Individual Mobility Attributes and Their Impact on Modality Style

Comparison Across Three Population Sectors in Jerusalem, Israel

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Mobility attributes such as driver's license, car ownership, reserved parking at work, and transit pass have a very strong impact on travel choices, in particular, mode choice. Mobility attributes are not acquired for a particular trip but rather are driven by the entire set of individual travel needs (commuting being the most basic of them). Some mobility attributes, for example, car ownership and transit pass, are substitutable; others, for example, car ownership and reserved parking at work, are complementary. For this reason, mobility attributes have to be analyzed and modeled jointly. The purpose of the current research is to analyze a wide set of mobility attributes and incorporate them in an operational activity-based model as a set of midterm choices. The approach suggested in this paper is based on an iterative application of three interlinked choice submodels: (*a*) joint choice of person driver's license, usual driver role (priority in using one of the household cars), car type choice, reserved or reimbursed parking at work, and transit pass; (*b*) household car ownership choice by type; and (*c*) intrahousehold car allocation by type. Model estimation results confirmed strong cross-attribute effects as well as revealed many impacts of person, household, and travel accessibility variables. In particular, historical and cultural differences between three population sectors in Jerusalem—secular Jewish, Orthodox Jewish, and Arab—manifested themselves quite strongly. Application of these models for future scenarios is discussed.

Mobility attributes constitute a wide set of interrelated parameters that directly constrain (or induce) the use of certain modes of transportation. For each person, it includes disability (or any associated limited mobility), driver's license, employer-provided transportation to work (if any), car available for work, employer-provided or subsidized parking, school bus availability for students, transit pass (and any discounts or subsidy associated with it), bicycle ownership, and the like. Other important attributes are rather household based than person based in nature. They include car ownership and car allocation to (usual) drivers, parking constraints at home location, toll transponder (might be also person based or car based as defined by the toll collection rules). It is quite obvious that changing any of these attributes might have a crucial impact on person mode choice (and other travel) decisions. For this reason, various mobility attributes were included as midlevel choice in activity-based models (ABMs) (*1, 2*).

Mobility attributes are not acquired for a particular trip but are rather driven by the entire set of individual travel needs (commuting being the most basic of them). It has been recognized that some mobility attributes (for example, car ownership and transit pass) are somewhat substitutable and some other ones (for example, car ownership and reserved parking at work) are complementary. For this reason, different mobility attributes have to be better analyzed and modeled jointly than separately or sequentially (*3–5*).

Mobility attributes are strongly correlated with (latent) modality styles (*6*) (i.e., a priori mode preferences). For example, in the context of mode choice, those who have more cars available, reserved parking at work, and no transit pass, would quite probably be biased toward private car and against transit even if transit provides a much better level of service than car for the given trip. Some recent research suggests that these modality styles intertwined with mobility attributes play a major role in mode choice decisions contrary to the prevailing practice that relies on travel time and cost variables (*7, 8*).

There are many research works regarding particular mobility attributes. They include numerous models for car ownership (*9–13*) including those that address car type choice (*14–17*), joint car ownership and season transit ticket holding (*3–5*), joint choice of mode and toll route transponder (*18*), and the like. Recently, a more holistic approach to model mobility attributes in conjunction with other choices was reported, for example, integrated choice of residential location, car ownership, bicycle ownership, and commuting mode (*1*). An additional facet of intrahousehold allocation of cars to usual drivers or to actual tours and trips received attention recently (*19*).

The purpose of the current research was to synthesize the existing approaches, formulate a model for a wider set of individual mobility attributes with the interlinkages between them, and apply this model as part of the Jerusalem ABM.

THREE POPULATION SECTORS IN JERUSALEM

The population of the Jerusalem metropolitan region (1.1 million) consists of three major sectors that are characterized by significant differences in socioeconomic levels, lifestyles, mobility attributes, and travel behavior:

- Secular Jewish population (45%). Socioeconomic mix, household composition, and travel behavior of secular Jewish people are quite similar to those of most urban metropolitan areas in the Western world.

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• Orthodox Jewish people (27%). They are characterized by striking differences from the secular Jewish people, including significantly greater household size, with multiple children, lower income level and car ownership, and lower participation in the labor force, in that many male household heads attend Jewish religious institutions (Yeshivas) on a full-time basis.

• Arabs, primarily citizens of eastern Jerusalem (28%). Arabs also represent a significantly different population group. In relation to household size (large) and income (relatively low), they are somewhat closer to the Orthodox Jewish people. However, they have a unique household structure that frequently combines several generations and married siblings living together. In labor force participation, Arabs more frequently have female household heads playing a housewife role, while their male labor force participation is close to that of the secular Jewish people.

Subsequent statistical analysis is primarily based on the Household Travel Survey (HTS) of the Jerusalem metropolitan regions, completed in 2010. The survey included 8,230 households, with all household members reporting their person and household attributes as well as all activities and trips during a regular workday by using an innovative GPS-assisted prompted recall method. The method is based on both initial processing of the GPS traces and creation of a list of trips before the retrieval stage, a procedure that practically eliminated underreporting (*20*). The new HTS was compared with the previous one (1996), which included 1,187 households from the Jerusalem metropolitan region in the subsequent analysis.

OBSERVED TRENDS AND TENDENCIES FOR MOBILITY ATTRIBUTES

First, possession of a driver's license for persons age 18 and older is analyzed. This analysis includes comparisons across the three population sectors in Jerusalem as well as with selected metropolitan regions in the United States, where data in a compatible format were available. The authors used relatively recent HTSs from Phoenix, Arizona (5,000 households from 2008); San Diego, California (3,600 households from 2007); San Francisco Bay Area, California (15,000 households from 2000); Atlanta, Georgia (8,000 households from 2001); and Chicago, Illinois (14,000 households from 2007). Of particular interest were cross-sectional impacts of gender, age, and income, as well as understanding of the dynamic trends in Jerusalem.

Statistics on driver's license percentage by gender are presented in Figure 1. Striking differences were found between the three population sectors in Jerusalem and between Jerusalem and the U.S. metropolitan regions. The percentage of driver's license possession in Jerusalem is significantly lower than in the United States, with the secular Jewish population the only one somewhat approaching U.S. levels. However, even the secular Jewish population has a significant gender bias. The gender bias is more striking for the Orthodox Jewish population and Arabs. In the dynamics between 1996 and 2010, a logical tendency for growth appears in the share of potential drivers across all population sectors and genders, except Orthodox Jewish females. Across all metropolitan regions in the United States and across the three population sectors in Jerusalem a logical cohort effect occurs. Younger

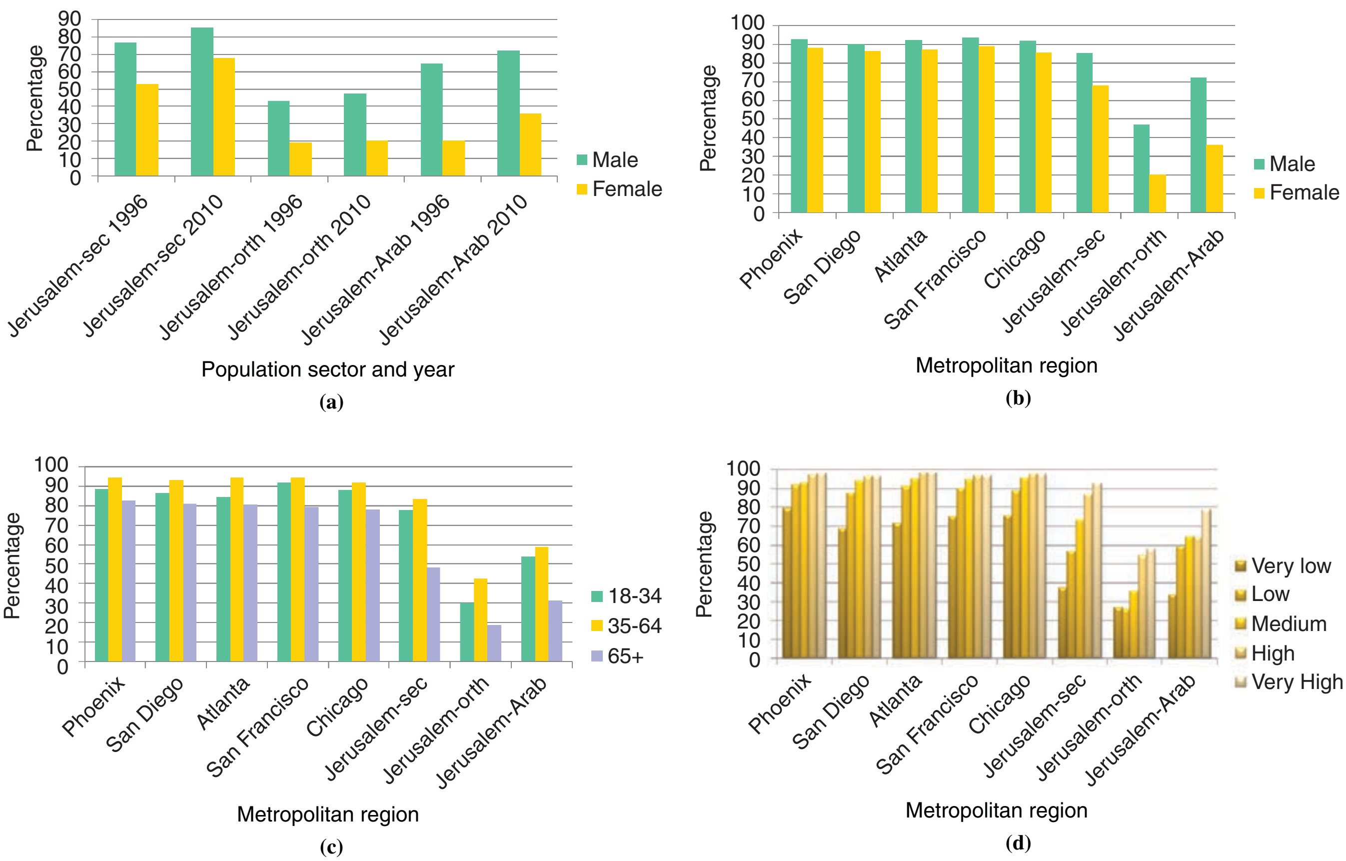

FIGURE 1 Trends in mobility attributes and comparison to Western countries: (*a*) gender effect dynamics, (*b*) gender effect comparison with United States, (*c*) age effect, and (*d*) income effect.

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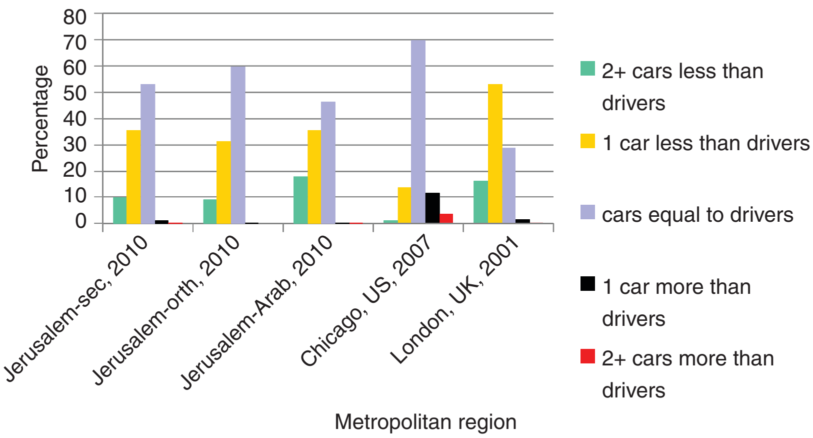
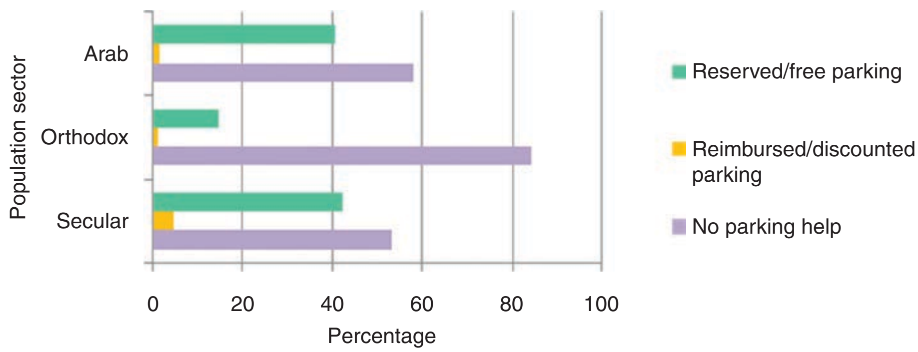


(e)



(f)

FIGURE 1 *(continued)* **Trends in mobility attributes and comparison to Western countries: (*e*) comparison of car sufficiency and (*f*) parking situations across population sectors.**

persons and older persons have a systematically lower percentage of driver's license holders than middle-age persons. The effect is less significant for younger persons and more significant for older persons.

Across all metropolitan regions, a logical positive correlation between income and driver's license holding can be seen. However, it is becoming less and less significant in the United States while it is still strong in Jerusalem. Even for the secular Jewish population, which is characterized by the highest average percentage of driver's license holders, the range is between 38% for the lowest-income percentile and 92% for the highest-income percentile. As with other distributions already discussed, the authors expect that the observed tendency will remain in Jerusalem but will be mitigated over time, approaching the U.S. distributions, except for Orthodox Jewish females.

The authors used relative car sufficiency, calculated as the difference between the number of cars in a household and number of drivers, for statistical analysis of car ownership. This measure allowed a pure effect of car ownership in addition to the growing percentage of driver's license holders to be revealed. The corresponding statistics for the three population sectors in Jerusalem are compared to data from Chicago and London, examples of urbanized metropolitan regions, in Figure 1. Overall, across all three population sectors in Jerusalem and in Chicago, the most frequent case is that the number of cars equals the number of drivers. Only the London data show a systematic shift toward "car deficiency," as the most common case is that the number of cars is one fewer than the number of drivers (with the majority being a household with two drivers and a single car). In Jerusalem, a significant share of households is car deficient, but this share is smaller than in London. Interestingly, the distribution by car sufficiency in Jerusalem is not dramatically different across the three population sectors; that is, the differences across population sectors are quite controlled by the number of drivers.

Another mobility attribute that is recognized as important in Jerusalem is parking condition at the workplace. In the HTS, every worker reported whether he or she had reserved, free parking provided (or fully reimbursed) by the employer, somewhat discounted (or partially reimbursed) parking, or no specific help. The corresponding statistics for Jerusalem are presented in Figure 1. A significant percentage of workers in Jerusalem is provided a free parking space by the employer. The percentage is lower for Orthodox Jewish workers; an explanation for this result is that many of them commute by transit or nonmotorized modes. In many respects, providing free parking to such a significant share of workers is an example of an antitransit policy that negatively affects modal split in Jerusalem and contributes to the growing congestion. In the authors' view, this situation represents one of the potential improvements in the transportation-related policy in Jerusalem.

MODALITY

The authors present several additional dimensions for statistical analysis to demonstrate the ways in which mobility attributes affect travel decisions, in particular mode choice (Table 1). The impact

TABLE 1 Impact of Mobility Attributes on Mode Choice Decisions

	Secular Jewish (%)			Orthodox Jewish (%)			Arab (%)		
Mobility Attribute	Auto	Transit	Nonmotorized	Auto	Transit	Nonmotorized	Auto	Transit	Nonmotorized
Zero cars, work trips	29	41	29	21	43	36	53	23	25
Cars fewer than adults, work trips	67	18	15	41	32	27	75	13	13
Cars equal to or more than adults, work trips	94	2	5	87	2	11	97	0	3
Zero cars, nonwork trips	24	28	49	15	19	66	29	21	50
Cars fewer than adults, nonwork trips	59	13	29	24	17	59	51	15	34
Cars equal to or more than adults, nonwork trips	82	3	15	68	6	26	87	3	9
Adult transit pass holders, work trips	35	51	13	21	60	20	61	29	10
Adults without transit pass, work trips	83	6	11	54	18	28	77	11	12
Adult transit pass holders, nonwork trips	44	30	27	21	40	39	61	16	23
Adults without transit pass, nonwork trips	72	8	19	29	17	54	61	15	24
Workers with reserved or subsidized parking, work trips	91	4	6	83	9	8	93	2	5
Workers without reserved or subsidized parking, work trips	65	20	15	34	38	28	62	20	18
Workers with reserved or subsidized parking, nonwork trips	89	2	9	74	7	19	89	2	9
Workers without reserved or subsidized parking, nonwork trips	70	9	22	32	22	46	60	13	26

of car ownership and car sufficiency is logical and very strong. For both work and nonwork trips, as well as across all three population sectors, higher car sufficiency is strongly correlated with a higher auto share in the modal split and a lower transit share. The tendency is somewhat stronger for nonwork trips, although they are characterized by a generally higher share of nonmotorized travel. The transit share for car-sufficient households is negligible.

Another strong and logical effect is associated with holding of a transit pass. For both work and nonwork purposes and across all three population sectors, holding of a transit pass proved to be a clear watershed between frequent and nonfrequent transit users. Those who do not have a transit pass are generally infrequent transit users. Transit pass holders constitute the cornerstone of transit ridership in Jerusalem. Therefore, it is essential to encourage people to acquire a transit pass through direct subsidy, reimbursement, or tax exemption by the employer, local government, or both. The impact of holding a transit pass is not observed for Arabs because, in eastern Jerusalem, the multitude of small transit operators of local lines does not apply transit passes.

An interesting and logical (although unexpected) effect of reserved parking was observed for modal split for nonwork trips made by workers. Across all three population sectors, workers with reserved parking at work proved to be much more car oriented than workers without reserved parking at work. This result does not follow the simple logic of a demand model because reserved parking at work is seemingly an irrelevant attribute for nonwork trips. Why would it have a systematic impact on nonwork trips? The answer lies in the individual-modality mechanism.

Modality is largely formed by commuting trips to work (and school) because they are the most frequent trips. Commuters by transit become more familiar with the transit system and acquire the corresponding attributes, like transit path. Commuters by auto are less familiar with the transit system and less equipped to use it. As some research in the United States indicated, a large percentage of the population is not even aware of transit service and does not consider it in the set of mode choices (*7*). Having reserved parking at work is a huge push to use an auto rather than transit for commuting, as Table 1 clearly shows. As a result, when the mode choice for nonwork trips is made, auto commuters with reserved parking are naturally inclined to use the auto.

STRUCTURE OF CHOICE MODELS FOR MOBILITY ATTRIBUTES

On the basis of regional conditions, for the Jerusalem ABM the following mobility attributes were recognized as the most important:

- Household car ownership by type and allocation. Four choice alternatives were defined with respect to car ownership (0, 1, 2, and 3 cars per household) as were seven type alternatives for each car as feasible combinations of three body types (1 = regular car, 2 = van–SUV, 3 = motorcycle) and three fuel types (1 = gasoline, 2 = diesel, 3 = hybrid); Body Types 1 and 2 were combined with the three possible fuel types, while Body Type 3 was combined only with Fuel Type 1.
- Intrahousehold car allocation to usual drivers. After the maximum number of cars was limited to three and truncation of the maximum number of drivers in the household by five on the basis of the observed data, this model results in $5 \times 4 \times 3 = 60$ alternatives in the choice set.
- Person driver's license. This attribute results in a binary choice modeled for each adult person.
- Person holding a transit pass. This attribute results in a binary choice modeled for each adult person.
- Person (worker) reserved parking. This attribute results in a trinal choice modeled for each worker (1 = fully paid–reserved, 2 = partially subsidized, 3 = no help).

Formulation of a choice model for the bundle of individual mobility attributes defined above is not a trivial task. This model has to address the following three aspects:

- Interactions and trade-offs between different mobility attributes. For this reason, development of a sequence of conditional-choice models, each one handling a particular mobility attribute, is not a good solution. However, a joint-choice model that includes all dimensions is not feasible as well, as a reconciliation of household-level and person-level attributes in a single choice tree is not straightforward. For example, if a complete joint model is formulated across all dimensions, even for a household with two adult members, it would include millions of combinatorial alternatives; this number explodes exponentially with the growing number of adults in the household.
- Sensitivity to a wide range of socioeconomic, demographic, and travel accessibility variables. Sensitivity is necessary to explain the existing cross-sectional relationships.
- Possibility of scenario analysis and incorporation of dynamic trends. Exploring different policy levers, through adjustment of constants or other model parameters, is necessary.

As part of the Jerusalem ABM, the authors suggested three interconnected-choice submodels that handle different mobility attributes. The system is applied in an iterative fashion with a feedback between the submodels to ensure that each mobility attribute has an impact on other attributes that eventually mimics a joint-choice model of all attributes; however, the decomposition into the three submodels makes the system manageable. This approach represents a particular case of the so-called blocked Gibbs sampler, for which discrete choice models are used to generate conditional distributions of which the joint distribution is constructed (*21*). The Gibbs sampler technique is important because it gives a theoretical background for the whole approach and substantiates convergence to a unique solution (at least under some general conditions).

The following three submodels and linkages between them were developed (Figure 2):

1. Person-level joint choice of driver's license, usual driver role, car type, reserved–reimbursed parking option (if person is a worker), and transit-pass holding. Usual driver role assumes that this person has a car for which he or she has the first access right, ahead of other household members. It can be thought of as an expression of the person's needs for a car. In an unconstrained framework, the household car ownership would be just a sum of the person car needs of household members. This submodel is estimated and applied in two versions. The first version is designed to start the iterative process

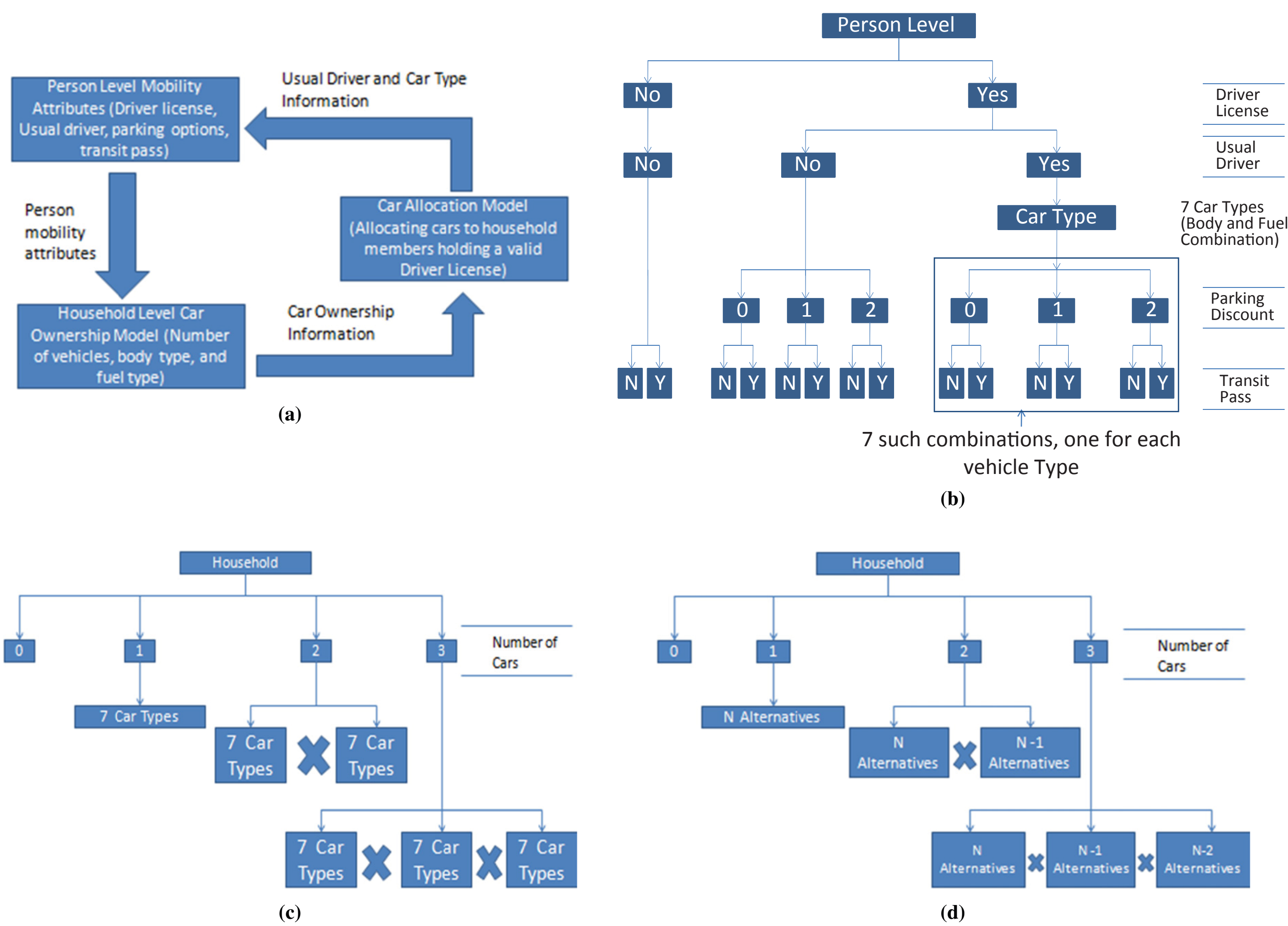


FIGURE 2 Three submodels for choice of individual mobility attributes: (*a*) linkage between submodels; (*b*) Submodel 1, person-level mobility attributes; (*c*) Submodel 2, household car ownership; and (*d*) Submodel 3, intrahousehold car allocation.

and includes all dimensions. The second version is applied on the subsequent iterations in a conditional fashion when the usual driver role and car type choices are refined by the other two submodels.

2. Household-level choice of number of vehicles by type. This submodel is estimated and applied conditionally upon person-level mobility attributes defined by the first submodel. However, a usual driver role and car type defined by the first submodel are not applied and are overridden by this household model. The essence of this overriding is that entire-household constraints now can be taken into account in addition to the person needs. For example, in a low-income household, only one car can be chosen despite two workers possibly exhibiting a need for a car at the person level. In contrast, in a high-income household at least one car would probably be chosen (for example, for weekend use or family events), even if all workers have no particular need for it.

3. Intrahousehold car allocation to usual drivers. This submodel is estimated and applied conditionally upon the household fleet of vehicles defined by the second model and other person-level mobility attributes (driver's license, reserved–reimbursed parking at work, and holding of a transit pass). Thus, this model defines only a usual driver for each car. The model system assumes that each household car has a single usual driver designated in the household survey. The data provided an insufficient number of cases of multiple cars assigned to the same driver in Jerusalem.

The proposed system of three submodels applied in an iterative fashion incorporates all types of cross-sectional effects and causality linkages between (household-level) car ownership and other (person-level) mobility attributes (Figure 2*a*). The proposed system is iterated several times in the ABM application (at each global iteration of the demand-network equilibration). Unfortunately, the word count limit precludes a discussion of model convergence, which will appear in future publications.

Submodel 1, for person-level mobility attributes, has the following nested logit structure, as shown in Figure 2*b.* The upper-level choice includes a binary driver's license–holding attribute as the most strategic one. At the second level, those who possess a driver's license are divided between usual drivers who have a priority in using a car and drivers who do not have a usual car. Drivers who do not have a usual car still can drive a car occasionally, but overall their priority of using a car is lower than that for usual drivers. At the third level, for usual drivers, Car Type 1 to 7 is predicted. At the fourth level, for workers, reserved or discounted parking at work is predicted. At the fifth level, for all adults, a binary choice of (monthly) transit pass is predicted. This model has 50 combined elemental alternatives at the lowest level. This submodel is applied as a full structure only at the beginning of the simulation process. When it is applied in a conditional fashion on subsequent iterations, the usual driver and car type attributes are fixed on the basis of the outcome of the other submodels. This method truncates the number of choice alternatives to eight if the person is not a usual driver (only driver's license, reserved parking, and transit path have to be predicted) and to six if the person is a usual driver (only reserved or discounted parking and transit path have to be predicted). The second version of this submodel refines details on other mobility attributes (driver's license, parking options, and transit pass) conditionally upon the predefined driver role and car type. In addition, the model is estimated only once for the entire structure. In the conditional application, the same exogenous variables are used, and the only difference is that certain choice alternatives become unavailable.

Submodel 2, for household car ownership, has the following hierarchical structure (estimated as a nested logit model), as shown in Figure 2. Four upper-level nests correspond to the number of cars. They themselves can be nested in several ways to account for a differential similarity across adjacent and nonadjacent alternatives. For example, having no car is a distinctive in-kind alternative; having two cars and having three cars are more similar than having one car. This principal difference between no car and one car can be captured only at the household level and does not fully emerge from the person-level needs. For example, one car is needed for weekends and family events that are not captured in the HTS. Thus, an additional mechanism should exist to push a household to have at least one car beyond a sum of individual person needs.

Under each nest are elemental alternatives that relate to car types. The one-car nest has seven alternatives. For two cars, $7 \times 8/2 = 28$ alternatives correspond to distinct nonordered pairs of car types. For three cars, $7 \times 8 \times 9/6 = 84$ alternatives correspond to distinct nonordered triples of car types. The number of elemental choice alternatives totals 120.

The third submodel for intrahousehold car allocation to usual drivers has the following structure (estimated as a multinomial logit model), as shown in Figure 2. The model is segmented by number of cars, and elemental-choice alternatives are formed for each car ownership category separately. However, in the model estimation, all observations and corresponding alternatives are processed jointly because they share the same utility components. Essentially, only one basic utility component that corresponds to a person type and car type pair is estimated. All utilities represent a linear combination of these basic components across the pairs of usual drivers and corresponding cars. For households with one car, up to five allocation alternatives exist. Households with two cars have up to $5 \times 4 = 20$ allocation alternatives (not allowing for one person to have more than one car). Households with three cars can have up to $5 \times 4 \times 3 = 60$ allocation alternatives. Because the cars are distinct in a general case, the order of cars in allocation is essential. The number of alternatives in the model structure is 85 but is available only as a subset of alternatives for each household and depends on the number of cars and number of drivers.

RESULTS OF MODEL ESTIMATION

Results of model estimation for unconditional person-level mobility attributes are shown as an example in Table 2. The results for other models are not shown because of space limits. In the table, "—" shows that the effect of the corresponding variable on the corresponding attribute is the same as that on the base attribute for the reference alternative.

The effect of person type is in line with the previous research. Full-time workers exhibit the most probability of having a driver's license, transit pass, reserved–reimbursed parking [for similar results, see Vovsha and Peterson (*5*) and Tsang et al. (*22*)]. Nonworkers and retirees are the most likely to be a usual driver when they have a driver's license. Part-time workers and university students have a relatively higher preference for motorcycles, which can be a manifestation of choosing a relatively less expensive vehicle type. Other observed effects of the person's age include that middle-aged people are the least probable to have a transit pass and that older household members prefer a bigger vehicle (*17*).

A unique feature of Jerusalem, as discussed earlier, is the three significantly different population sectors. Strong gender differences are observed for all sectors, with the weakest for secular Jewish households, which are closer to those of the United States in behavior. Both Arab and Orthodox Jewish females have a significantly lower probability of having a driver's license and usual driver role

TABLE 2 Estimated Results for Person-Level Mobility Attribute Model

Variable	Driver's License	Usual Driver	Transit Pass	Reserved Parking	Discounted Parking
Constant	6.989 (23.72)	0.627 (6.49)	5.575 (33.65)	−1.398 (−16.72)	−2.131 (−21.73)
Person type					
Full-time worker	—	—	—	—	—
Part-time worker	−0.615 (−3.68)	—	—	−0.582 (−7.67)	−0.190 (−1.95)
University students	−0.709 (−4.35)	—	−1.267 (−16.57)	−3.021 (−20.18)	−0.308 (−3.43)
Homemaker–nonworker or retiree	−1.105 (−7.95)	1.617 (7.98)	−5.110 (−16.90)	−6.636 (−20.98)	−1.608 (−8.17)
Age					
18–35 years	—	−0.726 (−13.69)	0.175 (2.74)	−0.174 (−3.12)	−0.745 (−6.03)
36–65 years	—	—	—	—	—
66+ years	−2.470 (−15.88)	0.284 (3.17)	0.089 (0.52)	—	−1.805 (−5.73)
Sector and gender (secular male as the base)					
Arab female	−3.687 (−16.89)	−0.298 (−2.44)	−2.326 (−8.60)	0.475 (3.25)	−2.177 (−3.68)
Arab male	−0.108 (−0.50)	0.258 (2.69)	−1.874 (−12.16)	0.515 (5.60)	−0.403 (−1.81)
Orthodox female	−5.103 (−24.33)	−0.999 (−8.03)	—	−0.935 (−7.39)	−2.059 (−5.66)
Orthodox male	−2.907 (−14.37)	−0.385 (−4.00)	−0.156 (−1.45)	−0.641 (−5.57)	−2.024 (−6.44)
Secular female	−2.232 (−13.62)	−0.075 (−0.99)	0.211 (4.54)	—	−0.253 (−3.24)
Flexibility in arrival time at work					
No flexibility	—	—	—	—	—
Some flexibility	—	0.119 (1.79)	—	0.562 (8.97)	0.651 (4.80)
High or not obliged to reach on time	1.200 (4.83)	0.222 (2.55)	−0.617 (−5.40)	0.407 (5.10)	1.225 (8.75)
Distance to work (continuous), km					
Distance	0.015 (1.35)	0.220 (7.08)	0.126 (3.75)	—	—
log(1+distance)	—	3.777 (6.42)	3.084 (4.83)	—	—
√(distance)	—	−3.548 (−6.60)	−2.485 (−4.25)	—	—
Accessibility					
log(1+auto accessibility)	—	—	—	—	—
log(1+transit accessibility)	—	—	−0.736 (−41.22)	—	—
log(1+nonmotorized accessibility)	—	—	0.125 (9.74)	—	—
Number of adults	−0.329 (−9.70)	−0.205 (−10.40)	0.133 (5.11)	—	—
Total number of children	−0.071 (−3.13)	—	−0.118 (−6.89)	—	—
Income effect (7,001–11,000 Israeli New Shekels as the base)					
0–3,500	−4.332 (−23.74)	−0.628 (−5.42)	−0.323 (−2.14)	−0.621 (−3.99)	−1.571 (−3.69)
3,501–7,000	−3.106 (−24.17)	−0.306 (−4.41)	−0.144 (−1.80)	−0.204 (−2.56)	−0.973 (−5.21)
7,001–11,000	—	—	—	—	—
11,001–19,000	—	0.293 (4.26)	−0.166 (−1.93)	0.557 (7.82)	—
19,001+	1.809 (5.59)	0.605 (6.03)	−0.972 (−5.94)	0.642 (6.60)	—
Parking availability at work location					
Deficit-free parking over jobs	—	—	—	0.088 (4.85)	—
Surplus-free parking over jobs	—	—	—	—	−0.090 (−2.48)
Deficit-free and paid parking over jobs	—	—	—	0.052 (4.47)	—
Deficit-free and restricted parking over jobs	—	—	—	—	0.184 (3.57)

NOTE: Interaction variables: usual driver and transit pass = −1.697 (−18.7); free parking and transit pass = −0.409 (−6.69); discount parking and transit pass = −1.271 (−7.1); usual driver and free parking = 1.909 (30.1); driver's license and transit pass = −0.701 (−10.29). Logsum parameter: driver's license versus non–driver's license = 0.342 (52.8[a]). Final log likelihood = 28,249.59.
[a]t-Statistic for the parameter is computed with respect to the value of 1.

than Arab and Orthodox Jewish males, respectively, but Orthodox Jewish females have a higher likelihood of having a transit pass.

Workers with higher flexibility in arrival time to work are observed to have the least likelihood of having a transit pass and a higher probability of a driver's license, usual driver role, and reserved–reimbursed parking at work (*7*). Several nonlinear distance-to-work terms were tested to capture the impact on holding a transit pass. The most behaviorally appealing forms included a combination of linear, log, and square root functions. The tendency to own a transit pass is quite low for a short (walkable) distance. It increases considerably after the walk-distance threshold (approximately 1 km). The rate of increase in the tendency of holding a transit pass diminishes as distance increases after a certain threshold (approximately 15 km).

Three accessibility measures (auto, transit, and nonmotorized) were included to evaluate the impact on transit pass utility. As expected, a decrease in auto accessibility, an increase in transit accessibility, or both promote the tendency to own a transit pass and thus the use of transit service (*8, 23*). Other demographic variables included are the number of adults, the number of children, and household income. An increase in the number of adults leads to an increase in the relative competition for the usual driver role of the car available in the household, and this competition compels the use of transit. The negative sign in Table 2 on the usual driver and the positive sign on transit pass manifest this trade-off. As expected, an increase in the number of children decreases the propensity to use a transit pass. A nonmonotonic effect of household income is observed for transit pass (which is not

Vehicle Type 1 (car, sedan with gasoline)	Vehicle Type 2 (car, sedan with diesel)	Vehicle Type 3 (car, sedan with hybrid)	Vehicle Type 4 (van or SUV with gasoline)	Vehicle Type 5 (van or SUV with diesel)	Vehicle Type 6 (van or SUV with hybrid)	Vehicle Type 7 (motorcycle)
—	–4.083 (–5.78)	–4.203 (–10.03)	–3.853 (–18.69)	–3.901 (–3.59)	–8.237 (–8.11)	–5.765 (–5.85)
—	—	—	—	—	—	—
—	—	—	—	—	—	1.373 (4.47)
—	–0.900 (–2.50)	–2.523 (–2.31)	–0.420 (–1.29)	–1.291 (–1.67)	—	1.373 (4.47)
—	–2.257 (–6.19)	–1.704 (–2.04)	–1.147 (–3.79)	–2.455 (–4.34)	—	—
—	0.959 (1.39)	—	—	1.093 (1.00)	—	2.281 (2.41)
—	1.025 (1.51)	—	—	1.486 (1.40)	—	1.659 (1.75)
—	—	—	0.519 (0.97)	—	—	—
—	—	—	–1.871 (–1.84)	–1.043 (–1.02)	–1.043 (–1.02)	–1.043 (–1.02)
—	0.497 (1.79)	—	—	—	—	—
—	—	—	0.345 (0.93)	–1.153 (–1.57)	–1.153 (–1.57)	–1.153 (–1.57)
—	0.630 (2.18)	—	—	–1.044 (–1.79)	–1.044 (–1.79)	–0.407 (–1.02)
—	–1.139 (–4.51)	—	—	–1.170 (–3.95)	–1.170 (–3.95)	–2.473 (–5.17)
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	0.110 (1.26)	–0.184 (–2.24)	—	—	—
—	—	—	–3.399 (–2.16)	—	—	—
—	—	–0.527 (–1.13)	3.125 (2.18)	—	—	0.121 (1.86)
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	–0.186 (–1.77)	—	—
—	0.094 (2.16)	—	0.193 (5.09)	0.281 (4.76)	0.281 (4.76)	—
—	—	—	–1.699 (–1.67)	–6.389 (–8.88)	–6.389 (–8.88)	–2.746 (–4.18)
—	–0.353 (–1.36)	–8.433 (–11.84)	—	–4.753 (–16.31)	–4.753 (–16.31)	–1.579 (–4.32)
—	—	—	—	—	—	—
—	—	–2.226 (–6.59)	—	–1.210 (–5.74)	–1.210 (–5.74)	—
—	—	–0.512 (–1.67)	0.530 (2.25)	–1.418 (–3.74)	–1.418 (–3.74)	1.100 (3.17)
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—
—	—	—	—	—	—	—

in line with the trend in Western countries). The authors observed that a person from a low-income household is least likely to have a transit pass. This observation may perhaps be attributable to the relative expense of a transit pass in Israel. A person from a middle-income household is most likely to own a transit pass, but the tendency to own a transit pass decreases for high-income households (because such households are more likely to use an auto).

In addition to the person and household characteristics, such parking-supply measures as total parking capacity and number of free parking spaces for each zone are applied. Surplus and deficit functions that relate free parking supply to total employment in the zone are applied to explain the demand or the necessity of reserved–reimbursed parking. A surplus of free parking over jobs is defined as the logarithm of the amount by which free parking exceeds total employment (set to zero if no surplus exists). A deficit of free and paid parking over jobs was defined as the logarithm of the amount by which the free and paid parking supply exceeds total employment or the logarithm of reserved parking, whichever is smaller (set to zero if no deficit exists). The authors observed that the tendency to provide reserved parking increases with an increase in the deficit of free and paid parking over jobs, and discounted parking decreases with an increase in the surplus of free parking over jobs. A large deficit of free and paid parking implies a parking problem, and thus reserved parking is more favorable. A greater surplus of free parking over jobs implies that finding a free parking space is relatively easy and the employer not need reimburse parking cost.

Other than person, household, and accessibility variables, the authors also explored interaction terms between various mobility attributes that show strong substitution or complementarity effects. Negatively correlated interactions include usual driver and transit pass; reserved parking and transit pass; reimbursed parking and transit pass; and driver's license and transit pass. In contrast, a positive correlation is observed between usual driver role and reserved parking. A nesting coefficient proved to be significant for the upper-level nest (i.e., having a driver's license versus not having a driver's license).

PLACEMENT IN ABM AND USE IN POLICY STUDIES

The developed model for mobility attributes is considered midterm, and it is placed after the population synthesis and long-term choices of usual workplace and school. Subsequently, the mobility attributes generated for each individual are used as explanatory variables in all day-level, tour-level, and trip-level travel choices. This placement reflects the fact that mobility attributes are primarily determined by commuting needs and that they largely shape individual modality; then, they dictate travel behavior with respect to other trips.

An important aspect of this research is how this system of submodels could be applied for policy analysis and future scenarios. This application is beyond the revealed cross-sectional dependencies in the base year. In this regard, the following four approaches can be considered:

- Generate the attribute through population synthesis from the base-year household sample; doing so helps avoid aggregation biases. However, it is not a policy-sensitive method, and it lacks dynamics. This approach can be recommended only for attributes such as disability.
- Explain attributes cross-sectionally by variables endogenous to the travel model, like transportation level of service and individual sociodemographic characteristics. This approach is the main paradigm adopted in the current research.
- Externally predict mobility attributes by using auxiliary (trend) models. Doing so may make sense for such attributes as driver's license, which is subject to long-term cohort effects. However, these types of models cannot provide individual distributions at fine geographic levels as required by an ABM. These models can supply aggregate targets only for recalibration of individual-choice models.
- Consider policy scenarios with respect to mobility attributes. Such attributes as reserved parking and, to some extent, holding of a transit pass represent examples for which individual choices can be strongly directed by promotions, discounts, and other regulations. An ideal model system would incorporate the corresponding policy levers directly as explanatory variables in the individual-choice model. However, in practice, this approach has some problems. First, it is not always possible to estimate a choice model with the policy-level variable explicitly (for example, car ownership with car price by type or transit pass with its cost) because this parameter has very little cross-sectional variation. Second, for such variables as reserved parking, the corresponding exogenous inputs cannot be provided at the necessary level of detail (for each job). Thus, more realistically, in model application, policy scenarios should be translated into aggregate targets for recalibration of individual-choice models.

Driver's license and reserved–reimbursed parking represent examples of mobility attributes that require dynamic trend analysis. Reserved–reimbursed parking can be also treated as a policy variable for future scenarios in which the observed trends might be reversed. Technically, reserved–reimbursed parking is expressed in the same recalibration procedure. However, the constants for the reserved parking alternative and reimbursed parking alternative are adjusted to replicate the target values for the corresponding number of workers. As they depend on the actual policy details, these targets can be stratified by geography, work occupation, or some other dimension. For example, one might envision a policy by which only 10% of workers with jobs in the downtown area will retain reserved–reimbursed parking. The model can be fine-tuned to replicate this target while the rest of the model system would respond appropriately (more transit passes and trips, probably fewer cars owned, etc.).

The attributes of car ownership and holding of a transit pass are considered primarily as endogenous choice dimensions subject to individual preferences. Some important policies, however, can also be envisioned with regard to these attributes. For example, one can envision a significant promotion of transit passes by discounts offered to certain population groups. Car ownership and vehicle type can also be a subject of a policy through, for example, taxation, direct price regulation, or fuel price regulation. Thus, it would be ideal to have these variables explicitly in car ownership utility functions. However, with the cross-sectional household survey, it is impossible to estimate coefficients for these variables. Therefore, the same approach for aggregate targets should be used. Making a choice model for mobility attributes directly sensitive to actual policy variables like prices and discounts through estimation of a combined revealed preference–stated preference model represents promising future research.

CONCLUSIONS ON MOBILITY ATTRIBUTES

Implemented statistical analysis and estimation of choice models for individual mobility attributes can be summarized as follows:

- Mobility attributes such as driver's license, car ownership, reserved parking at work, and transit pass have an extremely strong impact on travel choices, in particular, mode choice. In the ABM system, it is beneficial to have a special submodel for mobility attributes that predicts them. This submodel can be incorporated in an ABM as a set of midterm choices that are naturally placed after the population synthesis and usual locations of workplace and school but before the set of day-level models.
- Any particular pair of attributes has strong substitution or complementarity effects between them. Thus, mobility attributes cannot be predicted independently but rather must be modeled as a coherent set. The suggested approach is based on an iterative application of three interlinked choice submodels. Results of model estimation confirmed strong cross-attribute effects.
- Results of model estimation revealed many particular impacts of person, household, and travel accessibility variables on choice of mobility attributes. In particular, historical and cultural differences between the three population sectors in Jerusalem—secular Jewish, Orthodox Jewish, and Arab—were revealed quite strongly across all choice dimensions. In many cases, the differences between these population sectors could not be properly captured by a simple adjustment of alternative-specific constants in the choice models. These differences have a more structural character and were captured by full segmentation of certain variables (like gender) by population sector.
- A territory that is extremely important in practice but less charted relates to application of these models for future scenarios. A mechanical application of the model as it was estimated for the base year might not be the best strategy. Adjustment of the corresponding alternative-specific constants is recommended for future years. This

adjustment results in a model recalibration to match the established targets that reflect the observed or expected trends as well as the impacts of policies in future years. These targets need not be established in a detailed way. They rather have to be set at the aggregate regional level, where these corresponding trends can be predicted, while the model system would account for details in each particular geography and population segment. To establish future targets for Jerusalem, several other cities in the United States and the United Kingdom were used to portray the possible saturation levels, and comparisons were made to the previous HTS (1996) in Jerusalem to portray the actual trends in the past 14 years.

REFERENCES

1. Pinjari, A. R., R. M. Pendyala, C. R. Bhat, and P. Waddell. Modeling the Choice Continuum: Integrated Model of Residential Location, Automobile Ownership, Bicycle Ownership, and Commute Tour Mode Choice Decisions. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
2. Parsons Brinckerhoff. *The SANDAG CT-RAMP Activity Based Model. Toll Transponder Ownership Component.* San Diego Association of Governments, San Diego, Calif., 2011.
3. Beige, S., and K. W. Axhausen. Ownership of Mobility Tools During the Life Course. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
4. Beige, S., and K. W. Axhausen. Long-Term and Mid-Term Mobility Decisions During Life Course. Presented at 87th Annual Meeting of the Transportation Research Board, Washington, D.C., 2008.
5. Vovsha, P., and E. Petersen. Model for Person and Household Mobility Attributes. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2132,* Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 95–105.
6. Vij, A., A. Carrel, and J. L. Walker. Capturing Modality Styles Using Behavioral Mixture Models and Longitudinal Data. Presented at 2nd International Conference on Choice Modeling, Leeds, United Kingdom, 2011.
7. Outwater, M. L., G. M. Spitz, J. Lobb, M. Campbell, R. M. Pendyala, B. Sana, and W. Woodford. Project TCRP H-37: Characteristics of Premium Transit Services That Affect Mode Choice: Summary of Phase I. Presented at 90th Annual Meeting of the Transportation Research Board, Washington, D.C., 2011.
8. Badoe, D., and M. Yendeti. Impact of Transit-Pass Ownership on Daily Number of Trips Made by Urban Public Transit. *Journal of Urban Planning and Development,* Vol. 133, No. 4, 2007, pp. 242–249.
9. Bhat, C. R., and V. Pulugurta. A Comparison of Two Alternative Behavioral Choice Mechanisms for Household Auto Ownership Decisions. *Transportation Research Part B,* Vol. 32, No. 1, 1998, pp. 61–75.
10. Mohammadian, A., and E. J. Miller. Empirical Investigation of Household Vehicle Type Choice Decisions. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1854,* Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 99–106.
11. Feng, Y., D. Fullerton, and L. Gan. *Vehicle Choices, Miles Driven, and Pollution Policies.* Working paper 11553. National Bureau of Economic Research, Cambridge, Mass., 2005.
12. Brownstone, D., and H. Fang. Vehicle Ownership and Utilization Choice Model with Endogenous Resident Density. Presented at 88th Annual Meeting of the Transportation Research Board, Washington, D.C., 2009.
13. Potoglou, D., and Y. O. Susilo. Comparison of Vehicle-Ownership Models. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2076,* Transportation Research Board of the National Academies, Washington, D.C., 2008, pp. 97–105.
14. Bhat, C. R., and S. Sen. Household Vehicle Type Holdings and Usage: An Application of the Multiple Discrete–Continuous Extreme Value (MDCEV) Model. *Transportation Research Part B,* Vol. 40, No. 1, 2006, pp. 35–53.
15. Petersen, E., and P. Vovsha. Intrahousehold Car-Type Choice for Different Travel Needs. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1985,* Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 207–219.
16. Spissu, E., A. R. Pinjari, R. M. Pendyala, and C. R. Bhat. A Copula-Based Joint Multinomial Discrete-Continuous Model of Vehicle Type Choice and Miles of Travel. *Transportation,* Vol. 36, No. 4, 2009, pp. 403–422.
17. Vyas, G., R. Paleti, C. R. Bhat, K. G. Goulias, R. M. Pendyala, H.-H. Hu, T. J. Adler, and A. Bahreinian. Joint Vehicle Holdings, by Type and Vintage, and Primary Driver Assignment Model with Application for California. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2302,* Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 74–83.
18. Yan, J., K. A. Small, and E. C. Sullivan. Choice Models of Route, Occupancy, and Time of Day with Value-Priced Tolls. In *Transportation Research Record: Journal of the Transportation Research Board, No. 1812,* Transportation Research Board of the National Academies, Washington, D.C., 2002, pp. 69–77.
19. Vovsha, P., and E. Petersen. Incorporating Car-Type Preferences and Intrahousehold Car Allocation into Travel Demand Models. Presented at 86th Annual Meeting of the Transportation Research Board, Washington, D.C., 2007.
20. Oliveira, M. G. S., P. Vovsha, J. Wolf, Y. Birotker, D. Givon, and J. Paasche. Global Positioning System–Assisted Prompted Recall Household Travel Survey to Support Development of Advanced Travel Model in Jerusalem, Israel. In *Transportation Research Record: Journal of the Transportation Research Board, No. 2246,* Transportation Research Board of the National Academies, Washington, D.C., 2011, pp. 16–23.
21. Casella, G., and E. I. George. Explaining the Gibbs Sampler. *The American Statistician,* Vol. 46, No. 3, 1992, pp. 167–174.
22. Tsang, F., A. Daly, and F. Milthorpe. Forecasting Car Ownership in the Sydney Area. *Proc., Australasian Transport Research Forum,* Sept. 28–30, 2011, Adelaide, Australia.
23. Zegras, C. Transport. In *Chile: Energy Policy Review 2009,* International Energy Agency, Paris, 2009, pp. 209–232.

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