

EXPLORING THE RELATIONSHIP BETWEEN VEHICLE TYPE CHOICE AND DISTANCE TRAVELED: A LATENT SEGMENTATION APPROACH

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ABSTRACT

In the context of vehicle usage decisions, there are two important choice dimensions namely, the choice of vehicle from household fleet that will be utilized for trips and second, the distance traveled to pursue the planned activities. There are interrelationships between these two choice dimensions with one dimension potentially influencing the other. The direction of the interrelationship has important implications for transportation planning and policy analyses. In an effort to explore the interrelationships between choice dimensions, a number of joint modeling frameworks have been proposed in earlier studies. However, there are concerns about the representation of the underlying decision-making behavior in these joint modeling approaches. First, in joint model formulations that assume simultaneity, the choice decisions under consideration are assumed to be made at the same time and hence one decision cannot be conditional on another. Second, in model formulations that assume sequentiality in the choices, a single structure is assumed to explain the interrelationship between the choice dimensions; while in reality a single structure may not be sufficient and multiple structures may be needed to represent the behaviors exhibited by different population subgroups. In an effort to overcome the limitations of earlier studies, a latent segmentation based modeling approach is proposed in this paper that allows for exploring alternative interrelationship structures between choice dimensions in the same modeling framework. The methodology is demonstrated using an empirical exercise that utilizes travel survey data from the latest wave of the National Household Travel Survey (NHTS) in the United States. The results show that the model estimations are significant and are behaviorally plausible. Further, results also point to the need for accommodating alternative structures between choice dimensions to accurately describe the vehicle usage decision processes exhibited by individuals.

1. INTRODUCTION

With increasing concerns of sustainability and climate change, there has been a growing interest in understanding the vehicle ownership and usage decisions. The exploration of the vehicle ownership and utilization decisions is very important for not only capturing the direct implications of such decisions for greenhouse gas emissions and energy dependence but also for evaluating the various usage based revenue generation strategies that are being considered to replace the traditional gas tax based mechanisms (FHWA 2013). The literature on the study of vehicle related choices has focused mainly on the longer-term vehicle ownership related dimensions namely, composition of vehicles in the household fleet, the evolution of household fleets from year-to-year and the usage of each vehicle in the household fleet on an annual basis (Mannering 1983; Golob et al. 1995; Kavlec 1999; Choo 2004; Brownstone and Golob 2009; Bhat and Sen 2006; Cao et al. 2006; Fang 2008, Eluru et al. 2010a). Anowar et al. (2014) provides a comprehensive review of literature on vehicle ownership choices. However, there is limited literature on understanding the shorter-term vehicle usage decisions within the context of daily activities that are planned and trips that are executed to fulfill the activities (Konduri et al. 2011, Paleti et al. 2012, Nam et al. 2013, Faghieh-Imani et al., 2014, Angueira et al. 2015).

Within the shorter-term vehicle usage decisions, there are two important choice dimensions namely, the choice of the vehicle from the household fleet that will be utilized and second, the choice of the distance traveled to pursue the activities that are planned. While individuals may not directly make choice of the distance, the variable serves as a surrogate for representing the desired opportunity space and the location of destinations selected by individuals for pursuing activities. Interrelationships exist between these choice dimensions and can be represented using alternative structures namely, vehicle choice affects distance and distance affects vehicle choice. In the first

interrelationship structure, it is assumed that individuals choose a vehicle from the household vehicle fleet and then determine how far they have to travel to fulfill their activity needs. In the second interrelationship structure, individuals first choose the distance to travel to fulfill their activity pursuits and then make a decision about the household vehicle they want to use to pursue the activities.

The nature of the interrelationships between the choice variables has interesting transport policy implications. The interrelationships are of particular interest in households with multiple vehicles having different vehicle types where individuals potentially adjust and trade-off the usage decisions of various vehicles based on their activity agendas and travel needs. For example, if the interrelationship that tour length affects choice of vehicle holds then individuals potentially prefer larger vehicles from household fleet for shorter trips and vice-versa (i.e. preferring smaller vehicles for longer trips). In such a scenario, land use policies aimed at promoting high density mixed use built environments may not potentially yield the intended reduction in carbon emissions because individuals may now be using larger vehicles from the household fleet because they can monetarily afford to do so (because of the short trip lengths despite the poor fuel efficiencies associated with the larger vehicles). In the alternate interrelationship structure where vehicle choice affects travel distance, policies providing incentives for smaller more fuel efficient cars may also not yield the intended results of reducing emissions because individuals may potentially embark on longer trips to potentially more attractive destinations because the trips are monetarily reasonable due to the additional mileage afforded by the fuel efficient cars (Konduri et al. 2011). In light of the plausible alternative interrelationship structures between the vehicle choice and distance traveled, it can be seen that there is a need for a modeling framework which can be used to explore and confirm these interrelationships for formulating effective transport policies.

Vehicle choice is a discrete variable and distance traveled is a continuous variable, therefore, a discrete-continuous joint modeling framework is appropriate for modeling and exploring the interrelationships between the choice variables. A number of joint discrete-continuous modeling frameworks have been proposed in the literature to explore closely tied choice variables and to study the interrelationships between the choices. The studies can be divided into two subgroups based on the approach to modeling the interrelationships between the choice variables. In the first group of studies, the choices are modeled as a packaged (or simultaneous) choice (Mannering and Hensher 1987, Bhat 1996, Kitamura et al. 1996, Bhat and Sidharthan, 2012). However, the approach raises important concerns regarding the representation of the underlying behaviors in the model. The approach assumes that individuals are processing a relatively large number of choices simultaneously. However, such a simultaneous approach is not realistic as it imposes a significant burden on the individual to process the information associated with the choices and make decisions about multiple choices simultaneously. In fact, it is possible that when individuals are faced with multiple choices, rather than considering the entire set of choices as a unified package (see Eluru et al. 2010b for an example of such a framework), individuals may reduce the burden by actually considering one choice at a time and then making the subsequent choice conditional on earlier choice(s). This sequential approach to modeling the interrelated choices is the focus of the second set of studies (Ye and Pendyala 2009, Konduri et al. 2010, Konduri et al. 2011, Paleti et al. 2012, Angueira et al. 2015). The sequential approach allows the respondent to break the “package” into a series of decisions. Further, the sequential approach allows for accurately representing the interrelationships between choice dimensions by allowing the information about earlier choices far explaining subsequent choice dimensions. The

simultaneous approach to studying the interrelationships denies the opportunity to represent the influence of earlier choices in explaining the choice variable under consideration.

A limitation of the sequential approach is that an interrelationship structure must be assumed up front to represent the sequencing and to characterize the conditionality of choices. The structure chosen also has significant impact on the model developed and the inferences. However, this may be problematic because it is often difficult to identify the “true” interrelationship structure. Further, it is possible that a single interrelationship structure may not explain the behavioral processes for the full population. Multiple interrelationship structures may be needed to represent the behaviors exhibited by different population subgroups (Chakour and Eluru 2013). Therefore, there is a need for a sequential modeling approach which can accommodate multiple interrelationship structures within the same formulation.

In this paper, a sequential modeling approach utilizing the concept of latent segmentation (Bhat 1997; Greene and Hensher 2003; Bhat et al. 2004) is proposed to model the two vehicle usage decisions namely vehicle choice and distance traveled and the interrelationship between these variables. The methodology overcomes the limitations of most sequential approaches in literature that assume a single structure to apply to the entire population. In the paper, a latent segmentation approach is proposed, that can accommodate alternative interrelationship structures between the variables, for different subgroups of the population, within a single modeling framework (see Chakour and Eluru 2013 for a latent segmentation based model formulation for exploring the interrelationships between interrelated discrete variables). In the proposed approach, interrelationship structures are represented as latent segments to which individuals are probabilistically allocated based on a host of exogenous variables including socio-economic, demographic, land-use and built environment variables. Within each latent segment, the

interrelationship between the choice of vehicle and the distance traveled is modeled according to the assumed interrelationship for that segment. For instance in one segment, the vehicle type choice is modeled first and is followed by the modeling of distance traveled. Further, in modeling the distance variable, the choice of vehicle is used as an explanatory variable to represent the assumed interrelationship between the variables.

The proposed approach allows us to gain a rich understanding of the decision processes by first examining the affiliation of individuals to the alternative structures and then by exploring the interrelated choice dimensions consistent with the assumed interrelationship structure. Moreover, the estimation of the proposed model is free from simulation and easy to implement in comparison with the joint model frameworks which assume simultaneity in the choice dimensions. Subsequently, the parameter estimates are less prone to bias and loss in efficiency compared to those parameter estimates obtained using simulation based estimation techniques (see Bhat, 2011 for a more nuanced discussion)".

Data from the recent wave of the National Household Travel Survey (NHTS 2009) was used to study the two vehicle utilization choices: choice of vehicle and the distance traveled, and the interrelationships between the choices, using the proposed latent segmentation based methodology. In households with a single vehicle, the choice of vehicle is an obvious one and doesn't need any modeling, therefore, the study focuses on households with multiple vehicles where potential trade-offs and adjustments in choice of vehicle are involved based on the activity-travel engagement patterns of households and individuals. Further, in exploring the choice of vehicle, it was assumed that vehicles of the same type (i.e. vehicle body type e.g. car, van, SUV, truck) share same characteristics and are similar in their appeal for activity-travel engagement. Therefore, the choice of vehicle is explored by considering the vehicle type that was selected from

among available vehicle types. Additionally, the analysis is limited to households with multiple vehicle types as opposed to multiple vehicles consistent with the assumption of similarities in utilization of vehicles of same type. Thus, from this point forward, the choice of vehicle will be referred to as choice of vehicle type.

The remainder of the paper is organized as follows. In Section 2, the proposed latent segmentation based methodology for modeling the interrelationships between vehicle type choice and distance traveled is described. This is followed by a description of the data in Section 3. The model estimation results are presented in Section 4 and some concluding thoughts are presented in Section 5.

2. METHODOLOGY

The proposed latent segmentation based modeling approach is presented in this section. It must be noted that the description is specific to the study of the interrelationships between the two vehicle usage variables namely vehicle type choice and distance traveled. However, it must be noted that the latent segmentation approach is very robust and can easily be extended to model any combination of choice variables sequentially and study the many potential interrelationships between those variables within a single modeling framework.

The model formulation contains three choice components: (1) a component for modeling the latent segments, (2) a vehicle type choice component for each latent segment and (3) a distance component for each latent segment. The first component is represented as a binary logit model where the alternatives represent latent segments (characterized by the two interrelationship structures) and individuals are probabilistically allocated to a latent segment based on observed exogenous variables including socio-economic, demographic, land-use and built environment variables. This component also comprises the main difference between the proposed approach and

earlier sequential approaches to studying interrelationships between variables. In earlier sequential approaches, the interrelationships are studied by assuming a specific interrelationship structure a priori to apply to the entire population (Konduri et al. 2011, Paleti et al. 2012). However, the proposed latent segmentation based approach can accommodate a different interrelationship structure for subpopulations within the same modeling framework. The vehicle type component takes the form of a multinomial logit model with the choice of vehicle types as the alternatives. The distance component is a continuous variable represented as a linear regression model.

Let q be the index for individual decision maker ($q = 1, 2 \dots Q$), i denote the index for the latent segments ($i = 1$ or 2), v denote the index for the vehicle type alternatives ($v = 1, 2 \dots V$), and d denote the index for distance. With this notation, the mathematical notation for three components takes the following form:

$$u_{qi}^* = \alpha_i x_{qi} + \varepsilon_{qi} \quad (1)$$

$$u_{qiv}^* = \beta_i x_{qiv} + \varepsilon_{qiv} \quad (2)$$

$$u_{qid}^* = \gamma_i x_{qid} + \varepsilon_{qid} \quad (3)$$

where u_{qi}^* represents the utility derived by the q^{th} individual in selecting the i^{th} latent segment, u_{qiv}^* represents the utility derived by choosing vehicle type alternative v in the i^{th} latent segment, and u_{qid}^* represents distance travelled in the i^{th} latent segment. x_{qi} , x_{qiv} , and x_{qid} represent exogenous variables affecting the three choice components noted above and α_i , β_i , and γ_i represent the corresponding coefficient vectors to be estimated. The reader will note that the second model in each latent segment is conditional on the first model in the segment and this is accommodated by the specification of x_{qiv} , and x_{qid} . For example, in the latent segment where the vehicle type choice affects distance, vehicle type choice is modeled first without including any distance information in the specification of x_{qiv} . However, in modeling distance traveled, information about the vehicle

type that was selected is specified in x_{qid} . Further, the error terms ε_{qi} and ε_{qiv} are assumed to follow Type 1 Gumbel distribution and ε_{qid} is assumed to be normally distributed with a variance of σ^2 .

The probability expression for the choice of the latent segment takes the standard multinomial logit form as shown in Equation 4.

$$P_{qi} = \frac{\exp(\alpha_i x_{qi})}{\sum_{j=1}^2 \exp(\alpha_i x_{qj})} \quad (4)$$

Similarly, the probability for individual q in the latent segment i for selecting vehicle type choice v also takes the multinomial logit form and is expressed in 5 below:

$$P_{qiv} = \frac{\exp(\beta_i x_{qiv})}{\sum_{k=1}^V \exp(\beta_i x_{qik})} \quad (5)$$

For the distance variable, the probability expression for observing vehicle mileage travelled by individual q in the latent segment i is as follows:

$$P_{qid} = \frac{1}{\sigma} \varphi \left[\frac{(u_{qid}^* - \gamma_i x_{qid})}{\sigma} \right] \quad (6)$$

where φ represents the standard normal probability density function.

With these preliminaries, the latent segmentation based probability for joint choice of vehicle type and distance traveled with two latent segments can be formulated as follows:

$$P_{qvd} = \sum_{i=1}^2 P_{qi} \prod_{k=1}^V (P_{qik})^{\delta_k} (P_{qid}) \quad (7)$$

where δ_k represents an indicator variable for vehicle type selection and assumes a value 1 if a particular vehicle type alternative is selected and 0 otherwise. Equation 7 can also be expanded and expressed as shown in Equation 8 below:

$$P_{qvd} = P_{q1} \prod_{k=1}^V (P_{q1k})^{\delta_k} (P_{q1d}) + P_{q2} \prod_{k=1}^V (P_{q2k})^{\delta_k} (P_{q2d}) \quad (8)$$

The first term in Equation 8 represents the first latent segment representing the interrelationship structure where vehicle type selection is made first and this in turn affects the distance traveled. The second term represents the second interrelationship structure wherein the distance traveled affects the choice of vehicle type. The log-likelihood L_q for an individual decision maker q is defined as:

$$L_q = \ln(P_{qvd}) \quad (9)$$

The total log-likelihood value L for the sample can then be expressed as:

$$L = \sum_q L_q \quad (10)$$

The log-likelihood function is constructed according to the above expression, and maximum likelihood estimation is employed to estimate the $\alpha_i, \beta_i, \gamma_i, \sigma$ parameters. The model is programmed using GAUSS matrix programming language.

3. DATA AND SAMPLE COMPOSITION

In this study, data from the recent wave of the National Household Travel Survey (NHTS 2009) was used to study the interrelationship between vehicle type¹ choice and distance traveled. NHTS is a comprehensive travel survey collecting data about individual and household travel behavior. The survey provides information at four main levels: household, person, vehicle, and trip. The household and person file provide socio-economic and demographic information at the household- and person-level respectively for all respondent households. The vehicle file contains information

¹ The vehicle type variable used in the research was created by consolidating the VEHTYPE (defined as “Vehicle type” in the NHTS 2009). The vehicle type variable consists of four categories namely auto, van, SUV, Truck. As can be seen, the categorization is coarse and no distinction was drawn further for a specific vehicle type based on body type or fuel type. For example, one could have further classified auto based on body type as sub-compact, compact, mid-size, and luxury among others. Similarly, one could have classified auto based on fuel type as motor gas, diesel, natural gas, and electricity. The choice of coarse categorization was in part driven by the sample size requirements for each vehicle type category to obtain plausible model estimation results.

about the household vehicle fleet including make, model, year, and annual usage of the vehicles. The trip file contains information about the characteristics of all trips performed by each person in the household. The trip file also identifies the particular vehicle from the household fleet that was used on a trip.

The latest data release contains travel behavior information for nearly 150,147 households located all across the US. In an effort to accurately explore the shorter-term vehicle usage decision and avoid any regional influences, the survey sample was limited to a single metropolitan area – Dallas-Fort Worth in Texas. Further, the study sample was limited to only those individuals with multiple vehicle types in the household fleet. Additionally, analysis will be limited to only those persons who selected the same vehicle on all trips in the day. Unlike Konduri et al. (2011) and Paleti et al. (2012) which comprise a tour-level exploration of shorter-term vehicle usage decision, this study comprises a day-level exploration. The decision to adopt a day-level exploration was prompted by two considerations. First, tour-level studies (Konduri et al. 2011; Paleti et al. 2012) fail to recognize the constraints of vehicle type availability; the studies assume that when individuals are forming tours, they have all vehicle types from the household fleet available at their disposal irrespective of the usage of household vehicles by members of the household. Subsequently, the interrelationships between vehicle type and distance may be erroneous. Second, it was observed from the NHTS dataset that only a small percentage of the individuals (approximately 5 percent) actually switched vehicles across tours within the day. This observation is very plausible given the availability constraints noted above. Therefore, the shorter-term vehicle usage analysis in this study is conducted for each person at a day-level. Finally, only adults were considered in the analysis who reported valid distance values for all trips pursued during the day.

This data preparation process resulted in a final subsample of 3790 persons. Table 1 presents descriptive statistics for the subsample. The average household size is nearly three persons per household with mean vehicle ownership value of 2.65 vehicles. Nearly 19 percent of the households have an income of less than \$45,000 and about 28 percent of the households have an income between \$45,000 and \$100,000. Average trip rate is close to 4.19 trips per person with 1.43 trips bound for home, 0.60 trips destined to fixed activity locations including work and school, nearly 1.82 trips for out-of-home non-fixed activities and about 0.31 trips for serving household and non-household members. Average travel distance logged by individuals per day is nearly 49.54 miles with an average occupancy of 1.68. The subsample comprises of nearly equal percentage of males and females. 33 percent of the subsample comprises of non-workers with about 44 percent of the individuals holding a bachelors, graduate or professional degree. Almost about 28 percent of the people can alter or adjust their work schedules. The subsample is dominated by Caucasians (with about 85 percent of the subsample) followed by a small share of Black (about 5 percent) and Hispanic (about 3 percent) individuals.

Table 2 provides a summary of the vehicle fleet composition and utilization at the level of the household to which the person belongs. The diagonal (highlighted) represents those households where all vehicle types from the household fleet are utilized on the travel day. All cells under (and to the left of) the diagonal represent households where fewer vehicle types are utilized from the household vehicle fleet. It can be seen from the table that out of the 3790 persons, 1925 persons belong to households where fewer vehicle types are utilized compared to the full fleet of vehicle types available in the household. The non-zero cells below the diagonal points to the presence of potential trade-offs associated with selecting a vehicle type in households with multiple vehicle types and lend credence to the exploration of vehicle usage decisions. Such trade-off behaviors

may also be exhibited in the households along the diagonal with the full utilization of vehicle types wherein vehicle types may be allocated to the different household members based on daily activity-travel pursuits, household roles and individual preferences.

Table 3 presents an overview of activity-travel characteristics by vehicle type chosen. The table helps identify the potential relationship between the choice of vehicle type and the activity-travel agenda for the day. Van is associated with highest average trip occupancy followed by SUV, auto, and truck. The presence of household members on the trip also follows the same order. Trucks are associated with longer daily travel distance followed by SUV, van and auto. This observation may hint at a potential inverse relationship between body types and distance when the vehicle types and distance traveled are compared. However one has to be careful when interpreting aggregate comparisons that do not account for the composition of the household fleet of vehicle types. The real relationship between the vehicle type and distance is revealed when the activity-travel characteristics by vehicle type are explored while controlling for the household fleet composition. After controlling for household fleet composition, auto is associated with longer travel distances when the household fleet comprises of an auto, van, and SUV. SUV appears to be the preferred body type whenever there are two vehicle types in the household fleet. However, it is not the case when there are three or more vehicle types in the household fleet. These observations from Table 3 point to the role of vehicle fleet composition and availability in the selection and utilization of vehicle types. Therefore, it is important to represent the composition of the household vehicle type fleet in the specification of the vehicle type choice model (i.e. accommodating varying choice set of vehicle types based on household fleet composition) so that the model estimation results are appropriate.

Table 1: Descriptive Statistics for the Sample

Variable Description	Mean
<i>Vehicle Attributes</i>	
*Age of vehicle <= 5 yrs	0.49
*Age of vehicle is > 5 and <= 10	0.34
<i>Trip Attributes</i>	
Total number of trips during the day	4.19
Sum of home trip during the day	1.43
Sum of work trip during the day	0.58
Sum of school trip during the day	0.02
Sum of maintenance trip during the day	1.35
Sum of discretionary trip during the day	0.47
Sum of other trip during the day	0.03
Sum of pick-up/drop-off trip during the day	0.31
Total travel distance across all trips during the day	49.54
Average number of household occupants on all trips during the day	0.52
Average occupancy across all trips during the day	1.68
<i>Household Attributes</i>	
Average household size	3.03
Availability of vehicles (vehicle count / household size)	0.99
Ration of number of children to number of adults	0.21
*Households with income <= 44,999	0.19
*Households with income > 44,999 and <= 99,999	0.28
*Households with address in an urban area	0.71
*Households with address not in an urban area	0.23
<i>Person Attributes</i>	
*Individuals who are female	0.51
*Individuals who are non-workers	0.33
*Individuals with a Bachelors, Graduate or Professional Degree	0.44
*Individuals who can set or change start time of work day	0.28
*Individuals with age greater than equals 65	0.19
*Individuals who are White	0.85
*Individuals who are Black	0.05
*Individuals who are Hispanic	0.03
*Individuals whose occupation is sales / service	0.17
*Individuals whose occupation is Clerical / Administrative	0.08

Note:

* These represent indicator variables. Further, the corresponding value under column “mean” represents the percentages across observations in the sample

Table 2: Household Vehicle Fleet Composition and Utilization

Household Fleet Composition by Vehicle Type	Total	Household Fleet Usage by Vehicle Type														
		Auto	Van	Truck	SUV	SUV, Truck	Van, Truck	Van, SUV	Auto, Truck	Auto, SUV	Auto, Van	Van, SUV, Truck	Auto, SUV, Truck	Auto, Van, Truck	Auto, Van, SUV	Auto, Van, SUV, Truck
SUV, Truck	548	0	0	82	164	302	0	0	0	0	0	0	0	0	0	0
Van, Truck	138	0	62	21	0	0	55	0	0	0	0	0	0	0	0	0
Van, SUV	73	0	20	0	18	0	0	35	0	0	0	0	0	0	0	0
Auto, Truck	1043	381	0	169	0	0	0	0	493	0	0	0	0	0	0	0
Auto, SUV	1140	216	0	0	255	0	0	0	0	669	0	0	0	0	0	0
Auto, Van	380	90	73	0	0	0	0	0	0	0	217	0	0	0	0	0
Van, SUV, Truck	25	0	4	0	5	5	2	2	0	0	0	7	0	0	0	0
Auto, SUV, Truck	259	27	0	19	36	51	0	0	18	68	0	0	40	0	0	0
Auto, Van, Truck	94	5	8	5	0	0	16	0	20	0	16	0	0	24	0	0
Auto, Van, SUV	73	10	3	0	6	0	0	8	0	11	17	0	0	0	18	0
Auto, Van, SUV, Truck	17	2	2	1	0	0	1	3	0	0	0	0	0	3	0	5
Total	3790	731	172	297	484	358	74	48	531	748	250	7	40	27	18	5

Table 3: Daily Activity-travel Characteristics by Vehicle Type Chosen

Household Fleet Composition	Vehicle Type Selected	Frequency	Percentages	Mean Daily Travel Distance (miles)	Average Daily Trip Frequency	Number of Persons	Number of Household Members
	Auto	1518	40%	46.9	4.1	1.6	0.4
	Van	390	10%	48.4	5.0	2.2	0.9
	SUV	1095	29%	49.9	4.4	1.8	0.6
	Truck	787	21%	54.8	3.8	1.5	0.4
SUV, Truck	SUV	319	58%	47.1	4.4	1.9	0.6
SUV, Truck	Truck	229	42%	62.3	4.0	1.5	0.3
Van, Truck	Van	94	68%	45.6	5.2	2.5	1.0
Van, Truck	Truck	44	32%	36.5	4.0	1.6	0.5
Van, SUV	Van	36	49%	42.1	4.0	2.3	1.0
Van, SUV	SUV	37	51%	55.7	3.7	1.7	0.5
Auto, Truck	Auto	636	61%	46.7	4.0	1.6	0.5
Auto, Truck	Truck	407	39%	50.1	3.7	1.5	0.4
Auto, SUV	Auto	548	48%	43.1	4.1	1.5	0.4
Auto, SUV	SUV	592	52%	49.1	4.3	1.8	0.7
Auto, Van	Auto	193	51%	37.6	4.3	1.6	0.5
Auto, Van	Van	187	49%	54.3	5.1	2.0	0.8
Van, SUV, Truck	Van	10	40%	38.3	6.1	2.6	0.7
Van, SUV, Truck	SUV	9	36%	79.8	4.3	1.2	0.1
Van, SUV, Truck	Truck	6	24%	39.0	2.2	1.1	0.0
Auto, SUV, Truck	Auto	79	31%	63.2	3.9	1.4	0.3
Auto, SUV, Truck	SUV	115	44%	56.8	4.6	1.7	0.6
Auto, SUV, Truck	Truck	65	25%	75.5	3.8	1.6	0.5
Auto, Van, Truck	Auto	26	28%	44.0	3.9	1.3	0.2
Auto, Van, Truck	Van	36	38%	43.6	4.8	2.3	0.9
Auto, Van, Truck	Truck	32	34%	48.9	4.4	1.6	0.5
Auto, Van, SUV	Auto	32	44%	136.2	3.6	1.3	0.3
Auto, Van, SUV	Van	20	27%	32.5	3.8	2.3	1.2
Auto, Van, SUV	SUV	21	29%	51.0	4.6	1.9	0.8
Auto, Van, SUV, Truck	Auto	4	24%	27.0	4.8	1.6	0.6
Auto, Van, SUV, Truck	Van	7	41%	44.2	5.3	1.8	0.8
Auto, Van, SUV, Truck	SUV	2	12%	64.0	3.5	2.4	0.9
Auto, Van, SUV, Truck	Truck	4	24%	31.4	3.3	1.0	0.0

4. MODEL ESTIMATION RESULTS

As noted earlier, one of the key motivations of this research was to explore the interrelationships between vehicle type choice and daily distance traveled using the latent segmentation based modeling framework. The models were estimated in GAUSS statistical package. Further, in estimating the models, independent models assuming the two alternative interrelationship structures were used as starting points for estimating the latent segmentation based model.

As described in the methodology section, the latent segment representing the interrelationship structure takes the form of a binomial logit model, the vehicle type choice is modeled as a multinomial logit model and the distance traveled is modeled as a linear regression model. The choice alternatives in the latent segment model are the alternative interrelationship structures namely, the vehicle type choice affecting distance traveled and the distance affecting vehicle type choice. The alternatives for the vehicle type choice are auto, van, SUV, and truck with truck alternative serving as the reference category. Further, the choice set of vehicle type alternatives is varying with the decision maker and is based on the composition of the fleet of vehicle types in the household to which the decision maker belongs.

Table 4 presents a summary of the model estimation results. The complete model estimation results are presented in Table 5 and 6. Table 5 presents the specification of the latent segmentation component. The interrelationship structure where the vehicle type choice affects distance is assumed to be the chosen alternative with the alternate interrelationship structure serving as a reference. The table also presents the estimation results for the two choice dimensions namely, vehicle type choice and distance for interrelationship structure where vehicle type choice is made first and it affects the choice of distance traveled. Table 6 presents the model estimation results for the two choice dimensions under the alternate interrelationship structure where distance

affects vehicle type choice. In specifying the different models, a number of vehicle-², household-, and person-level exogenous variables were explored. Additionally, characteristics of planned activity-travel agendas were also used to explain the choice of vehicle type and distance. The estimation results are intuitive and are behaviorally plausible.

The structure where vehicle type choice affects distance will hereon be referred to as VTD and the alternative model structure where distance affects vehicle type choice will hereon be referred to as DVT. As can be seen from summary of the model estimation results in Table 4, the latent segmentation model results are significantly superior to other models. The Bayesian Information Criterion (BIC) value of 43405.059 for the latent segmentation model is much smaller than the BIC value for the independent model specifications of VTD and DVT. The superior fit of the latent segmentation model is also corroborated by the higher value of log-likelihood and the large McFadden's adjusted ρ^2 compared to the two independent model specifications.

Table 4 also reports interesting observations that lend credence to the notion that a single structure may not be appropriate to explain the interrelationships between choice variables for the entire population. It can be seen that the model estimation results point to shares of about 89 percent of the sample individuals following the VTD interrelationship structure and the remaining 11 percent of the sample individuals following the DVT interrelationship structure. The segment shares were obtained subsequent to the model estimation using the latent segmentation component of the model formulation. The probability of each individual belonging to either of the VTD or DVT latent segments was calculated utilizing Equation 4. The probabilities were then aggregated across the entire sample for each latent segment to obtain the segment shares shown in Table 5. Further, it can also be seen that individuals belonging to these two interrelationship structures also

² A variety of vehicle attributes including vehicle age, fuel type, and mileage were explored.

exhibit different preferences for the choice of vehicle type. In the VTD interrelationship structure, auto is the dominant vehicle type whereas in the DVT interrelationship, SUV is the dominant vehicle type. The difference in preferences of individuals belonging to the two interrelationship structures is also evident by examining the model specification of the distance traveled. Further, it can be seen from Table 4 that the mean daily travel distance for the VTD interrelationship is much smaller (33.1 miles) compared to the DVT interrelationship with a daily travel distance nearly six times larger (163.8 miles). This last observation of mean daily travel distances is consistent with what is behaviorally expected from individuals belonging to the interrelationship structures i.e. VTD interrelationship is associated with smaller travel distances whereas the DVT interrelationship is associated with larger daily travel distances.

The first column block in Table 5 shows the model estimation results for the latent segment model. Most of exogenous variables are significant at the five percent level of significance. The positive constant indicates that all other factors assumed to be equal between the two structures, individuals generally fall more within the VTD structure compared to the DVT structure. Individuals who do not reside in an urban area are negatively inclined to exhibit the VTD interrelationship structure. The negative inclination towards the VTD interrelationship structure is reasonable because these individuals likely have to travel farther to access opportunities and engage in activities. As a result, they may be making choices of distance first (i.e. selecting the destination locations) and then making choice of vehicle from the household fleet that offers them the best utility given the activity-travel engagement schedule. It is interesting to note that females are positively associated with exhibiting the VTD interrelationship structure. This appears plausible because females often assume household roles such as caring and tending to household members. Thus the female household members may be allocated a vehicle from the household

fleet first based on their assumed household roles and their activity-travel engagement schedule and subsequently the distance is determined afterwards. Non-workers may also be exhibiting a preference to exhibit the VTD interrelationship owing to the additional household responsibilities they may be shouldering compared to working household members.

4.1. Vehicle Type Choice Affects Distance Traveled

The second column block in Table 5 presents the coefficient estimates for the VTD interrelationship structure. Observing the constants, van appears to be the preferred alternative followed by auto and SUV compared to truck. In this interrelationship, the impact of auto on distance traveled is positive whereas the impact of van and SUV vehicle types is negative. It must be noted that all the effects of vehicle types on distance are only marginally significant or insignificant therefore caution must be exercised when making inferences. It is interesting to note that once the choice of the vehicle is made, the age of the vehicle has an impact on the distance traveled with newer vehicles and moderately new vehicles positively impacting the distance traveled. It may be the case that when individuals select newer vehicles, they are willing to assume activity responsibilities to farther destinations due to the reliability of the vehicle. It is also possible that individuals who select newer cars travel to farther destinations because of the pleasure derived in driving a newer car.

A host of activity-travel attributes were used to explain the choice of vehicle type and distance traveled. The number of household occupants on the trip has a negative impact on the choice of auto vehicle type but it positively impacts the SUV vehicle type. This is consistent with expectation because as the number of passengers increase, a larger body type is likely used owing to the comfort and convenience afforded by the larger body type. Also, as expected, the total number of planned trips during a day has a positive impact on the distance traveled. Further, the

type of activities pursued in a day was explored for inclusion in the model specification. Presence of a discretionary activity trip has a positive impact on choice of van as the vehicle type and presence of a maintenance trip in the daily activity agenda has a negative impact on the distance traveled.

Table 5 also includes results from the exploration of a number socio-economic and demographic attributes to explain the choice of vehicle type and distance traveled. It can be seen from the table that females prefer the auto vehicle type over trucks. Females also prefer to travel shorter distances as can be seen from the negative coefficient. Non-workers appear to prefer the auto vehicle body type. Individuals with work flexibility appear not to prefer the larger body types.

4.2. Distance Traveled Affects Vehicle Type Choice

Table 6 presents results for the DVT interrelationship structure. In this interrelationship structure the choice of distance traveled is assumed to be made first. The distance is then assumed to influence the choice of the vehicle type from the household fleet. Observing constants of the vehicle type choice model, van again appears to be the preferred alternative. However, it is interesting to note that the ordering of the other two vehicle types is switched in this interrelationship structure with SUV being preferred over auto when compared to truck. Distance traveled has a negative influence on the choice of auto, van, and SUV vehicle types. The number of occupants positively influences the choice of SUV. It also positively affects the distance traveled. The presence of discretionary activities also positively impacts the distance traveled.

In terms of the socio-economic and demographic attributes, the specification of the vehicle type choice model and the distance model in the DVT interrelationship structure is sparse compared to the VTD. This may partly be explained by the smaller share of individuals that follow this interrelationship structure and hence fewer observations to yield significant coefficient

estimates. The model estimations are valid nonetheless and provide behaviorally plausible interpretations.

Table 4: Model Estimation Summary

Model Fit	Log-likelihood	Number of Parameters	BIC	Adjusted ρ^2
Independent Specification: Vehicle Type Choice affects Distance	-24577.4299	36	49451.504	0.0068
Independent Specification: Distance affects Vehicle Type Choice	-24612.4116	33	49496.747	0.0055
Latent Segmentation Based Model of Vehicle Type Choice and Distance	-21463.5659	58	43405.059	0.1315
Latent Segment Characteristics				
Share of Individuals belonging to the interrelationship where Vehicle Type Choice affecting Distance	89.2%			
Share of Individuals belonging to the interrelationship where Distance affects Vehicle Type Choice	10.8%			
Interrelationship where Vehicle Type Choice affects Distance				
Average distance	33.1			
Share of Auto Vehicle Type	40.7%			
Share of Van Vehicle Type	10.1%			
Share of SUV Vehicle Type	28.4%			
Share of Truck Vehicle Type	20.7%			
Interrelationship where Distance affects Vehicle Type Choice				
Average distance	163.8			
Share of Auto Vehicle Type	31.8%			
Share of Van Vehicle Type	13.0%			
Share of SUV Vehicle Type	37.1%			
Share of Truck Vehicle Type	18.1%			

Table 5: Model Estimation Results for the Latent Segment, and Model Segment where Vehicle Type Choice Affects Distance Traveled

Variable Name	Latent Segmentation Model		Vehicle Type Choice Affects Distance							
			Vehicle Type Choice Model						Distance Model	
			Auto		Van		SUV		Coef	t-stat
Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat	Coef	t-stat	
Constant	1.9345	16.8	0.4543	4.258	0.5056	2.291	0.3878	4.506	17.7231	10.138
<i>Vehicle Type Choice</i>										
Auto									1.7085	1.45
Van									-1.8476	-1.10
SUV									-0.3671	-0.29
<i>Distance Traveled Across All Trips</i>										
<i>Vehicle Attributes</i>										
Age of vehicle <= 5 yrs									5.4076	4.69
Age of vehicle is > 5 and <= 10									2.6815	2.23
<i>Daily Activity-Travel Schedule Related</i>										
Number of household occupants			-0.1413	-1.90			0.3255	3.80		
Total number of trips during the day			-0.0353	-1.99					3.9951	19.89
Presence of a discretionary trip(s)					0.3530	2.09				
Presence of maintenance trip(s)									-7.5098	-7.72
<i>Household Related</i>										
Availability of vehicles					-0.3684	-1.69			1.5156	1.73
Income > 99,999					0.6340	3.47				
Income <= 44,999	0.2289	1.37								
Household not in urban area	-0.2480	-1.72	-0.2233	-2.19					9.3443	9.25
<i>Person Related</i>										
Female	0.2079	1.62	0.5729	6.58					-5.9128	-6.69
Age greater than equals 65					0.6155	2.78			-5.7153	-5.27
Non-worker	-0.3000	-2.24	0.1596	1.76						
Occupation - Clerical / Admin Support			0.8925	3.69	1.2932	3.55	1.0579	4.08		
Occupation - Professional, managerial	0.3054	2.18								
Occupation - Manufacturing/Construction			-1.0156	-5.51	-1.1462	-3.58	-1.2083	-5.12		
Work Flexibility					-0.7231	-3.69	-0.2348	-2.19		
σ									22.0313	54.73

Table 6: Model Estimation Results for Model Segment where Distance Traveled Affects Vehicle Type Choice

Variable Name	Distance Affects Vehicle Type Choice							
	Vehicle Type Choice Model						Distance Model	
	Auto		Van		SUV		Coef	t-stat
Constant	0.4118	1.08	1.9496	2.505	1.0314	2.137	71.6638	2.352
<i>Vehicle Type Choice</i>								
Auto								
Van								
SUV								
<i>Distance Traveled Across All Trips</i>	-0.0016	-1.31	-0.0022	-1.46	-0.0043	-2.82		
<i>Vehicle Attributes</i>								
Age of vehicle <= 5 yrs								
Age of vehicle is > 5 and <= 10								
<i>Daily Activity-Travel Schedule Related</i>								
Number of household occupants					0.6984	3.30	43.8865	3.56
Total number of trips during the day								
Presence of a discretionary trip(s)							39.0647	1.98
Presence of maintenance trip(s)					0.4569	1.25		
<i>Household Related</i>								
Availability of vehicles			-0.7862	-1.11			56.0655	2.30
Income > 99,999								
Income <= 44,999								
Household not in urban area	-0.3671	-1.04						
<i>Person Related</i>								
Female								
Age greater than equals 65								
Non-worker	0.3811	1.16						
Occupation - Clerical / Admin Support	0.8442	1.24						
Occupation - Professional, managerial								
Occupation - Manufacturing/Construction	-0.9687	-1.63			-1.2658	-1.99		
Work Flexibility					-0.6401	-1.75		
σ							182.6631	25.777

5. CONCLUSIONS

In this study, a latent segmentation based model is proposed that builds on the sequential approach to studying the interrelationships between choice variables. The latent segmentation model addresses one of the key limitations of earlier sequential approaches by accommodating the exploration of multiple interrelationship structures across choice dimensions of interest within a single modeling framework. Individuals are allocated probabilistically to different latent segments defined by interrelationship structures based on exogenous variables. The choice variables are then modeled according to the interrelationship structure within each latent segment. The latent segmentation based methodology was demonstrated in this study using data from the recent wave of the National Household Travel Survey (NHTS 2009) to study the interrelationship between choice of vehicle in households with multiple vehicles and the daily distance traveled. In exploring the choice of vehicle, it was assumed that vehicles of the same type (i.e. vehicle body type) appeal equally to individuals when making decisions. Therefore, individuals are actually assumed to be making a choice of the vehicle type from among available vehicle types and thus the associated behaviors of vehicle type choice are of interest.

A host of socio-economic and demographic attributes were explored to explain the vehicle type choice and distance behaviors. The results are plausible and consistent with expectations. One of the key findings from the research is the importance of accounting for multiple structures when explaining the interrelationship between choice dimensions of interest. In particular, it was found that different interrelationship structures between the vehicle choice and distance variables of interest (namely vehicle type choice affecting distance and distance affecting vehicle type choice) apply to different groups within the subpopulations. Further, assuming a single structure a priori to apply to all groups in the population ignore the potential differences that exist and could lead to

erroneous inferences. The interrelationship structure where vehicle type choice affects distance explains the vehicle usage behaviors of 89 percent of survey respondents and the interrelationship structure where distance affects vehicle type choice explains the vehicle usage behaviors for the remaining 11 percent of the survey respondents. Significant differences were observed in the model specifications of the vehicle type choice and distance under the two interrelationships. The empirical exercise sheds light on the presence of alternative interrelationship structures and highlights the need for employing model formulations that can accommodate the exploration of multiple interrelationship structures.

The study is not without limitations and the limitations open up avenues for future research and inquiry. First, the appropriate temporal scale of the shorter-term vehicle usage decision is still up for debate. In Konduri et al. (2011) a tour-level exploration of vehicle type choice and usage employing a discrete-continuous joint modeling framework provided significant results. On the other hand, in this empirical exercise, the choice dimensions modeled at a day-level also provided significant results. Therefore, it is not known if shorter-term vehicle usage is a tour-, day- or multiday-level choice process. Therefore, additional data in the form of multi-day travel diaries and panel data over a longer term period are needed to address this question. Second, the latent segmentation model proposed considers the two choice dimensions sequentially. The focus of this study was on modeling multiple interrelationship structures and in capturing variability of the choice variables from specification of the systematic component. However, it does not accommodate the error correlations due to common unobserved factors that may be affecting the two shorter-term vehicle usage variables. The exploration of such statistical improvements is left for a future exercise. Third, while the proposed approach is quite useful, it might be beneficial to compare the modeling approach to causal approaches such as structural equation modeling to

explore similarities and differences in the findings. Finally, the study comprises a person-level modeling of the vehicle choice from the household fleet and the distance traveled. However, vehicle type may be a household-level decision process that is influenced by the interactions and dependencies between members of the household. Therefore, future studies should incorporate this consideration in the analysis.

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