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What Influences the Choice Between Private Car and Public Transport for Shopping Trips? Impact of Socio-economic and Built Environment Factors

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Abstract

Shifting toward sustainable daily travel will play a significant role in the future of sustainable development and the lowering of carbon emissions. This study provides an in-depth comparison of transport mode choice and corresponding CO_2 emissions between private cars and public transport used for shopping trips based on individual data from a travel survey conducted in Shenyang, China. The analysis found that bus travel accounted for the majority of motorized transportation. Public transport users were closely distributed along the bus or metro lines, and aggregated private car users were mainly clustered within the second circumferential road. Furthermore, average per trip emissions for private car travel were 8-fold that of public transport. Binary logistic regression modeling was employed to examine factors that were related to the choice between private car and public transport, and the results indicated that car ownership and gender were the most important factors in explaining the preference of car driving. Age and per capita monthly income were negatively correlated with car driving. In addition, there were also negative impacts associated to the built environment factors of access to the closest metro stations and the number of bus stops near the residence on car driving. This study is vital to formulate more effective transportation policy measures in the future development for a sustainable low-carbon city.

Keywords: transport carbon emission, socio-economic factors, built environment, shopping mobility, China

1. Introduction

The contributions of transportation development to the sustainability of cities has been widely recognized by various scholars throughout the world [1,2]. According to a recently issued report,

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the transportation sector alone contributes to 23% of global CO_2 emissions [3,4]. It is predicted that emissions from the transport sector will grow by between 125% and 150% by 2030; moreover, China's transport sector will contribute about one-third of the total CO_2 emissions [5,6]. As cities contain high population densities and increasing human activities, the most pressing problems are often correlated with urban passenger transport [7–9]. Notably, urban passenger transport has received increasing concern for its impact on energy consumption, urban pollution and public health and is also the area where the most effective carbon mitigation could be made, which is perceived as playing a key role in sustainable development [10,11].

With rapid economic growth and increasing urbanization, there is a rapidly surging trend of automobilization, particularly private vehicles, significantly exerting tremendous pressure on energy consumption and environmental emissions in China [12]. According to the China Statistical Yearbook, private passenger cars increased from 10.80 million in 2005 to 146.46 million in 2016, which is a nearly 14-fold increase. This trend has led to a widespread use of private transport and rising greenhouse gas emissions from urban mobility in Chinese cities experiencing rapid urbanization and expansion [13]. Therefore, it is particularly effective to replace private vehicle use with low carbon modes of public transport in cities [14], as public transport systems can offer higher transport capacity, use less space and result in lower overall environmental impacts [15,16]. Accordingly, travel mode choice behavior in residents' daily travel plays a crucial role in the future development of urban regions [17].

There is a large body of research concerned with reducing energy consumption and emissions from the transportation sector. In general, studies have focused on transportation regulatory measures and technological innovations [18,19]. Shifting toward a low carbon travel behavior, especially by changing transport mode, has been discussed as another important strategy for mitigating emissions from the transport sector [20,21]. Existing research has shown that cities where the modal share of private vehicles is above 75% produce 2.5 t more CO_2 per passenger per year, or more than four times more than cities where the combined share of public transport, cycling and walking is more than 55% [20]. The major factors affecting transport mode choices are divided into two interrelated categories of built environment and personal factors [22]. Extensive literature has explored the impact of built environment attributes, including street design, population density, land use diversity, destination accessibility, and distance to transit on individuals' travel behaviors [23–27]. Specifically, Zahabi, et al. [28] found that land use mix, population density and public transit accessibility had statistically significant and negative effects on the carbon footprint of daily travel. Ewing and Cervero [29] summarized that transit access, intersection density and street connectivity were associated with travel mode choices. While a number of studies have examined personal factors that constitute the socio-demographic characteristics of individuals, such as age, gender, education level, profession, income, attitudes, beliefs and lifestyle as other determinants of mode choice [30–34]. Carse, et al. [35] noted that car availability and lower levels of education were associated with car use in daily travel. Ben-Elia and Ettema [36] found that the travelers' choices regarding how to change behavior was influenced by factors including education, habitual behavior, attitudes, and travel information availability. Accordingly, it is thus necessary to investigate the factors which influence travel behavior and reduce CO_2 emissions by considering physical aspects of the built environment and social aspects of individual characteristics.

However, research on transport mode choice and its induced carbon emissions is still relatively sparse and has primarily focused on either personal vehicles or public transport modes. In addition, most studies only focus on travel behavior and CO_2 emissions from commuting [25,37–39]. There is still much to learn concerning the effect of environmental factors on daily travel for non-work purposes, especially shopping trips [40,41]. Therefore, our study contributes to the existing studies on China's sustainable transport by comparing transport mode choice and its impacts on CO_2

emissions from private cars and public transport travel (including bus and metro) during shopping trips within the city of Shenyang, one of the largest metropolitan areas in China. An important aspect of the study is to expand previous research by understanding how built environmental characteristics interact with individual socio-economic factors to examine predictors affecting the choice of private car and public transport modes for shopping trips in Shenyang. The remainder of this paper is organized as follows: Section 2 describes the study area, data collection and modeling methodology. Sample characteristics, travel patterns and their carbon emissions and simulation results of influencing factors on transport mode choices are analyzed in Section 3. Section 4 includes key conclusions and the discussion.

2. Materials and Methods

2.1. Case study

Shenyang is the capital city of Liaoning Province and the largest city in northeast China [41,42]. It includes nine districts: Heping, Shenhe, Dadong, Huanggu, Tiexi, Sujiatun, Hunnan, Yuhong and Shenbei, with a total area of 3471 km^2 and a total population of 5.3 million. This study focuses on the areas within the fourth-ring road of Shenyang, covering 1227 km^2 (Figure 1). Shenyang has been an important heavy industrial city since the early 1900s, and after the reform and opening up in the late 1970s, it has experienced successful economic redevelopment and transformation [43–45]. By the end of 2015, urban retail sales of consumer goods reached 336.98 billion CNY. According to the Shenyang Statistical Yearbook of 2016, approximately 25 families per hundred urban households owned a private car. Buses are the main form of public transport, with 229 operating routes of public transport, including 2 metro lines.

2.2. Data collection

The survey data was collected on weekends and weekdays using a structured questionnaire distributed to residents in Shenyang. There were 1300 surveys distributed, and 1164 respondents using private car or public transport (including bus and metro) were successfully interviewed, which corresponds to a response rate of 89.5%. The questionnaire used in interviews was composed of three parts: (1) collection of detailed travel information such as the origin and destination, the mode used, time spent and traffic vehicles' fuel consumption; (2) gathering of the built environment characteristics of residence location, distribution of metro stations and bus stops and (3) collection of the respondents' socio-economic characteristics regarding car ownership, gender, age, education, occupation, income, respondents' attitudes toward driving for shopping and the satisfaction levels with public transport. The data sets used in this study also comprised the road and public transport network of Shenyang.

2.3. Emissions estimation procedure

The CO_2 intensity from shopping trips using private cars, bus and metro in this study were calculated respectively using the bottom-up approach based on the Guidelines for National Greenhouse Gas Inventories published by IPCC, which is more commonly used to estimate emissions from detailed travel data including vehicle miles of travel (VMT), mode choice, and fuel consumption, etc. for each trip [38,46–49]. In this study, CO_2 emissions from private car and bus travel were calculated using Eq. (1), and emissions from metro travel were calculated using Eq. (2) [50].

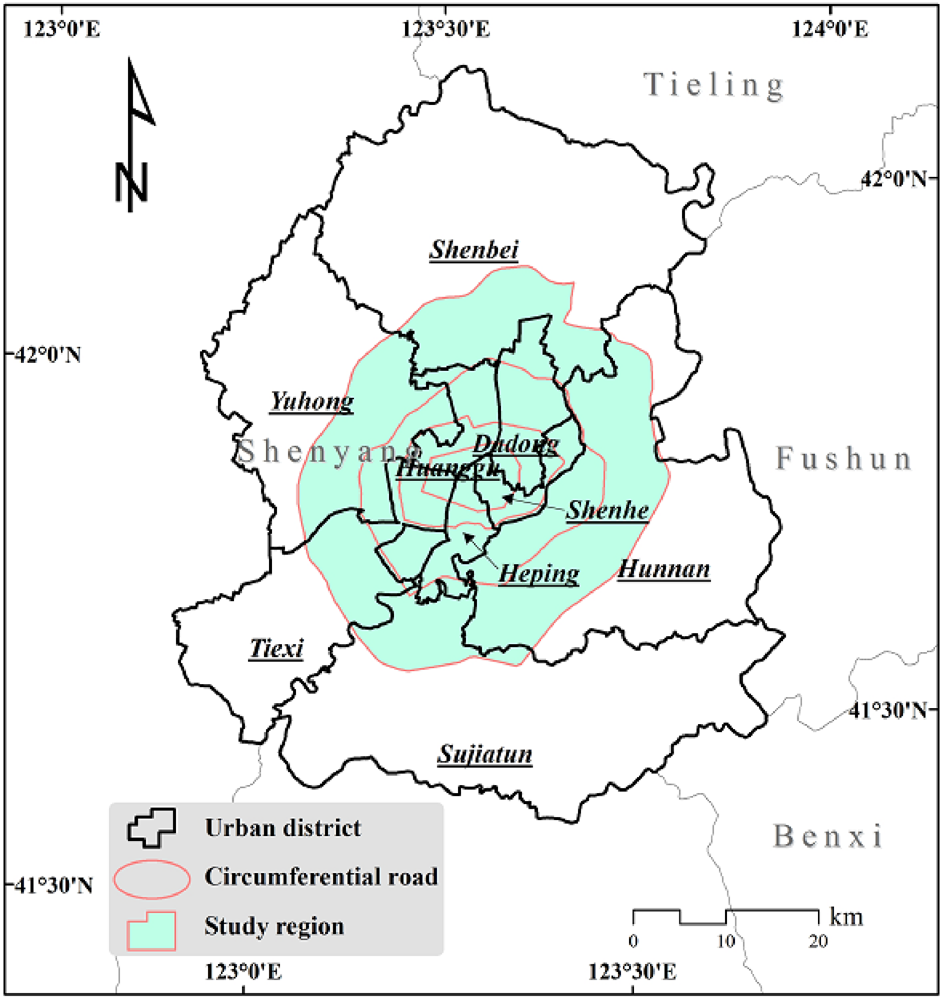

Figure 1: *Location of the study area*

$$E_p = \frac{F_p \times \rho_p \times D_p \times EF_p}{AC_p} \tag{1}$$

where E_p is CO_2 emissions (kg) from travel mode p; F_p is the average fuel consumption rate (m^3/100 km or L/100 km); ρ_p is the fuel density (kg/m^3); D_p is the travel distance (km); EF_p is the carbon emissions factor (t CO_2/1000 Nm^3 or t CO_2/t) and AC_p is the estimated passenger capacity.

$$E_m = \frac{C_m \times D_m \times EF_m}{AC_m} \tag{2}$$

where m represents the metro travel mode, E is estimated CO_2 emissions (kg), C is average power consumption (kWh/100 km), D is the travel distance (km), EF is the carbon emissions factor of power (kg/kWh) and AC is the estimated transport capacity.

Table 1: *Parameters of CO_2 emissions model for private cars and public transport*

Travel mode	Average fuel/power consumption rate (F or C)	Fuel density (ρ)	Emission factor (EF)	Transport capacity (AC)
Private car	10.5 L/100 km	740.8 kg/m^3	2.9 tCO_2/t	2.2
Bus	34.0 m^3/100 km	-	2.2 tCO_2 /1000 Nm^3	49.5
Metro	454.0 kWh/100 km	-	0.8 kg/kWh	360.0

The average petrol consumption rate for private car ($F_{private\ car}$), the natural gas consumption rates for bus (F_{bus}) and the power consumption rates for metro (C_{metro}) in Shenyang are 10.5 L/100 km, 34.0 m^3/100 km and 454.0 kWh/100 km, respectively. Data on the origins (respondents' residency), destinations (commercial centers), and transport routes (extracted from detailed descriptions provided by the respondents) were entered into ArcGIS 10.4 (Esri, Redlands, CA, USA) to calculate the vehicle kilometers traveled (D). Other parameters of CO_2 emissions model were shown in Table 1 [50–55].

2.4. The regression analysis of the study

Binary logistic regression has been commonly used to forecast the probability of choice decisions from two alternatives for individuals based on utility maximization in the context of transport behavioral studies [56–59]. In this study, a binary model was applied to identify and investigate the major determinants of the choice between private car and public transport during shopping trips in Shenyang. The dependent variable that is the respondents' travel decisions for shopping in this study, Y (transport mode), can only have one of two values, 1 or 0 (i.e., 1 for using private car transport, 0 for public transport) and is considered to be influenced by the explanatory variables of residential built environment and socio-economic characteristics. The logit is a function of covariates and the model form for this study is represented by the utility function shown as Eq. (3) [60, 61].

$$y_r = \ln(\frac{p_r}{1-p_r}) = \beta_0 + \sum_{r=1}^{n} \beta_r x_r \tag{3}$$

where p_r is the probability of response variable being equal to 1 (car driving), β_0 is the model constant, x_r is the set of continuous or categorical explanatory variables and β_r are the coefficients of estimated parameters corresponding to the explanatory variables x_r.

3. Results

3.1. Socio-economic characteristics between respondents using private car and public transport

Car ownership, gender, age, education level, employment status and monthly incomes of respondents are compared between respondents using private cars and public transport modes in Table 2. It was noted that car ownership was quite differently distributed between private car and public transport users. Over 72% of the respondents that selected public transport modes

Table 2: *Socio-economic characteristics of respondents (% private car/public transport)*

Car ownership	Gender	Age group	Education	Occupation	Per capita monthly income
Yes (87.10/ 27.56); No (12.90/ 72.44)	Male (52.53/ 32.31); Female (47.47/ 67.69)	<19 (1.84/ 2.53); 19-25 (11.52/ 30.20); 26-35 (46.54/ 33.58); 36-50 (29.03/ 16.79); >50 (11.06/ 16.90)	Below high school (9.68/ 17.53); High school (24.42/ 23.02); Undergraduate (59.91/ 55.54); Above Master (5.99/ 3.91)	Public (18.43/ 17.85); Business (36.41/ 34.11); Self-employed (25.81/ 15.21); Unemployed and retirement (19.35/ 32.84)	< 2000 CNY (4.15/ 17.11); 2000-3000 (15.67/ 30.62); 3000-5000 (32.26/ 32.42); > 5000 (47.93/ 19.85)

for shopping did not own a private car, and nearly 90% of the respondents that selected car driving had a private car. Of the public transport users, there was an uneven divide between males (32.31%) and females (67.69%). However, the gender difference for those respondents driving a car for shopping differed, with slightly more than half of the respondents being male. Respondents ranging from 19 years to 25 years of age and from 26 years to 35 years of age were the most numerous, constituting 30.20% and 33.58%, respectively, of the total public transport users. Respondents ranging from 26 years to 35 years of age were highest (46.54%) among car driving users. Education level distribution was quite similar; the largest group were college-educated, each constituting 59.91% and 55.54% of the private car and public transport users, respectively. An analysis of the occupation of respondents showed that business employees were the highest, each constituting 36.41% and 34.11% respectively among private car and public transport users for shopping. It was further observed that there was a difference in the second-highest employment status group among all the samples. Over 33% of the respondents who were unemployed or retired selected public transport, while 25.81% of respondents who were self-employed constituted the second-highest occupation group among private car mode users. With respect to monthly incomes, the largest group was formed of respondents earning more than 5000 CNY per month representing almost half of the private car users, but only 19.85% of public transport users at that monthly income level. There were 32.42% and 30.62% of respondents earning 3000 to 5000 CNY and 2000 to 3000 CNY per person each month constituting the largest groups selecting public transport modes for shopping.

3.2. Travel patterns of private car and public transport

Among the 1164 respondents sampled for interview, approximately 80% of the respondents used public transport modes, either buses (64.3%) or metro (17.0%), with 18.6% respondents using private cars. The average shopping trip distance in Shenyang city by private car or public transport was similar, approximately 8.4 km. Among public transport modes, the average travel distance for shopping by metro (10.59 km) was slightly higher than by bus (7.87 km). A total of 31.78% of bus trips were shorter than 4.5 km, and 30.84% respondents travelled between 4.51 km and 8.10 km. However, a total share of 32.83% of those surveyed travelled between 9.91 km and 15.20 km for shopping trips by metro. Large percentages of private car users' (41.01%) trips were between 5.01

km and 9.60 km and nearly 30% were shorter than 5.0 km.

Figure 2 presents the respondents' spatial patterns for private cars and public transport modes of bus and metro. More than half of the respondents that travelled for shopping by private car or public transport were located within the second circumferential road, and the shares were 70.63%, 65.66% and 61.75%, respectively for bus, metro and private car. Among public transport modes, bus was most frequently used, and almost one-fifth of respondents were distributed between the second and third circumferential roads. The residents choosing metro travel for shopping were closely distributed along the metro lines, especially within the first circumferential road where accessibility to metro stations was relatively higher. In addition, aggregated private car users were mainly clustered in the inner suburbs of Hunnan area and Shenbei area between the second and third circumferential roads (see Figure 1 for their location).

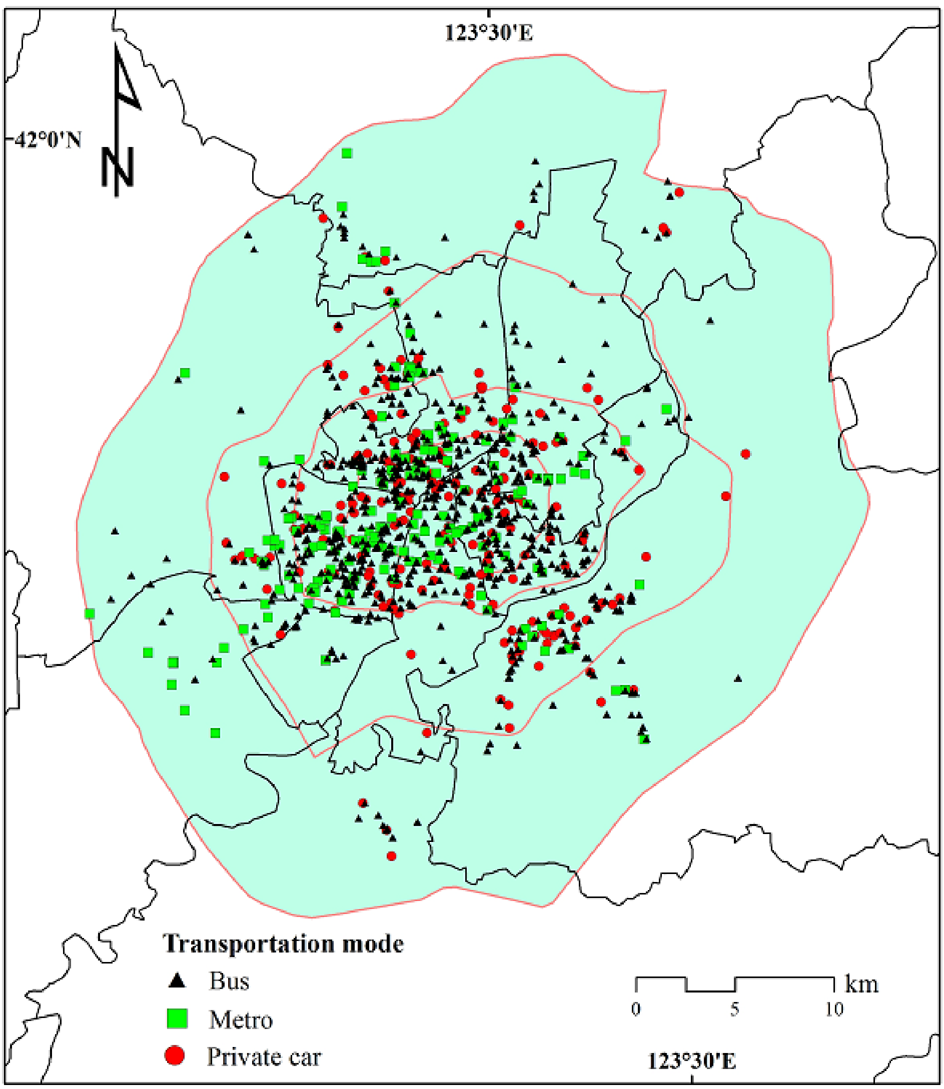

Figure 2: *Spatial distribution of private car and public transport users*

Table 3: *Emissions level for private car and public transport*

Carbon emissions level	Range (kg)	Private car (%)	Bus (%)	Metro (%)
Very high	2.20-5.43	100.00	0.00	0.00
High	1.20-2.19	100.00	0.00	0.00
Medium	0.59-1.19	100.00	0.00	0.00
Low	0.23-0.58	46.88	46.09	7.03
Very low	0.00-0.22	2.12	76.92	20.96

3.3. CO_2 emissions between private car and public transport

Based on the CO_2 emissions estimation model mentioned above, we calculated transport CO_2 emissions per shopping trip by different transport modes. Average per trip CO_2 emissions by public transport modes and private car were 0.11 kg and 0.88 kg, respectively. Average per trip CO_2 emissions of bus users were similar to metro users. The CO_2 emissions of these transport modes were classified into five levels, very high, high, medium, low, and very low, using the natural breaks (Jenks) method in Table 3. The results showed that the respondents producing very high, high and medium CO_2 emissions during their shopping trips accounted for 12% of respondents, all of which involved use of private cars. The shares for the low level transport CO_2 emissions per shopping trip by using different modes are as follows: private car - 46.88%, bus - 46.09%, metro - 7.03%. A further analysis among the very low transport CO_2 emissions per shopping trip level indicated that almost 98% of respondents used public transport.

3.4. Binary logistic regression analysis for choice between private car and public transport

We studied the impact of the residential built environment and socio-economic characteristics on the choice between private car and public transport modes utilizing a binary logistic regression modeling approach. Built environment variables, including population density, the number of bus stops within a 1-km radius of a respondent's home, road density and metro station, which is a dummy variable where 0 means not having a metro station within a 1-km radius of a respondent's home and 1 means the alternative and socio-economic variables of car ownership (a dummy variable where 0 means not having a private car per household and 1 means the alternative), gender, age, education level, occupation and per capita monthly income, were chosen for analysis.

The regression results for the choice between private car and public transport are shown in Table 4. The Hosmer-Lemeshow statistic indicated the model well fitted the data ($\chi^2(8)$ = 13.9, p = 0.083), although its explanatory power was low (Nagelkerke R^2 = 0.40). The results showed that socio-economic characteristics of car ownership and gender were significant at a 99.9% confidence level while age and per capita monthly income were significant at a 90% confidence level. The results revealed a significant effect for car ownership. The odds ratio (OR) of 13.653 indicated that residents owning their own vehicles were nearly 14 times more likely to be associated with car driving than those who did not own a car. The effect of gender was also highly significant. Male respondents were almost 2.4 times more likely than females to use a private car during shopping trips in Shenyang city. It was observed that respondents between the ages 19-25 had a minor driving propensity (OR = 0.39) compared with respondents above 51 years of age. With regards to income, the OR of the income group of less than 2000 CNY per month in the model pointed to more public transport mode choices when compared to respondents with monthly incomes

Table 4: *Logistic regression results of impacts on car driving and public transport*

Explanatory factors	Coefficient	Standard error	Odds ratio
Socio-economic indicators			
Car ownership (ref: no)	2.614***	0.232	13.653
Gender (ref: female)	0.859***	0.185	2.360
Age (ref: >50)			
Age (<19)	-0.909	0.673	0.403
Age (19-25)	-0.942*	0.376	0.390
Age (26-35)	-0.051	0.328	0.951
Age (36-50)	0.225	0.343	1.252
Per capita monthly income (ref: > 5000 CNY)			
Per capita monthly income (<2000)	-0.778*	0.473	0.459
Per capita monthly income (2000-3000)	-0.367	0.329	0.693
Per capita monthly income (3000-5000)	-0.454	0.297	0.635
Built environmental indicators			
Metro station (ref: no)	-0.879*	0.332	0.415
Bus stops	-0.736*	0.207	0.479
Constant	-3.027***	0.587	0.048
-2 Log Likelihood	787.378		
Pseudo R^2 (Nagelkerke)	0.402		
Chi^2 (Omnibus tests of model coefficients)	332.388		

***p <0 .001; ** p <0 .01; *p <0 .05

higher than 5000 CNY.

With respect to built environment characteristics, results showed that access to the closest metro station around residences and the number of bus stations within a 1-km radius of a respondent's home were significant at a 90% confidence level. The explanatory variable of metro station and bus station had a negative coefficient. The results showed that respondents with close access to a metro station near their residence were 0.415 times more likely to use a private car than those who did not have close access to a metro station. Furthermore, an increase in the number of bus stations within a 1-km radius of a respondent's home was associated with a decrease (52%) in the chances of car driving.

4. Discussion and conclusions

4.1. Significant research achievements

A shift toward a more sustainable society requires a better understanding of residents' daily mobility and the drivers that influence the individual choice between urban transportation modes, especially the preference motives between the private car and public transport users [62]. This study presents an in-depth comparison of transport mode choice, its corresponding CO_2 emissions and identification of the major determinants of the mode choice between private cars and public transport with regard to shopping mobility in the city of Shenyang, one of the largest metropolitan areas in China.

Results of the study revealed significant research findings. First, analyses showed that bus travel was frequently used, hence the bus accounted for the majority of motorized transport.

Although metro travel had a relatively smaller share than bus travel, trip distance for the rail-based system was greater than bus use due to its transfer condition, reliable speed and convenient services. It was found that spatial distribution of public transport users was closely distributed along the bus or metro lines, aggregated private car users were mainly clustered within the second circumferential road, and nearly 30% of respondents travelled less than 5.0 km for shopping. Second, although average shopping trip distance was similar by private car and public transport, average per trip emissions for private car travel was 8 times that of public transport. Furthermore, CO_2 emissions produced by private cars contributed much more to the total emissions. Third, the results showed that availability of a car was a major factor, and the relatively smaller share of 18.6% of respondents using private cars for shopping could be due to lower car ownership rates and its greater travel cost. This confirmed previous findings of Loo, Corcoran, Mateo-Babiano and Zahnow [62] as well as Fairnie, et al. [63], who had also shown that the dominance of cars for shopping trips was correlated to a high percentage of people who were current car owners, and, the more cars available, the less likely participants were to travel by public transport usage. The results also showed that gender was a significant predictor of transport mode choice, which was consistent with other gender travel studies that showed males were highly correlated with car driving, and females were more likely to use public transport modes because of their weaker driving habits especially on days with bad weather, or poor road conditions [64, 65]. Moreover, we found individual socio-economic characteristics of the 19-25 year age group may point to better public transport system performance, as a previous study indicated that the student age group had low rates of driver's license ownership and more subtle environmental preferences among those categories, leading to reduced car use in line with lower purchasing power and increased probability of public transport use [66]. Additionally, our results showed that the group with a per capita monthly income less than 2000 CNY were the most likely to use public transport modes to go shopping, as they could not afford a high transportation cost. Previously, Birago, Opoku Mensah and Sharma [2] had demonstrated similar results, which stated that the respondents who frequently used metro mass transit were low income earners due to the relatively low fares.

The results demonstrated that apart from socio-economic characteristics, some built environment factors, including access to the closest metro stations and the number of bus stops within a 1-km radius of the household location also played a negative effect on the choice of private car during shopping trips. On the one hand, we found that there was a slight difference in accessibility to public transport around household locations between different transport modes. The results showed that the average bus stops around residences of bus users was nearly 1.7 times higher when compared to private car users. On the other hand, we discovered that respondents living along metro lines did not noticeably choose the public transport mode, as the results showed that the proximity of metro stations to residences of private car users was merely 6.5 percent lower than those of metro users, due to the greater comfort and flexibility in trip scheduling associated with private car travel.

4.2. Policy implications

The findings highlight that China's cities have taken various transportation policy actions and initiatives to reduce car dependency and stimulate sustainable mobility. Thus, policies on discouraging ownership and car use and promoting the potential modal shift of current car users to public transport may be more effective in minimizing transport carbon emissions [67]. Formulating further investigations and improving urban rail transit systems is vital to the public transport strategy, which is also acknowledged by Chaturvedi and Kim [20]. It was found in our results that metro travel carries urban passengers the longest distances and produces the fewest carbon emissions compared with bus and private car travel. Moreover, current public transportation policy is apparently not effective in attracting private car users to choose public transport. The respondents investigated in our study stated that reasons for non-preference of bus for shopping included over-crowding, discomfort, long waiting times, low seat availability and lack of door-to-door service. Hence, there is a need to improve the quality of transportation infrastructure and bus services by optimizing routes and scheduling, enhancing the accessibility of bus stops, increasing service frequency, improving seat availability, and increasing the level of public transport subsidies, etc., which was demonstrated in Indian cities ensuring safety and comfort with the high use of low carbon modes of transportation [67]. There are significant relationships between the socio-economic variables and respondents' preference for public transport, hence socio-economic variables can be used to create infrastructural improvements and designs that are more attractive for promoting an increase in public transport users, especially with groups of females, students, the elderly and low income earners who prefer to use public transport before policy interventions. As stated in Chidambaram, et al. [68] reducing the use of cars has not often been achieved voluntarily, complementary measures and actions are needed to promote the viability of the switch of car users to public transport, including car use restrictions, car and fuel taxes, road pricing, congestion charging, parking constraints and parking costs, and notable technology improvements and innovations of new clean energy and fuel efficient vehicles, which have been adopted in parts of cities to promote public transport and reduce the adverse effects of environment pollutants [66,68–70].

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