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Impact of Urban Spatial Transformation on the Mobility of Commuters with Different Transportation Modes in China: Evidence from Kunming 2011–2016

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Abstract: Many emerging economies, including China, are undergoing rapid and large-scale urban spatial transformation. Thus, the daily mobility of transportation-disadvantaged groups, especially non-car users, has received increased attention, as these people may experience significant restrictions in their daily activities. Such restrictions raise issues with respect to transport-related social exclusion, which are detrimental to the sustainability of urban transportation systems. Activity participation and time use have been used to measure the spatial barriers and inequalities that travelers face in their daily lives. However, limited research has been conducted on how the daily mobility of different transportation modes has evolved over a longer period relative to urban development. Therefore, this study aimed to investigate the activity participation and time use of car travelers in comparison with other transportation mode groups in Kunming from 2011 to 2016, a period of rapid growth in motorization. A three-layer activity structure was used to characterize the hierarchy of activity requirements. Propensity score matching was used to compare the mobility of commuters across different urban periods and transportation modes while controlling several confounding factors. Three conclusions were drawn from the results of the study: First, changes in urban form and transportation system cause residential suburbanization and a considerable increase in private-car and public transportation at the expense of non-motorized transportation modes. Second, the degree of impact of urban space transformation on personal mobility is ranked in descending order of public transit, cycling and walking, e-bike, and cars. Third, the traffic disadvantage of non-car users is obvious, and the mobility gap of commuters with different travel modes tends to widen over time. We discuss the consequences of transport-related social exclusion and highlight directions for future sustainable transportation planning research.

Keywords: mobility; change; social exclusion; China city; sustainable transport

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1. Introduction

Global urbanization has experienced three major waves. After Europe and the United States, China and some developing countries in Latin America have become the center of the third ongoing urbanization wave, which may be long lasting [1]. Urbanization has led to rapid spatial transformation accompanied by motorization [2]. From 2010 to 2020, the average annual growth rate of Chinese civil vehicles was 13.67%, which was higher than that of the United States motorization peak period of 1945–1980, far surpassing that of the European Union and Japan. Urbanization sustainability problems caused by motorization and urban sprawl include, but are not limited to, environmental pollution by water, air, and noise [3]. Other relevant problems include social equity issues, such as barriers and exclusion, faced by non-car users (e.g., public transit, e-bike, and bicycle users) in performing daily activities [4]. These problems severely affect sustainable urban development.

Since the European Union issued the Sustainable Urban Mobility Plan (SUMP) [5] in 2014, urban transportation research and planning practices have gradually shifted focus from infrastructure construction to "mobility planning," prioritizing the actual needs of residents. Becker and Gerike [6] regarded transportation policy initiatives aimed at satisfying human needs as sustainable transportation development. The basis for developing interventions is inequalities in mobility for different transportation mode groups during urban spatial transformation. Here, residents' daily activity participation and time use have been increasingly used as a measure of mobility. Participation in activities indicates that an individual has overcome the spatial, temporal, and social transportation barriers of those activities. Furthermore, the amount of time allocated to an activity indicates the level of individual engagement with the activity. Fu [7] empirically studied workers in five cities in China and found differences in the time use patterns of commuters participating in subsistence, maintenance, and leisure activities and travel. Farber et al. [8] compared the activity participation and time use of residents in Canada from 1992 to 2005 and found that the car-oriented urban spatial structure caused traffic congestion and scattered activities, thereby discouraging the relative interests of non-drivers and leading to possible exclusion from certain social activities. Several findings have indicated that residents with different transportation modes tend to experience varying levels of restrictions on mobility in different city contexts.

China is currently the largest developing country in the world, and most cities in China now face huge traffic crises. The country was once a famous "Bicycle Kingdom," with slow traffic dominated by walking and cycling, and these were the main transportation modes for urban residents [9]. However, the development of transportation facilities, such as high-speed rail, has resulted in significant positive impacts on urban economic efficiency [10]. Consequently, slow-traffic transportation modes have gradually become undesirable, transforming into rapid traffic modes at extremely high speeds [11]. During this transformation period, urban transit agencies have endeavored to promote public transportation [12] over auto-dependency [13]. The construction of public transportation infrastructure was extremely expensive, yet no significant increase in bus ridership was recorded. Inon et al. [14] proposed a dynamic public transportation demand forecasting method and applied it to public transportation construction, but these measures have not yet been applied to Chinese cities. The city's transportation system undergoes a vicious circle of "more motor vehicles–urban congestion–more vehicle lanes–fewer people traveling by non-cars–more reliance on motor vehicles–more congestion in the city," referred to as the "Downs law" [15].

The current understanding of the mobility of transport-related social exclusion groups, especially non-car users, remains incomplete. First, identifying traffic-vulnerable groups relies mainly on the consideration of certain socio-demographic characteristics (e.g., low-income people [16], the elderly [17], and floating population [18]). However, Kenyon et al. [19] stated that social exclusion is a wider concept that should not focus on the outcomes of unequal access to material resources alone but should also consider the processes of unequal access to participation in society. The differences in social participation between non-car users and car users may be unclear over a short period of time, but in the long run, such exclusion does exist [4,20]. However, only a few studies have focused on this area. Second, limited evidence exists on how the mobility of various transportation mode groups evolves during urban spatial transformation [21]. Ortúzar [22] proposed three directions for future transportation research: sustainability, complexity, and individualization of choices. For sustainability, the author calls for more attention to the study of habit and inertia for restraining cars. In addition, longitudinal studies are crucial for investigating the experiences of transportation-disadvantaged groups excluded or not involved because of changes in their city's spatial structure and for identifying the needs of these groups.

The aim of this study was to identify the dynamics of residents' mobility over time during urban spatial transformation by investigating the activity participation and time use of various transportation mode groups in Kunming at different periods. We considered

Kunming as a representation of the traffic situation in most medium-sized cities in China, which is an interesting research background. Numerous Chinese urban residents have not benefited from economic growth, leading to social exclusion [23]. This phenomenon is related to the limited mobility of individuals; however, mobility differences among Chinese residents have yet to be fully understood. Furthermore, Pojani and Stead [24] highlighted the need to focus on small- and medium-sized cities for achieving substantial progress toward more sustainable urban development not only because they are home to at least a quarter of the world's population but also because they offer great potential for sustainable transformation. In principle, their size enables flexibility in terms of urban expansion, the adoption of "green" transportation modes, and environmental protection. Based on repeated cross-sectional data from residents' travel diaries in 2011 and 2016, a comparison of the activity participation and time use of car commuters with commuters of other transportation modes was first conducted, and the confounding effects of other socio-demographic characteristics were removed through propensity score matching. For modeling analysis, the transportation mode was designated as the dependent variable, and the car transportation group was set as the reference group for analyzing changes in mobility gap between cars and other transportation modes during urban development. Specifically, the objective was achieved by answering these questions: (1) How do commuters of different transportation modes organize their subsistence, maintenance, leisure activities, and travel at different times within the city? (2) What social exclusions and inequalities might non-car commuters encounter?

The rest of this paper is organized as follows: Section 2 reviews relevant research on mobility and transportation-related social exclusion. Section 3 explains the research background, data sources, and research methods. Sections 4 and 5 present the results of the study. The discussion and conclusions are presented in Section 6.

2. Literature Review

2.1. Space–Time Impacts of Individual Mobility

In the 1960s, Chapin [25] first introduced the concept that travel is a demand derived from the necessity to participate in activities, reflecting the internal needs, desires, and commitments of individuals and households. Hägerstrand [26] then developed the two-dimensional space–time prism, where time and space were used to describe individual mobility. In time geography, the space–time prism has been conceptualized as a space–time that encapsulates an individual's travel path and activity participation within a certain time frame [27]. The interior of the prism is described from three aspects: "location in space," "expansion in area," and "continuity in time". In the spatial dimension, researchers have projected the space–time prism onto a two-dimensional plane named "activity space", representing the area containing potential locations for all daily travels and activities [28]. Numerous methods are used for measuring activity spaces. The research using the activity space concept is, however, inadequate for identifying individual activity-travel participation and temporal factors.

For activity participation, Hägerstrand first makes a binary distinction: fixed and flexible activities. The author believes that residents' daily activities can either be fixed (e.g., work and picking up children) or flexible (e.g., shopping and socializing), where a natural competition mechanism exists between these types of activities because of the required cost of time and space. This dichotomy was criticized since the extent to which an activity is spatially and/or temporally fixed may vary, and a binary scheme may not adequately capture such variability [29]. On this basis, Kuppam and Pendyala [30] proposed three categories of activities, namely, subsistence activities, maintenance activities, and leisure activities. Subsistence activities are activities that must be performed to maintain the basic essence of life, and an example is work. Such activities are relatively stable. Maintenance activities are performed to maintain a normal state of living; examples are shopping and caring for children, and these activities are of secondary importance. Leisure activities can be freely chosen in time and space and belong to higher-level activity needs, such as sports leisure, and cultural entertainment; these activities are more flexible than others [31].

The time dimension of individual mobility has attracted considerable research attention. Time use is the allocation of individual time to various activities during a certain period. It can reflect the individual time allocation decisions for various activities such as a mirror reflecting residents' daily lives. Dharmowijoyo et al. [32] examined the relationship among travel time, discretionary activity duration, and activity space and found that travel time for subsistence activities has a stronger effect on discretionary activity duration than on the time for subsistence activities. Kuppam and Pendyala [30] found a positive correlation between maintenance and leisure activity times, indicating that commuters who participated in more maintenance activities showed a greater tendency to participate in leisure activities. Wang et al. [33] found a trade-off mechanism for three types of activity time. Specifically, people's time resources are limited, and when they are more involved in a certain type of activity, they are less involved in other activities because of other unobserved properties reflecting the individual's space and time constraints.

2.2. Mobility and Transport-Related Social Exclusion

The term "social exclusion" originated from French literature in the 1970s and mainly refers to a relationship disruption between the individual and society: the individual's separation from the social whole [34–37]. Social exclusion was introduced into the British government's policy procedure with the establishment of the Social Exclusion Unit (SEU) [35–39]. In 1994, the United States government introduced a similar concept with the title "environmental justice" [34]. Since the 1990s, social exclusion has been featured in social inequality and social policy discourses in most countries and regions [40].

Social exclusion is a theoretical concept that acknowledges the undesired alienation of certain individuals from society and examines the process, causes, and consequences of alienation [39]. In the transportation sector, social exclusion can be due to spatial factors combined with a lack of certain transportation options, preventing individuals from engaging in desired activities [41], such as participation in employment, education, healthcare, and leisure. Kamruzzaman et al. [42] summarized this phenomenon as "transport-related social exclusion". European countries have focused on the interlinkages between transportation and social exclusion of specific social groups since the late 1990s. For example, the Centre for Social Exclusion in the United Kingdom maintains that transportation disadvantages may cause social problems in many key areas of society and that the core of developing social integration is the improvement of accessibility to key services and opportunities [43]. Preston et al. [44] recommended that we should focus on regional planning as well as individual and group differences in the research on transportation-related social exclusion. Lucas [45] noted that personal accessibility is the main factor affecting transportation-related social exclusion. In addition, several studies have shown that high travel costs, physical barriers, geographic or distance constraints, and poor service accessibility can result in individuals being socially excluded through difficulty in accessing transportation services [46,47]. Church et al. [48] proposed a conceptual framework linking transport and social exclusion and examined a series of indicators identifying transportation-related social exclusion in previous studies. In "Church's Social Exclusion Framework", transportation-related social exclusion was related to seven primary areas, which were economic, physical, geographic, spatial, fear-based, time-based, and facility-access. Katarzyna [49] proposed the phenomenon of social exclusion in car-sharing services based on Church's conceptual framework. In addition, Katarzyna put forward remedial measures (i.e., policy, markets, technology, and infrastructure) for each area of social exclusion from transportation that car-sharing services may suffer.

In the field of sociology, researchers regard social exclusion as a subjective feeling about the quality of life and design questionnaire indicators from multiple dimensions, such as physiological adaptation, economic level, social interaction, identity, and psychological integration [40]. However, Xia and Shen [50] found that residents may subjectively feel that they are not excluded from transportation even when they are less mobile than others. A lack of participation in activities has been identified as a vital outcome of social exclusion [35,51]. Significant barriers to participation in key activities may be caused by a lack of suitable transportation, a lack of accessible opportunities, or a combination of both [52–56]. According to Maslow's theory of human motivation [57], people are thought to engage first in activities that meet physiological needs, such as earning an income through work, then those that meet needs for love and belonging, such as dining with family, and finally those that meet needs that contribute to self-actualization, such as fitness. These activities help people achieve love and belonging, personal fulfillment, and other life pursuits. Thus, the satisfaction derived from maintenance and leisure activities is essential for personal fulfillment and active living [58,59]. This study directly analyzed activity participation and time use at different levels of need to determine residents' transportation-related social exclusion. The method adopted here addresses the problem encountered by Xia and Shen [50] (i.e., individuals' subjective assessment of whether they suffer from transportation-related social exclusion is inaccurate). Previous methods based on accessibility and activity space have also noted the results of traffic exclusion; however, He et al. [60] showed that these methods are relatively insufficient for considering the time dimension and, therefore, lack the time dimension for analyzing the traffic-related social exclusion suffered by residents. Consequently, it is difficult to provide support for appropriate time management policies.

Transportation mode greatly influences transport-related social exclusion, which is reflected in the mobility of individuals. First, numerous studies have demonstrated the role of cars in alleviating social exclusion. Cars allow people to eliminate time and space constraints, increase travel rates, cover longer distances, and participate in more free activities [61]. However, for groups of a lower social status or those that are economically disadvantaged (e.g., immigrants and the poor), the ownership and use of automobiles require considerable resources that are inaccessible to the groups [62]. In contrast, the adjustment of transportation modes such as public transportation [63], electric bicycle [64], cycling, and walking [65], is more beneficial for improving the mobility of such groups to reduce transport-related social exclusion. In addition, the study by Luo et al. [66] shows that car-sharing, as a new urban travel mode, has played an essential role in the sustainable development of urban transportation systems.

This literature review demonstrates that numerous studies use activity participation and time-use to determine the constraints and inequalities that disadvantaged groups experience in daily mobility and activities. However, most of these studies were performed on a cross-section, with limited work examining long-term changes in mobility (e.g., years or more). During urban spatial transformation, with changes in economic level and the built environment, the mobility of groups with different transportation modes is affected by heterogeneity. This difference in mobility change may involve a cumulation of transportation-related social exclusion phenomena [67], which has not been studied in detail. Therefore, it is crucial to study the dynamic relationship between transportation modes and mobility on a longitudinal level to provide a more comprehensive understanding of transport-related social exclusion.

3. Data and Methods

3.1. Study Area and Data

This study examined the central urban areas of Kunming (the capital of Yunnan province): Panlong, Wuhua, Xishan, Guandu, and Chenggong Districts (see Figure 1). In 2016, the population of Kunming was approximately 6.728 million. Unlike China's megacities, Kunming is representative of China's medium-sized cities, which accounts for three-quarters of China's urban population. Kunming is a monocentric metropolitan area characterized by a hierarchical urban structure. According to the distance from the city's center (Dongfeng CBD city), Kunming is divided into three parts: the inner city (within 4 km from Dongfeng CBD), inner suburb (4–7 km from Dongfeng CBD), and outer suburb (more than 7 km from Dongfeng CBD). The time and space data of residents' travel behavior were obtained from the residents' travel survey conducted in Kunming in 2011 and 2016. We selected a sample of commuters with regular out-of-home jobs in the travel log: 1765 in 2011 and 49,707 in 2016.

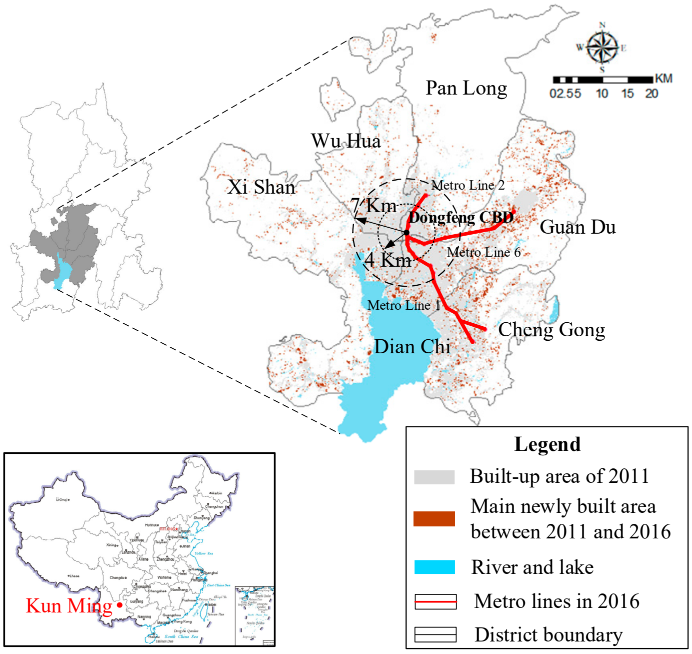


Figure 1. Land use map of Kunming in 2011 and 2016.

The data are presented in Table 1, which presents a comparison of basic socio-demographics, built environment, and public transportation information for Kunming in 2011 and 2016. The average population density of built-up areas in Kunming has dropped substantially over the last five years because the number of built-up areas has increased more than population growth. The rapid commercialization of land use in urban centers is also a contributing factor as some residents move away from these centers. The rapid growth of per capita income and GDP has led to a rapid increase in the number of motor vehicles. The availability of public transportation has also increased considerably, especially the subway (which grew out of nothing).

Table 1. Basic statistics of Kunming in 2011 and 2016.

	2011	2016	Changes (%)
Population of Kunming city (ten thousand)	648.64	672.8	+1.83%
Regional GDP (RMB 100 million)	2510	4300	+26.28%
Built-up area (km^2)	298	412	+16.06%
Population density (person/km^2)	300.5	320	+3.14%
Population density of built-up area (person/km^2)	217.66	163.3	−14.27%
Average disposable income (RMB/year)	21966	36739	+25.16%
Car ownership (ten thousand)	150.8	226.8	+20.13%
Number of buses in operation	4292	6397	+19.69%
Length of metro line (km)	0	64.7	+100.00%
Length of road line (km)	1642	1997	+9.76%
Length of urban expressway (km)	119.0	119.2	+0.17%
Motor vehicle parking lot (ten thousand)	11.0	32.3	+193.64%

Note: The data source is the 2016 Kunming Urban Transport Development Annual Report (http://kmuti.km.org.cn/jtnb/2016/ (accessed on 20 May 2022)).

3.2. Methods

3.2.1. Activity Classification

According to the Charter of Athens, the city has four functions: dwelling, recreation, work, and transportation [68], and the functions can also represent the main activities of modern urban residents. The human motivation theory states that human needs are arranged in a hierarchy of dominance; that is, the emergence of one need usually depends on the prior satisfaction of another latent need. Needs are ranked in descending order of importance as physiological, love and belonging, and self-actualization needs. Upper-level needs do not appear until lower-level needs are fully satisfied. Different individuals may have equal time resources, but their decision-making mechanisms for resource allocation among different levels of needs are different [57]. The desire to fulfill upper-level needs drives diversified lifestyles. According to this desire, we categorized commuters' daily activities into a three-tier structure (see Figure 2). Activities are divided into 6 categories (i.e., transportation, working, family, shopping, home, and personal) and 15 sub-categories (travel, commute, work, work-related activities, dinner, accompanying the elderly, taking care of children, medical care, shopping, all home activities catering, personal care, sports, social, entertainment, and leisure) according to departure time and resident destination, land use type, and activity intent in the residents' questionnaire. These activities are placed in their corresponding demand level (see Table 2).

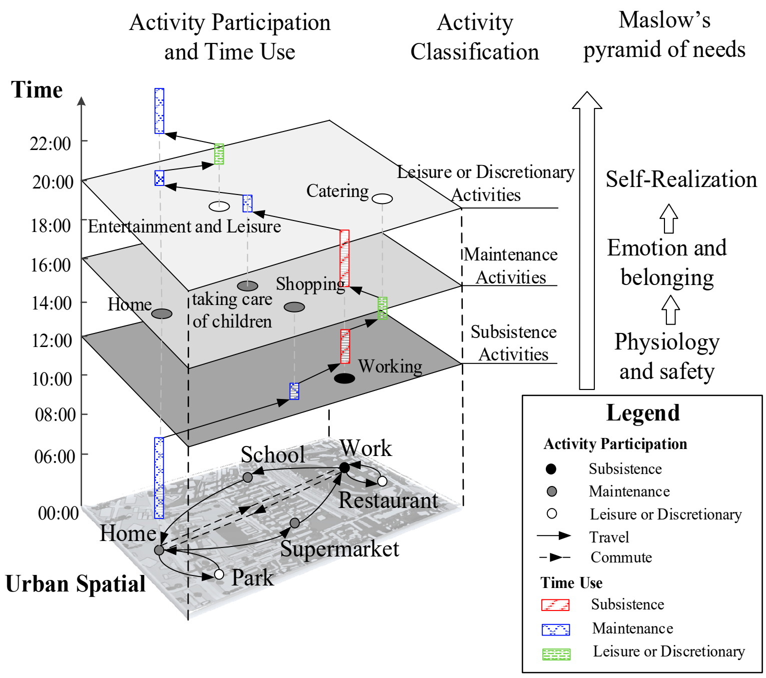


Figure 2. Hierarchical structure of personal daily activity participation and time use.

Table 2. Classification of activities.

Activity	Activity Classification	Description
Transportation	Travel	Actual travel of individuals participating in all activities
	Commute	Euclidean distance between home and work. It means that the traveler does not participate in other activities, but only participate in work activities
Subsistence Activities	Working	Work and work-related activities (e.g., business)

Table 2. *Cont.*

Activity	Activity Classification	Description
Maintenance activities	Family	Outdoor activities with family (including 4 subcategories: dinner, accompanying the elderly, taking care of children and medical care)
	Shopping	Shopping alone or with family
	Home	All activities at home
Leisure or Discretionary Activities	Personal	Outdoor activities completed alone (including 6 subcategories: catering, personal care, sports, social, entertainment and leisure)

3.2.2. Propensity Score Matching

Changes in personal mobility are influenced by important factors such as socio-demographic attributes and the built environment in urban development. The sample sizes of commuters in the Kunming residents travel logs in 2011 and 2016 are different, which may cause a sample selection bias. Consequently, comparing activity participation and the time use of commuters across time periods without accounting for these factors can cause estimation bias. Therefore, we employed propensity score matching (PSM) to address the problem. The PSM theoretical framework is a "counterfactual inference model." In this study, for urban workers, counterfactual inference refers to the impossibility of simultaneously observing commuter time-use outcomes at different periods in the city. The essence of the method is data dimensionality reduction, that is, extracting multiple feature variables into one indicator—propensity score (PS)—thus making multivariate matching possible. We used the logit model to calculate the PS value, found a group of control groups (commuters in Kunming in 2016, $p = 0$) with similar PSs to the treated group (commuters in Kunming in 2011, $p = 0$), and assigned the groups to the PS values using one-to-one matching. The matching principle was based on the "nearest neighbor matching," which implies that matching only occurs when the PS of experimental group individual i is closest to the PS of control group j. These steps kept the overall socio-demographic characteristics of the 2011 random sample of commuters within a similar range as that of the 2016 random sample of commuters. The phenomenon ensures the robustness of the results of subsequent discussions of changes in mobility between the treated and control groups.

The specific steps are as follows.

Step 1: Calculate the PS value using the logit model:

$$P(X_i) = P(T_i|X_i) = \frac{EXP(\alpha + \beta X_i)}{1 + EXP(\alpha + \beta X_i)} \quad (1)$$

where α is a constant, β is a vector of logit regression coefficients, and X is a feature variable vector (see Table 3).

Step 2: According to the nearest neighbor principle, match the treated and control groups using the PS.

The assessment of the urban spatial transformation impact was based on various activity-travel effects in the experimental and control groups:

$$I_{ud(a)} = Y_i(1) - Y_j(0) \quad (2)$$

where $I_{ud(a)}$ is the urban development impact of type a activities, $Y_i(1)$ is the outcome variable of individual i in the treated group, and $Y_j(0)$ is the outcome variable of individual j in the control group.

Step 3: Evaluate the effectiveness of the measures.

The mean difference of the target variable between the treatment and control groups was estimated to obtain the mean treatment effect (*ATE*). Here, the target variable is the change in activity-travel time.

$$ATE = E[Y(1) - Y(0)|Y = 1] = \frac{1}{N}\sum\nolimits_{i=1}^{N}(Y_i(1) - Y_j(0)) \quad (3)$$

Table 3 presents the matching results and the pseudo-R2 of the logistic regression models for estimating the PS. The pseudo-R2 is less than 0.1, which may indicate a higher similarity between the two groups. A series of chi-square and *t*-tests performed on the socio-demographic characteristics of the reselected samples did not yield a significant difference between the car commuters and other groups at a significance level of 5%. These findings show that the matching balanced the data adequately [69]. From the above steps, we obtained two sample groups with similar socio-economic attributes in Kunming in 2011 and 2016, obtaining 3530 cases (1765 in one year) for further analysis.

Table 3. Matching of workers in 2011 and 2016.

		2011	**2016**
		(*n* = 1765)	**(*n* = 1765)**
Age	18–24	2.60%	3.60%
	25–34	24.50%	30.10%
	35–44	37.50%	35.70%
	45–54	27.30%	23.80%
	55 and above	7.90%	6.50%
Gender	Male	52.40%	51.20%
	Female	47.60%	48.70%
Education level	Low	6.00%	2.20%
	middle	58.90%	46.80%
	high	35.00%	50.90%
Occupation	Freelance	9.30%	5.40%
	Private	22.90%	19.60%
	Company	19.30%	15.90%
	Enterprise	13.10%	17.70%
	Government	35.20%	41.00%
Family Size	1	18.00%	19.80%
	2	31.60%	29.90%
	3	39.40%	40.40%
	4	7.70%	6.10%
	5 and above	3.10%	3.50%
Family with multiple workers		70.70%	67.10%
Family with children under 6 years old		13.30%	15.00%
Family with seniors over 60 years old		10.30%	20.00%
Family with more than 1 car		30.10%	37.40%
Family has its own house		66.80%	64.40%
Income	Low	39.70%	31.70%
	Middle	56.80%	65.50%
	High	3.30%	2.60%
Pseudo-R2 of regression = 0.098			

3.2.3. Multinomial Logit Model

A multinomial logit (MNL) model was established to examine how mobility changes because of the urban spatial transformation effect on commuter groups with different travel modes. Mobility changes are characterized by differences in time use among subsistence, maintenance, and leisure activities. In addition, PS (preserved information on socioeconomic attributes) and residential location were included in the model as control variables. We used the MNL model to generalize the logit regression for obtaining multiclass discrete outcomes. The MNL model is suitable for data modeling when the dependent variable belongs to three or more categories, and the influence of the independent variable on the multivariate dependent variable can be obtained.

The utility of the nth commuter choosing travel mode i can be expressed as follows:

$$U_{in} = V_{in} + \varepsilon_{in} \quad (4)$$

where V_{in} is the utility fixed term of the observable variable when the nth individual chooses travel mode i; and ε_{in} is the utility random term of the unobservable variable when the nth individual chooses travel mode i.

When the relationship between variables is linear, the model is expressed as follows:

$$V_{in} = \sum\nolimits_{k=1}^{K} \theta_k x_{ink} \quad (5)$$

where i is the travel mode of commuters, K is the number of explanatory variables, θ is the parameter matrix, θ_k is the parameter corresponding to the kth variable, and x_{ink} is the kth characteristic variable of the ith travel mode selected by individual n.

Assuming that the random term of the utility function obeys double exponential distribution, then the probability of the nth individual choosing travel mode i is calculated as follows.

$$P_{in} = \frac{e^{V_{ij}}}{\sum_{k=1}^{k} e^{V_{ij}}} = \frac{\exp(\sum_{k=1}^{K} \theta_k x_{ink})}{\sum_{k=1}^{K} \exp(\sum_{k=1}^{K} \theta_k x_{ink})} \quad (6)$$

When the MNL model is used, a category of the dependent variable is selected as the reference category. We assume that the reference group M = private car:

$$\eta_m = \log(P_r(m)/P_r(M)) \quad (7)$$

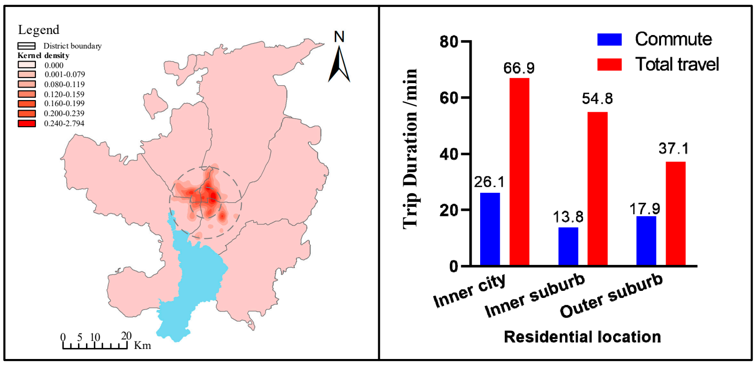
where p_r is the probability of choosing a certain type of travel mode, and η_m is the logarithm probability occurrence ratio of the multinomial logit model entering a category m relative to entering category M.

We separately modeled the commuter samples of different travel modes in 2011 and 2016 and calculated the maximum likelihood estimation. The models use car travelers as the reference group, which can directly compare mobility differences between car users and other mobility groups for identifying mobility inequalities in transportation. Comparing the fitting coefficients of the two models, we obtained the transportation-related social exclusion of some groups in urban spatial transformation to recommend policies. The suitability of the models can be statistically tested by verifying the estimated coefficients of the MNL models.

4. Descriptive Analyses

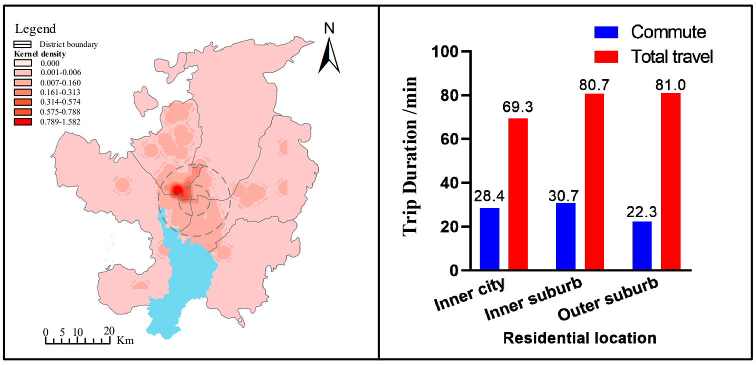
4.1. Residential Location and Mobility Changes of Commuters

Kernel density estimates were used for illustrating participants' residential location distribution, as shown in Figure 3. Comparing Figure 3a,b, we observed that the difference in commuters' residence is highly obvious over time. Since outer suburbs have been replaced by low-density expansion, having the vast majority of people living in urban centers and inner suburbs is no longer the case. Column charts in Figure 3c illustrate the dispersion of participants' daily activities. Between 2011 and 2016, commuters' travel and commuting times in various parts of the city increased, indicating that the degree of activity dispersion increased during that period. In particular, this phenomenon is more obvious in the inner and outer suburbs, and the difference is smaller in the central urban area.



(a) Kernel density of residential locations of commuters in Kunming, 2011

(c) Travel time of commuters in Kunming in 2011



(b) Kernel density of residential locations of commuters in Kunming, 2016

(d) Travel time of commuters in Kunming in 2016

Figure 3. Residential location changes of commuters from 2011 to 2016.

For each activity type, Figure 4 shows that people generally demonstrate a large increase in the need for flexible activities. The farther the residential location is from the city center, the lower the commuters' participation in maintenance and leisure activities. In 2011, commuters in the outer suburbs and new urban areas devoted almost all their time to subsistence activities and transportation. Since the research participants were commuters, participation rate in subsistence activities was 100% in both periods, masking the time use characteristics of maintenance and leisure activities. Hence, the three activities are not indicated in Figure 4. The results show that urban sprawl had commenced in Kunming, and facility construction was centered in the central business district and developed radially. This situation prevented the rapid development of facility construction in the inner and outer suburbs, resulting in an increasing difference in residents' participation in different urban locations. This impact is reflected in travel patterns and mobility, where activities that were previously achieved on foot are now elusive, and buses that used to operate efficiently on radial corridors centered in central business districts are increasingly unable to adapt to suburban interiors. Thus, the demand for travel between cities and suburbs is rapidly growing. Therefore, people must adjust their transportation mode to cope with the impact of urban spatial transformation to meet their activity needs and avoid becoming a part of the transport-related social exclusion groups.

The statistical analysis of the activity participation rate is performed in two steps: First, commuters are divided into three categories according to their residential locations, namely inner city, inner suburb, and outer suburb; second, based on the activities listed in Table 2, the classification provides a sub-aggregation of the types of activities that three categories of commuters participate in. For example, inner city commuters had an individual activity participation rate of 1.2%, meaning that personal activities accounted for 1.2% of all out-of-home activities for all inner-city commuters.

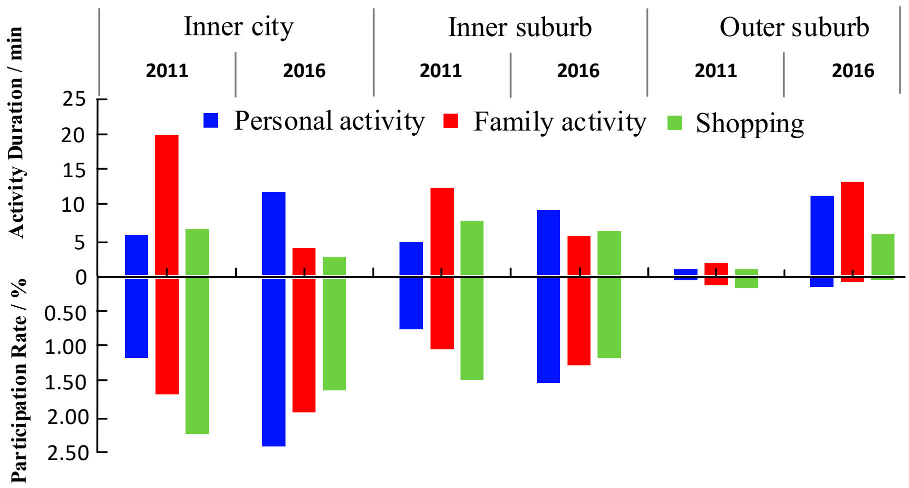


Figure 4. Characteristics of commuters' living time utilization at different periods.

4.2. Travel Patterns and Mobility Changes of Commuters

4.2.1. Choice of Transportation Mode

Figure 5 illustrates changes in the proportion of commuters' transportation modes for all study participants and different urban locations in 2011 and 2016. Between both years, travel mode structure changed considerably. Overall, car and transit commuters had the highest increase of 6% and 7%, respectively, while cyclists and walkers had a 16% decrease. This phenomenon suggests that rapid urban area expansion and suburbanization of residential locations increased average travel distances, promoting the development of faster transportation modes. The general trend of this change differed in different urban locations: (1) The number of cars in the central area did not increase, and the largest increase was of electric vehicles (+16%). (2) The proportion of cars farther away from the city center increased; the larger the ratio, the smaller the increase in the public transportation proportion. (3) Bicycle and walking (−19%) were the transportation modes that mainly reduced in the suburbs, and electric vehicles (−21%) were the transportation mode that mainly reduced in the outer suburbs. We merged walking and cycling into non-motorized transportation, as they were two of the most common transportation modes among Chinese commuters in the last century; moreover, the common characteristics of both transportation modes are low spatial accessibility and low speed. Furthermore, e-bikes can reach speeds of over 30 km/h and weigh between 40 and 60 kg. In 2000, China's central government classified e-bikes as ordinary bicycles. However, the government has recently reviewed the classification, which now distinguishes between e-bikes and bicycles while requiring e-bike travelers to own a driver's license and wear a helmet (Chinese Central Government, 2020). In this study, we distinguished between bicycles and e-bikes mainly because e-bikes are faster and more costly than bicycles.

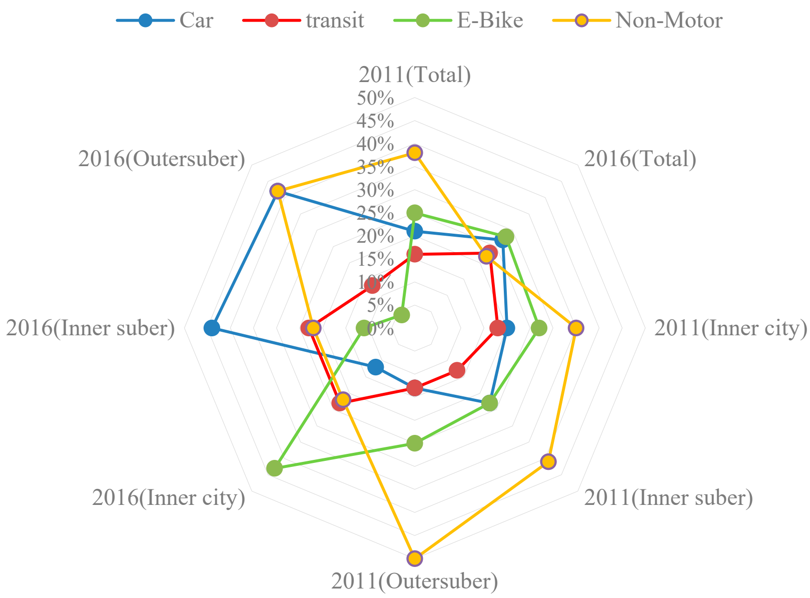


Figure 5. Composition of travel mode types.

4.2.2. Comparison of Time Use among Groups of Different Travel Modes

For urban transportation, we categorized commuters into four groups according to transportation mode: cars, buses, electric bicycles, and non-motor. To explore the impact of urban spatial transformation on the mobility of different groups, we analyzed the time distribution of the four groups at different periods in the city. Statistical analysis was performed by calculating the time-utilized mean of the four groups. The Mann–Whitney U test was used to examine whether substantial differences existed in the time-use patterns of the different groups in 2011 and 2016. The Mann–Whitney U test, as a nonparametric method, was appropriate for the situation because the tested samples were independent, uncorrelated, and not normally distributed [70].

Table 4 presents the test results, which show that travel and commuting time increased considerably among the three groups for cars, electric bicycles, and non-motor, whereas the bus group's travel time decreased slightly. These findings show that with the expansion of cities, the scope of people's activities increased. The expansion not only included the separation of living and workplaces but also included many spatial changes such as escorting children, medical care, leisure, and entertainment. In contrast, cars and electric vehicles were effective in meeting people's space pursuits; hence, travel modes increased considerably. Subsistence activities represent the rhythm of activities in an area. From 2011 to 2016, people spent less time at home and more time at work. The average working time of the electric bicycle group was the longest (2011 = 432.55 min and 2016 = 510.3 min), showing that the economic conditions of individuals strongly influence their decision to choose electric bicycles as a transitional product. When the transition period was completed, individuals faced the risk of shifts in travel mode. The average duration of maintenance activities decreased across all commuter groups, with the largest and most pronounced decrease in transit groups. Thus, improving the ability of transit to satisfy the needs of people's maintenance activities is the most effective approach for closing the mobility gap between bus and other travel mode groups. When people engage in maintenance activities, they rarely use public transportation. As the most flexible leisure activity, the car group maintained a relatively stable participation time while the travel time increased significantly. The participation time of the electric bicycles and non-motor groups in leisure activities increased significantly, indicating that facility planning can meet the needs of people's leisure activities in a small area and encourage them to choose a relatively environmentally friendly transportation mode. Evidence suggests that mobility differences between different groups will increase over time, ultimately causing social exclusion and car dependence of the transport disadvantaged group.

Table 4. Change in average activity time in 2011 and 2016 by transportation mode (min).

	Car	Transit	E-Bike	Non-Motor
2011				
Travel	73.49	92.12	60.83	42.53
commute	29.43	42.70	24.96	14.18
Working	412.83	391.13	432.55	301.82
Personal	11.34	14.03	3.07	4.05
Family	11.33	26.37	14.71	16.34
Shopping	6.23	7.99	6.06	7.91
Home	921.11	913.66	921.09	1065.6
2016				
Travel	88.70	86.46	64.80	57.83
commute	30.95	41.58	25.86	18.98
Working	476.12	478.86	510.3	416.24
Personal	10.7	3.89	6.21	12.34
Family	7.64	3.96	1.82	6.67
Shopping	6.15	3.64	3.22	4.65
Home	848.84	850.95	852.91	941.17
Change				
Travel	+15.21 ***	−5.66	+3.96 **	+15.3 ***
commute	+1.51	−1.12	+0.86 **	+4.81 ***
Working	+63.29 **	+87.73 ***	+77.75 ***	+114.42 ***
Personal	−0.64	−10.13 **	+3.14 **	+8.28 ***
Family	−3.69 **	−22.4 *	−12.9	−9.68
Shopping	−0.07	−4.36 **	−2.84	−3.26
Home	−72.28 ***	−62.71 ***	−68.17 **	−124.42 ***

* Significant at the 0.10 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Table 4 shows that urban spatial structure transformation has had the greatest impact on the activity needs of the public transportation groups. This is demonstrated in two ways. First, the public transportation groups are the only groups that have not expanded their travel range, implying that the groups have less access to urban facilities than that of other groups. Second, the maintenance and leisure activities of the transit group have less time in decline. These factors make the public transportation group a transportation-disadvantaged group among many commuters. Cycling and walking groups experienced the second-highest impact. With changes in the urban spatial structure, many travelers have abandoned cycling and walking in favor of other travel modes (Figure 5). Other people may experience the spatial advantages of jobs–housing matching and high facility density. These people do not need to bother about long commutes and scattered activities; therefore, they are less affected by the urbanization wave than the transit group. The e-bike group was less affected than the first two groups. The e-bike group comprises "self-helpers" under the impact of the wave of urbanization. When slow traffic cannot meet the travel needs of the e-bike group, the group actively seeks travel methods with higher mobility. However, because of economic constraints and other factors, the e-bike group cannot choose cars. The car group was least affected because of cars' higher speed and flexibility than those of other travel modes. The car group had an increasing range of activity spaces and mainly spent spare time on maintenance activities; however, people in the group did not focus on leisure activities. We conducted a more detailed analysis of how these mobility changes affected commuter travel patterns and contributed to the exacerbation of transportation-related social exclusion by constructing MNL models.

5. Modeling and Results

This paper argues that urban spatial transformation has been disadvantageous to the mobility of non-car travelers, especially transit groups, which is manifested in reduced participation and time use in their maintenance and leisure activities. This transport-related social exclusion detected through different transportation modes becomes more pronounced over time. Therefore, it is important to construct and comparatively analyze models of the impact of commuters' time use on transportation mode choices at different periods of the day within the city (2011 = Model I, 2016 = Model II). The PS value generated during PS matching considers numerous socioeconomic factors and retains important information; we included the PS value as a control variable in the model. Residential location was also considered and incorporated into the model. All explanatory variables were tested for multicollinearity before their inclusion into the model.

Table 5 presents the estimation and evaluation results of Models I and II (in parentheses). LR-chi2 = 774.524 for Model I, and LR-chi2 = 918.6 for Model II. The corresponding p values of both LR-chi2 cases were 0.00, which is less than 0.05; thus, the joint significance of the respective coefficients of both models was high. In addition, the software provided a pseudo-R2 to compare the goodness of fit of both models. The pseudo-R2 of Model I was 0.355, which was smaller than that of Model II (0.406). The pseudo-R2 was closer to or even higher than that of the previous MNL model [71] according to commuters' transportation mode choices, indicating that the pseudo-R2 model has strong interpretability. Therefore, time use (a proxy for mobility) has a significant impact on transportation mode choices, and the degree of impact tends to increase over time.

Table 5. Regression results for Commuters' daily transportation mode choices.

	Transit		**E-Bike**		**Non-Motor**	
	Coef.	***p***	**Coef.**	***p***	**Coef.**	***p***
Constant	11.244 (−2.751)	0.000 *** (0.003 **)	13.226 (−17.647)	0.000 *** (0.000 ***)	14.601 (0.580)	0.000 *** (0.493)
PS	0.593 (0.866)	0.377 (0.140)	2.090 (0.533)	0.000 *** (0.374)	2.127 (2.501)	0.000 *** (0.000 ***)
Residential Location (ref. = Outer Suburb)						
Inner city	−14.131 (1.676)	0.000 *** (0.001 **)	−13.891 (19.200)	0.000 *** (0.000 ***)	−13.906 (1.493)	0.000 *** (0.000 ***)
Inner suburb	−14.524 (0.399)	0.000 *** (0.415)	−14.299 (16.579)	0.000 *** (0.210)	−14.271 (0.216)	0.124 (0.554)
Total travel	0.002 (−0.005)	0.397 (0.002 **)	−0.003 (−0.004)	0.340 (0.007 **)	−0.006 (−0.008)	0.079 * (0.000 ***)
Commute	0.035 (0.040)	0.000 *** (0.000 ***)	−0.017 (−0.023)	0.001 ** (0.000 ***)	−0.083 (−0.075)	0.000 *** (0.000 ***)
Subsistence activities	0.001 (0.000)	0.768 (0.648)	0.001 (0.001)	0.595 (0.224)	0.000 (−0.001)	0.883 (0.089 *)
Maintenance activities	0.001 (0.001)	0.536 (0.431)	0.001 (0.001)	0.686 (0.613)	0.002 (0.001)	0.536 (0.074 *)
Leisure or discretionary activities	−0.003 (−0.001)	0.342 (0.376)	−0.004 (−0.003)	0.197 (0.222)	−0.003 (−0.001)	0.287 (0.714)
Cases = 1765 (1765) LR chi^2 = 774.524 (918.6) Cox and Snell R^2 = 0.355 (0.406) Reference category = Car (Car)						

* Significant at the 0.10 level. ** Significant at the 0.05 level. *** Significant at the 0.01 level.

Compared with the reference group, PS had a significant effect on the positive selection of electric bicycles and non-motor modes in 2011, but most positive correlation coefficients of the PS variables in the 2016 model were significantly reduced. Central and peri-urban areas had similar trends, with all coefficients being positive in 2011 compared with those of outer suburbs; in 2016, these coefficients became negative. These findings suggest that people are exhibiting more diverse transportation behaviors because of factors such as increased urbanization and economic growth. The influence of "classic" socio-demographic characteristics and residential location on transportation mode choices is gradually diminishing, whereas the influence of subjective aspects such as lifestyle and activity needs is expected to become increasingly prominent. In contrast, some subjective factors (such as activity participation and time use) have an increasingly obvious impact on people's daily mobility.

The total travel time represents the spatial range of people's daily activities to a certain extent. In 2011, the overall travel time was not significant for transportation mode choices, but in 2016, it became highly significant. This proves that the scope of people's activities expanded in the process of urban spatial transformation. Furthermore, the correlation coefficients were all negative, indicating that the longer the total travel time, the more likely people are to choose a car as their transportation mode. Therefore, the diversification of people's lifestyles and the increase in activity demands lead to an expansion of the scope of personal activity space, which is an important reason for restricting people's choice of non-car travel. The results of the travel behavior change study conducted by Feng et al. [72] in Nanjing are similar to ours; our results show that the effects of commuting time and subsistence activities are relatively stable regardless of the period, which is related to their inflexibility. In 2016, the correlation coefficient of the subsistence activities time of the cycling and walking groups was negative and more significant than that of the car group. This finding indicates that if the subsistence activities time continues to increase, the initial bicycle and walking travelers will become more inclined to choose cars as their transportation mode.

In 2011, the increase in maintenance activities time was positively correlated with the choice of a non-car transportation mode. In 2016, the correlation coefficient for maintenance activities time turned negative. One possible reason for this result is that the spatial distance of commuters participating in maintenance activities was more dispersed in 2016 than in 2011, resulting in cars being more likely to be allocated to household members primarily responsible for maintenance activities. Thus, urban sprawl results in preferential access to cars for members with more household responsibilities. Another possible reason is that most non-car commuters might be at a certain stage of life, such as being unmarried and without children, resulting in light family burden and a low need for maintenance activities. Both reasons lead to a persistently high participation demand in maintenance activities. If other transportation modes aside cars cannot guarantee people's growing demand for maintenance activities, the "Downs Law" aforementioned for urban transportation development will remain unsolved. The consequence of this is that traffic congestion, environmental degradation, and the increased possibility of vulnerable groups getting stuck in traffic as caused by the proliferation of cars become vital issues in preventing the sustainable development of cities. Leisure activities are an important symbol of social civilization; leisure activities time is an important indicator of residents' quality of life [73]. Research has shown that a positive relationship exists between leisure activities time and car use; that is, car use is indeed an important reason for people's increased participation in leisure activities over a long period of time. However, the results also show that the impact of current leisure activities time on car use is not significantly different from that of other transportation modes. This implies that, in current medium-sized cities in China, people's car dependence has not been fully formed; hence, a good opportunity exists to guide the transportation system toward sustainable development.

6. Discussion and Policy Implications

As the largest developing country in the world, China's social background is different from that of Western countries and the United States. For example, in the United States, people in the same social class live in the same communities and use the same transportation modes. In China, on the contrary, a community is typically mixed with people from all social classes. Therefore, social exclusion in China is more dependent on people's behavioral differences. As several means of travel exist in Kunming, it is necessary to study the behavioral responses of residents in the process of urbanization. Thus, this study deepens the understanding of the dynamics of residents' mobility.

In the 1990s, the World Bank recommended that China should not build car-oriented cities as in most developed countries. However, urban space transformation in the early development of some megacities in China plunged the cities into car-building cities [1]. This experience provides lessons for creating effective sustainable development strategies for transportation in small and medium-sized cities to avoid repeating the same mistakes. In addition, our research shows that the residents of China's small and medium-sized cities are not yet completely "car-dependent", suggesting that now is a critical stage to determine the path of future urban development. Mobility gaps created by transportation modes are gradually translating into large gaps in access to different activities, which can ultimately lead to severe transport-related social exclusion. Without timely policy intervention, this will undoubtedly create serious environmental and social pressures for Chinese cities. China has conducted a series of recent urban experiments on activity participation and public transportation empowerment, which are now addressing some inequalities [74–76]. In the near future, it will be seen whether other cities in China that are undergoing or about to face urban spatial transformation will pursue sustainable development as a necessity.

From the cultural and institutional contexts of Kunming, traffic exclusion for non-car users can be reduced in at least three ways. First, we found that urbanization has amplified the mobility advantages of cars, and people have become more dependent on cars. As the city expanded, residents rapidly owned more cars, which may lead to a reduction in transportation facilities (such as sidewalks and non-motorized vehicle lanes) that non-car users can use [77]. Our results are consistent with previous research assumptions that urban form and major modes of transportation are dynamically linked [78]. Urban sprawl has proven to be inevitable, and given the proliferation of cars, the transportation exclusion of non-car users is expected to increase. Therefore, it is necessary to perform the demand-side management of urban cars. We recommend various measures to curb the growth of car use and quantity, including policy measures (such as increasing parking fees and car restrictions) and market measures (such as increasing gasoline prices and car tax rates). Implementing new mobility solutions based on electric vehicles, such as electric cars, electric scooters, and electric bikes in urban transport systems, may bring several advantages for society, from environmental and economic benefits to improved quality of life. [79] However, the study by Katarzyna et al. [80] indicated that the lack of education and publicity to support electric vehicles in Poland has led to people's reluctance to use new transportation technologies due to cognitive impairment. Electric vehicle education proposed by Katarzyna et al. is divided into three phases: 1. an educational diagnostic survey to identify educational gaps and concerns about EV use; 2. expert research; 3. develop the concept of teaching about electric mobility based on a detailed analysis of the available pedagogical methods (including presenting, exposing, problematic, programmed, and practical techniques), proposing appropriate forms of education, and adapting educational content to them. In cities that are facing or are about to face severe transportation-related social exclusion, these educational measures about electric vehicles should receive more attention and be implemented quickly.

Second, our findings show that during urbanization, the lack of maintenance and leisure activities of residents is the main manifestation of transportation-related social exclusion. Considering the research of Faber and Páez [8], we note that the free activity participation of non-car travelers is more seriously affected by commuting time. With the lack of free time, residents are more willing to choose faster travel modes (such as public transportation and cars). Owing to the current lag in the development of the public transportation system, it is difficult to attract these commuters by public transportation alone.

Therefore, walking, cycling, e-bikes, and public transportation should be combined. Moreover, denser public facilities and dedicated public transportation lines must be provided, especially in areas further from the city center. The government should also prioritize the integrated resource allocation of non-car transportation, which can be achieved by increasing the supply of bicycles near subway stations, for example.

Finally, as discussed above, commuters' time use has an increasing influence on travel patterns, which in turn affects transport-related social exclusion. Therefore, policymakers should consider time policy measures. For example, this study shows that the increased time commuters spend in maintenance activities, such as caring for older family members and childcare, worsens transport-related social exclusion. Initiatives such as the creation of dedicated escort routes for children to school should be implemented so that commuters can collectivize the time dedicated to escorting and walking, providing them with more opportunities to socialize [81]. In addition, increasing mobility education is crucial. For example, people have to wait for at least two years in Western Europe to start their driving career despite obtaining a driver's license, thereby traveling by public transport, walking, or cycling through high school and even college. During this time and beyond, the government encourages such people to choose non-car travel options. Even if the people become drivers, early mobility education and non-car travel experience will teach them how to treat walkers and cyclists [82]. However, these policies are currently not implemented in most cities in China.

Fu [7] compared and analyzed the activity schedules of workers in five Chinese cities and found that differences in the social, cultural, economic, and geographical backgrounds of different cities resulted in the diverse use of workers' travel time for activities. Therefore, implementing the recommendations in this paper should be based on the urban context; i.e., transportation strategies and operations that are effective in a particular city may not be applicable to other cities.

7. Conclusions

This study examined the impact of urban spatial transformation in China on the mobility of residents with different travel modes. Furthermore, we identified the underlying mechanisms of transport-related social exclusion for different travel mode groups. The case study of Kunming from 2011 to 2016 shows that, overall, the spatial expansion of small and medium-sized cities has begun, the structure of commuters' travel modes is rapidly developing toward rapid transportation, and urbanization has caused different levels of mobility for commuters with different travel modes. The public transportation group is the most affected because of the suburbanization of residential locations and decentralization of activity sites; this effect is mainly because the radial transportation corridors in which public transportation departed from the city center in the past cannot adapt to the current demands of transportation between and within suburbs. These factors make the transit group tightly bound to subsistence activities, making it difficult to participate in maintenance and leisure activities. The cycling and walking groups have the highest proportions of transferring to other transportation modes, and some of the remaining travelers are guaranteed to perform certain leisure activities, but their participation in maintenance activities has been greatly reduced. The current size of Kunming's small and medium-sized cities constitutes a large proportion of e-bikes, but the analysis shows that e-bike transportation is only a stopgap solution for those with lower needs for maintenance activities. E-bikes will become increasingly incapable of meeting travel needs as the distance between activity locations as well as the need for discretionary activities increase. Expectedly, the car group is least affected by urbanization, and its faster and higher flexibility than that of other transportation modes enables the group to maintain a relatively stable mobility under the wave of urbanization. Consequently, other transportation modes, especially public transport, are more susceptible to transport-related social exclusion than cars.

In addition, after controlling other confounding factors, our findings become consistent with those of Vos et al. [83]: The influence of socio-demographic characteristics on travel mode gradually diminishes. In contrast, subjective aspects of travel behavior (e.g., travel demand and activity intention) that have long been overlooked in transportation research will become increasingly prominent. This finding provides a new direction for predicting people's travel needs and transportation mode choices in the future. On the basis of meeting the needs of grassroots activities, people desire to pursue the needs of the middle and upper classes. If urbanization evolves in the direction of adaptation to cars without appropriate corresponding measures, the wave of urbanization will have a greater impact on urban traffic in developing countries in the future, causing more problems for sustainability. Therefore, the following issues need more attention in medium-sized cities in developing countries. First, as urban spaces are transformed, the scope of residents' activity space will be further expanded, and the demand for maintenance and leisure activities will grow, further stimulating people's mobility needs. Inevitably, the transportation system will shift toward the direction of rapid traffic. Secondly, according to the current situation, it is difficult for public transportation to self-escape from the predicament. Although research on bus service level is increasingly becoming common studies mainly focus on planning for efficiency [84] and comfort [85]. In future research, attention should be paid to the social exclusion experienced by transit travelers. Finally, the activity needs of electric bicycles and non-motor groups are changing rapidly, and transportation mode choices are also changing to more mobile alternatives. If transit continues to maintain the status quo for a while in the future, a large proportion of non-car users will become the "reserve" of the car. These findings are highly relevant to sustainable development policies for most urban transportation systems in China and other developing countries.

This study has some limitations that should be addressed in future studies. First, the current method needs to be applied to other social groups and regions to verify its robustness. Second, people's activity-travel behaviors are strongly influenced by family members, and further examination of the impact of the interaction between family members (such as companionship, substitution, and cooperation) on individuals under the wave of urbanization is needed. Finally, it is necessary to conduct a detailed analysis of the interrelationships between activities at different levels and between activities and trips.

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