Feasibility Analysis of Green Travel in Public Transportation: A Case Study of Wuhan

Junjun Zheng, Yi Cheng, Gang Ma*, Xue Han and Liukai Yu

Economics and Management School, Wuhan University, Wuhan 430072, China;
zhengjunjun@whu.edu.cn (J.Z.); chengyi@whu.edu.cn (Y.C.); 2015302350021@whu.edu.cn (X.H.);
whuylk@whu.edu.cn (L.Y.)
* Correspondence: 2019101050054@whu.edu.cn

Received: 3 July 2020; Accepted: 11 August 2020; Published: 12 August 2020

Abstract: The demand to alleviate urban traffic and reduce air pollution puts forward high requirements for green travel in public transportation. Thus, study of the feasibility of urban green travel in public transportation is necessary. This study focuses on it from two aspects: City level by complex network and individual level by structural equation model. As for the former, point of interest data on the spatial distribution of urban public transportation in Wuhan city are quantitatively analyzed. Then, a complex network of public transportation in Wuhan is constructed by using the Space L method, and the network characteristics are analyzed. Results show that accessibility coverage is mainly concentrated in the central urban area, and two significant central nodes exist, namely, Linshi and Zhaohu stations. At the individual level, 354 valid questionnaires and the structural equation model were used to explore the factors affecting individual intention of public transportation. Behavioral perceptual outcome, behavioral attitudes, and subjective norms have positive influences on the behavioral intention of public transportation, among which the behavioral attitudes are the most significant, and the subjective norms had the lowest influence. Some suggestions are proposed for Wuhan to improve urban accessibility and for individuals to increase green travel in public transportation.

Keywords: complex network; green travel; structural equation model; theory of planned behavior

1. Introduction

1.1. Context

Public transportation can alleviate urban air pollution problems and has attracted extensive attention from governments of various countries [1]. Urban areas, urban population density, public facilities construction, and spatial distribution constantly develop and change, followed by the diversification and complexity of people’s value orientation, desire evolution, and behavior choices in aspects, such as food, clothing, housing, and transportation. How to guarantee public transportation at a city level effectively is a difficult problem. As shown in Figure 1, China’s urbanization is in a period of rapid development, but the supply growth of urban public facilities and infrastructure services does not fully match with urbanization development.
Given the rapid increase of urban areas and population, urban facilities and public transport services have developed gradually, as shown in Figure 2. Moreover, as shown in Figure 3, the growth rate of total urban public transport passenger volume has slowed significantly (in blue), and passenger volume of rail transit remarkably increased (in grey) but a marked decrease happened in the passenger volume of public bus and tram traffic (in red) in detail, from 2014 to 2017. On the one hand, the phenomenon of urban road congestion became increasingly serious, and the demand of urban residents for buses decreased. On the other hand, given the increase of urban subway, rail transit lines, and train schedules, traveling has become highly convenient and punctual. More people prefer tram public transportation, such as the subway. However, the subway is in need of more investment than bus public transportation, which leads many cities to have fewer tram public transportation. The above analysis shows an imbalance between the supply of urban public transport services and the development of urbanization in China. Therefore, scientific and reasonable space network planning is crucial for improving urban environmental quality [2].
Figure 3. Passenger volume change of urban public transport in China. (Source: China Statistical Yearbook).

Obviously, the construction of urban rail lines requires a large amount of social resources and government financial revenue. Therefore, resources in urban rail public transport are mainly concentrated in the central urban areas of first-tier and second-tier cities and radiate to the remote urban areas. However, the lines currently in operation are still limited. Residents in large-sized and medium-sized cities have a large demand for convenient and punctual public transport resources; therefore, the distribution of urban public transport resources is unbalanced and geographically different to a certain extent [3]. Spatial distribution features are essential [4,5], but previous studies on spatial analysis are few and mostly from the macro description, such as satellite maps. Ren et al. [1] used the China–Brazil Earth Resources Satellite-02B to analyze land-use change. Moreover, complex network theory can analyze the reliability of networks and evaluate node importance [6]. However, for the construction of green travel network, it is generally only simulation, not combined with actual data, used to construct an actual effective network. Zheng et al. [7] employed a scale-free network to simulate the group choice behavior in green travel. Alexander [8] proposed a seed network using the Nash equilibrium allocation method from the perspective of game theory and defined the conditions of an optimal green travel and transportation network. The deepening of urbanization to urban public transport service presents new requirements and challenges. China’s urbanization lag and regional distribution imbalance significantly reduce the willingness of urban residents to green travel. A vicious cycle is shown, where the inconvenience of public transportation leads to the decrease of green travel intention, then the congestion of urban roads, and finally the aggravation of urban air and environmental pollution.

The annual reports of China’s motor vehicle environmental management (2018) and mobile source environmental management (2019) released by the ministry of ecology and environment showed that China has been the world’s largest producer of motor vehicles in the past 10 years. Motor vehicle emission has become the first element of urban air pollution in China [9]; it affects urban air quality and is a key factor of city residents’ health; it also reduces gasoline consumption and greenhouse gas emissions [10]. Studies have shown that reducing the number of private cars can positively promote green travel in public transportation [4]. Therefore, controlling the use of motor vehicles and encouraging urban green travel in public transportation are the key to solve the problem of air pollution.

Influenced and restricted by external conditions, people who are willing to travel green in public transportation sometimes have to choose non-green travel [11]; for example, they have to choose to travel by air because of the distance, as well as other reasons [12]. However, personal attitudes are important to public transportation [13,14]. For example, some people may lessen their trips because
they are unable to travel green in public transportation[12]. Therefore, on the basis of the theory of planned behavior (TPB), the factors influencing individuals’ green travel intentions in public transportation were analyzed, and an empirical study on the above factors was conducted using the structural equation model. In terms of the research on individuals’ green travel intentions in public transportation, on the basis of the TPB, Jia et al. [15] studied the relationship between environmental factors and green travel intentions using a questionnaire survey and showed that the government needs to take new measures on relevant policies and transportation systems to increase the proportion of green travel. Ru et al. [16] researched the interaction effects of norms and attitudes on green travel intention. Shi et al. [17] found that individuals’ subjective norm and attitude are important in affecting factors of individuals’ pro-environment intention and further influence actual behavior. Wu [18] adopted the structural equation modeling and showed that nostalgia enhances tourists’ pro-environmental behavior through subjective attitude, perceived behavioral control, subjective norms, and meaning in life.

To sum up, the key to urban air pollution control lies in the prevention and control of urban motor vehicle pollution, and the adoption of green travel mode by urban residents is vital to reduce the emission of motor vehicles and control air pollution. Thus, the present study contributes to two aspects. First, on the basis of the spatial distribution data of various functional facilities in Wuhan, the spatial distribution and correlation of various functional facilities were quantitatively analyzed by using ArcGIS technology. This study discusses the spatial distribution and accessibility of urban public transport service systems from the perspectives of 13 administrative divisions and central and remote districts to provide policy suggestions for the optimization of the urban public transport network. Second, on the basis of the index system constructed by TPB, a survey on the permanent residents of Wuhan was conducted, and their willingness to go by public transportation way was analyzed. A total of 724 valid survey samples were obtained. AMOS was used to construct the corresponding structural equation model of Wuhan residents’ willingness to green travel in public transportation, which further identified the deep-seated psychological driving factors of urban residents’ willingness to green travel in public transportation. Finally, the strategies and ways to guide urban residents to green travel were given.

1.2. Overview of Wuhan City

In Wuhan, the new energy vehicles used in public transportation take account of 66.1% in 2018, and the rail traffic is also pro-environmental [19], which belongs to green travel compared with private car travel. The scientific and reasonable supply of the urban public transport service system is the prerequisite for urban residents to adopt behavior of green travel in public transportation. However, the insufficient supply of public transport, insufficient coverage, and unsatisfactory accessibility of public transport are important reasons for the low willingness to green travel in public transportation of urban residents and the difficulty in promoting green behavioral patterns. Therefore, the spatial distribution of the urban public transport service system provides a preliminary basis for this study.

This study takes Wuhan as the case and divides it into the core and far cities. The core city comprises Jiangan, Qingshan, Jianghan, Qiaokou, Wuchang, Hanyang, and Hongshan Districts, whereas the far city comprises Huangpi, Xinzhou, Dongxihu, Caidian, Hanan, and Jiangxia Districts, as shown in Figure 4.
Figure 4. Thirteen administrative districts in Wuhan city.

The research data were collected from the point of interest (POI) data of March 2019 on Baidu Map. Each record contained the name, address, administrative division location, classification, and longitude and latitude of Baidu coordinates of a POI. Wuhan currently operates a total of 456 bus lines and 9 subway lines.

After reweighing, sorting, and classifying data, 3903 records about bus stations in daily operation, and 206 records about subway stations in daily operation are selected. The spatial distribution of urban public transport stations provides the research background for the study on the green travel behavior of urban residents in Wuhan in the following paragraphs. The stations that have a practical impact on the residents’ travel behavior are mainly built stations. Thus, the planning and construction of public transport stations are excluded from this study.

This paper is organized as follows. Section 2 depicts the network of public transportation and extension of TPB. In Section 3, data and method are shown, in which we also consider city level and individual level. Section 4 analyzes some results. Some concluding remarks are shown in Section 5. In Section 6, some discussions have been given.

2. Conceptual Model

2.1. Network of Public Transportation by ArcGIS

The POI data of Wuhan bus stations and subway stations were collected on Baidu Map in March 2019 to understand the spatial distribution of Wuhan’s public transport system. Each record contained the name of the POI point, location of the administrative division, address, category, latitude, and longitude. The data were converted into the WGS84 coordinate system and imported into the ArcGIS as shown in Figure 5. The subway stations in Wuhan mainly have core areas. Huangpi, Xinzhou, and Jiangxia Districts only have a few stations close to the core urban areas, whereas Caidian and Hanan Districts have almost no stations. More bus stops exist in the city, and
they are more widely distributed than subway stations. These bus stations make up for the shortage of subways and are the main means to connect the core and far cities.

![Figure 5](image)

**Figure 5.** (a) Spatial distribution of subway stations in Wuhan city; (b) spatial distribution of bus stations in Wuhan city.

Wuhan was divided into 9740 compartments, and the bus and subway stations in each compartment were counted. The results are shown in Figure 6. The color of the small grid is the deepest in Jianghan and Qiaokou Districts, indicating that these districts have the most bus stations. Hongshan, Wuchang, Hanyang, Huangpi, and Jiangxia Districts have a red grid, indicating that the bus stations in these districts are dense. The spatial quantity distribution of subway stations in Wuhan is also mainly concentrated in the core area of the city. As shown in Figure 6, the subway stations are concentrated on Shengli Street, Yangsigang Fast Track, Dingziqiao Road, and Dongfeng Avenue. Most of the areas in the far city have almost no subway stations.

![Figure 6](image)

**Figure 6.** (a) Spatial quantity distribution of bus stations in Wuhan; (b) spatial quantity distribution of subway stations in Wuhan.

2.2. Extension of TPB

According to the TPB, when an individual chooses whether to green travel in public transportation, his behavioral intention directly affects his behavior occurrence. The stronger the willingness to act, the more likely he takes action. The core factor of individual behavior is individual behavioral intention, which depends on the comprehensive effect of behavioral attitude, subjective norm, and perceived behavioral control. An individual’s behavioral intention of green travel in public transportation can affect his behavior only when he can decide whether or not to green travel in
public transportation. That is, the individual is constrained by external opportunities and resources and can have actual control over the behavior only when the necessary opportunities and resources are available. People’s choice of green travel in public transportation is also influenced by their own and external factors and perception of behavioral results. Previous studies have proven that, due to the callback effect of behavioral outcome perception on green travel behavior and intention, the corresponding outcome perception is mainly reflected in three aspects, namely, economic saving, spiritual satisfaction, and health improvement.

Based on the above analysis, this study mainly analyzes the influencing factors of choice of individual behavior of green travel in public transportation with bounded rationality and establishes the conceptual model shown in Figure 7.

Figure 7. Conceptual model of individual green travel behavior.

3. Data and Method

3.1. Data Sources

To build a complex public transport network in Wuhan, in addition to the POI data, this study captured the road distribution information from Baidu Map. Given that completed stations will have a real impact on residents’ travel behavior, the planning and construction of public transport stations were not considered. Moreover, a road with multiple turns was considered as a road with multiple connections. To unify the geographical location information and projection state of various POI data, all data were transformed into the form in the WGS-84 coordinate system. After sorting data and refining the classification, this study selected the information on operating bus and subway stations (3903), subway stations (206), and roads (10189).

Moreover, to analyze the influencing factors of individual green travel behavior choice, a five-point Likert scale was used to investigate and analyze the resident population of Wuhan. A total of 746 questionnaires were distributed at bus stations, subway stations, and business districts of Jiedaokou and the Nanhu community. In order to close to the structure of Wuhan residents, we referred to data from Wuhan statistical yearbook in 2018, and collected 354 valid questionnaires. The age distributions of the statistical yearbook and respondents are shown in Table 1. Table 2 shows the questions and indicators affecting willingness to green travel in the questionnaire.

Table 1. Age distribution of people in Wuhan.

| Proportion   | ≤19 | [20,35) | [35,50) | [50,65) | [65,80) | ≥80 |
|--------------|-----|---------|---------|---------|---------|-----|
| Statistical Yearbook | 17.80% | 23.35% | 23.07% | 22.08% | 10.93% | 2.77%|
| Respondents  | 18.16% | 28.82% | 25.36% | 18.44% | 8.36%  | 0.86%|
Table 2. Investigation indicators of individual green travel choice behavior.

| Factor                        | Research Indicators and Questions                                      |
|-------------------------------|--------------------------------------------------------------------------|
| Behavior intention            | I would like to travel in a green way. (Q12)                             |
| Individual attitude (IA)      | I think air quality is very important, and pay attention to the emission of pollutants. (Q1) |
|                               | Green travel is better than other forms of travel. (Q2)                 |
|                               | I’m under a lot of financial pressure right now. (Q3)                  |
|                               | Many people recommended me to travel by bus or subway. (Q4)             |
| Subjective Norms (SN)         | I am willing to consider the suggestions of people around me and adjust my travel style. (Q5) |
|                               | TV, Internet and other media often recommend me to travel in public transportation. (Q6) |
| Perceived behavioral control (BC) | It is not difficult for me to green travel alone without other people’s company or help. (Q7) |
|                               | Green travel is safe. (Q8)                                              |
|                               | Green travel is convenient. (Q9)                                         |
| Behavioral outcome perception (OP) | It’s cheaper for green travel in public transportation. (Q10)         |
|                               | Choosing green travel can protect the environment, which makes me feel very happy. (Q11) |

3.2. Method

3.2.1. Complex Network Analysis of Public Transportation

In the Space L modeling method, the actual road network station corresponded to the model node [20]. If the two nodes can reach each other, an edge is established at the corresponding location of the model. Figure 8 is a schematic diagram of the Space L modeling. The network constructed by the Space L method can represent the line transformation of the public transportation network. All stations on the same line can be directly connected, forming a line cluster in the figure. The nodes that the two clusters are connected to represent the actual transformation site.

The Space L method is the most common method for building complex public transportation networks [21,22]. This method fully considers the relative position relation of adjacent stations on the public transport route and can reflect the service order relation of public transport on the actual operating route. Therefore, the collected POI information on bus and subway stations represents the public transport nodes in complex networks. The public transportation operation route of adjacent nodes was used to show the network connection relationship, which was used to construct public transportation in Wuhan’s complex networks and analyze complex network topology and characteristics.
Using the Space L method, the node information in the complex network of public transportation in Wuhan was sorted out. The node name, ID, longitude, and latitude were included, which total 4109 pieces of information. Given that the majority of public transport routes are two-way, this study did not consider the directionality of the connection relationship in the complex network of public transport. The result contains 4109 points and 4914 edges, one of which represents the adjacent relationship between two stations on a public transport route. Two adjacent stations may exist on multiple public transport routes. Therefore, this study introduced the weight concept of edges in the complex network to represent the number of public transport routes where these edges are located. The existence of a certain edge on N public transport routes shows that residents in Wuhan can reach neighboring stations by taking buses or subways on N lines. The weight of this edge is denoted as N.

The topological structure relationship of this complex network is shown according to the Force Atlas and Fruchterman–Reingold diagram in physics. The specific results are shown in Figure 9a,b. In a complex network, the set node size is positively correlated with its degree size. Therefore, the nodes in the complex network with many edge connections are represented by large points. The distribution map of the public transport complex network based on Force Atlas shows two prominent central nodes in the network, namely, Linshi and Zhaohu stations in Huangpi District. These two nodes have many side connections, which play a decisive role in the normal operation of Wuhan’s public transport system.

![Figure 9](image)

**Figure 9.** (a) Complex network of public transport based on Force Atlas; (b) complex network of public transport based on Fruchterman–Reingold.

The Fruchterman–Reingold diagram of the public transportation complex network places nodes in the middle of the circle, and their positions extend outward with the decrease of node degree. Therefore, the distribution diagram shows that the size distribution of each node degree moves outward from the circular center. As shown in the Figure 9, a few nodes in the center of the circle have a large degree, and most of the nodes in the network have a small degree. Therefore, the complex public transport network in Wuhan presents some scale-free network features, that is, a small number of nodes have more edge connections in the complex network.

To analyze the index, some inductions are shown as following:

1. **Degree distribution**

   If the network’s adjacency matrix is \( A = (a_{g})_{N \times N} \), the degree of node \( i \), \( k_{i} \) can be described as:

   \[
   k_{i} = \sum_{j \neq N} a_{ij}
   \]  

   \[(1)\]
Further, if \( n(k) \) is used to represent the number of nodes with degree \( k \), the degree distribution \( P(k) \) can be expressed as:

\[
P(k) = \frac{n(k)}{\sum_{j=1}^{\infty} n(j)}
\]  

(2)

Degree of nodes can reflect the influence of themselves in the network. The more adjacent nodes a node has, the more important its position in the network will be. Degree distribution refers to the probability distribution of node degrees in the network, that is, the ratio of the number of nodes with the same degree to the total number of nodes. Moreover, degree distribution can describe the dispersion degree of the overall network. The overall structural characteristics and dynamic behavior of complex networks are closely related to degree distribution, so degree distribution is often used in quantitative analysis of complex networks.

2. Clustering coefficient

The phenomenon that two nodes of a network are connected to each other is called clustering. The clustering coefficient is the ratio of the actual number of edges between nodes connected to a certain node to the most possible number of edges between them. The larger the clustering coefficient is, the more information exchange channels there are between them, which reflects the tight degree of connection between nodes in the local network. We use \( C_i \) to denote clustering coefficient of node \( i \), \( k_i \) is degree, and \( E_i \) is the number of edges between adjacent nodes of \( k_i \). Moreover, \( k_i \) nodes can have as many edges as \( \frac{k_i(k_i - 1)}{2} \). The clustering coefficient can be written as

\[
C_i = \frac{2E_i}{k_i(k_i - 1)}
\]  

(3)

The clustering coefficient of the network is the average value of the local clustering coefficient, i.e.,

\[
C = \frac{1}{N} \sum_{i=1}^{N} C_i
\]  

(4)

If the clustering coefficient of one node is greater than the clustering coefficient of the network, then the network is considered to have clustering phenomenon.

3. Eigenvector Centrality

The importance of each node in the network is different, and centrality can measure whether a single node is in the center of the network, in which eigenvector centrality is one of the indexes. A node in network with higher eigenvector centrality should be connected with more nodes, and its adjacent nodes are also of high importance. For any node \( i \), the eigenvector centrality is:

\[
x_i = \frac{1}{\lambda} \sum_{j \in M(i)} x_j = \frac{1}{\lambda} \sum_{j=1}^{N} a_{ij} x_j
\]  

(5)

where \( a_{ij} \) is an element of node \( i \)'s adjacency matrix, and it denotes whether the node \( i \) is connected to the node \( j \). \( \lambda \) is a constant.
4. Modularity class value

Modularity class value is a quantitative index that can be used to evaluate the structural strength of the community. If the value is big, it indicates that effect of community division is good. The calculation is shown as following:

\[
Q = \frac{1}{2n} \sum_{c \in C} \sum_{i,j \in c} \delta_{ci} \delta_{cj} (A_{ij} - \frac{k_i k_j}{2n})
\]

where \(A_{ij}\) is the adjacent matrix of networks, \(k_i\) and \(k_j\) denote degree of node \(i\) and node \(j\), respectively. \(C\) is a set of communities on the network, and \(c\) represents one of the community structures. \(n\) is the number of edges. \(\delta_{cj}\) is an indicator variable, which means if the node \(i\) is inside of \(c\), \(\delta_{cj}\) equals to 1; otherwise, it is 0.

3.2.2. Structural Equation Model of Individual Behavior of Green Travel in Public Transportation

This section models individual green behavioral intention on the basis of the TPB. According to a reasonable survey index system, the reliability and validity of the questionnaire and survey data are analyzed, which ensures the effectiveness of the structural equation model of residents’ green travel behavioral intention in public transportation.

The initial model was built, and total statistics of questionnaire were shown in Table 3. Moreover, in Cronbach’s alpha was used to analyze the reliability of the survey results. KMO (Kaiser-Meyer-Olkin) and Bartlett’s tests were used to analyze their validity. The results show that the validity of the questionnaire data is 0.823, indicating good internal consistency and high reliability (Tables 3 and 4).

**Table 3. Reliability analysis.**

| Cronbach’s Alpha | Cronbach’s Alpha Based on Standardized Items | N of Items |
|------------------|---------------------------------------------|------------|
| 0.830            | 0.823                                       | 12         |

**Table 4. Questionnaire index statistics.**

| Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item Total Correlation | Squared Multiple Correlation | Cronbach’s Alpha if Item Deleted |
|---------------------------|-------------------------------|---------------------------------|-------------------------------|---------------------------------|
| Q1 44.69                  | 24.029                        | 0.663                           | 0.488                         | 0.802                           |
| Q2 44.70                  | 23.903                        | 0.709                           | 0.548                         | 0.799                           |
| Q3 46.98                  | 33.498                        | -0.501                          | 0.354                         | 0.881                           |
| Q4 44.79                  | 24.438                        | 0.624                           | 0.456                         | 0.806                           |
| Q5 44.90                  | 24.673                        | 0.591                           | 0.384                         | 0.809                           |
| Q6 44.75                  | 25.247                        | 0.561                           | 0.352                         | 0.812                           |
| Q7 44.52                  | 24.715                        | 0.559                           | 0.331                         | 0.811                           |
| Q8 44.69                  | 26.896                        | 0.334                           | 0.167                         | 0.829                           |
| Q9 44.69                  | 26.152                        | 0.382                           | 0.203                         | 0.826                           |
| Q10 44.67                 | 24.800                        | 0.576                           | 0.394                         | 0.810                           |
| Q11 44.62                 | 24186                         | 0.669                           | 0.521                         | 0.802                           |
| Q12 44.63                 | 24.098                        | 0.754                           | 0.711                         | 0.797                           |

From Table 5, the result of the validity test shows that the value of KMO is 0.930, which is greater than 0.5. Therefore, the research result is suitable for factor analysis. Therefore, the hypothesis that all variables are independent should be rejected, and the questionnaire has structural validity.
Table 5. KMO (Kaiser-Meyer-Olkin) and Bartlett’s Test.

| Kaiser-Meyer-Olkin Measure of Sampling Adequacy | 0.930 |
|-----------------------------------------------|-------|
| Approx. Chi-Square                           | 1690.500 |
| Bartlett’s Test of Sphericity                 | df 66 | Sig. 0.000 |

According to the concept of the extended TPB in Section 2.2, Wuhan residents’ green travel behavioral intention is influenced by behavioral attitude, subjective norm, perceived behavioral control, and behavioral perceptual outcome. Moreover, behavioral attitude can be measured by Q1, Q2, and Q3; subjective norms can be measured by Q4, Q5, and Q6; perceived behavioral control can be measured by Q7, Q8, and Q9; and behavioral perceptual outcome can be measured by Q10 and Q11, which are also shown in Figure 10.

Moreover, the initial model was built by Amos software on the basis of survey data. The fitting results of the initial structural equation model can be obtained, as shown in Table 6. The model of the chi-square value is 234.167. CFI and GLI values are close to 0.9. IFI and TLI values are 0.957 and 0.942, which are greater than 0.9.

Table 6. Initial model fitting degree of green travel intention.

| Intention | $\chi^2$ | df | $\chi^2 / df$ | RMSEA | IFI | CFI | GFI | TLI |
|-----------|---------|----|---------------|-------|-----|-----|-----|-----|
| Intention | 234.167 | 52 | 4.503         | 0.097 | 0.957 | 0.868 | 0.896 | 0.942 |

The initial model of green travel behavioral intention in public transportation corresponds to the path coefficient, load coefficient, and significance ratio, as shown in Table 7. The path coefficient of perceived behavioral control (BC) on green travel behavioral intention in public transportation is -0.029. The SE and CR values are 0.069 and -0.423, respectively. The P value is 0.672 and greater than 0.01, which shows there is no difference between the path coefficient and 0 under the confidence level of 99%. The previous analysis shows that the questionnaire and data have met the requirements of reliability and validity. Combined with the fitting analysis results of the initial model of green travel behavioral intention in public transportation, this section considers eliminating the factor of perceptual behavioral control from the initial structural equation model. The modified model of green travel behavioral intention is shown in Figure 11.
Table 7. Estimated results of the initial structural equation model.

|                | Estimate | S.E.  | C.R.   | P   | ST   |
|----------------|----------|-------|--------|-----|------|
| Intention      | 1.000    |       |        |     |      |
| Intention      | 0.327    | 0.053 | 6.182  | *** |      |
| Intention      | -0.029   | 0.069 | -0.423 | 0.672|      |
| Intention      | 0.412    | 0.064 | 6.459  | *** |      |
| Q1  | IA      | 1.000 |       |      |      |
| Q2  | IA      | 1.135 | 0.099  | 11.422 | *** |
| Q3  | IA      | -1.006| 0.088  | -11.397 | *** |
| Q4  | SN      | 1.000 |       |      |      |
| Q5  | SN      | 1.009 | 0.122  | 8.200 | *** |
| Q6  | SN      | 0.807 | 0.101  | 7.990 | *** |
| Q7  | BC      | 1.000 |       |      |      |
| Q8  | BC      | 0.843 | 0.198  | 4.257 | *** |
| Q9  | BC      | 1.043 | 0.254  | 4.108 | *** |
| Q10 | OP      | 1.000 |       |      |      |
| Q11 | OP      | 1.178 | 0.195  | 6.033 | *** |
| Q11 | Intention | 1.000 |       |      |      |

Figure 11. Modification model of behavioral intention to green travel.

The P values in Table 8 are all less than 0.05, indicating that all the estimated parameters in the modified model are significant at the 95% confidence level, which can be considered as having a significant impact. Moreover, the standardized result (ST) of the path coefficient of the modification model of green travel behavior intention is also shown in Table 8.

Table 8. Coefficient estimation results of the green travel in public transportation behavior intention modification model.

|                | Estimate | S.E.  | C.R.   | P   | ST   |
|----------------|----------|-------|--------|-----|------|
| Intention      | 1.000    |       |        |     |      |
| Intention      | 0.323    | 0.053 | 6.120  | *** | 0.35 |
| Intention      | 0.409    | 0.064 | 6.420  | *** | 0.41 |
| Q1  | IA      | 1.000 |       |      | 0.58 |
| Q2  | IA      | 1.140 | 0.100  | 11.374 | *** |
| Q4  | SN      | 1.000 |       |      | 0.47 |
| Q5  | SN      | 1.008 | 0.122  | 8.281 | *** |
| Q6  | SN      | 0.807 | 0.101  | 7.980 | *** |
| Q10 | OP      | 1.000 |       |      | 0.40 |
(1) The path coefficient between the behavioral attitude and green travel intention in public transportation is 0.89. Therefore, the behavioral attitude has a significant positive influence on green travel behavioral intention, and its influence on green travel behavioral intention is greater than the two factors of subjective norms and behavioral perceptual outcome.

(2) The path coefficient from subjective norm to green travel intention in public transportation is 0.35. Therefore, behavioral attitude has a positive influence on green travel intention, but its influence is lower than behavioral attitude and the result of behavioral perception.

(3) The path coefficient from a behavioral perceptual outcome to green travel behavioral intention in public transportation is 0.41. Therefore, the subjective norm has a positive influence on green travel behavioral intention, but its influence is lower than the behavioral perceptual outcome.

4. Results

4.1. Network Analysis

4.1.1. Analysis of Topological Parameter in Complex Networks

To characterize quantitatively the topological structure of the complex public transport network in Wuhan, this section calculates and analyzes the topological structure parameters of the network, including degree distribution, network path, clustering coefficient, feature vector centrality, and modularization.

The degree distribution of all nodes in the complex network is shown in Table 9 and Figure 12. A total of 2275 nodes have a degree of 3. Using node degree distribution, the number of nodes in the node degrees of 1 to 3 has a proportion of more than 70% of the summary points, the number of nodes in the node degree not more than 5 has a proportion that is as high as 92.5%, and the number of nodes in the node degree not less than 9 has a proportion of 1.095%. Therefore, Wuhan’s public traffic complex network with a small number of node degree is large. The vast majority of the node degree is small, which indicates that the corresponding complex networks present obvious characteristics of scale-free networks. The calculation shows that the average value of the complex network of bus-subway stations in Wuhan is 2.392 and the average weighted value is 4.14. Therefore, each bus-subway station in Wuhan is connected with two to three other stations on average, which provides guarantee for people to travel nearby places by public transportation.

| Degree | Number | Degree | Number |
|--------|--------|--------|--------|
| 1      | 328    | 9      | 22     |
| 2      | 275    | 10     | 12     |
| 3      | 2275   | 11     | 6      |
| 4      | 547    | 12     | 1      |
| 5      | 376    | 13     | 1      |
| 6      | 152    | 16     | 1      |
| 7      | 75     | 19     | 1      |
| 8      | 36     | 35     | 1      |

Table 9. Node statistics of Wuhan public transportation complex network.
The calculation results show that the diameter of the complex public transport network in Wuhan is 103, the average path length is 24, and the values are relatively large. Therefore, the transmission performance and circulation efficiency of the complex network in the field of public transport are low, which brings trouble to people when they choose to travel in public transportation, and the whole complex public transport network still has room for further optimization. The value corresponding to each node in the middle of the center degree distribution is shown in Figure 13. Most of the nodes in the middle of the center value degree are low. Only a handful of node values are high, as shown in Wuhan’s public traffic complex network. A few sites exist, such as Linshi station, which shows the shortest path for the circulation and effective utilization of all public traffic resources.

The clustering coefficient index of the complex network can be used to measure clustering characteristics. The analysis results show that the average clustering coefficient of Wuhan’s complex public transport network is 0.083, which is lower than Qingdao 0.734 [23]. Therefore, Wuhan’s complex public transport network is of poor clustering and collectivity, which causes more difficulties for people to travel by public transportation. On the one hand, the lower the value of the index, the more likely it is that people face inconvenient problems of public transportation, which leads people to have lower willingness of green travel in public transportation. On the other hand, just owing to the inconvenience of green travel in public transportation, demand for improving the present situation and travelling in public transportation conveniently of people is high. The growing willingness of green travel in public transportation promotes the improvement of public transportation, which reflects people’s demand and the government’s response. The clustering coefficient of each station in Wuhan is statistically analyzed, and the specific results are shown in Figure 14. Given that the clustering coefficient of a single station can be used to measure the density of other public transport stations around the station, the high clustering coefficient of a single station indicates that more stations exist around the station, and the traffic stations in the area are relatively dense. Figure 14 shows that the clustering coefficient of most nodes (i.e., more than 3200) in the complex public transport network of Wuhan is 0, and 80% of the public transport stations is poor. On the contrary, the clustering coefficient of approximately 100 stations is 1, which indicates that the
connectivity of approximately 2.4% of the stations in this complex network is good. Based on the spatial distribution of bus and subway stations in Chapter 3, these 100 stations are mainly concentrated in the following regions: The central urban area of Wuhan; the core areas of Jiangxia, Xinzhou, and Huangpi District; the junction of Dongxihu and Caidian Districts; and the central urban area.

**Figure 14.** The clustering coefficient distribution of Wuhan public transportation network (except score = 0, count around 3300).

The nodes in the complex network have eigenvector center degree values, which can be used to measure the centrality of adjacent nodes. If the eigenvector of a node center degree is big, it means other nodes adjacent the node centrality are also big. Wuhan’s public traffic complex network analysis results show each node of the eigenvector center degree has huge differences, as shown in Figure 15. Only a few eigenvector center nodes are big, which includes Linshi and Zhaohu stations, Qindai station of Parrot Avenue subway, Zhuye Mountain of Huangxiaohe Road, and Yima Farm of Wuluo Road.

**Figure 15.** Eigenvector centrality distribution of Wuhan public transportation network (except score = 0, count around 340).

The modularity of Wuhan’s public traffic complex network is 0.903, which can be divided into 934 communities and is shown in Figure 16. The seven largest communities are shown in Figure 17. The largest red community has biggest scale and good connectivity that has better condition of green travel in public transportation. However, the gray communities in which the gray nodes are located have poor connectivity. These communities are important areas to improve the integration and connectivity of Wuhan’s complex public transportation network.

**Figure 16.** The community scale of Wuhan public transportation network.
Figure 17. Well-connected communities in Wuhan public transportation network.

4.1.2. Accessibility of Bus-Subway Station Network

After analyzing the topological structure of the complex public transportation network of bus and subway stations in Wuhan, the accessibility of each station was discussed to show the accessibility and coverage of public transportation in each street and micro area. The collected and screened road information of Wuhan was imported into the geographic space, and the road network dataset obtained is shown in Figure 18.

Figure 18. Schematic diagram of Wuhan road network.

The information of 206 subway stations was imported into the above network dataset, and the traffic accessibility of each subway station within 2000 m was calculated. The accessibility coverage of subway stations shown in Figure 19 can be obtained.
The analysis shows that the six subway stations are mainly distributed in Wuhan city center. Thus, accessibility is mainly concentrated in the central urban area, specifically known as Jianghan District, which is within 1000 m from the subway. Within 2000 m, the Jinaghan, Jiangan, Qiaokou, and Wuchang Districts can all be accessed. The subway stations of three above districts can cover the most space. As for other areas, accessibility is also mainly concentrated in Dongfeng Road, Chaoyang Road, Panlong Road, South Road, and so on. However, the accessibility of Hongshan District and Qingshan District is poor, which shows these districts are the key areas for subway planning and construction to strengthen the connectivity of Wuhan’s public transportation network.

As for bus stations, Wuhan’s bus network accessibility within 2000 m is shown in Figure 20. The bus site network accessibility is bigger than that of the subway site coverage. Jiangan, Jiangxia, Hanyang, Qiaokou, Qingshan, Wuchang, and Hongshan districts are almost within 2000 m in terms of accessibility, and there are many bus stations. In other words, the bus station network connectivity and integration in these six core areas have been ideal. In terms of accessibility, the green travel needs of residents in these areas can be met.
Moreover, Huangpi, Xinzhou, and Jiangxia Districts form a considerably accessible area, and the number of bus stations is mainly concentrated in the core areas of these districts and counties. At the junction of Caidian and Xinzhou Districts and the central urban area, considerable accessibility coverage is formed, which can be regarded as the extension of public transport resources in the core region within the scope of two districts and counties. Dongxihu District forms a considerably reachable area but does not form highly concentrated accessibility coverage in Huangpi district, which indicates that the spatial distribution of bus resources in Dongxihu District is balanced. However, the accessibility coverage of bus stations in Hannan District is low. The number of bus stations is small, which is not conducive to the development of public transport in Hannan District and restricts the connection of public transport between Hannan District and other districts and counties in Wuhan.

4.2. Analysis of Factors on Green Travel Behavioral Intention

The overall Cronbach’s alpha of the 724 survey data is 0.795. The Friedman chi-square test value is 836.675. The significance of the chi-square test is 0.000. Therefore, the internal consistency of the questionnaire is good, and the reliability is high. The KMO value is 0.803. The chi-square value of Bartlett’s test is 857. The corresponding significance is 0.000, which is less than 0.001. Therefore, the hypothesis that all variables are independent should be rejected. The questionnaire has structural validity. The above reliability and validity analysis results show that the research data are suitable for factor analysis and structural equation model analysis.

Based on the TPB, the green travel behavioral intention of the initial model fitting results show that the model fitting results are highly reasonable, but it can be modified further. In our analysis, the variable of perceived behavioral control has no significant difference with the latent variable of green travel behavioral intention under the confidence degree of 99%. Thus, the path coefficient is removed when the above initial model is modified. The modified model of green travel behavioral intention showed significant improvement in all aspects of the fitting degree. The analysis results show that all the estimated parameters in the modified model are significant at 95% confidence level.
The standardized results of the path coefficient of the green travel behavioral intention modification model are as follows. The behavioral perceptual outcome has a significant positive influence on the green travel behavioral intention, and its influence on the green travel behavioral intention is greater than behavioral attitude and subjective norms. Behavioral attitude has a significant positive influence on the behavioral intention of green travel, but its influence is lower than the behavioral perceived result. The subjective norm has a positive influence on the behavioral intention of green travel, but its influence is lower than the behavioral perceived result and behavioral attitude.

5. Discussion and Suggestions

The Space L method is used on the basis of the distribution of the Wuhan’s public transportation complex network. On the one hand, public transportation in Wuhan has complex network topologies. On the other hand, combined with Wuhan city road information, Wuhan’s public transportation accessibility and complicated network coverage are analyzed. Moreover, the influencing factors from the perspective of individual green travel intention in public transportation are analyzed. The research results show the following:

City level: (1) Two significant central nodes exist in the complex network of Wuhan’s public transport. They are Linshi and Zhaohu stations located in Huangpi District. These two nodes have the highest side connection. Moreover, each site in Wuhan is connected with two to three other sites on average. The degree of most nodes in the network is small, showing a relatively obvious scale-free network feature. (2) From the analysis of topological parameter, we can find each bus and subway station in Wuhan is connected with two to three other stations on average and the clustering coefficient is low. Therefore, the transmission performance and circulation efficiency in the field of public transport are low, and the agglomeration and collectivity are poor, which shows the complex public transport network has room for further optimization. Furthermore, the whole complex network of public transport in Wuhan is divided into 934 communities, among which are seven significant and large-scale associations with good integration and connectivity. (3) The accessibility of Wuchang District’s subway network coverage is big, which indicates the district has better public transportation feasibility. However, the subway accessibility of Hongshan and Qingshan Districts in the central urban area is poor. They are the key areas for the layout and construction of the subway network. Furthermore, the accessibility coverage of the bus station network is larger than that of the subway station.

Individual level: (1) Behavioral attitude has a significant positive impact on the behavioral intention of green travel, which is greater than that of behavioral perceptual outcome and subjective norms. (2) Behavioral perceptual outcome also has a significant positive influence on the behavioral intention of green travel, but its influence is lower than the behavioral attitude. (3) Subjective norms have a positive influence on the behavioral intention of green travel, but their influence is lower than the behavioral perceived result and behavioral attitude.

The following policy suggestions are given at the city level: (1) The stability of the daily operation of Linshi and Zhaohu stations must be increased. The two stations are connected to many stations. They play a pivotal role in the normal operation of the public transport system in Wuhan, especially in Huangpi District. The situation of unstable travel has a great impact on the public transport operation in Huangpi District and the public transport connection between Huangpi District and the central city. (2) The complex network of public transport must be further optimized. For example, the intermediate centrality and clustering coefficient of Linshi station, which is in the core hub of the whole complex public transport network, play an important role in circulation connection. Therefore, the management of these stations can be strengthened. (3) A reasonable layout of public transport stations must be created according to spatial characteristics. For example, the accessibility coverage of bus stations in Hannan District is limited, and the public transport network needs to be constructed and optimized. However, the East-West Lake areas have formed an important accessible area. Thus, the public transport resources in the East-West Lake areas are evenly distributed. Increasing optimization effort is unnecessary.
The following suggestions are given at the individual level: (1) Attention should be given to relevant pro-environment information to improve the awareness of green travel in public transportation (i.e., the behavioral attitude). (2) The spiritual satisfaction brought by green travel and environmental protection should be improved, and more attention should be given to the behavioral results. (3) Individuals should consider suggestions put forward by people around him, and actively adopt relevant aspects of the corresponding media, which can improve subjective norms.

6. Conclusions

The feasibility analysis of urban green travel was conducted from two levels, the city level and the individual level. (1) City level: Wuhan's spatial distribution of public transportation network, its topology, and accessibility were studied, which shows some nodes that have a significant impact on the public transportation network. The results show the connectivity and circulation efficiency of 13 administrative districts of network are low, but 7 core districts where stations are distributed can meet the residents' demand for green travel in public transportation, otherwise the far districts. (2) Individual level: Based on TPB, Wuhan residents' intention to green travel behavior and its influencing factors were analyzed, whose data is from questionnaires on Wuhan residents. Then, according to the reliability and validity of the survey data, the intention of Wuhan residents to green travel behavior was analyzed using the structural equation model. The corresponding influence factors and path were discussed. Behavioral perceptual outcome, behavioral attitude, and subjective norm had a positive effect on green travel intention, but subjective norms were minimally affected.

This study has the following limitations. Many new sites did not consider the rapid development of Wuhan, and behavioral intention is influenced by various factors [24]. Although several aspects were emphasized in this study, other significant factors should be added in future studies. Furthermore, as for public transport network, scheduling is also important and needed to be supplemented, because waiting times make the difference.

Author Contributions: Conceptualization and supervision: J.Z. and G.M.; methodology: Y.C., L.Y., and X.H.; software: X.H.; validation: M.Y.; writing—original draft preparation: Y.C. and G.M.; writing—review and editing: G.M., L.Y., and X.H.; project administration: J.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 71771181.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Jia, H.; Appolloni, A.; Wang, Y.Q. Green Travel: Exploring the Characteristics and Behavior Transformation of Urban Residents in China. *Sustainability* 2017, 9, 1043–1056.
2. Ren, Y.; Wang, D.Y.; Wang, D.R.; Chen, F. Designing a green-space network with geospatial technology for Lijiang City. *Int. J. Sustain. Dev. World Ecol.* 2011, 18, 503–508.
3. Crucitti, P.; Latora, V.; Porta, S. Centrality in networks of urban streets. *Chaos Interdiscip. J. Nonlinear Sci.* 2006, 16, 15113.
4. Zhang, W.B.; Tian, Z.H.; Zhang, G.Y.; Dong, G.G. Spatial-temporal characteristics of green travel behavior based on vector perspective. *J. Clean Prod.* 2019, 234, 549–558.
5. Ahn, K.G.; Rakha, H. The effects of route choice decisions on vehicle energy consumption and emissions. *Transp. Res. Part D Transp. Environ.* 2008, 13, 151–167.
6. Zhang, X.; Chen, B.Z. Study on node importance evaluation of the high-speed passenger traffic complex network based on the Structural Hole Theory. *Open Phys.* 2017, 15, 1–11.
7. Zheng, J.J.; Xu, M.Y.; Li, R.F.; Yu, L.K. Research on Group Choice Behavior in Green Travel Based on Planned Behavior Theory and Complex Network. *Sustainability* 2019, 11, 3765.
8. Krylatov, A.Y.; Zakharov, V.V. Competitive Traffic Assignment in a Green Transit Network. *Int. Game Theory Rev.* 2016, 18, 1640003.
9. Muslim, N.H.; Keyvanfar, A.; Shafaghat, A.; Abdullahi, M.M.; Khorami, M. Green Driver: Travel Behaviors Revisited on Fuel Saving and Less Emission. *Sustainability* 2018, 10, 3–25.
10. Kahn, M.E.; Morris, E.A. Walking the Walk: The Association between Community Environmentalism and Green Travel Behavior. *J. Am. Plan. Assoc.* 2009, 75, 389–405.
11. McDonald, S.; Oates, C.J.; Thyne, M.; Timmis, A.J.; Carlile, C. Flying in the face of environmental concern: Why green consumers continue to fly. *J. Mark. Manag.* 2015, 31, 1503–1528.
12. Enzler, H.B. Air travel for private purposes. An analysis of airport access, income and environmental concern in Switzerland. *J. Transp. Geogr.* 2017, 61, 1–8.
13. Ho, C.; Mulley, C.; Tsai, C.H.; Ison, S.; Wiblin, S. Area-wide travel plans—Targeting strategies for greater participation in green travel initiatives: A case study of Rouse Hill Town Centre. *Transportation* 2017, 44, 325–352.
14. Geng, J.C.; Long, R.Y.; Chen, H.; Li, W.B. Exploring the motivation-behavior gap in urban residents’ green travel behavior: A theoretical and empirical study. *Resour. Conserv. Recycl.* 2017, 125, 282–292.
15. Jia, H. Green Travel Behavior in Urban China: Influencing Factors and their Effects. *Sustain. Dev.* 2018, 26, 350–364.
16. Ru, X.J.; Wang, S.Y.; Chen, Q.; Yan, S. Exploring the interaction effects of norms and attitudes on green travel intention: An empirical study in eastern China. *J. Clean Prod.* 2018, 197, 1317–1327.
17. Shi, H.X.; Wang, S.Y.; Guo, S.D. Predicting the impacts of psychological factors and policy factors on individual’s PM2.5 reduction behavior: An empirical study in China. *J. Clean Prod.* 2019, 241, 118416.
18. Wu, Z.; Chen, Y.; Geng, L.; Zhou, L.; Zhou, K. Greening in nostalgia? How nostalgic traveling enhances tourists’ proenvironmental behavior. *Sustain. Dev.* 2019, 28, 1–12.
19. Wuhan Institute of Traffic Development Strategy. *Wuhan Traffic Development Annual Report in 2018*; Wuhan Institute of Traffic Development Strategy: Wuhan, China, 2018.
20. Kurant, M.; Thiran, P. Layered complex networks. *Phys. Rev. Lett.* 2006, 96, 138701.
21. Von Ferber, C.J.; Holovatch, T.; Holovatch, Y.; Palchykov, V. Public transport networks: Empirical analysis and modeling. *Eur. Phys. J. B* 2009, 68, 261–275.
22. Seaton, K.A.; Hackett, L.M. Stations, trains and small-world networks. *Phys. A Stat. Mech. Appl.* 2004, 339, 635–644.
23. Sun, R.C.; Shao, F.J. Complexity of Qingdao’s public transport line network. *Complex Syst. Complex. Sci.* 2009, 6, 63–68.
24. Rhodes, R.E.; Beauchamp, M.R.; Conner, M.; de Bruijn, G.J.; Kaushal, N.; Latimer-Cheung, A. Prediction of depot-based specialty recycling behavior using an extended theory of planned behavior. *Environ. Behav.* 2015, 47, 1001–1023.

© 2020 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/).