs and integrate various transportation modes in a unified service system and platform, using big data for decision-making to optimize resource allocation and meet residents' travel needs. Users can book, pay and enjoy various transportation services, such as public transportation, shared bikes, cabs, rental cars, etc., through a unified APP or platform. In recent years, MaaS systems have been widely used and developed worldwide. For example, Whim app in Finland and MaaS platform in Beijing are typical MaaS system application cases. These systems provide users with a one-stop travel service experience by integrating multiple transportation modes.

In view of the increasingly serious problem of traffic congestion and the continuous growth of travel time, there is an urgent need to build a cross-modal integrated transportation information service system to strengthen the service effectiveness of the transportation system. In this context, MaaS (Mobility as a Service), an innovative service model, came into being, which covers a wide range of key areas such as integration of multiple transportation needs, seamless integration of multi-modal transportation information services, path optimization decision-making, and information interaction between intelligent devices, bringing intelligent links, comprehensive interconnectivity, information synchronization, and new experience of service upgrading for intelligent transportation. and service upgrading.

The booming development of mobile internet, vehicle-circuit coordination and artificial intelligence technologies enables us to collect, store, parse and integrate diversified traffic data and travel demand information with unprecedented speed and efficiency. Relying on these rich big data resources, we address the demand for MaaS + integrated transportation information services, combining the MaaS travel service framework with big data-driven decision-making mechanisms to realize the deep integration of multi-modal transportation information, so as to accurately deploy resources and provide one-stop convenient travel services. In contrast, traditional transportation services often rely on fixed-route operating fleets. MaaS, as an emerging trend and mode of transportation and travel information service, pays more attention to customizing the service system according to the user's personalized travel preferences, bringing more intimate and efficient travel solutions to users.

ISSN: 2710-0588

2. Analysis of the Current Status of The Domestic and International MaaS Travel Chain

In recent years, MaaS (Mobility as a Service) transportation system framework has become the focus of extensive research by experts and scholars at home and abroad. Sampo Hietanen, president of the Finnish Transportation Association, took the lead in introducing the concept of MaaS at the European Union Intelligent Transportation Systems (ITS) Conference held in Finland in 2014. In response to China's specific national conditions and urban transportation characteristics, domestic scholars have carried out in-depth explorations. For example, Liu Xianglong et al [1] constructed a MaaS ecosystem framework and its development blueprint in line with China's national conditions on the basis of comparing the differences between MaaS and traditional transportation modes, laying a solid foundation for the development of MaaS in China. Yang Zhenghang [2], on the other hand, from the perspective of residents' micro-behavior, through analyzing the characteristics of the travel chain, deeply studied the characteristics of the residents' travel chain under different modes of transportation, and revealed the key factors affecting the residents' choice of travel modes, especially the green modes of transportation. Acheampong Lee [3] explored the relationship between land space use and travel and analyzed the relationship between different travel modes and travelers with different demand categories. On the other hand, Koushki et al [4] explored the impact of commuter travel chains on traffic congestion, they considered several factors such as trip purpose, mode, vehicle occupancy, time, and trip duration, and compared and analyzed different travel chain modes. Gao Tingting et al [5], on the other hand, quantitatively assessed the travel costs of various modes of transportation within the city and constructed a corresponding urban transportation travel cost model. Yue Wang et al [6] constructed a multi-objective optimization model of transportation cost under the guidance of low-carbon concept and service benefit. Yang Zhongwei et al [7], on the other hand, took Beijing as an example to analyze the influence mechanism of different kinds of travel costs on travel structure. Liu Xianmei [8] used a bilateral regional spatial decomposition model to analyze the factors affecting the differences in carbon emissions among the four municipalities directly under the central government in China from the spatial dimension. Pei Yulong et al [9] constructed the generalized cost functions of different travel modes from multiple dimensions, such as time, economy and comfort, as an alternative to the traditional utility function, and used a Logit multinomial choice model to explore the competitive relationship between public transportation and private transportation in depth. Lu Ming [10], on the other hand, comprehensively elaborated the benefits of the three aspects of society, transportation and economy, and took Beijing as an example to analyze in detail the comprehensive benefits of rail transit on urban development, and then put forward the development strategy of urban rail transit system.

3. Research Program

3.1. Research ideas

Traditional low-carbon travel solutions rely mainly on demand suppression strategies, i.e., reducing carbon emissions by increasing travel costs or restricting travel demand. Although this method can reduce carbon emissions to a certain extent, it also brings a lot of inconvenience to the daily travel of urban residents. In addition, residents' transportation choices in each link of the travel chain are highly random, making it difficult to accurately predict and guide them. In contrast, the MaaS system, as an innovative mode of shared mobility, provides a new way of thinking to solve this problem. However, since a perfect MaaS system has not yet been established in China, this paper suggests introducing an intelligent optimization model in the user route recommendation link, considering multiple factors such as travel cost, time

ISSN: 2710-0588

efficiency and carbon emission, and applying a multi-objective optimization algorithm to achieve the optimal balance between green and economic travel in the MaaS system, so as to enhance the overall system effectiveness.

3.2. Generalized travel cost model construction

In order to build a relatively idealized model, the following modeling assumptions need to be met:

(1) Market size assumptions: MaaS system has already established a certain market size, and the vast majority of residents within the city are accustomed to using the MaaS system to make travel demand reservations before traveling.

(2) Assumption of sufficient vehicle supply: The number of cruising cabs and online taxis in the city is sufficient to meet the travel demand of users, and there is no situation where users cannot be picked up and dropped off on demand due to insufficient vehicles.

(3) Traffic condition constraints: Considering the fluctuation of urban traffic conditions, to ensure that the path planning can adapt to the traffic congestion of different time periods.

(4) Environmental protection constraints: Considering the reduction of adverse impacts on the environment, route planning should minimize carbon emissions and give priority to environmentally friendly travel modes.

In MaaS systems, the advantage of understanding each user's travel needs allows travel path planning to maximize the optimization of the urban transportation system while satisfying the needs of individual users in order to improve the operational efficiency of the overall system. Taking the generalized travel cost function of the MaaS system as the objective, it aims to consider multiple optimization objectives such as travel time, cost, and carbon dioxide emission, and integrate them into a single objective, which in turn simplifies the optimization difficulty. Through the size of the generalized travel cost function becomes an indicator of the optimization of the system, which intuitively reflects the optimization effect of the MaaS system on urban transportation. By solving the minimum value of the function, the MaaS system can effectively promote the optimization of the entire urban transportation system while meeting individualized needs. Therefore, the objective function of the MaaS system travel path planning model is:

$$Min_U(total_t, total_m, total_{CO_2}) = w_t \cdot total_t + w_m \cdot total_m + w_{CO_2} \cdot total_{CO_2}$$

3.2.1. Constraints on rated passenger capacity for each travel mode

Since the various modes of travel have different carrying capacities, it is necessary to consider the maximum number of passengers to be carried by each mode of travel during the same time period. Therefore, the rated passenger capacity constraints for the travel modes can be expressed as follows:

$$bus_{capI} \le bus_{\max I}$$

$$ride_{capI} \le ride_{\max I}$$

$$taxi_{capI} \le taxi_{\max I}$$

Wherebus_{capI} denotes the total rated capacity of regular public transportation in MaaS system (person-times); $ride_{capI}$ denotes the total rated capacity of shared bikes in MaaS system (person-times);$taxi_{capI}$ denotes the total rated capacity of taxis/Internet taxis in MaaS system (person-times); bus_{maxI} denotes the maximum capacity of regular public transportation in MaaS system (person-times);$ride_{maxI}$ denotes the maximum capacity of shared bikes in MaaS system (person-times);$taxi_{maxI}$ denotes the Maximum number of passengers (person-times) for MaaS system cruising taxis/internet taxis.

ISSN: 2710-0588

3.2.2. Walking Transfer Distance Constraints

Considering the actual transfer situation, users are required to make walking transfers between stations of different travel modes. Interchange can be performed only when the walking interchange distance is less than the maximum walking interchange distance. Therefore, the constraint of walking transfer distance can be expressed as:

$$walk_{changeL} \leq Max\, walk_{changeL}$$

Where,$walk_{changeL}$ represents the user's single walking transfer distance; Max$walk_{changeL}$ represents the maximum walking transfer distance, according to the existing research, the transfer penalty time is 150~600 seconds, taking the maximum transfer time as 300 seconds, and the maximum walking transfer distance is 0.4 kilometers calculated according to the walking speed.

3.2.3. User personalized travel constraints

The constraints of the MaaS system travel path planning model should reflect user preferences and personalization of the MaaS system travel path. The user personalization constraints include time constraints, cost constraints and number of transfers constraints.

① Time constraints

The user is required to provide the trip start timestartT and the latest arrival time ariveT when making a trip reservation, with the time constraint that the trip time is less than or equal to the maximum acceptable trip duration T_{max} :

$$T \leq T_{\max}$$

$$\max(0, arriveT - startT) \leq T_{\max}$$

Where,T_{max} denotes the maximum travel time acceptable to the user; startT denotes the travel starting moment; and arriveT denotes the latest arrival moment.

② Cost constraints

The user is required to provide the maximum acceptable cost of the trip when making a trip reservationss_m , with the cost constraint that the cost of the trip is less than or equal to the maximum acceptable cost of the trip:

$$s_m \leq s_m^{\max}$$

Wheres_m denotes the cost of the trip; ands_m^{max} denotes the maximum cost of the trip acceptable to the user.

③ Stopover time constraints

Limit the maximum amount of time a user can stay en route:

$$T_{stopover} \leq T_{stopover}^{\max}$$

Where $T_{stopover}$ indicates the time the user stays en route; $T_{stopover}^{max}$ is the maximum acceptable stay for the user.

④Interchange time limit

To improve the user experience, it is possible to limit the amount of time required for interchange to ensure that users do not have to wait too long:

$$T_{transfer} \leq T_{transfer}^{\max}$$

Where$T_{transfer}$ indicates the transfer time between two modes of transportation and$T_{transfer}^{max}$ is the maximum transfer time acceptable to the user.

ISSN: 2710-0588

3.3. Optimization models

Combining the above analyses and considering the rated passenger capacity constraints of each travel mode, the walking transfer distance constraints and the user's personalized travel constraints, the following mathematical model is established for the MaaS system travel path planning problem:

$$MinU(total_t, total_m, total_{CO_2}) = w_t \cdot total_t + w_m \cdot total_m + w_{CO_2} \cdot total_{CO_2}$$

$$\text{S.t.} \quad \begin{cases} bus_{capI} \le bus_{\max I} \\ ride_{capI} \le ride_{\max I} \\ taxi_{capI} \le taxi_{\max I} \\ walk_{changeL} \le \max walk_{changeL} \\ T \le T_{\max} \\ \max(0, arriveT - startT) \le T_{\max} \\ s_m \le s_m^{\max} \\ T_{stopover} \le T_{stopover}^{max} \\ T_{transfer} \le T_{transfer}^{\max} \end{cases}$$

3.4. Model Analysis and Application

MaaS system planning travel paths need to be based on the total urban transportation resource data, car travel data and user travel demand. The total urban traffic resource data include: bus schedule time and station information, rated number of passengers, shared service points, network car service points; car travel data include: different car models, car driving speed; user travel demand include: origin and destination, acceptable travel cost, acceptable number of transfers, acceptable travel time and other personalized needs.

The simulation area and urban transportation resource data in Bengshan District of Bengbu City can be obtained by combining with Gaode Map, the car driving speed takes the average speed of vehicles traveling on urban roads, and the travel modes include buses, shared cars and online cars. The basic information of the simulation area and each traveling mode is as follows:

Figure 1. Example of simulation area

ISSN: 2710-0588

a.Regular Public Transportation

Three bus routes are selected in the simulation area, three regular buses are selected in each route, each bus is rated for 56 passengers, and the bus is rated for 4,536 passengers under the MaaS system.

b.car sharing

There are 39 shared bicycle service points in Bengshan District, assuming that 40 shared cars can be parked in each shared bicycle service point, and the rated capacity of shared cars under the MaaS system is 1,560 passenger trips.

c.online taxi

Bengshan District contains a total of 4 network car service points, assuming that each network car service point has a total of 3 empty vehicles, each vehicle rated for 4 passengers, the network car rated for 48 passengers under the MaaS system.

Randomly selected five Bengbu City, Bengshan District, Bengbu City, the user travel demand as MaaS system travel path planning model simulation of travel information, and assumed that the five users in the MaaS system before becoming a user has been using a private car as a means of commuting, and now the five users to travel using the MaaS system, according to the user's travel needs and purposes of the different start and end point coordinates and personalized needs given as the travel constraints The following table shows:

Table 1. Selected user information table

user ID	starting point coordinates	coordinates of the destination	starting moment	arrival time	time constraint	Cost constraints	Interchange constraints
1	[117.364421,32.922733]	[117.37678,32.928209]	7:30	7:47	0.3	5	1
2	[117.361674,32.934548]	[117.379183,32.93426]	7:45	7:52	0.1	10	0
3	[117.359614,32.940887]	[117.360644,32.931667]	7:00	7:13	0.2	2	0
4	[117.38296,32.935413]	[117.386737,32.935989]	8:10	8:16	0.1	5	2
5	[117.371974,32.904287]	[117.36854,32.924174]	8:05	8:11	0.3	15	1

Bengbu City, Bengshan District topology network has a total of 52 nodes of three types, including 9 regular public transportation nodes, numbered "1-9"; 39 bike-sharing nodes, numbered "10-48"; and 4 online car nodes, numbered "49-52". The regular bus nodes in Bengshan District of Bengbu City are numbered as shown in the table below:

Table 2. Conventional Bus Stop Numbers

Site name	Site number
Anhui University of Finance and Economics, West Campus (East Gate)	1
Hongye Road - Lanling Road	2
Yinghu Road - Hongye Road	3
Linghu Villa	4
South Lake Road - Yinghu Road	5
Nanhu District	6
Yinghu Road-Nanhu Road	7
Anhui University of Finance and Economics, West Campus (South Gate)	8
Beng Medical Second Affiliated Hospital-Railway High School	9

The association matrix of network nodes is used to determine the nature of topological network edges, through the association matrix more intuitive understanding of whether the nodes are

ISSN: 2710-0588

connected to each other, assigning a value of 0 indicates that the nodes are not connected to each other, and assigning a value of 1 indicates that the nodes are connected to each other, and through the node association matrix to determine whether it is possible to combine the different modes of travel to obtain the optimal path planning under various constraints.

The regular transit node association matrix is shown in the table below:

Table 3. Conventional public transportation node association matrix

	1	2	3	4	5	6	7	8	9
1	0	1	0	0	0	1	1	1	1
2	0	0	0	0	0	0	1	0	1
3	0	1	0	0	0	1	0	1	1
4	0	0	0	0	1	0	0	1	1
5	0	0	0	1	0	1	0	0	1
6	1	0	1	0	1	0	1	1	1
7	1	1	0	0	0	1	0	1	1
8	1	0	1	1	1	1	0	0	1
9	1	1	1	0	0	1	1	1	0

The network car node association matrix is shown in the following table, due to the large amount of data, only the node association matrix of nodes 10-15 is shown:

Table 4. Nodal association matrix for Netflix

	10	11	12	13	14	15
10	1	1	1	0	0	1
11	0	1	0	0	1	0
12	0	1	1	0	0	1
13	0	0	0	1	1	0
14	0	1	0	1	1	1
15	1	0	1	0	1	0

3.4.1. Simulation results and

Based on the constructed travel path planning model, the travel paths of the users of the MaaS system above are planned, and transportation resources are reasonably allocated by counting the demand for transportation resources in each time period.

Table 5. MaaS system trip path results

user ID	timing (h)	(manufacturing, production etc) costs (dollars)	carbon dioxide emission reduction (kg)	Number of interchanges (times)	Broad travel costs (dollars)
1	0.24	4	0.13	1	5.31
2	0.09	10	0.21	0	12.17
3	0.16	2	0.11	0	3
4	0.1	4	0.52	1	4.92
5	0.27	12	0.37	1	20.73
(grand) total	0.86	32	1.34	3	46.13

ISSN: 2710-0588

In order to reflect the advantages of MaaS system path planning compared to traditional transportation travel, the car is selected to drive the trip at the starting point of five users, and the results of MaaS system path planning are compared from four aspects: commuting time, travel cost, travel carbon dioxide emissions, and generalized travel cost.

Table 6. Traditional Transportation Travel Results

user ID	timing (h)	(manufacturing, production etc) costs (dollars)	Carbon dioxide emissions (kg)	Broad travel costs ($)
1	0.32	21.72	1.28	23.82
2	0.12	12.38	0.48	15.79
3	0.22	17.29	0.85	13.42
4	0.17	15.74	0.69	16.94
5	0.24	19.31	0.94	21.77
(grand) total	1.07	86.44	4.24	91.74

Table 7. Comparison table of travel results

	timing (h)	(manufacturing, production etc) costs (dollars)	Carbon dioxide emissions (kg)	Broad travel costs ($)
MaaS system travel results	0.86	32	1.34	46.13
Car travel results	1.07	86.44	4.24	91.74
optimization rate	19.6%	62.9%	68.4%	49.7%

As can be seen from the above comparison table of total travel results, the MaaS system operates better than traditional automobile travel in all aspects, and is optimized to a certain extent in terms of carbon dioxide emissions and generalized travel costs compared to automobile travel. In summary, the use of this model for travel path planning for users within the MaaS system significantly saves the total system travel into the total generalized travel cost, the

In summary MaaS system can not only improve the travel efficiency, while reducing the travel of carbon dioxide emissions, in line with the concept of green development, conducive to the realization of China's "dual-carbon" goal.

4. Conclusion

Based on the core idea of MaaS (Mobility-as-a-Service) system, this paper constructs a generalized mobility transportation cost model by considering the carbon emission and time-consuming factors in the travel process. Through simulation, the parameters within the transportation cost model of the MaaS system are analyzed in depth and quantitatively. In addition, the article also compares and analyzes the MaaS system model with the traditional transportation cost model, revealing the significant superiority of the MaaS model. This research not only lays a solid theoretical foundation for the implementation of MaaS system in cities, but also further enriches the MaaS system, which can help to promote the more efficient allocation of transportation resources, thus playing a positive role in promoting energy saving and emission reduction in the field of transportation.

ISSN: 2710-0588

Acknowledgements

This work is supported by Innovation and Entrepreneurship Training Project for College Students of Anhui University of Finance and Economics in 2023, Project number: 202310378125.

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