# Incorporation of Escorting Children to School in Modeling Individual Daily Activity Patterns of Household Members

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**Escorting children to school is a common travel arrangement in a household with schoolchildren. This escorting task affects travel patterns of the adult household members as accommodations are made for dropping children off at school or picking them up or doing both. Approaches to modeling joint travel arrangements between adults and children with respect to escorting have been previously suggested. However, examples of implementing such models in the framework of an operational activity-based model (ABM) are limited. This paper focuses on the explicit modeling of the escorting of children to school by adults and takes into account the possible bundling of escorting tasks in households with multiple children. The developed model is part of the regional ABM system currently being developed for the Maricopa Association of Governments in Arizona. Such a model allows for constraining the travel schedules of workers who tend to escort children on their way to and from work. Escorting has important policy implications because workers who escort children to and from school are very restricted in changing their departure times to and from work and in switching to transit; these restrictions are not evident otherwise. A choice model was formulated and estimated for each household by outbound (to school) and inbound (from school) escorting needs that were dependent on the number of schoolchildren, options of bundling children for escorting on one tour, and number of available chauffeurs in the household.**

Escorting children to school by adult household members (workers and nonworkers) is a frequent travel arrangement. Approximately 30% to 40% of schoolchildren in the major metropolitan regions in the United States are driven by one of the parents to school (*1*). Understanding the activity travel patterns of children is becoming increasingly important to various policy makers from the transportation perspective (*2, 3*) as well as from the general perspective of health and an active lifestyle (*4*). Further, there is a growing recognition that intrahousehold interactions need to be explicitly accommodated in travel models for realistic forecasts and policy evaluation (*2, 5, 6*).

School-travel behavior of children is strongly linked with the travel behavior of the parents and other adult household members. The interdependencies created between the travel patterns of parents and children have to be addressed in travel models. The need for escorting is characterized by a fixed schedule constraint on the school activity side; thus this arrangement requires a schedule consolidation on the side of the chauffeur. Escorting children to school is a complicated intrahousehold choice in which several considerations are intertwined including possible alternative mode options for children and chauffeurs, schedule constraints, as well as possible forms of escorting such as dropping children off at school on the way to work (ridesharing) versus escorting them in a separate tour (pure escort).

A good specific example of the effect of escorting on travel patterns is a two-way linkage between commuting mode choices made by the household heads and mode choices for schoolchildren. When the commuting choice is considered, the need for escorting a child to school frequently results in strong transit-averse behavior. In modeling terms, the implication is that when mode choice for workers is modeled the school mode choice should be defined first as an important constraint. However, if a very convenient transit option is offered to one of the workers in the household, rearranging the escorting responsibilities in the household might result (the other worker could take this task). Therefore the workers' mode choice should come first. In reality, these choices are closely intertwined and should have been modeled simultaneously, but doing so would result in an infeasible choice set size. Putting these choices into any sequence would always lead to a restricted sensitivity to some policies. If the school mode choice is modeled first, the model will probably be too conservative in shifting workers to transit when a good transit option is offered. If the worker mode choice is modeled first, the model will not be able to recognize that a policy such as improved school bus service might make many workers more receptive to commuting by transit.

Incorporation of an explicit model for school escorting decisions in the travel model chain before modeling of mode choices for workers and schoolchildren helps address these linkages and improve the integrity of the entire model system. It is also behaviorally appealing that intrahousehold escorting decisions would be modeled earlier than individual choices in the model chain. In general, joint activities and travel that require schedule consolidations from several household members should be prioritized in the modeled decision-making process.

Until recently the resulting choice construct was considered too complicated for an operational activity-based model (ABM), and the published research approaches were in general limited to modeling only one child at a time. Recently, because of the recognized importance of this factor in practice, several ABMs being developed in practice (e.g., for Houston, Texas, and Philadelphia, Pennsylvania)

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included this component in the model design (*6*). In this paper a general approach that can effectively handle the associated choice complexity for the entire household day is presented. The presented model is included as part of the operational ABM developed for the Maricopa Association of Governments (MAG).

## REVIEW OF THE LITERATURE AND COMPARISON WITH PROPOSED APPROACH

Escorting children to school has been recognized as an important phenomenon that strongly affects travel behavior, in particular, scheduling and mode choice of work commuters. There is a growing body of literature that analyzes this phenomenon in regard to the factors that form the need for escorting as well as the effect of escorting on other travel choices in the household.

Yoon et al. analyzed the spatial distribution of children's school commute behavior from three perspectives: unescorted travel to school, use of active modes for travel to school, and allocation of escorting tasks between parents (*3*). Propensity regression models with accessibility measures and population density around schools were used to identify spatial distributions of behavioral patterns. The combined effects of spatial variables are presented on maps to show the spatial patterns of behavior and intrahousehold interaction. These patterns show a negative effect of barriers such as park areas on independent mobility of children's travel to school and create different intrahousehold interaction patterns at different locations in the region.

Lemp et al. presented a conceptual model design for incorporating the school escorting model in the Houston–Galveston Area Council ABM (*6*). The paper discussed issues that arise from including such a model in the ABM, such as the linking of a half tour between child and adult, modeling stops on joint school tour legs, changes in the daily activity pattern, and tour mode choice models. The paper also identified the need to link half tours between multiple children sharing identical school tour patterns. Future work (as identified at the time of publishing) included analysis of these issues, estimation of a school escorting model, and measuring the effect of school escorting behavior on other models.

Several recent well-documented examples have been chosen; these are the most relevant for constructing an operational travel model, for a more systematic analysis and comparisons. Vovsha and Petersen presented a statistical analysis showing the importance of escorting children to school in the overall system of household activity and travel (*1*). A choice model was developed for possible inclusion in the regional ABM. For each individual school tour, seven outbound alternatives and seven inbound alternatives (including ridesharing with one of the three potential chauffeurs, pure escorting by one of the three potential chauffeurs, and a nonescort option) were considered. At the level of an entire school tour $7 \times 7 = 49$ escorting alternatives were generated. Empirical analysis and model estimation were implemented with the 2001 Atlanta regional household travel survey. Significant differences were revealed across children of different ages as well as across chauffeur characteristics (such as gender and work status) with respect to the propensity of different types of escorting. A very similar model structure was adopted for the Houston–Galveston Area Council ABM (*4*).

Guo et al. presented a sequence of logit models to handle the main travel dimensions related to escorting (*5*). First, the mode of travel to and from school is determined for the child. The following alternatives were considered: escorted by parents, escorted by others, school bus, and nonmotorized. If the chosen mode was escorted by parents, the escorting responsibilities were assigned to parents (father or mother) by using binary logit models. Results show that the mode is affected by the number of children going to school and the number of potential chauffeurs (workers and nonworkers) in the household. In most cases (70% for drop-off and 78% for pickup), the escorting responsibility was assigned to the mother. The allocation of escorting tasks was also dependent on the work start time and the work duration of the parent.

Yarlagadda and Srinivasan formulated a model to simultaneously determine the choice of mode and the escorting person for children's travel to and from school (*2*). This analysis considered an exhaustive set of travel modes including motorized and nonmotorized and explicitly identified the chauffeur as part of the mode-choice decision. Data from the *2000 San Francisco Bay Area Travel Survey* were used for the model estimation. Results showed that the characteristics of the child, employment and work flexibility of the parents, and distance to school strongly affect the school mode choice decisions. Also, significant differences were observed in the determinants of the mode choice behavior between the outbound (to school) and inbound (from school) directions.

Mammen et al. presented a cross-sectional analysis to examine perceptions of parents toward children's school travel and independent mobility (*4*). The study compared household demographics and perceptions of parents who let their children walk unescorted to and from school with those of parents who escort their children to and from school. A self-reported questionnaire (1,016 respondents) in the Greater Toronto and Hamilton area, Canada, was used for the analysis. Findings revealed that the factors affecting school escorting were the age of the child, closeness to school, English-speaking households, parents' perceptions of traffic volumes around the school, parents' choice to reside in current neighborhood, and parents' worry about strangers approaching their child.

He mentioned that independent mobility for children has been declining in many urban areas in the United States and has led to more escorting needs in the household (*7*). That study focused on dual-earner households and examined the factors that affect the decision to escort children to school. The household travel diaries from the 2001 *Southern California Association of Governments Post Census Regional Household Travel Survey* for the five-county Los Angeles region were used for this study. The findings revealed that the school escorting trip for children is dependent on parents' work schedule and location. Longer working hours reduce the probability of a child being escorted by a parent. However, work schedule flexibility compensates for the negative effect of long working hours. Results also revealed that the likelihood of a child being escorted to school increases with the closeness of the mother's workplace to school.

In the current study most of the explanatory factors that were found to be significant in previous studies were explored, and those that proved to be significant and nonduplicative were adopted. In general there is a great deal of consensus with regard to the main factors that affect escorting decisions. The factors that should be included are characteristics of the schoolchild (age and school location being the most agreed on), characteristics of the available chauffeurs (work schedule, gender, and work location being the most agreed on), household characteristics (such as income and car ownership), and specifics of possible escorting arrangements (e.g., in both directions or just in one). A very good behavioral foundation for understanding the escorting phenomenon is created. However, the actual model structure that could be incorporated in an operational regional model is yet far from being settled. In fact, only in three studies was the purpose of the study to develop an operational model (*1, 2, 5*).

The complexity of a model for school escorting arises from the multitude of interlinked travel dimensions and factors that affect school escorting decisions. The problem easily explodes if all possible options of escorting are enumerated in a household with several children and several chauffeurs. That is why all previous models considered a single child (one at a time), and additional decomposition of the choice was applied in some approaches. However, in a household with several schoolchildren, the children cannot be modeled independently or sequentially since the escorting decision inherently takes advantage of bundling several children on the same tour. That aspect is addressed specifically in the current research.

## STATISTICAL EVIDENCE ON ESCORTING CHILDREN TO SCHOOL

Table 1 and Table 2 show some key statistics on escorting children to school in the Phoenix and Tucson, Arizona, metropolitan regions, which constitute the MAG ABM modeled area. The data were drawn from the add-on 2008 *National Household Travel Survey.* The survey included 5,067 households on weekdays with 1,451 observed school tours, out of which 1,334 half tours in the outbound direction and 1,320 half tours in the inbound direction were adopted for statistical analysis and model estimation. The remaining tours were discarded as a result of reporting errors or missing attributes necessary for model estimation. Escorting frequency by main child characteristic (age) is presented in Table 1. Children were divided into three person types—preschool child (younger than 6 years old), pre-driving-age schoolchild (6 to 15 years old), and driving-age schoolchild (16+ years). Escorting frequency by chauffeur characteristics is presented in Table 2.

Every school tour has an outbound half tour and an inbound half tour. With respect to escorting arrangements, each half tour can be classified into one of the following three categories:

- Ridesharing. The child is dropped off or picked up by one of the household members on his or her mandatory tour to and from work or university.
- Pure escorting. A household member does not have any mandatory activity on this tour and escorts the child to school. A nonmandatory activity such as shopping, maintenance, or discretionary can be accomplished on this tour.
- No escort. The child travels to and from school alone (by school bus, transit, walking, etc.) or is escorted by a nonhousehold member.

Ridesharing and pure escorting together represent nearly 50% of the school tours as shown in Table 1. Also, there is a logical trend of increased escorting needs by child age (the younger the child is the more he or she relies on escorting). Ridesharing is characterized by a relatively higher percentage in the outbound direction compared with the inbound direction; this difference can be explained by easier schedule synchronization between schoolchildren and workers in the

**TABLE 1 Observed Escorting Frequency by Child Person Type**

| | Number of School Tours, by Child Person Type | | | | Percentage, by Child Person Type | | | |
|---|---|---|---|---|---|---|---|---|
| Escort Type | Driving-Age Schoolchild | Pre-Driving-Age Schoolchild | Preschool Child | Total | Driving-Age Schoolchild | Pre-Driving-Age Schoolchild | Preschool Child | Total |
| Outbound Half Tour | | | | | | | | |
| Ridesharing | 23 | 186 | 69 | 278 | 10.9 | 19.6 | 40.1 | 20.8 |
| Pure escort | 40 | 271 | 65 | 376 | 19.0 | 28.5 | 37.8 | 28.2 |
| No escort | 148 | 494 | 38 | 680 | 70.1 | 51.9 | 22.1 | 51.0 |
| Total | 211 | 951 | 172 | 1,334 | 100.0 | 100.0 | 100.0 | 100.0 |
| Inbound Half Tour | | | | | | | | |
| Ridesharing | 10 | 128 | 58 | 196 | 4.8 | 13.5 | 35.8 | 14.8 |
| Pure escort | 35 | 299 | 68 | 402 | 16.7 | 31.5 | 42.0 | 30.5 |
| No escort | 165 | 521 | 36 | 722 | 78.6 | 55.0 | 22.2 | 54.7 |
| Total | 210 | 948 | 162 | 1,320 | 100.0 | 100.0 | 100.0 | 100.0 |
| Outbound–Inbound Combinations | | | | | | | | |
| Ridesharing–ridesharing | 3 | 83 | 53 | 139 | 1.4 | 8.8 | 32.7 | 10.5 |
| Ridesharing–pure escort | 7 | 52 | 8 | 67 | 3.3 | 5.5 | 4.9 | 5.1 |
| Ridesharing–no escort | 12 | 49 | 3 | 64 | 5.7 | 5.2 | 1.9 | 4.8 |
| Pure escort–ridesharing | 4 | 10 | 2 | 16 | 1.9 | 1.1 | 1.2 | 1.2 |
| Pure escort–pure escort | 21 | 186 | 51 | 258 | 10.0 | 19.6 | 31.5 | 19.5 |
| Pure escort–no escort | 15 | 75 | 7 | 97 | 7.1 | 7.9 | 4.3 | 7.3 |
| No escort–ridesharing | 3 | 35 | 3 | 41 | 1.4 | 3.7 | 1.9 | 3.1 |
| No escort–pure escort | 7 | 61 | 9 | 77 | 3.3 | 6.4 | 5.6 | 5.8 |
| No escort–no escort | 138 | 397 | 26 | 561 | 65.7 | 41.9 | 16.0 | 42.5 |
| Total | 210 | 948 | 162 | 1,320 | 100.0 | 100.0 | 100.0 | 100.0 |
| Symmetric Outbound–Inbound Combinations with Same Chauffeur | | | | | | | | |
| Ridesharing–ridesharing | 3 | 70 | 49 | 122 | 1.4 | 7.4 | 30.2 | 9.2 |
| Pure escort–pure escort | 18 | 167 | 45 | 230 | 8.6 | 17.6 | 27.8 | 17.4 |

**TABLE 2 Observed Distribution of Escorted School Tours by Chauffeur Person Type**

| Escort Type | Unknown Person Type | Full-Time Worker | Part-Time Worker | University Student | Nonworker (younger than 65 years) | Retired (65 years or older) | Schoolchild (16 years or older) | Total |
|---|---|---|---|---|---|---|---|---|
| | Number (percentage) of Escorted School Tours, by Chauffeur Person Type | | | | | | | |
| Outbound Half Tours | | | | | | | | |
| Ridesharing | 0 (0.0) | 216 (74.2) | 32 (11.0) | 37 (12.7) | 6 (2.1) | 0 (0.0) | 0 (0.0) | 291 (100.0) |
| Pure escort | 0 (0.0) | 124 (31.3) | 69 (17.4) | 22 (5.6) | 175 (44.2) | 6 (1.5) | 0 (0.0) | 396 (100.0) |
| Inbound Half Tours | | | | | | | | |
| Ridesharing | 41 (25.6) | 109 (68.1) | 22 (13.8) | 25 (15.6) | 4 (2.5) | 0 (0.0) | 0 (0.0) | 160 (100.0) |
| Pure escort | 77 (22.6) | 88 (25.9) | 68 (20.0) | 18 (5.3) | 162 (47.6) | 4 (1.2) | 0 (0.0) | 340 (100.0) |
| Symmetric Outbound–Inbound Combinations with Same Chauffeur | | | | | | | | |
| Ride–ride | 0 (0.0) | 85 (66.9) | 17 (13.4) | 21 (16.5) | 4 (3.1) | 0 (0.0) | 0 (0.0) | 127 (100.0) |
| Escort–escort | 0 (0.0) | 60 (24.7) | 44 (18.1) | 7 (2.9) | 129 (53.1) | 3 (1.2) | 0 (0.0) | 243 (100.0) |

morning. For the entire tour, the symmetric escorting types in both directions are the most frequent cases.

Potential chauffeurs are divided into six person types:

- Full-time workers,
- Part-time workers,
- University students,
- Nonworkers younger than 65 years old (e.g., homemakers),
- Retired (65 years or older), and
- Driving-age schoolchild (16 years or older).

Driving-age schoolchildren can play a role as chauffeurs for younger children in the household or may require escorting by other household members. There are no observed cases of a driving-age schoolchild acting as a chauffeur, as shown in Table 2. Full-time workers and nonworkers serve as chauffeurs for most school tours, and retired household members rarely escort children to school.

## PLACEMENT OF ESCORTING SUBMODEL IN ABM MODEL CHAIN

The general model framework adopted for MAG ABM follows the coordinate travel and regional activity modeling platform family of models [see Vovsha et al. for details (*8*)]. However, most of the linkages between the escorting submodel and other submodels would be similar to those in other ABM structures. The proposed escorting model is applied in the ABM system after the following submodels:

- Population synthesis;
- Long-term choices of work locations for workers and school locations for students;
- Midterm choices for an individual mobility attribute such as household car ownership and person transit pass holding;
- Daily activity pattern type for each household member that defines whether the person has an out-of-home work or school activity, has some other out-of-home activities but not work or school, or is not travel active on the given day; and
- Preferred time-of-day choice for all work and school activities planned for the day (tours).

Placement of the escorting model in the day-level activity participation, the tour formation and time allocation submodels, as well as main linkages between them are shown in Figure 1. In the escorting choice submodels, the outcomes of the previous submodels are considered as inputs. In particular, all school tours and corresponding escorting needs in regard to school activity start and end times are known as are potential chauffeurs (adult household members with an active travel day). In addition, all chauffeurs are broken into two groups: (*a*) workers and students who have a work or school activity on the given day and could incorporate escorting as an additional stop on the way to work or school and (*b*) nonworkers who do not have a work or school activity on the given day and could escort children to or from school or both as a separate home-based tour. In the case of ridesharing, the preferred work or school schedule of the chauffeurs provides an important constraint in the schedule consolidation process.

Engagement in an escorting activity either as the chauffeur or as an escorted child has an effect on the following subsequently modeled choices:

- All nonwork tours and activities modeled for chauffeurs are subject to whether an escorting activity is assigned to the person; if the chauffeur is a worker, the escorting activity is inserted as a stop on the work tour; if the chauffeur is a nonworker, the escorting activity forms a separate nonwork tour. The mode for the work tour with escorting or for the escorting tour is assumed to be auto (except for very short tours for which nonmotorized modes are also considered). A schedule consolidation procedure for workers is applied that synchronizes the original work schedule with the school schedule of the escorted child.

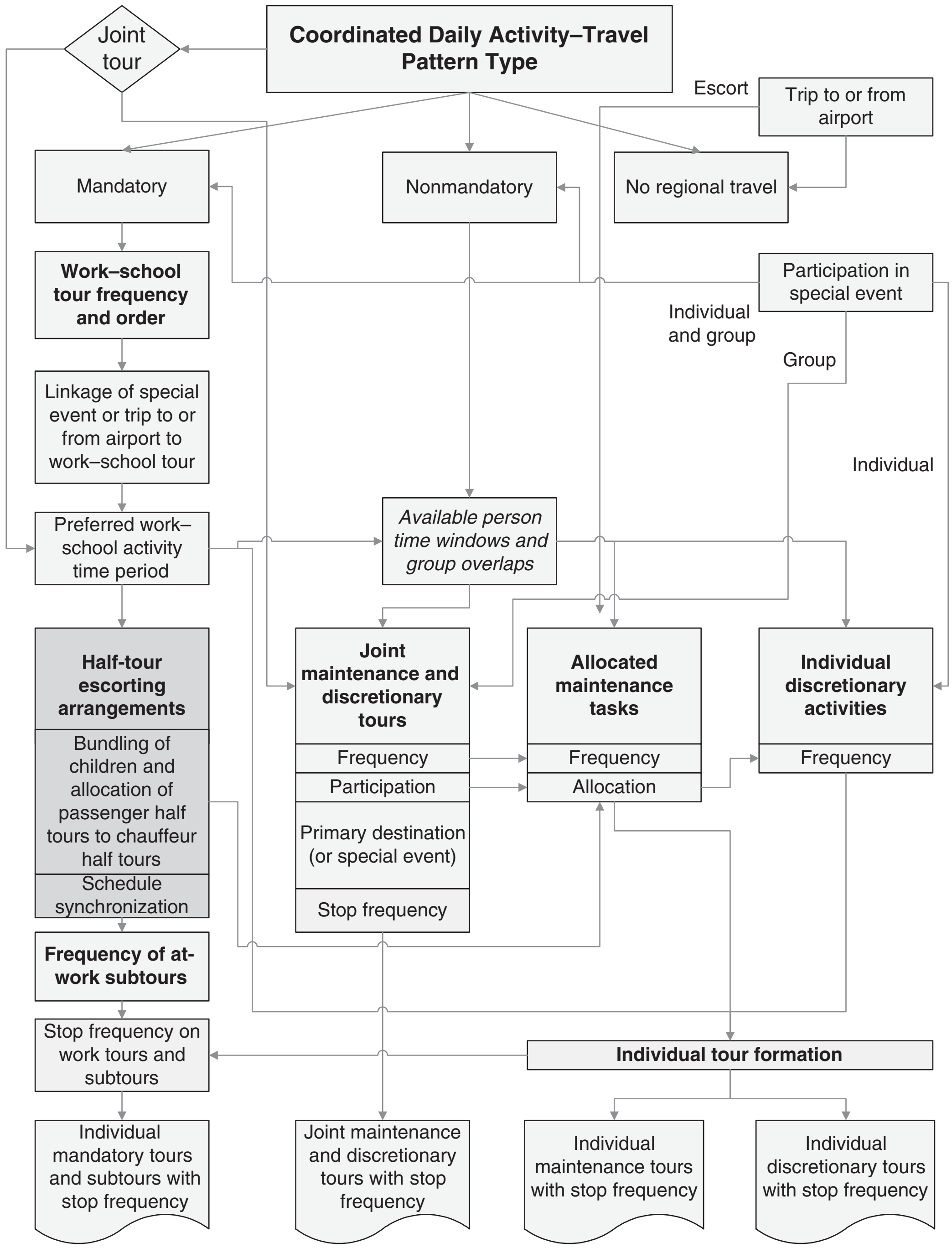


FIGURE 1 Placement of escorting submodel in ABM model chain.

- For children who are escorted to school the assumed mode is auto passenger (except for short distances to school for which nonmotorized modes are also considered). If a child is escorted, no additional stops are modeled on the corresponding school half tour except for cases in which several children are escorted by the same chauffeurs on the same tour. Children who are not escorted by household members can choose a different mode for the school tour (transit, school bus, or nonmotorized) or can be escorted by a nonhousehold member.

## CHOICE MODEL SPECIFICATIONS

### Defining Choice Alternatives

The choice model was applied for the entire household day and involved the following household members who were modeled simultaneously:

- Up to three schoolchildren with escorting need including day care, preschool children, and schoolchildren. If a household had more than three children with escorting needs, the youngest three were considered in the model. Because younger children are limited in individual mobility, the escorting needs for them were considered first. That case covers more than 99% of the observed cases of escorting.

- Up to two potential adult chauffeurs with an active travel pattern on the given day including workers, nonworkers, retirees, university students, and schoolchildren of driving age. If a household had more than two chauffeurs available, a rule-based algorithm was applied to choose the most probable ones based on the person type (for example, female nonworkers and part-time workers proved to be the most frequent child chauffeurs). In the available data set, that case covers 100% of the observed cases. In other words the survey of more than 5,000 households did not include a single case in which three or more different chauffeurs were engaged in escorting children to school on the same day.

The modeled choice alternatives for each household with school tours are shown in Table 3. The total number of choice alternatives of this model is formidable when all escorting alternatives with respect to children's needs are combined with the possible assignment of chauffeurs and escorting type (ridesharing versus pure escort). For a household with three children going to school, there are 15 combinations of bundling options and escorting needs that can create zero, one, two, or three school-escorting tasks. For each escorting task there are up to four possible chauffeur assignments:

- First chauffeur, escorting on the way to and from work;
- First chauffeur, pure escorting as a separate home-based tour;
- Second chauffeur, escorting on the way to and from work; and
- Second chauffeur, pure escorting as a separate home-based tour.

For a household with three children and two available chauffeurs, the number of unique alternatives considering both directions will constitute $189 \times 189 = 35{,}721$. The choice tree is truncated significantly for smaller households with respect to the number of children (one or two instead of one) or the number of chauffeurs (one instead of two) or both. In the model estimation and application, the entire structure is considered to cover all possible cases in which smaller households are treated by making irrelevant alternatives unavailable.

Since a simultaneous estimation of a joint choice model with all possible alternatives is technically cumbersome, a decomposition method is applied. In general, the escorting decisions in outbound and inbound directions are in many respects independent of each other; however, there can be a limited number of linking factors. The linkage between outbound and inbound escorting decisions includes the fact that the same child who relies on escorting when going to school might be more dependent on escorting from school since he or she would be less likely to use transit and the school bus. On the chauffeur side, the same person would probably take care of escorting in both directions because of willingness to adjust the schedule or of school's proximity on the way to and from work or both. This linkage creates some symmetry in outbound and inbound escorting decisions that cannot be completely ignored. For that situation, the model is decomposed into the following sequence choices applied iteratively:

1. Choice of outbound escorting arrangements independently of inbound arrangements,
2. Choice of inbound escorting arrangements conditional on the chosen outbound arrangements,
3. Choice of outbound escorting arrangements conditional on the chosen inbound arrangements, and
4. Iteration of 2 and 3 until convergence occurs in regard to aggregate shares of the chosen alternatives across all modeled households in the synthetic population.

This approach represents a particular case of the (so-called) blocked Gibbs sampler in which discrete choice models are used to generate

**TABLE 3 Number of Escorting Alternatives by Choice Dimensions**

| | Escorting Need and Bundling for Three Children[a] | | | Number of Escorting Tasks After Bundling | Number of Chauffeur Assignments and Escort Types[b] |
|---|---|---|---|---|---|
| Alternative | First | Second | Third | | |
| 1 | Escort with second and third | Escort with first and third | Escort with first and second | 1 | 4 |
| 2 | Escort with second | Escort with first | Escort separately | 2 | $4 \times 4 = 16$ |
| 3 | Escort with third | Escort separately | Escort with first | 2 | $4 \times 4 = 16$ |
| 4 | Escort separately | Escort with third | Escort with second | 2 | $4 \times 4 = 16$ |
| 5 | Escort separately | Escort separately | Escort separately | 3 | $4 \times 4 \times 4 = 64$ |
| 6 | Escort with second | Escort with first | No escort | 1 | 4 |
| 7 | Escort separately | Escort separately | No escort | 2 | $4 \times 4 = 16$ |
| 8 | Escort with third | No escort | Escort with first | 1 | 4 |
| 9 | Escort separately | No escort | Escort separately | 2 | $4 \times 4 = 16$ |
| 10 | No escort | Escort with third | Escort with second | 1 | 4 |
| 11 | No escort | Escort separately | Escort separately | 2 | $4 \times 4 = 16$ |
| 12 | Escort separately | No escort | No escort | 1 | 4 |
| 13 | No escort | Escort separately | No escort | 1 | 4 |
| 14 | No escort | No escort | Escort separately | 1 | 4 |
| 15 | No escort | No escort | No escort | 0 | 1 |

[a]Calculated for outbound and inbound directions separately.
[b]Total = 189.

conditional distributions of which the joint distribution is constructed through an iterative procedure (*9*). The blocked Gibbs sampler gives a theoretical background for the suggested approach and substantiates convergence to a unique solution at least under some general conditions.

### Utility Structure and Explanatory Variables

A number of variables were tested in the statistical estimation procedure, including person attributes of potential chauffeurs and characteristics of their work or university tours, person attributes for the child and his or her school tour, household attributes, as well as choices made for the other school escort half tour (outbound for inbound escorting and vice versa). The utility function is calculated for the outbound and inbound direction separately and includes the following components:

- For each child, a utility of being escorted versus going to school on his or her own (by transit, school bus, nonmotorized mode, or as a passenger of a nonhousehold carpool) is formulated as a function of the corresponding level-of-service characteristics (such as distance to school and travel time to school), person variables (such as age), and household characteristics (such as income and car sufficiency).
- For each chauffeur, a (dis)utility of taking an escorting task is formulated. For workers and university students, this disutility is associated primarily with a detour for the school from their direct commuting route (calculated as additional distance traveled to accommodate the school escorting stop). For nonworkers, this disutility is associated primarily with the distance and time to implement the escorting task as well as the schedule adjustment needed to accommodate escorting. Bundling of several children on one half tour reduces the total detour or travel time from home compared with escorting each of them separately. Chauffeur's access to work or university location by walking (considered only if it is within 3 mi) also increases the chance of taking up escorting tasks. Person characteristics such as gender, age, and person type (worker, student, retiree, etc.) were also statistically tested.
- For each child, a symmetry component for escorting need is included to address the fact that in general it is inconvenient to have escorting in only one direction. This component creates a linkage between escorting decisions made for the outbound and inbound directions.
- For each child and chauffeur combination, a symmetry component for escorting task allocation is included to address the fact that escorting tasks for the same child are more frequently implemented by the same chauffeur than by different chauffeurs. This component creates a linkage between escorting decisions made for outbound and inbound directions.
- For each household (with cars), the number of cars versus number of escorting tasks is also included in the utility to address the need for bundling based on car availability.
- Availability of ridesharing is dependent on the departure time (for outbound half tour) or arrival time (for inbound half tour) synchronization for chauffeur's mandatory tour and child's school half tour. A 30-min time discrepancy in reported departure and arrival times is allowed as a threshold for availability of an alternative with specific chauffeur and child. The same rule is applied in model application conditional on initial work and school schedules.

The proposed model avoids nonbehavioral flat constants for each particular escorting alternative. Thus, the utility of each alternative is composed of the corresponding components that reflect the worth of each particular arrangement from the perspective of all household members involved.

## MODEL ESTIMATION RESULTS

The estimation results for the escorting models are presented in Table 4. There are two versions of the outbound escorting model (with and without dependence on the inbound escorting model outcomes) and one inbound escorting model (dependent on outbound escorting model outcome). The unconditional (marginal) outbound model is applied to start the application iterative procedure, while the subsequent models are applied in a conditional fashion. The results include the coefficients and *t*-statistics for the final model specifications. All models currently have multinomial logit specification. Main behavioral insights from the model estimation are summarized below.

Logically, part-time workers and nonworkers have a higher propensity than full-time workers toward pure escorting in both directions. Also, part-time workers are less likely to participate in ridesharing in the outbound direction but more likely to do so in the inbound direction. Outbound ridesharing is feasible when the start times for work and school match, which usually is the case for full-time workers since most schools start between 8:00 and 9:00 a.m. Part-time workers may have later departure times for the outbound commute but they might be better able to match the afternoon school closing times with earlier inbound work departure times, which is evident from the positive coefficient for ridesharing in the inbound direction. Overall, females have a higher participation in ridesharing and pure escorting in both directions.

Route deviation has a significant negative effect on outbound and inbound ridesharing. Coefficients on both absolute detour (longer total commute distance) and relative detour (versus the direct commute distance) are statistically significant and negative. For pure-escort tours, the distance to school was not found to be negative as expected in the chauffeur utility component. This variable is correlated with the distance-to-school term for the child and is therefore difficult to estimate in a joint model. Total auto travel time to and from work proved to negatively affect ridesharing in the inbound direction. The option of nonmotorized mode for work commute worked in favor of escorting in the outbound direction but against it in the inbound direction. Workers whose workplace is close to home (within 3 mi; thus they could walk to and from work) can be more involved in dropping off children at school in the morning for two reasons. First, shorter commute reduces the overall time pressure in the morning. Second, these households are located primarily in more urban neighborhoods where schools are also located close to home. Since it is more difficult to match time schedules of children and workers in the afternoon, a walk tour from work to school and then to home in the inbound direction is not frequently observed.

For a child, the age is one of the most important determinants of whether he or she needs escorting or not. Preschoolers (younger than 6 years old) demand more escorting than a pre-driving-age schoolchild (6 to 15 years old), who demands more escorting than a driving-age schoolchild (16+ years). Within the pre-driving-age schoolchild category, the age group of 6 to 9 years is more dependent on escorting as compared with the 10- to 15-year-old group.

**TABLE 4 Estimation Results**

| | Outbound Half Tour[a] [coefficient (*t*-statistic)], by Escort Type | | | Outbound Half Tour[b] [coefficient (*t*-statistic)], by Escort Type | | | Inbound Half Tour[c] [coefficient (*t*-statistic)], by Escort Type | | |
|---|---|---|---|---|---|---|---|---|---|
| Variable | Ridesharing | Pure Escort | No Escort | Ridesharing | Pure Escort | No Escort | Ridesharing | Pure Escort | No Escort |
| Chauffeur and Commuting Characteristics | | | | | | | | | |
| Female | –0.0805 (–0.3) | –0.934 (–2.9) | | 0.3624 (1.7) | –0.5477 (–1.8) | | 1.1327 (2) | –0.3794 (–1.1) | |
| Male | –0.4602 (–1.5) | –0.8996 (–2.7) | | | –0.5716 (–1.8) | | 0.8256 (1.5) | –0.6781 (–1.9) | |
| Part-time worker | –0.097 (–0.3) | 0.5019 (1.5) | | –0.6244 (–1.4) | 0.3205 (0.9) | | 0.3059 (0.5) | 0.2629 (0.7) | |
| University student | | | | | | | 0.5931 (0.8) | | |
| Nonworking adult retiree | | 0.5122 (2.1) | | | 0.254 (0.9) | | | 0.7191 (2.2) | |
| Age 35 years or younger | | –0.3455 (–1.3) | | | –0.4281 (–1.4) | | | | |
| Absolute distance deviation (mi) | –0.0723 (–2.7) | | | –0.0587 (–2.1) | | | –0.0663 (–1.7) | | |
| Relative distance deviation | –0.0984 (–1.8) | | | –0.0985 (–1.5) | | | | | |
| Walking distance-to-work (or university) dummy | 0.7751 (2.5) | | | 0.4984 (1.5) | | | –0.8347 (–1.5) | –0.0606 (–0.2) | |
| Auto time to–from work (min) | | | | | | | –0.0319 (–2) | | |
| Child and School Tour Characteristics | | | | | | | | | |
| Age (years) | | | | | | | | | |
| ≥16 | | | 0.5757 (2.6) | | | 0.2497 (1) | | | 0.444 (1.6) |
| 6–9 | | | –0.3169 (–1.1) | | | –0.3623 (–1.9) | | | |
| ≤5 | | | –0.3169 (–1.1) | | | –0.3623 (–1.9) | | | –0.8181 (–1.5) |
| Distance to school (linear) | | –0.0547 (–2.3) | | | –0.0704 (–2.9) | | | –0.0421 (–1.1) | –0.056 (–1.5) |
| Distance to school (logged) | | | –0.3648 (–2.4) | | | –0.3371 (–2.9) | | | |
| Age 0–5 years | | | | | | | | | |
| Distance to school (linear) | | | | | | | | | –0.2521 (–1.6) |
| Distance to school (logged) | | | –1.0281 (–4) | | | –0.6769 (–2.9) | | | |
| Age 6–9 years | | | | | | | | | |
| Distance to school (linear) | | | | | | | | | –0.0932 (–2.2) |
| Distance to school (logged) | | | –0.1046 (–0.5) | | | | | | |
| Household Characteristics | | | | | | | | | |
| Income | | | | | | | | | |
| ≤$24,999 | | | 0.1884 (0.9) | | | 0.3258 (1.1) | | | |
| $25,000–$49,999 | | | 0.1294 (0.8) | | | | | | |
| No cars in the household | | | 9 (fixed) | | | 9 (fixed) | | | 0.2321 (0.3) |
| Cars fewer than workers dummy | –0.8659 (–1.4) | –0.5662 (–0.9) | | –0.4023 (–0.6) | –0.0752 (–0.1) | | –3.5325 (–2.1) | –1.2592 (–1.1) | |
| Bundling of Children | | | | | | | | | |
| No. of escorting bundles—no. of cars (up to 3) | –0.3986 (–1.3) | –0.3986 (–1.3) | –0.3986 (–1.3) | | | | | | |
| Same school TAZ | 2.8109 (8.4) | 2.8109 (8.4) | 2.6442 (8.9) | 2.9428 (9.8) | 2.9428 (9.8) | 2.2198 (7.1) | 1.6856 (7.3) | 1.6856 (7.3) | 1.9489 (7.4) |
| Escorting Arrangements in Other Half Tour | | | | | | | | | |
| Same escorting option in both directions | | | | | | 1.5746 (9) | 1.4782 (2.9) | | 1.6599 (8.2) |
| Same chauffeur in both directions | | | | 0.6075 (4) | 0.6075 (4) | | 0.6621 (3.8) | 0.6621 (3.8) | |

NOTE: No. = number; TAZ = travel analysis zone; blanks = zero values.
[a]No. of observations = 629, likelihood with constants only = –748.3309, final likelihood = –609.3068, $\rho^2$ with respect to zero = 0.3191, $\rho^2$ with respect to constants = 0.1858.
[b]Conditional on inbound. No. of observations = 629, likelihood with constants only = –748.3309, final likelihood = –504.4065, $\rho^2$ with respect to zero = 0.4364, $\rho^2$ with respect to constants = 0.326.
[c] No. of observations = 537, likelihood with constants only = –635.0311, final likelihood = –440.0553, $\rho^2$ with respect to zero = 0.3992, $\rho^2$ with respect to constants = 0.3074.

A composite distance-to-school term segmented by age group categories was included in the utility of no escorting. Results show that the farther the school location is from home the higher the probability of the child being escorted to school. The propensity of escorting a child increases with distance to school and decreases with the age of the child. In addition, the propensity to pure escorting is reduced when the distance to school grows. The results are intuitive because pure escorting requires a round-trip from home to school, and the time required to make the entire round-trip will increase substantially with longer distances.

Household characteristics also have a strong effect on escorting choices. In low-income households, the propensity to escort children is lower than in medium- and higher-income households. Because escorting is dominated by the auto mode, the effect of car ownership on escorting is expected to be strong. In the estimation data set, there were no cases of outbound escorting for a household with zero cars; therefore, the coefficient was set to a large positive number (9.0) for the no-escorting alternative. In such households, the children can be escorted by nonhousehold members or can take the school bus or go on their own to school. In the inbound direction, the estimated coefficient was found to be positive as well. Fewer cars than workers proved to have a negative influence on ridesharing and pure escorting in both directions. For households with at least one car, the difference in number of escorting tasks and number of cars proved to affect negatively and significantly the utility of escorting in the outbound direction. This effect shows that the household chauffeurs are more likely to bundle escorting tasks if fewer cars are available. However, this effect was not found to be significant in models conditional on the escorting choices in the other half tour direction.

There is a strong correlation between the choices for outbound and inbound direction in regard to escorting type and choice of chauffeur, as shown in Table 1. The inbound escorting model was estimated conditional on the outbound escorting model and vice versa. The results show that if a child is not escorted in the outbound direction then it is more likely that the child will not be escorted in the inbound direction, and vice versa. The same is also true for ridesharing in the inbound direction. This symmetry can be explained by the necessity to find an alternative arrangement for a child (walk, transit, escorting by a nonhousehold member, etc.) if escorting is not considered in one direction. However, if such an arrangement exists in one direction it quite probably could be considered in the opposite direction as well, thus reducing the need for escorting. The same chauffeur is more likely to undertake escorting tasks in both directions regardless of whether it is ridesharing or pure escorting. This situation is an indication of the intrahousehold specialization of household members for certain tasks.

The chances of two or more children who go together to school to be either escorted together or not escorted at all is high if they are going to the same school. The coefficients on the same school dummy are strongly positive and significant in both directions. That result confirms that school escorting arrangements in households with multiple children cannot be modeled separately for each child (as was an implicit assumption in most of the previous modeling studies). The bundling component is essential and has to be incorporated.

## CONCLUSIONS AND FURTHER RESEARCH

The proposed model for school escorting is included as part of the MAG ABM currently at the final stage of development. Inclusion of this submodel enhances the behavioral realism of the entire model system by creating more linkages between different household members and accounting for associated constraints. The following are the main conclusions and findings:

- Escorting children to school by adult household members (workers, nonworkers, or both) is a frequent travel arrangement. An understanding of the activity travel patterns of children is becoming increasingly important to various policy makers from the transportation perspective. Children's school travel behavior is strongly linked with the travel behavior of the parents and other adult household members. This factor creates interdependencies between the travel patterns of parents and children that have to be addressed in travel models.
- Escorting arrangements can be effectively formulated as a discrete choice model albeit at the expense of a quite substantial number of alternatives that represent combinations of escorting needs of the children in each direction (to and from school), choices of chauffeurs, and bundling of several children in the same escorting tour. The efficient Gibbs sampler approach allows for decomposition of the household-day-level model by outbound and inbound direction (*9*); this approach makes each conditional submodel manageable.
- The formulated models were estimated on the 2008 *National Household Travel Survey* add-on implemented in the MAG modeled area. In general, the estimation results provided many interesting and logical behavioral insights with respect to the effect of the children's characteristics, chauffeurs' characteristics, locations of school and work, and other variables on the propensity to escort children to school. Many of the behavioral findings proved to be very much in line with the previously published research work. Some of the results, for example, with respect to the bundling of multiple children on the same escorting tour, are unique and had never been explored before.

Several new research dimensions have become clear in the process of developing this model:

- Escorting decisions are closely intertwined with mode choice decisions. In particular, commuting mode choice for workers and mode choice for school trips are linked through escorting. This linkage is somewhat taken into account in the current model formulation through level-of-service variables for nonescorting options that compete with escorting. However, there could possibly be a more integrated formulation in which commuting mode choice decisions of workers and schoolchildren are modeled simultaneously. This approach is beneficial for certain types of projects and policies. For example, promoting transit commuting could be properly related not only to the transit improvement for workers but also to improvements in walkability (friendliness of an area for walking), transit service, and a school bus for school trips.
- Escorting children to school is closely intertwined with the scheduling of work and school activities. In the current research, certain simplified assumptions were made about possible schedule adjustments that workers could make to consolidate their schedules with school start and end times (30 min). In reality, these adjustments are highly individual and depend on schedule flexibility. Understanding and modeling schedule consolidations in the household (of which escorting children to school is just one particular component) is yet another important layer of intrahousehold interactions that is currently missing in most models.
- The need for escorting is also dependent on the school bus policies of different school boards. If school bus availability (not available for the current survey) and the corresponding level of service were

known, it would be possible to include them as variables explaining the escorting need.

• Escorting children is not bound to school activities. There are many cases of escorting to nonschool discretionary activities (e.g., soccer moms). These cases require a choice structure different from the structure described in this paper.

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