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How household roles influence individuals' travel mode choice under intra-household interactions?

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Abstract: The household is usually an essential element for activity-based travel decision-making of individuals. From the perspective of household context, activities are often allocated to individuals based on their household roles, thereby affecting individuals' travel behavior. By defining the household role using spatial-temporal constraints which are associated with individual activities and household activities, this paper investigates the travel mode choice of individuals considering the effect of different household roles. The descriptive statistics of the household roles and their corresponding travel mode choice are presented using the data from Kunming, China. The statistical results show that the modal splits between females and males perform a significant difference in the same household roles. Furthermore, the travel mode choice of females and males are estimated separately using multinomial logistic regression model. The results show that the household role has a great influence on the travel mode choice for both female and male. Those who face more space-time constraints associated with household tasks prefer to travel by non-motorized modes. While with the increasing of commuting constraints, household heads, especially female-heads, tend to use car to meet the travel demands of household activity. Besides, individuals' age, education level, the number of cars and bikes in household also have a significant impact on travel mode choices of individuals.

Keywords: Travel mode choice; Intra-household interactions; Household roles; Space-time constraints; Gender

1. Introduction

Transport studies have long focused on how to promote urban sustainable development by guiding a change in individuals' mobility behavior. Since individuals live within households and share resources with other household members, decisions of different household members are usually made on a household scale. For this reason, household is a central decision-making unit for individual behavior in most cases. And travel derived from activity participation could be considered as a result of interactions among household members, namely intra-household interactions (Timmermans and Zhang, 2009; Bhat et al., 2005; Ho and Mulley, 2013; Lim, 2015; Zhang and Fujiwara et al., 2006). Several studies have confirmed that intra-household interactions not only influence daily activity-travel patterns of individuals, but also affect long-term decisions in families (Renni Anggraini et al., 2012; Borgers and Timmermans, 1993; Kato and Matsumoto, 2009; Zhang and Fujiwara, 2009). A better understanding of travel behaviors taking intra-household interactions into account, therefore, is essential to policy making for promoting low-carbon travel of individuals by changing their travel modes.

In transport research, intra-household interaction is regarded as the allocation and distribution of household resources, tasks, and activities among each household member to satisfy individual and household activity needs under social, spatial, and resource constraints (Ho and Mulley, 2015). This concept began with time geography, in which individuals will face with the inseparability and limitedness of space and time when they conduct and interact with activities (Arentze and Timmermans,2002). Gliebe and Koppelman(2005), Tijs Neutens et.al (2010), Gao et.al (2017) have found that extra spatial-temporal constraints may be imposed on an individual who is assigned extra activities from his/her social network. Under these circumstances, household members are more likely to transfer domestic activities under intra-household interactions. Further, they tend to choose the appropriate travel modes to reduce the space-time constraints that they suffer from extra activities. Many scholars have investigated the influence of intra-household interactions on travel mode choice. An example on this topic was the work of Miller et al. (2005) and Roorda et al. (2006) in which the travel mode choice was generated for each trip of an individual's home-based tour through considering the influence of household interactions. In these studies, car allocation and joint household travel arrangements and household tasks such as drop-off/pick-up arrangement were usually recognized as the household interactions. The activity participation, in a manner, can reflect the space-time constraints that individuals suffering. However, it is hard to explain why members in a household choose such a travel mode under limited time among activities in space. In this regard, it is necessary to present a suitable method for measuring the activities participation of household members, which can reflect the intra-household interactions under space-time constraints.

As we know, individuals who play different household roles may have different influences on a household decision (Ho and Mulley, 2015; Lee et al., 2007). Household activities are often allocated to individuals based on their household roles,

which indicates that activities participation of individuals is associated with their household roles (Schwanen et al., 2007). For instance, mothers prefer to share more household tasks such as escorting their children to and from school rather than fathers. It suggests that household role can measure the activities participation of household members to some extent. Present studies tend to investigate intra-household interactions by modeling a set of specific household activity-travel patterns such as those between the two household heads, between parents and children or between work and non-work activities (Brewer and Hensher,2007; Scott and Kanaroglou, 2002; Vovsha et al., 2004) And household roles are classified by personal characteristics such as gender, age and employment status, dependent on scholars' research interests. While the decision of different activities may vary by the preference intensity, experience, and characteristics of household members. It is difficult to analyze daily travel mode choices of individuals due to different activities participation. Since time-geography can provide a powerful framework to understand human behavior, the household role can be measured from a space-time constraints' perspective. Although individuals in different households suffer from different space-time constraints, they have a similar influence on activities decision making in the household due to the similar household roles they play. Thus, the role of a member can be reflected by his/her space-time constraints relative to other household members, thereby the intra-household interaction can be simplified by clustering different space-time constraints of individuals. Once the household roles are determined, it is possible to analyze travel mode choices of an individual household member under intra-household interactions.

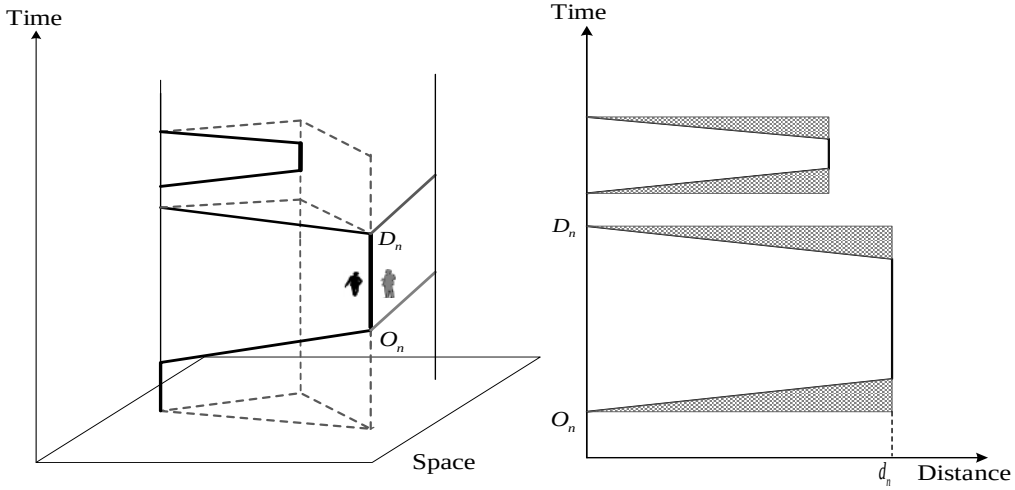
Based on this, household role is defined as household members who schedule activities and allocate household resources under space-time constraints in this paper. We assume that a member's travel mode choice is influenced by the household role that he/she plays in the household, and the household role is decided by his/her spatial and temporal constraints. Besides, a member's travel mode choice could also be conditioned by opportunities differ by the physical, institutional, social and cultural context in which different members are embedded (Ettema et al., 2007; Miller, 2007). Therefore, characteristics of household and individual also have an influence on member's travel mode choice besides of household roles. It should be noted that females' preferences in the household decisions seem to be a better proxy than those of males to some extent (Dosman and Adamowicz, 2006). For this reason, the influence of household roles on individuals' choices of travel mode should take males and females into consideration respectively.

The goal of this study is to investigate how household roles influence travel mode choice of individuals under intra-household interactions from a perspective of space-time constraints. The following sections will introduce the study method, and use the data collected from Kunming, a city of China, as a study case to confirm the research findings. A discussion section with recommendations for future research is also provided. Although most Chinese families have only one child because of the family planning policy, the impacts of household roles on individual travel mode choices under intra-household interactions are interlinked.

2. Method

2.1 Time-space Constraints Measure

Time geography was proposed and developed by Hagerstrand in the late 1960s. In this theory, Hägerstrand (1997) suggested that people travel and live through time and space and three types of constraints make our behavior explainable and predictable: capability constraints, coupling constraints and authority constraints. This paper focuses on understanding travel behavior under coupling constraints which refers to the limits that are caused by the need of other people or things to undertake. Since individuals cannot be in more than one place at the same time and all tasks are time-consuming base on the coupling constraints, individuals' activity-travel patterns can be represented by space-time paths. As shown in **Fig 1(a),** a household member who undertakes two activities at different times can be represented by two space-time paths respectively. The coexistence of time and space (such as from O_n to D_n) with others reflect the space-time constraints he/she suffers. In other words, the more space-time resources are consumed under space-time coexistence, the less likely for household members to participate in other activities. Because time and space are limited resources, the movement between the stops and the travel mode choice are not completely free in individual activity paths. If a household member has to undertake extra household tasks, he/she would be more likely to choose a motorized travel mode such as private cars. According to this, individuals' space-time constraints may be regarded as a space-time consumption and measured by all feasible space-time paths for their activities participation. Since it is complicated to calculate space-time consumptions for each household member in a three-dimensional environment, space-time paths can be transformed into a two-dimensional path (Chen et al,. 2001; Liu et al,. 2017), as shown in **Fig 1(b)**. In like manner, space-time consumptions of household members could be measured by enclosed area of their space-time paths (Gao et al., 2016; He et al,. 2015).



(a) Space-time paths in 3D (b)Space-time path in 2D

Fig.1. Space-time paths of household members.

2.2 Household Roles Associated with Space-time Constraints

In most cases, individuals are not only limited by the space-time constraints of their own activities but also by the constraints from the household or other household members. Hence activities fulfilled by individuals can be categorized as individual tasks and household tasks. Individual tasks such as commuting refer to the activities that individuals participate for their own demands, while household tasks refer to the activities that individuals participate for family or other household members. Further, space-time constraints of household members for participating in individual tasks and household tasks are taken as indicators to measure the intra-household interactions.

(1) Individual tasks

Work or work-related activities are one of the most important individual tasks for most commuters in daily life, which can be used to show individual's tasks in daily life (Clark et al., 2003). Based on the method of measuring space-time constraints, we calculate the enclosed area of individual's space-time paths for work and work-related activities. The equation is defined as:

$$W_i = \sum_{n=1}^{k} \int_{D(f_i(t))} f_i(t)dt \tag{1}$$

Where, W_i represents space-time consumptions of individual i for work and work-related activities $n(n=1,2,3\mathrm{K}\ k)$ within a day. $f_i(t)$ is a distance function of individual i's commuting journeys, $D(f_i(t))$ is a domain of $f_i(t)$, the range of t is from 0 to 24. A rectangular area is used to represent space-time constraints for individual's commuting journeys and named as commuting constraints. The equation is given by:

$$W_i^{'} = \sum_{n=1}^{k} d_{in} \times (t_{D_{in}} - t_{O_{in}}) \tag{2}$$

Where $W_i^{'}$ represents commuting constraints of individual i for work-related activities $n(n=1,2,3\mathrm{K}\ k)$ within a day. d_n represents the nth commuting Euclidian distance of individual i from home to workplace (units: kilometer), t_{O_n} is the nth departure time from home, t_{D_n} is the nth arrival time from workplace (units: hour). To reflect members' relative commuting constraints within the household, a treatment is conducted using equation (3):

$$C_{pi} = \frac{W_{pi}^{'} - \min(W_{pi}^{'})}{\max(W_{pi}^{'}) - \min(W_{pi}^{'})} \tag{3}$$

Where C_{pi} is the constraints degree of individual i for commuting in family p, $W_{pi}^{'}$ represents commuting constraints of individual i in family p.

(2) Household tasks

Individual's household tasks can be measured by space-time constraints associated with household-related activities and travels. Different from commuting activities, such activities are characterized by flexible schedules and various durations. Since it is impossible for traditional resident travel surveys to obtain information

about household chores shouldered by individuals, especially indoor activities, this paper demonstrates the possibilities of household members in undertaking potential household tasks with the space-time constraints of individual participating in outdoor maintenance activities, such as shopping. The space-time constraints of individuals for household tasks can be measured by equation (4):

$$H_i = \sum_{m=1}^{l} d_{im} \times (t_{D_{im}} - t_{O_{im}}) \tag{4}$$

Where H_i is the space-time constraints of individual i for outdoor maintenance activities $m(m=1,2,3\mathrm{K}\ l)$ within a day. d_m represents the m th commuting Euclidian distance of individual i from home to workplace (units: kilometer), t_{O_m} is the m th departure time from home, t_{D_m} is the m th arrival time from workplace (units: hour). To reflect members' relative household tasks constraints within the household, a treatment is conducted using equation (5):

$$S_i = \frac{\sum_{m=1}^{l} d_{im} \times (t_{D_{im}} - t_{O_{im}})}{\sum_{i=1}^{k} \sum_{m=1}^{l} d_{im} \times (t_{D_{im}} - t_{O_{im}})} \tag{5}$$

Where S_i is the sharing degree of individual i for outdoor household tasks $m(m=1,2,3\mathrm{K}\ l)$ within a day. k represents the k th member in household. The larger the S_i, the more likely a household member to share household tasks and making greater contribution to the family. It should be noted, if the household activity is a commuting travel, the space and time consumptions of traveling should not be repeated in calculation. A cluster analysis is performed on the two indicators where constraints degree of commuting and sharing degree for household tasks can be reflected simultaneously.

2.3 Model of travel mode choice

Multinomial logistic regression analysis as an important used multivariate method can be used in this paper. To investigate the influence of intra-household interactions and other variables on travel mode choice for females and males, we regard household characteristics, individual characteristics and household roles as explanatory variables and establish regression models for females and males separately. The model can be calculated as follows:

$$p(i=k) = \frac{e^{(v_{ik})}}{\sum_{m \in K} e^{(v_{im})}} \tag{6}$$

Assume there are *k* travel modes, a utility that is only known by the household member can be obtained as $\mathrm{U_{nj}}, \mathrm{j}=1,\mathrm{L}\ ,K$. The expression of the utility is given as $\mathrm{U_{nj}} = \mathrm{V_{nj}} + \varepsilon_{\mathrm{nj}}$, where $\varepsilon_{\mathrm{nj}}$ is an unobserved attribute. In the model, a household member was assumed to choose the alternative with the maximum utility from all travel modes, and maximum likelihood estimation was performed (McFadden, 1973). By verifying the estimate coefficients of logistic regression models, thereby statistically testing the

suitability of assumed models for the research.

3. Empirical study

3.1 Date and study area

Kunming, the capital of Yunnan province is adopted for this case study because (a) it is a typical Chinese big city which shares similar characteristics with other Chinese cities, (b) traffic problems are increasingly prominent in Kunming because the number of cars has increased at a rate of more than 10% a year. Kunming possesses 4.3 million residents in the urban area and 1.2 million cars, with the per capita GDP of ¥38,831 (approximately $5,631) (Kunming Statistics Bureau, 2011). The data resource comes from the Travel Survey of Residents in Kunming in 2011. The data covers household characteristics, individual characteristics of household members above the age of 6 and their participation in activities and travels within a day, and involves 1255 households and 3195 residents. The samplings are evenly distributed in the four main districts of Kunming (as shown in **Fig 2**). Respondents were asked to record their activity and travel information in 24h. For each trip, the survey records the trip purpose and transport mode, start time/location, end time/location, as well as other important information such as the location latitude and longitude, destination building type.

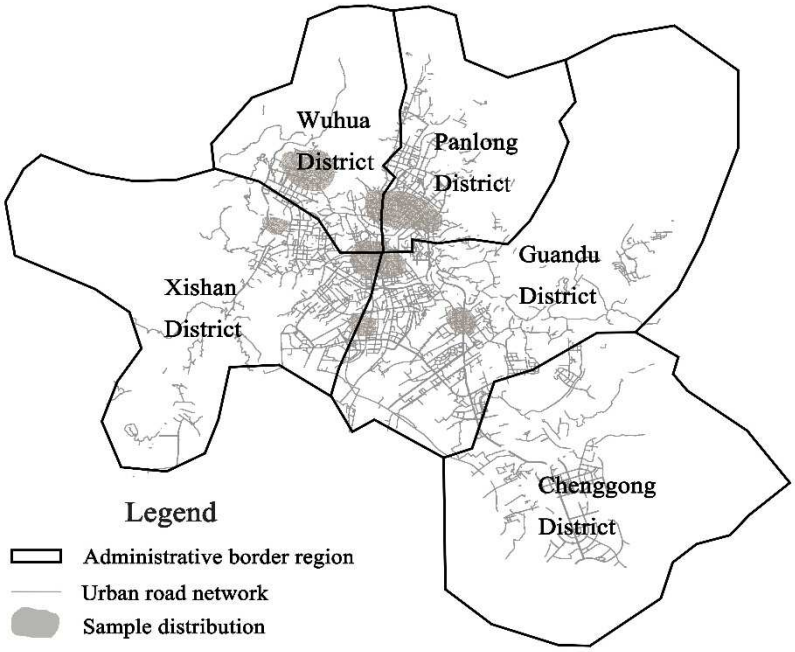


Fig.2. Studied areas

3.2 Characteristics of household role types

Based on the clustering demands mentioned above, the paper adopts K-means to cluster household roles. A total of 952 families with 1947 household members are included in this cluster analysis. Firstly, we calculate the constraints degree of commuting and the sharing of household tasks for each household members by using **Eqs (2) to (3)** and **Eqs (4) to (5)** separately. **Table 1** shows summary statistics of the

calculation of these two indicators. The variance of constraints degree of commuting is larger than that of sharing degree for household tasks. This suggests space-time constraints for commuting are significantly differences among household members.

Table 1 Travel Mode Choice, by Household Roles (N = 1947)

	Constraints degree of commuting	Sharing degree for household tasks
Mean	0.55	0.34
Variance	0.45	0.23
Maximum	1	1
Minimum	0	0
Median	0.71	0.22

Secondly, we set the value of K to 2-5 as expected result based on possible household role types in daily life. By comparing outline figure for all clustering results, three types of household role are finally identified because most cluster points in each type have high outline values (＞0.8). The clustering result is shown in **Fig 3**.

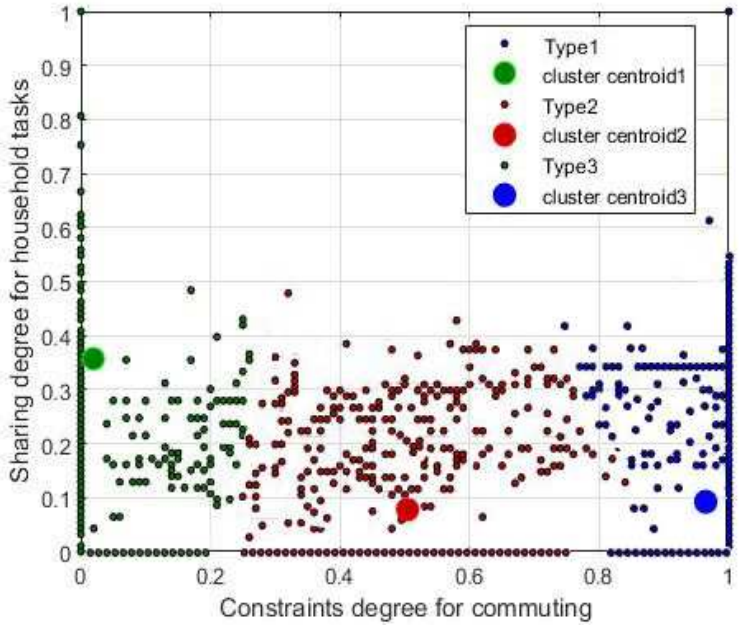


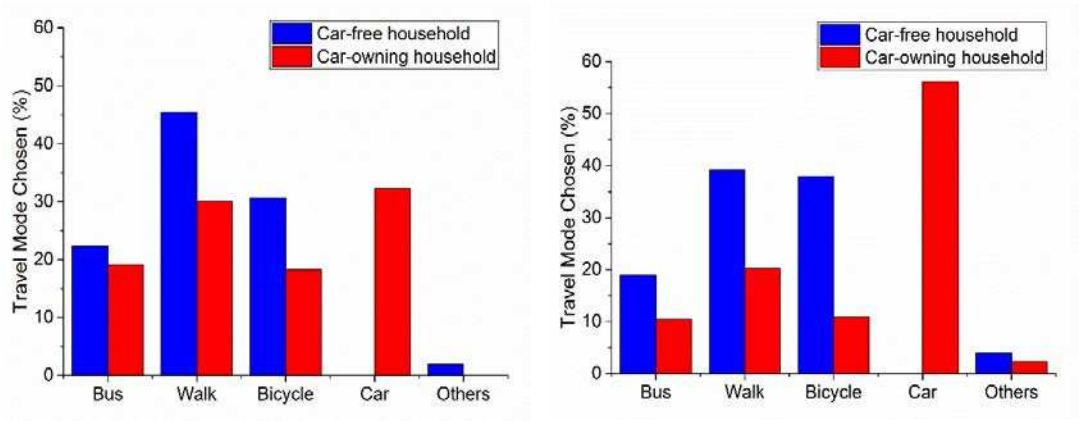
Fig.3. Cluster results

38.5% Type I, 13.3% Type II and 48.2% Type III constitutes all household roles. Judging from constraints degree of commuting (individual tasks) and sharing degree for household tasks (household tasks) in **Fig 3**, Type I household roles have the least constraints of individual tasks in households but have a larger number of household tasks than other household roles. This type of roles is likely to assist other household members by sharing household tasks due to a comparably low commuting constraint. Type II household roles which account for the smallest proportion are imposed more extra space-time constraints associated with individual tasks than Type I. Type III household roles have the largest space-time constraints of individual tasks among household roles.

3.2 Characteristics of travel mode choice

According to our research objective, the characteristics of travel mode choice for

household members should be analyzed. Since individuals are more likely to choose appropriate travel modes to decrease their space-time constraints based on our hypothesis, alternative transport tools in the family will have a great influence on individual's travel mode choice. In 952 families, about 39% families own cars, and up to 69% families have one or more bikes (52% regular bicycle and 82 % electric bike). We take electric bike and bicycle as bike because only 7% bikes and 19% electric bikes are chosen by household members. **Fig 4** compares travel mode choices between car-free and car-owning households for female and male separately.



(a) Travel mode choice for female (b) Travel mode choice for male

Fig.4. Travel mode choices by household transport means

The results show that members' travel mode choice differs by car ownership in households. The car is the main travel mode for both female (32%) and male (56%) in car-owning households. However, the walk is the primary (45%, 39%) travel mode, followed by bike (31%, 38%) and bus (22%, 19%) for both female and male in car-free households. Nevertheless, the difference in travel mode choice between car-free households and car-owning households for males is more significant than for female. There is no significant difference between these two types of households in bus choice for females, which is contrary to males. Results are similar in bike choice. To investigate the influence of space-time constraints on travel mode choice of household members under intra-household interactions, further analysis is showed in **Table 2**.

Table 2 Travel Mode Choice, by Household Roles (N = 1947)

	Travel Mode Choice (%)					
Household Roles	Bus (18.3%)	Walk (35.6%)	Bike[(a)] (26.3%)	Car (17.6%)	Others[(b)] (2.2%)	Total
Female, 51.3%						
Type I (with the lowest ITs and the highest HTs)	4.7	13.1	3.1	1.4	0.1	22.4
Type II (with higher ITs and lower HTs than Type I)	1.4	1.9	2.4	0.6	0.1	6.4
Type III (with the highest ITs and higher HTs than Type II)	4.7	5.3	7.9	4.2	0.4	22.5

Total	10.8	20.3	13.4	6.2	0.6	51.3
Male, 48.7%						
Type I	2.4	8.0	2.2	3.1	0.4	16.0
Type II	0.9	2.3	1.9	1.5	0.3	6.9
Type III	4.3	5.0	8.9	6.8	0.9	25.8
Total	7.5	15.3	13.0	11.4	1.6	48.7

(a) ITs refers to individual tasks; HTs refers to household tasks.

(b) The bike includes regular bicycle and electric bike (two-wheels),

(c) Others refer to motorcycles, taxis and public cars.

From the perspective of space-time constraints, the household role that the family member plays is no significant difference between female and male. Type III household roles in both female and male account for the highest percentage, followed by Type I and Type III. However, males have been involved in more individual tasks than females because the proportion of Type I household roles in males (16% vs 22.4%) is relatively lower. To some extent, females are more likely to share household tasks with a low constraints degree of commuting. Type II household roles in males and females have no significant difference. In terms of travel mode choice, we find bike and car dominate in travel mode choice of Type III household roles. It suggests that both female and male tend to choose motorized travel mode with the increase of their space-time constraints of individual tasks. For the reason that the constraint degree of commuting largely determines the household role that the family member plays compared with the constraints degree of household tasks. In contrast, household members are likely to fulfill their household tasks on foot, especially for females (13.1%), because the walk is the primary travel mode for Type I household roles. We can also find household members are less willing to choose bus as their travel mode with the increase of space-time constraints, even if an increase in the proportion of bus for mode choice of males. Overall, although household roles associated with space-time constraints of males and females are similar, it has a significant difference in travel mode choice between them.

Besides of household roles associated with space-time constraints, other variables can also affect travel mode choice for household members as stated before. On the one hand, as individuals share family resources with other household members, the characteristic of household is an important factor of travel mode choice for household members. On the other hand, social-economic characteristics of household members such as age, educational level and employment status should be considered in modeling. It should be noted that the type ‘others’ in travel modes are especially scarce, it is therefore not considered in the modeling. Thus, travel modes studied in this research are bus, walk, bike and car; walk was chosen as the reference group for comparison with other modes. Finally, 987 females (including 624 adults, 223 retirees and 151 children) and 918 males (including 633 adults, 117 retirees and 168 children) were examined and measured with the multinomial logistic regression respectively. A summary of household role variables and other variables which can affect modal choices of household members are listed in **Table3.**

Table 3 Explanation of Observation Variables

Variables	Definitions
Household	
Structure	Couples =1(reference group), Nuclear=2, Extended families=3
Annual income (RMB)	⩽3,0000=1, 3,0000-5,0000=2, ⩾50,000=3
Number of cars	Actual number
Number of bikes	Actual number
Individual	
Household role	Type1=1(reference group), Type2=2, Type3=3
Groups	Adults=1(reference group), Retirees=2, Children=3
Age	Actual value
Education level	Junior high school and lower education=1, high school/ secondary vocational school=2, graduates and higher education=3
Employment status	Regular work=1, Otherwise=0
Travel	
Departure time	Rush hour (7:00-9:00)=1, Otherwise=0
Trip numbers	Actual number
Travel mode	Bus=1, Walk=2, Bike or Eclectic bike=3, Car =4 (reference group)

3.3 Regression results

Considering the significance of the selected variables, the explanatory variables which were not significant at the 0.10 level were excluded in model results. Because the p-value of both models is 0.00 (＜0.05), it indicated the final models with the household role and other variables contained superior regressions than their null models. The estimates and fitting information of models for females and males are listed in **Table 4** and **Table 5** separately. As expected, characteristics of household and attributes of household members, particularly for household roles in this study have a significant impact on travel mode choice for both males and females. Moreover, the results also reflect the difference between males and females under space-time constraints and household resource allocations.

Table 4 Regression Results for females

Mode	**Bus (M1)**			**Walk (M2)**			**Bike (M3)**		
	Coef.	S.E	P>|z|	Coef	S.E	P>|z|	Coef.	S.E	P>|z|
Constant	5.23	0.77	0.00*	5.59	0.72	0.00*	2.37	0.76	0.00*
Household									
Extended household	1.89	0.50	0.00*	1.87	0.49	0.00*	1.38	0.51	0.01*
Number of cars	-3.45	0.40	0.00*	-3.64	0.39	0.00*	-3.61	0.39	0.00*

Number of bikes	-0.16	0.19	0.39	-0.08	0.18	0.65	0.96	0.19	0.00*
Individual									
Type III	-1.55	0.39	0.00*	-1.49	0.46	0.00*	-0.74	0.38	0.05*
Retiree	0.64	0.67	0.34	0.13	0.65	0.85	-2.26	0.89	0.01*
Education level	-0.35	0.17	0.04*	0.71	0.17	0.00*	-0.50	0.17	0.00*
Regular work	1.19	0.37	0.00*	0.72	0.35	0.04*	0.66	0.36	0.07*
Travel									
Trip numbers	-0.37	0.20	0.06*	0.18	0.16	0.27	0.24	0.16	0.15
Rush hour	-0.71	0.36	0.05*	-0.31	0.35	0.37	0.32	0.39	0.40
N=987 LR chi^2 =634.44 Log likelihood: L(0)= -1286.881 L(β)= -969.66 Pseudo R2 0.25									

Note: * significance at the 10% level

Table 5 Regression Results for males

Mode	**Bus (M1)**			**Walk (M2)**			**Bike (M3)**		
	Coef.	S.E	P>|z|	Coef.	S.E	P>|z|	Coef.	S.E	P>|z|
Constant	5.82	1.21	0.00*	5.57	1.08	0.00*	2.84	1.12	0.01*
Household									
Nuclear household	-0.59	0.31	0.05*	-0.73	0.27	0.00*	-0.32	0.28	0.25
Annual income	-0.12	0.20	0.56	-0.43	0.18	0.02*	0.12	0.19	0.88
Number of cars	-4.39	0.43	0.00*	-4.15	0.41	0.00*	-4.89	0.42	0.00*
Number of bikes	-0.37	0.18	0.04*	-0.37	0.16	0.02*	0.67	0.16	0.00*
Individual									
Type III	-0.37	0.36	0.37	-1.55	0.32	0.00*	0.28	0.35	0.43
Retiree	3.89	0.76	0.00*	2.41	0.70	0.00*	1.29	0.75	0.08*
Child	1.32	0.68	0.05*	1.48	0.65	0.02*	-0.23	0.66	0.73
Education level	0.15	0.20	0.45	-0.44	0.18	0.02*	-0.49	0.19	0.01*
Regular work	0.86	0.38	0.02*	1.25	0.34	0.00*	1.32	0.35	0.00*
Travel									
Trip numbers	-0.61	0.24	0.01*	0.16	0.27	0.00*	-0.02	0.16	0.88
N=918 LR chi^2 =826.04 Log likelihood: L(0)=-1244.79 L(β)= - 831.77 Pseudo R^2 0.33									

Note: * significance at the 10% level

The significant effects of the household role which presented by the dummy variable ‘type’ confirm that there is a strong link between relative space-time constraints and travel mode choice of household members. As shown in **Table 4,** the negative coefficients of the Type III household roles, compared to those of the reference group (Type I household roles), are highly significant for bus, walk and bike.

It indicates that compared with Type I, the Type III household role females are more inclined to travel by car than other travel modes. Similar results can be found in males as shown in **Table 5**. The negative Type III household roles coefficients of males for walk indicates that the ratio between the probabilities of choosing walking and car is Or = exp (-1.55) =0.21 times as much as that of the reference group. However, regarding the choice between car and other travel modes except walk, there is no statistically significant difference in the three types of household roles. These findings suggest females who are involved in heavy individual tasks as well as a high sharing degree of household tasks prefer to use cars. Base on this, we can assume that the Type II household role is an important critical point for females, before which we find a split among bus, walk and bike, but after which females' car use significantly increases. When females play the Type III role in car-owning households, cars tend to be allocated to them under intra-household interactions. Although the household role of males has a similar effect on their car use in Table 5, there is no significant critical point of males' travel mode choice.

For other individual characteristics, the group type of household member is a significant factor for travel mode choice. For female-retirees, the ratio between the probabilities of them choosing bike and car is Or = exp (-2.26) = 0.10, while the ratio is 3.63 for males. This is probably because elderly females are less physically active than males. And the coefficients of male-retirees are positively related to bus, walk and bike, it suggests that male-retirees are less likely to use car for traveling. Male-children tend to travel by walking or bus rather than use car. Females with higher education are more likely to travel by car and walk rather than bus or bike. With a unit increase of the education level, the ratio between the probabilities of females choosing car and bus, bike increases by 1.42 and 1.64 times respectively. The similar results can be found in the males as shown in **Table 5**. Besides, household members with a regular work have a negative influence on car use for both females and males. Among the household variables, household car ownership has the strongest effect on individuals' travel mode choice. As shown in **Table 4** and **Table 5,** the number of cars coefficients for bus, walk and bike are negative, so an increase in number of cars in the household would increase the car use of both females and males. For the number of bikes, owning a bike not only significantly increases the use of bike for both males and females, but also positively influences the use of car for males. This suggests that cars are usually allocated to males in car-owner families. Besides, females living in the extended household are less likely to use a car. The probable reason is that space-time constraints of female commuters are reduced due to the assistance from retirees. Males in nuclear households are more likely to use car, which also verifies the previous result about car allocation within the household. Other variables have a low influence on the travel mode choice of individuals compared to household roles.

4. Conclusion and discussion

The intra-household interactions among household members under space-time constraints are of great significance for understanding their travel mode choice. By

taking household roles associated with intra-household interactions and other properties at the household level, this study focuses on the modal split among household members using the data from Kunming, China. The space-time constraints from individual tasks and household tasks relative to other household members are identified to reflect household roles. The statistical results show that the distribution of household roles is similar for both males and females. However, modal split between females and males performs a significant difference in the same household role. Based on this, the travel mode choice for females and males are estimated separately using multinomial logistic regression model. The results indicate that household roles, which are associated with space-time constraints have a significant influence on the travel mode choice of individuals.

Individuals with a high share of household tasks are less willing to travel by car, which indicates that individuals are more willing to finish household tasks at close range. With the increase of constraints degree of commuting, the existence of intra-household interactions will decrease individuals' sharing degree of household tasks. It makes no significant change to individual travel mode choice. However, if constraints degree of commuting increase, individuals tend to transfer to car use, especially female-heads. Since females carry prime responsibility for household tasks, they are less willing to travel far from home. When the distance exceeds their acceptable range of walk or bike, they are more likely to use car than their spouse, so as to meet household tasks. This situation usually occurs by parents escorting their children to and from school. In China, about 89% commuting parents escort their children to school, and over 51% of them are mothers (Liu et al., 2017). Because of the unequal distribution of education resources, parents usually choose dwelling place nearby the school with a better resource for their children, especially for parents from high-income households (Li. and Zhao, 2015). It may result in a long distance from home to the workplace. Parents, especially parents in nuclear households prefer to use motor vehicles to relieve commuting space-time constraints caused by escorting children. Therefore, it is particularly important for sustainable transport planning to short the work time (Park et al., 2017) or commuting distance for parents and to help employees to balance their work and families.

Car ownership is also an important factor influencing individual's travel mode choice. According to our analysis results, the number of cars has a positive influence on car usage for both females and males. In China, although more than 28% people have driving licenses, lots of them (especially females) still choose other travel modes in daily travels due to no extra cars in households or other reasons. However, with the development of social economy and conceptual changes, many young people are likely to buy their second car, especially young couples. Since cars are mainly allocated to male household heads, it is females who usually need the second car in nuclear household. Notably, the two-child policy has been implemented since October 2015, replacing thirty years of the one-child policy. Consequently, young females are facing more burdensome household tasks, especially for young mothers in nuclear households, they are more likely to use cars to reduce these extra space-time constraints. Moreover, most of young females are better educated than their mothers,

which could considerably increase the second car ownership and use. To reduce their car trips, it is crucial to reduce their space-time constraints for commuting. Previous studies confirmed that commuters may choose a faster travel mode to keep their commuting time tolerance within an acceptable range (He et al., 2016). By providing housings or dormitories for employees (such as young employees) nearby their workplaces can help to decrease the commuting distances. At the same time, improving the planning of transit-oriented land use and increasing accessibility of public transits can decrease the negative effects brought by the separation of jobs and residences. On the other hand, because females' travel mode choice is more easily affected by commuting constraints than males, relevant policies should take females' special needs into account if possible, such as reducing their work hours. In addition, bike is an important travel mode for individuals who live in car-free family or one-car family. Both females and males are more likely to use the bike for two or more trips than other travel modes. It is generally the preferred mode with the increase of space-time constraints of individual's commuting.

This paper focuses on the travel mode choice of individuals considering the effect of different household roles. It provides a new perspective on intra-household interactions analysis by taking into consideration of different household roles in activity participation. According to this, it is possible to understand long-term travel behaviors of household members influenced by their lifestyle and household roles. Because of the limited data information, this paper takes individuals' outdoor maintenance activities as their potential capacity for sharing household tasks. However, the measure of household role can be used to investigate intra-household interactions. In order to explore travel behaviors and possibly changed behaviors of individuals from more detailed intra-household interactions and lifestyles, a long-term activity-based survey diary data and corresponding questionnaires are needed. And this is an important question for further studies.

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