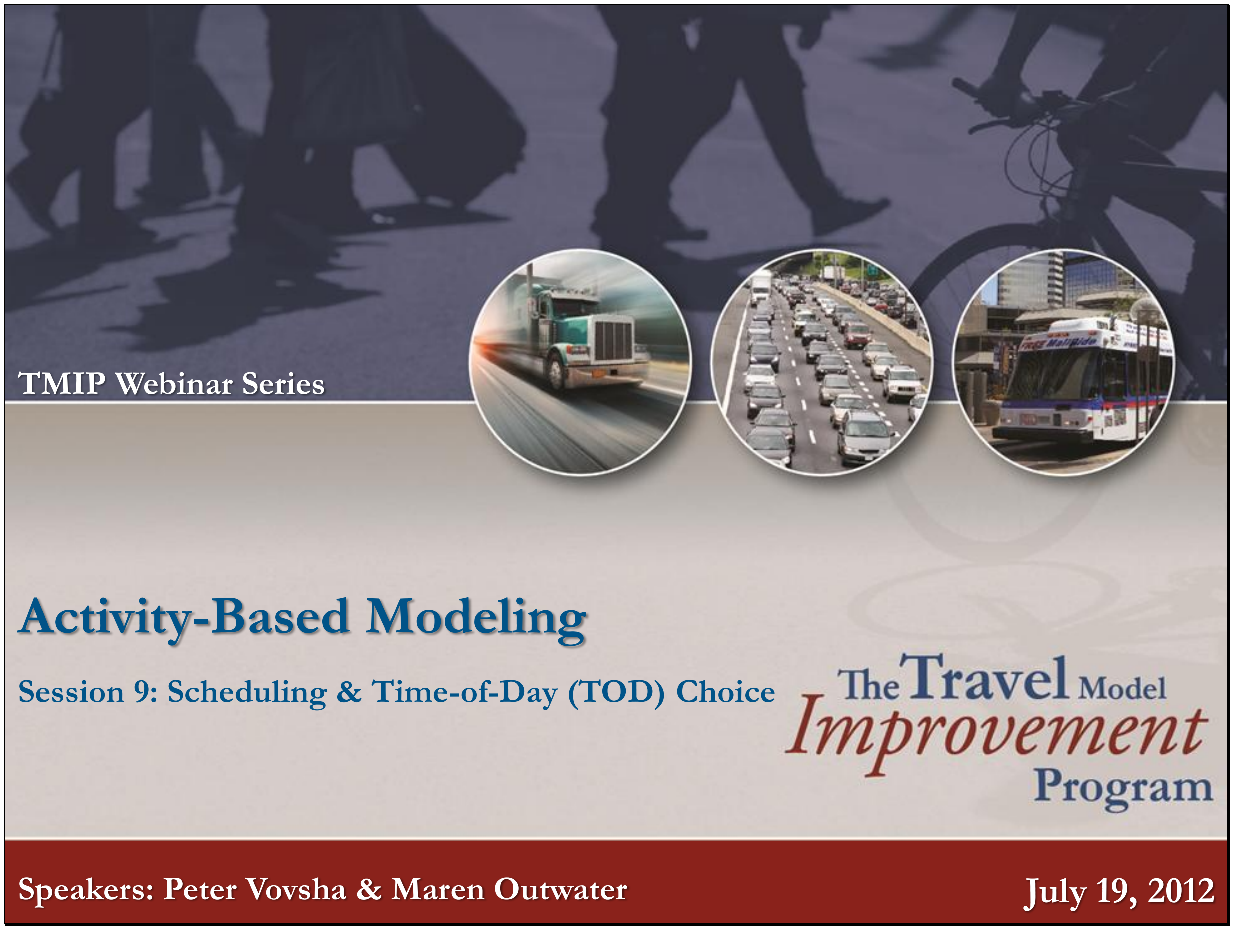
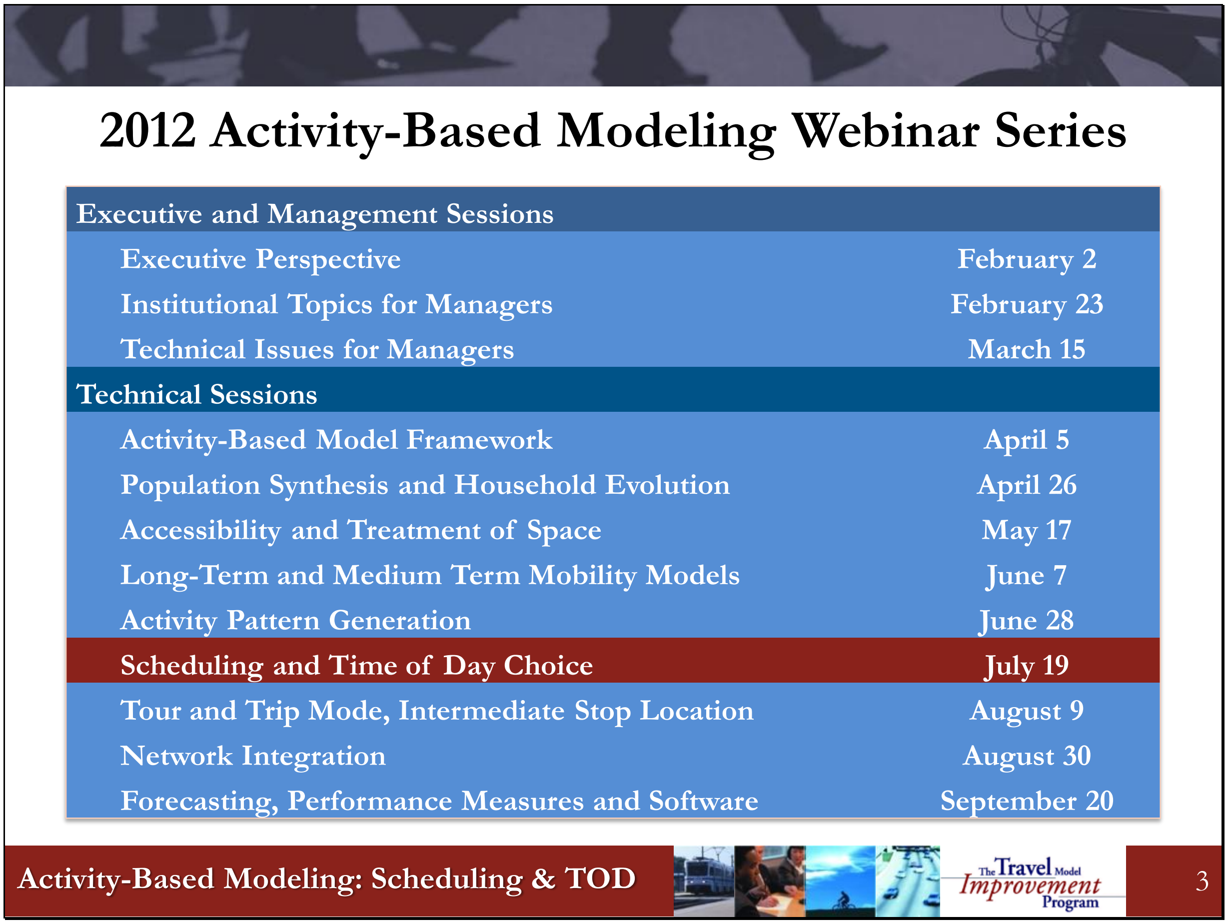
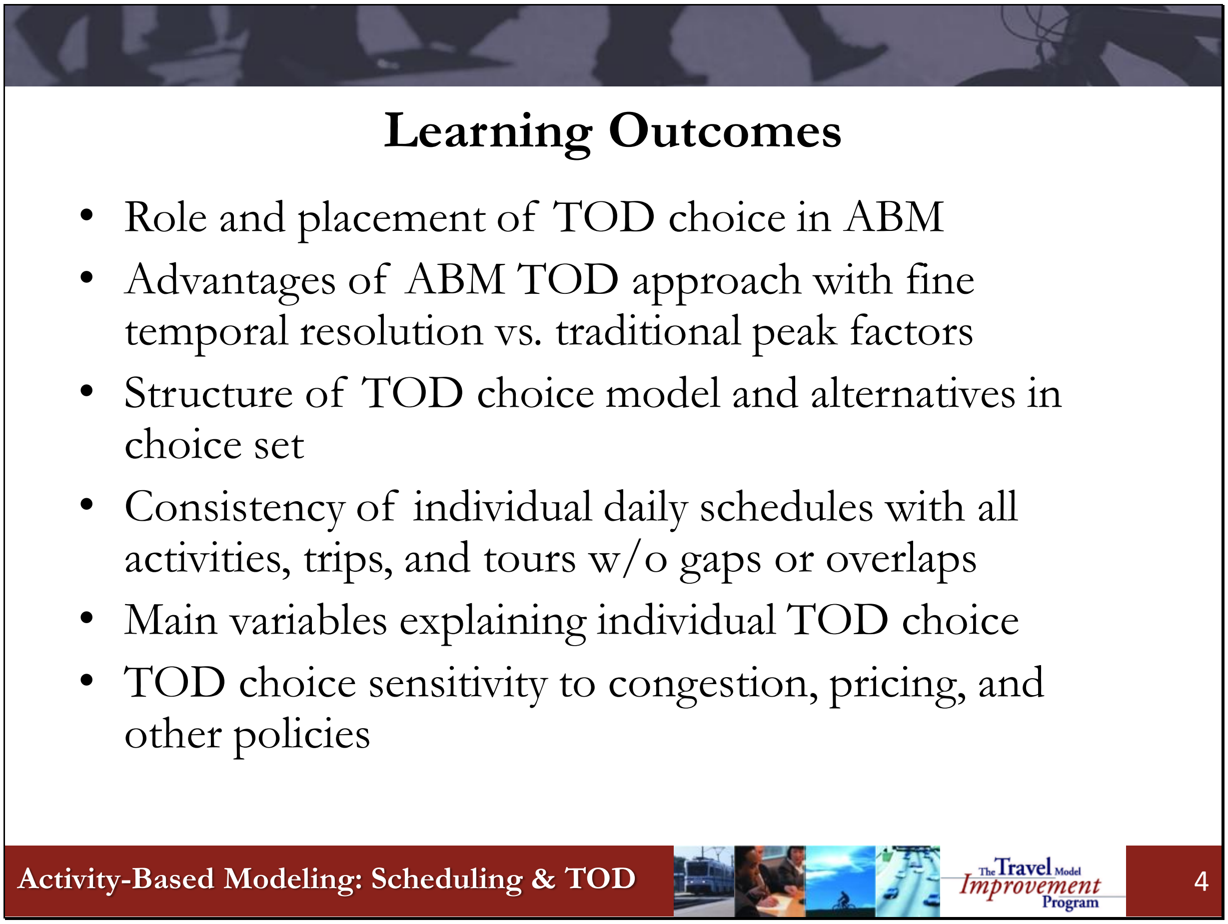

TMIP Webinar Series
Activity-Based Modeling
Session 9: Scheduling & Time-of-Day (TOD) Choice
The Travel Model Improvement Program
Speakers: Peter Vovsha & Maren Outwater
July 19, 2012

This is a collective effort of RSG & PB. It is largely built on our experience with many activity-based models in practice.

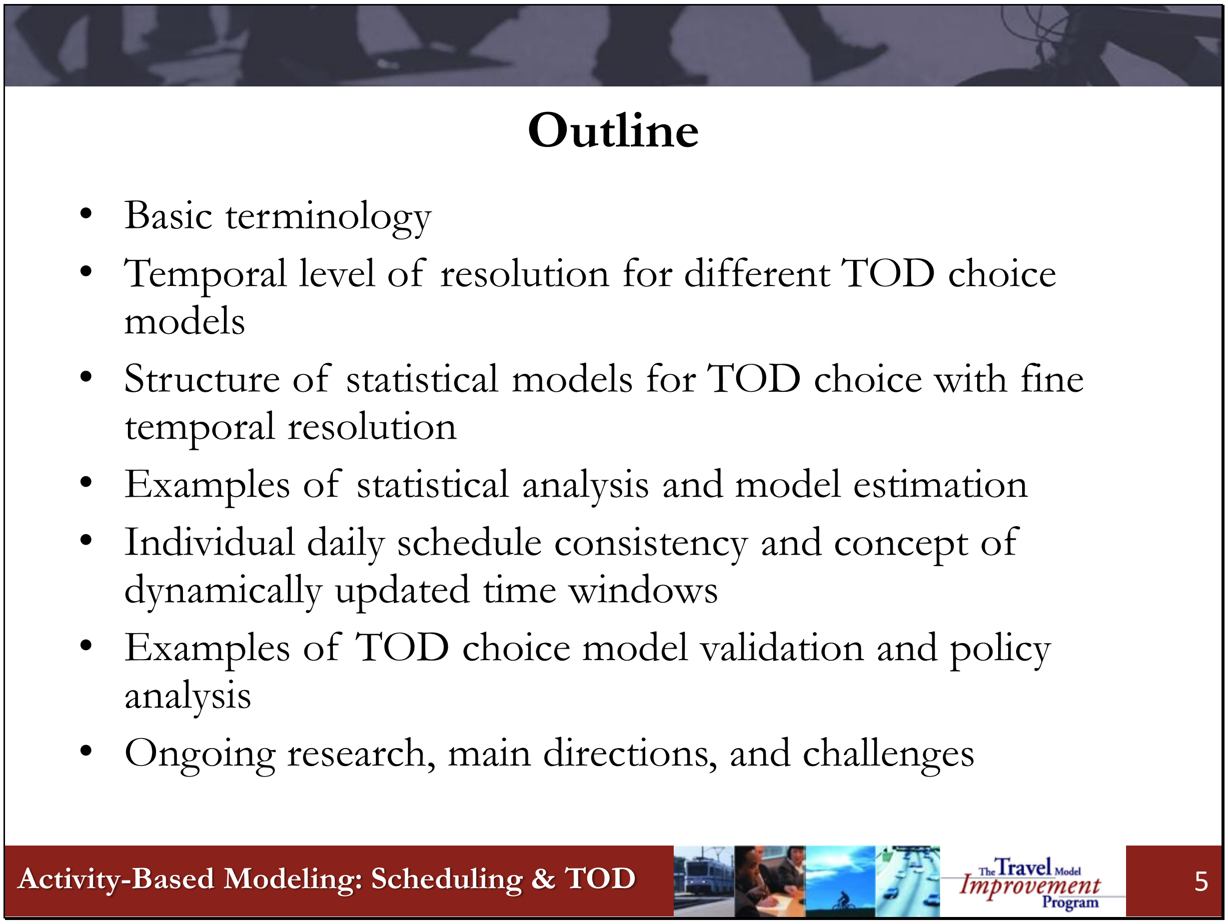
- Peter Vovsha and Maren Outwater are co-presenters. They were also primarily responsible for preparing the material presented in this session.
- Stephen Lawe is the session moderator.
- Content development was also provided by Joel Freedman, John Gliebe, and Rosella Picado. John Bowman provided review.
- Bhargava Sana was responsible for media production, including setting up and managing the webinar presentation.



Today’s webinar is devoted to activity scheduling and time-of-day choice modeling. It is a natural follow up to the previous webinar on activity patterns. It will be followed by the next webinar on mode choice.



You will learn today about the role and placement of time-of-day choice in the activity-based model system as well as important advantages of activity-based models with respect to time-of-day choice, in particular a finer level of temporal resolution compared to traditional peak factors and other simplified techniques. We hope you will have a clear idea how the time-of-day choice model is structured and how the main alternatives are specified. Another important lesson is to understand how consistency of individual daily schedules can be ensured when all activities, tours, and trips are scheduled w/o gaps or overlaps. This is something that is principally different from the 4-step approach. Finally, you will learn about main factors and corresponding variables explaining time-of-day choice and ensuring its sensitivity to congestion, pricing, and other policies.



We will start with the basic terminology and then consider such topics as:

- Temporal level of resolution for different time-of-day choice models
- Structure of statistical models for time-of-day choice with fine temporal resolution
- Examples of statistical analysis and model estimation
- Individual daily schedule consistency and concept of dynamically updated time windows
- Examples of time-of-day choice model validation and policy analysis
- Ongoing research, main directions, and challenges

Terminology – Tour TOD Choice

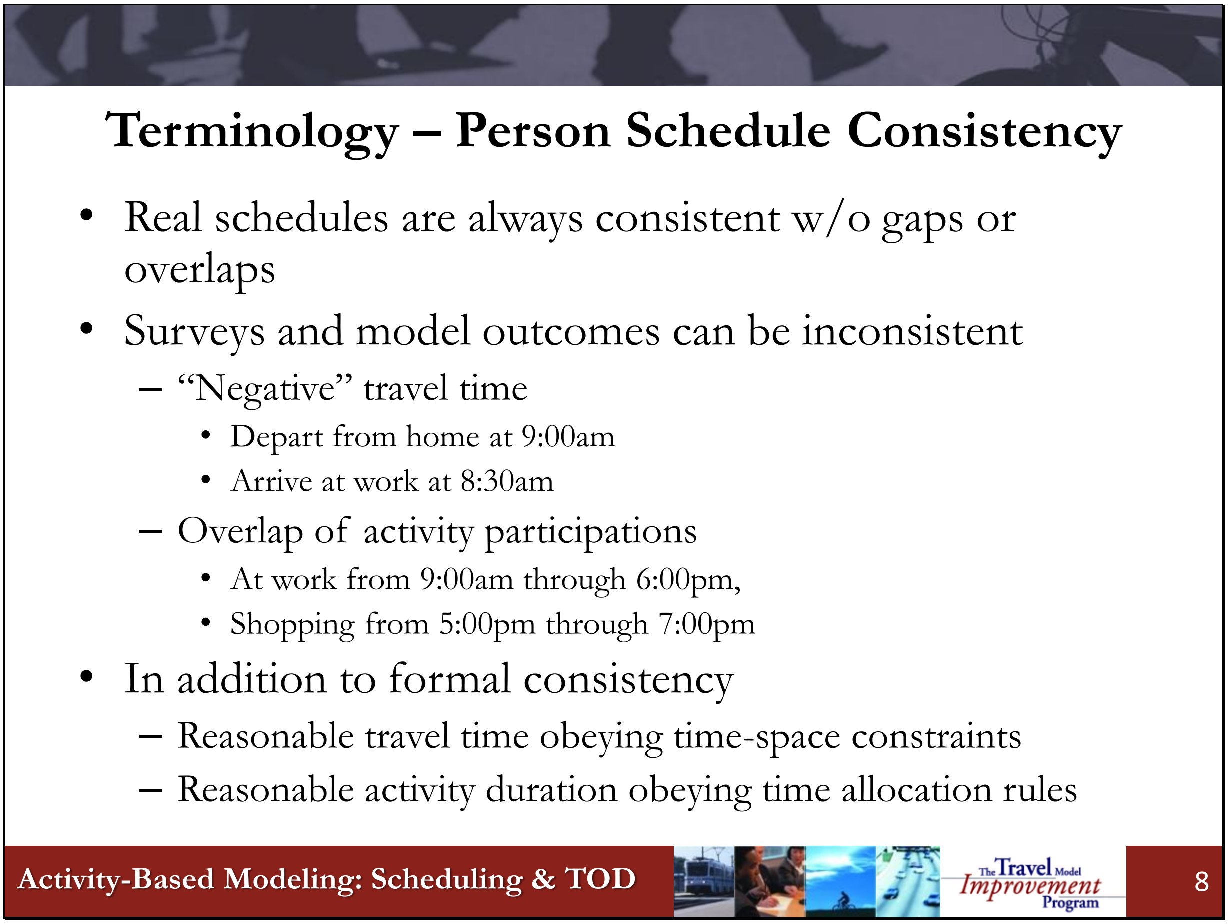
Actual time	Event	Entire Tour	Primary Activity
7:00am	Depart from home	Start (outbound)	
7:10am	Stop at Starbucks		
7:20am	Depart from Starbucks		
7:50am	Arrive at work		Start
12:00am	Leave for lunch	Tour duration 12hours 20min	Activity duration 8hours 10min
12:50am	Return to workplace		
5:00pm	Depart from work		End
5:30pm	Arrive at shopping mall		
6:40pm	Depart from shopping mall		
7:20:pm	Arrive back home	End (inbound)	
8:00pm	Depart from home	Start	…
….	….	…	…

Tour time-of-day choice is a choice of tour start and end times. It is a 2-dimensional characteristic. In this example, we have a person who departs from home to work, stops for breakfast on the way, have a lunch break, then depart from work, visit a shopping mall on the way home and finally arrives back home. The entire framework from 7am until 7:20pm is spanned by a single work (commuting) tour that lasts more than 12 hours. This is quite a usual case, not an extreme one since the tour framework may include multiple activities and trips. If we want to single the primary activity on this tour, it is work that starts at 7:50 and ends at 5pm. The duration of the primary activity is 8 hours 10 min., and includes a work-based sub-tour for lunch.

Terminology – Trip TOD Choice

Actual time	Event	Trip	Activity at Destination
7:00am	Depart from home	Departure	
7:10am	Stop at Starbucks	Arrival	Duration 10min
7:20am	Depart from Starbucks	Departure	
7:50am	Arrive at work	Arrival	Duration 8hours 10min
12:00am	Leave for lunch	Departure	…
12:50am	Return to workplace	Arrival	…
5:00pm	Depart from work	Departure	
5:30pm	Arrive at shopping mall	Arrival	Duration 1hour 10min
6:40pm	Depart from shopping mall	Departure	
7:20:pm	Arrive back home	Arrival	Duration 40 min
8:00pm	Depart from home	Departure	…
….	….	…	…

If we focus on particular trips then for each trip we need to model departure time, arrival time, and corresponding activity duration at the destination. In most activity-based models tours are scheduled first and then trip-level details are added conditional upon the tour schedule. In practical terms only one of dimensions (departure time) has to be modeled, while other dimensions like arrival time and duration are identified by the schedule information of prior modeled activities and the travel time required for the trip.



One of the key theoretical advantages of a micro-simulation activity-based model is consistency of schedules generated for each individual:

- Real schedules are always consistent w/o gaps or overlaps
- Surveys and model outcomes can be inconsistent in a sense that they can have:
- "Negative" travel time
- Depart from home at 9:00am
- Arrive at work at 8:30am
- Overlap of activity participations
- At work from 9:00am through 6:00pm,
- Shopping from 5:00pm through 7:00pm

In addition to formal consistency, we also control for reasonability of travel times and activity duration. This level of analysis and modeling is not possible at all with an aggregate 4-step model. Day schedule consistency is essential for portraying congestion pricing impacts. If one trip or activity is rescheduled in reality it would trigger a chain of adjustments for other trips.

Possible Levels of Temporal Resolution

Continuous time – 1,440 min	5 min (ABM/trips) – 288 bins	30 min (ABM/tours) – 48 bins	Aggregate TOD periods (4-Step)
3:00am, 3:01am…	3:00am-3:04am	3:00am-3:29am	Night
3:05am, 3:06am…	3:05am-3:09am		
…	…		
3:25am, 3:26am…	3:25am-3:29am		
…	…	…	
5:55am, 5:56am…	5:55am-5:59am…	5:30am-5:59am	
6:00am, 6:01am	6:00am-6:04am…	6:00am-6:29am	AM
…	…	….	
8:30am, 8:31am	8:30am-8:34am…	8:30am-8:59am	
…	…	…	…
4:00am, 4:01am	4:00pm-4:04am	4:00pm-4:29pm	PM
…	….	…	

Activity-Based Modeling: Scheduling & TOD

The Travel Model Improvement Program

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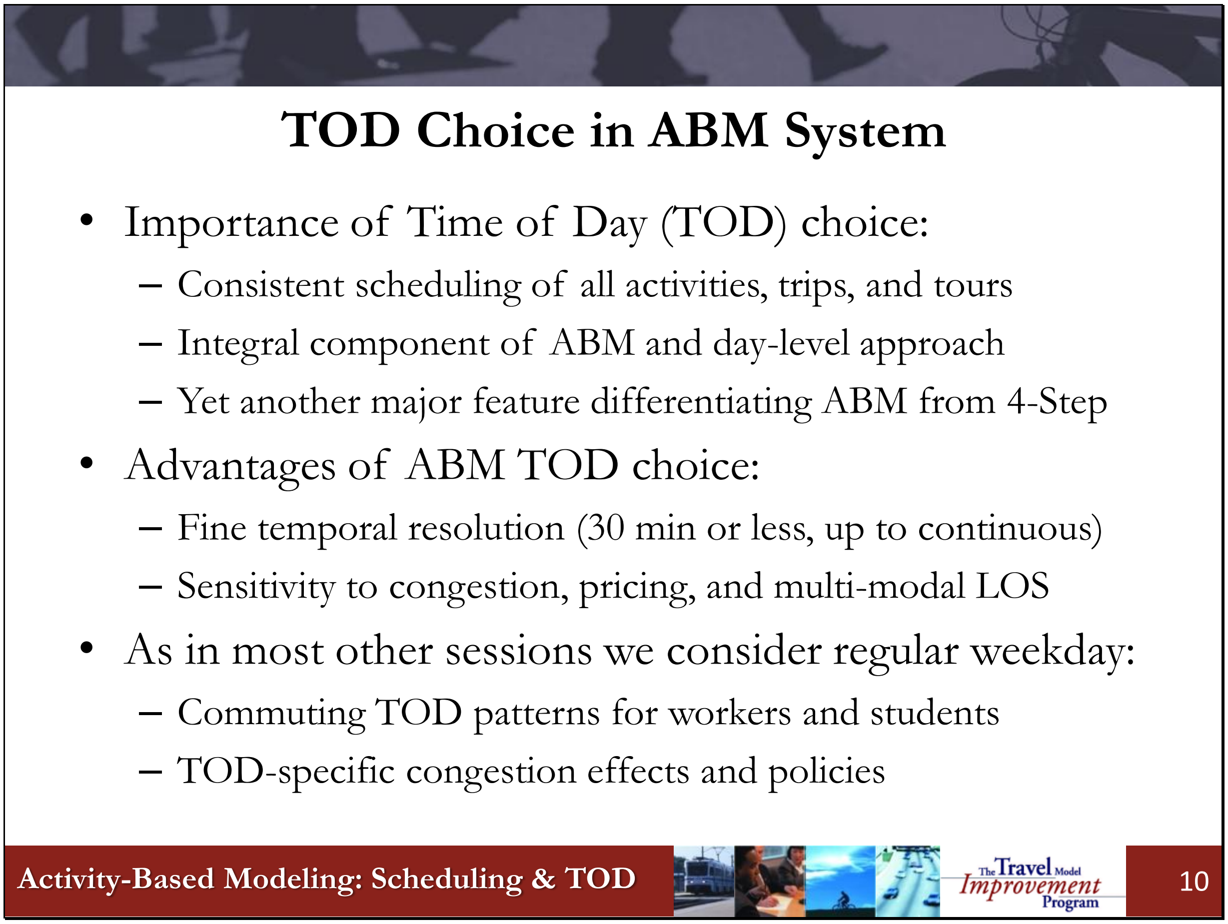
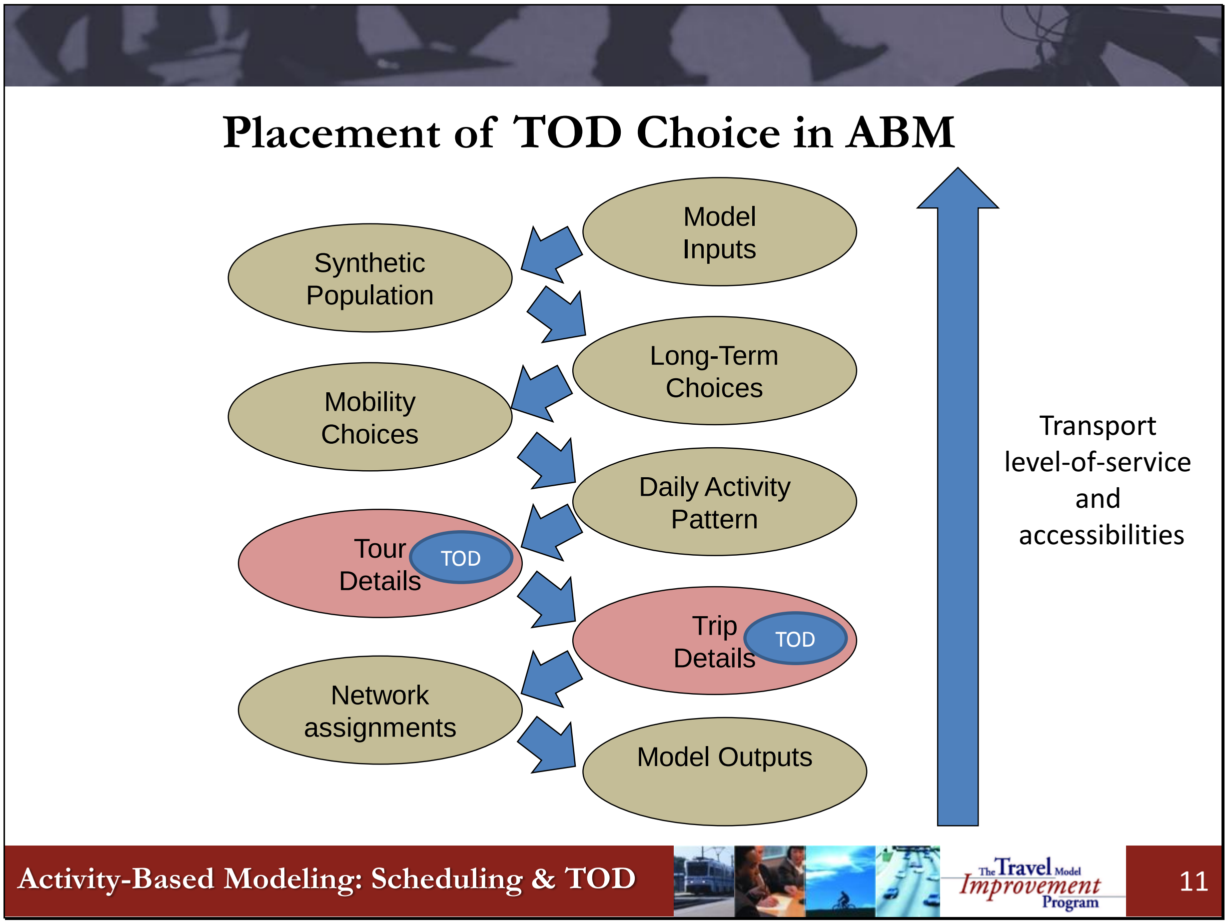
First, we need to distinguish between 4 levels of temporal resolution (or accuracy of the time-of-day choice model) and we have to understand the corresponding implications for the model structure in terms of number of time-of-day alternatives. The most exact way is to operate with continuous time that some advanced models do. This means that we literally have 1,440 min to model explicitly as choices for each trip departure time, etc. The second best is to operate with a 5-min resolution that results in 288 time bins per day. It is enough in many respects for planning purposes, in particular, for portraying congestion effects. It can be applied in activity-based models today at least for the trip-level time-of-day. At the tour-level it is more realistic to operate with a 30-min resolution that results in 48 time bins per day. We will be using this level of temporal resolution in many illustrations in this webinar. Finally, in aggregate 4-step models we are forced to use even cruder time-of-day periods that may span several hours. It is always a good idea to operate with a high level of temporal resolution but it has to be balanced with the model complexity and associated run time.



Time-of-day choice plays a very important role in an activity-based model system. An essential feature of an advanced activity-based model is a consistent scheduling of all activities, trips, and tours for each individual. It is an integral component of an activity-based model and of the day-level approach in general. It is also yet another major feature differentiating activity-based model from 4-Step. Activity-based models have principal advantages over 4-step models w.r.t. time-of-day choice such as a fine level of temporal resolution and sensitivity to congestion, pricing, and transit improvements. We will be again focusing a regular weekday and all statistics that you will see relate to a regular weekday. In particular, commuting time-of-day patterns and associated congestion effects will be the primary focus of our discussion.

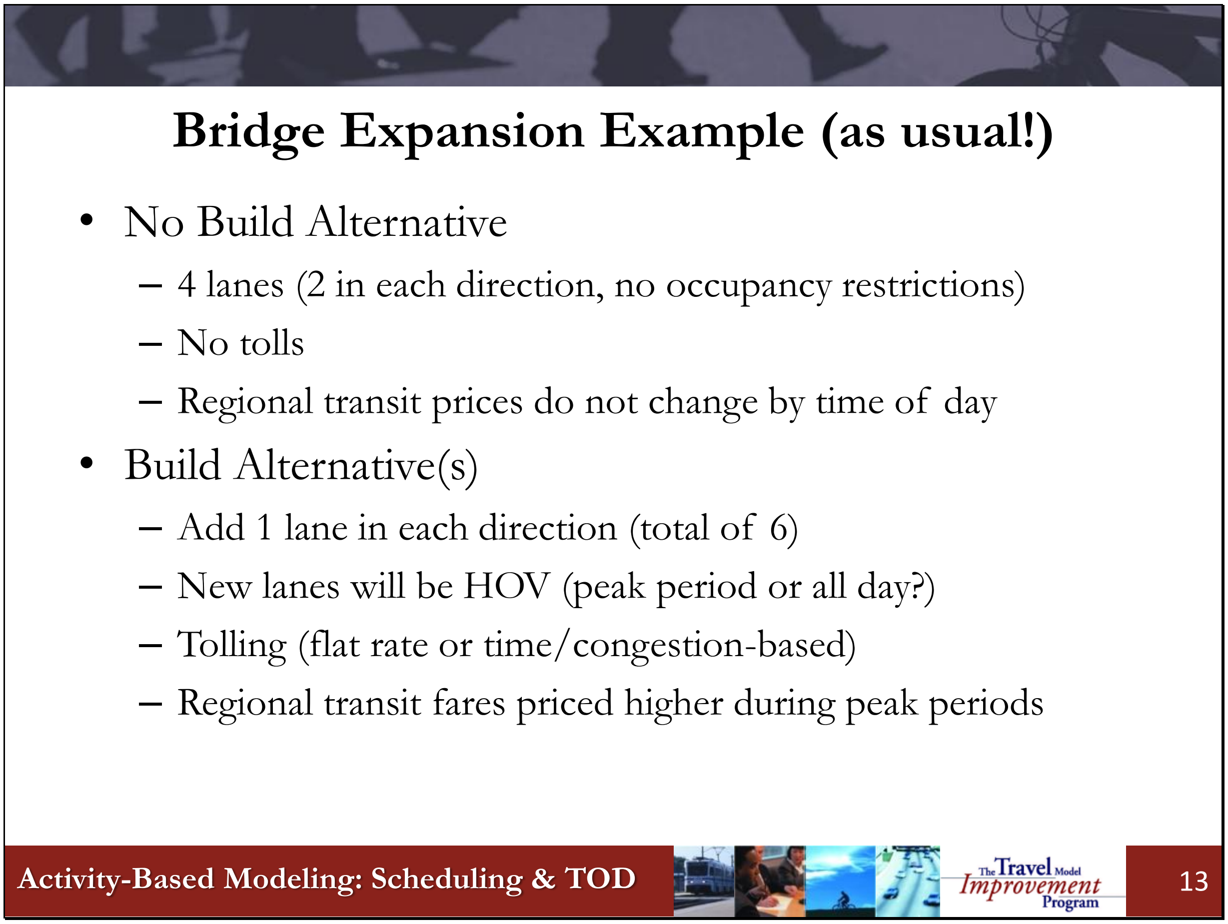


Time-of-day choice is not a single mode component. Time-of-day choice is applied for each travel tour in the package of tour-level models. This will be the primary topic for our webinar. Subsequently, time-of-day choice is modeled for each trip within each tour in the package of trip-level models. When we model time-of-day choice for each tour we already know the outcomes of the upper-level models. In particular we know, the person and HH characteristics, location of work and school for each worker and student, car ownership and other mobility attributes, and we know the daily activity pattern for each person in terms of number of tours and main activities. Now we have to schedule these activities and model the corresponding tour/trip departure and arrival times.

Limitations of 4-Step w.r.t. TOD Choice

- Placement and structure of TOD choice never established
  - Between trip generation and trip distribution?
  - Between trip distribution and mode choice?
  - Between mode choice and assignment?
- Aggregate level of temporal resolution
  - Normally corresponds to 3-5 network TOD periods
  - Post-model 30-60 min peak-spreading procedures applied to AM and/or PM
- Cannot adequately address tour-level consistency
  - Simplified symmetry assumptions (PA format)
  - Ignoring activity duration
- Cannot adequately address congestion and pricing effects
  - All round-trip TOD combinations with 30 min resolution results in 800 segments per each travel segment (trip purpose, income, car ownership, etc)
  - Microsimulation ABM framework offers a better solution

It is important to recognize that the conventional 4-step structure is very limited with respect to time-of-day choice. First of all, it is very difficult to find a place of time-of-day choice that would be the 5th step. Different schemes were tried in the past and none of them were satisfactory. Secondly, it is difficult to move from the crude time-of-day periods to finer level of resolution. Thirdly, we lose a tour-level consistency between different trips. For this reason in many 4-step models some simplified assumption on round-trip symmetry were applied. Finally, it is difficult to prepare and apply a 4-step model for congestion pricing studies. It results in an infeasible number of time-of-day slices and segments. The micro-simulation activity-based model framework that we discuss today offers a much better solution.



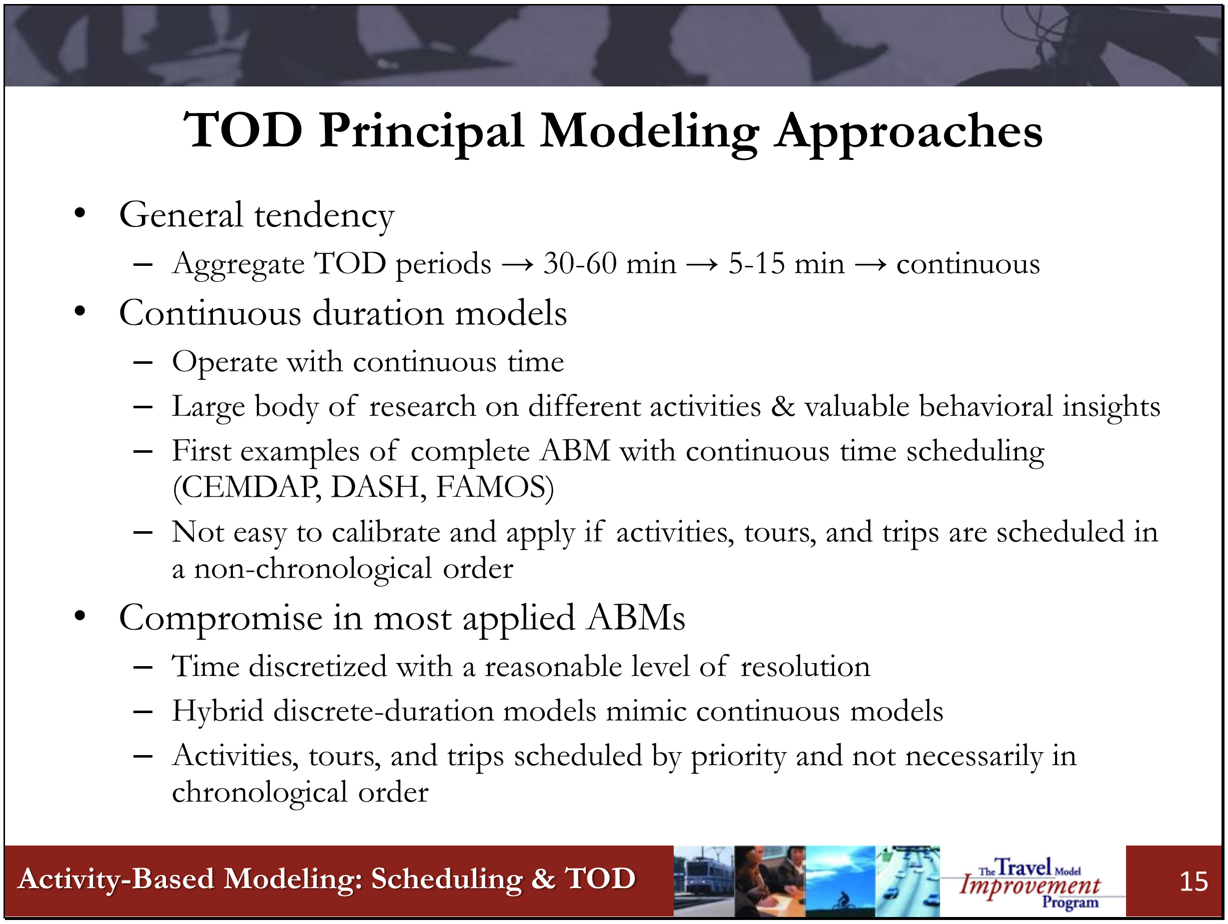
Let's consider a transportation planning and policy project that might be faced by an MPO or DOT and how daily activity pattern modeling fits into the picture. We have used this example in several previous sessions to talk about how activity-based modeling components might affect the analysis.

For this scenario analysis, we will be considering a number of alternatives: a no-build alternative and a various configurations of the build alternative. In the no-build alternative the bridge has 4 lanes (2 in each direction), there are no tolls, and the transit fare stays the same all day. In the various build alternatives, there are 6 lanes on the bridge. In some alternatives the two additional lanes will be HOV lanes all day, while in other alternatives the two additional lanes will be HOV lanes only during peak periods. In addition, in some build alternatives there will be a new toll that is the same across the entire day, while in other build alternatives there will be a toll that will be only applied during peak periods, or when certain levels of congestion occur. Finally, in the build alternatives regional transit fares will be higher during peak periods.

Bridge Expansion Example: Relevance to Time of Day Choice

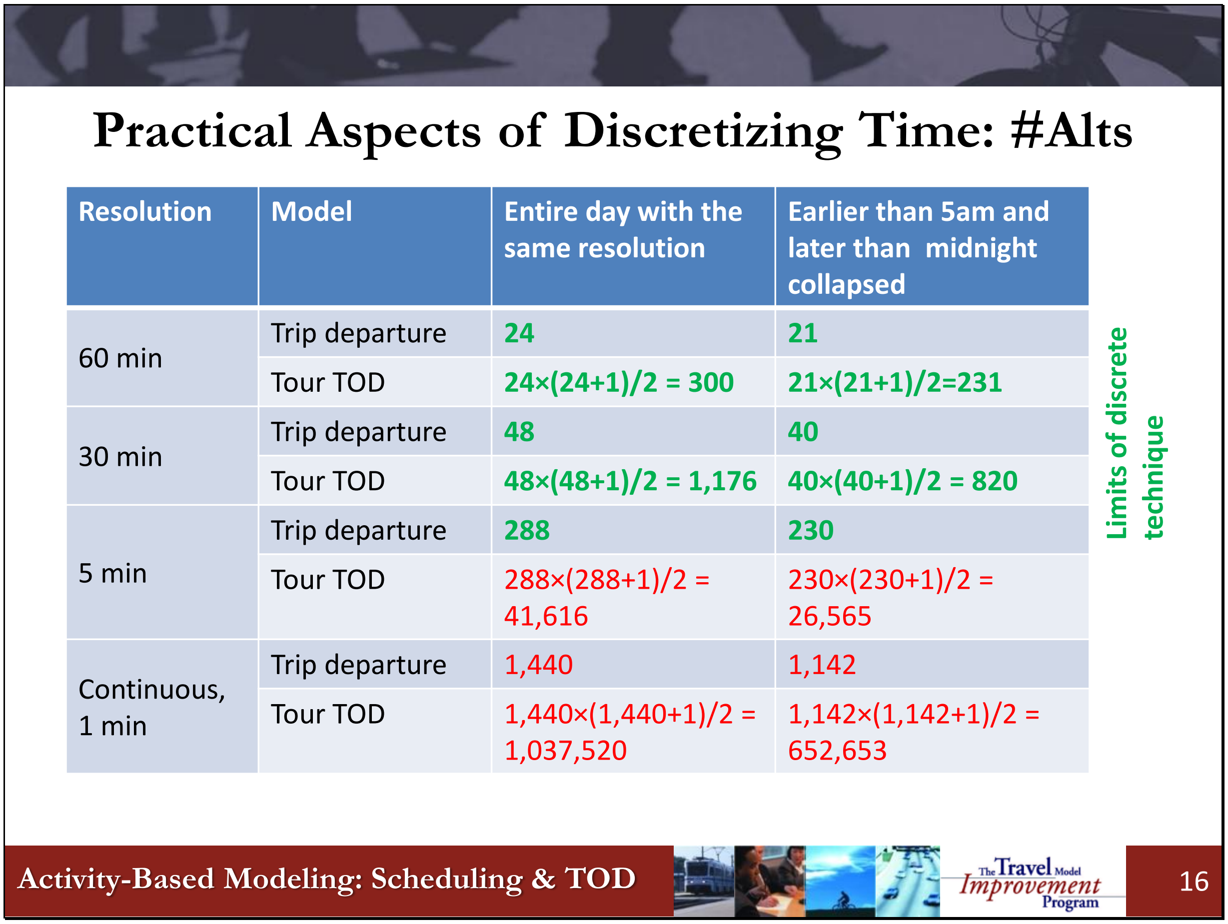
- Congestion pricing results in shifting SOV trips to off-peak periods
  – More SOV trips in the off-peak periods
  – Less SOV trips in the peak periods
- Potential increase in intra-household ridesharing to take advantage of HOV
  – More HOV trips in both peak and off-peak periods:
    - Peak HOV trips take advantage of better conditions in the peak period (including a shift from peak)
    - Off-peak HOV trips generated by overall improvement of accessibility for HOV in all periods

For this bridge example, DAP generation may be affected in the following ways. If a person's accessibility is improved by the bridge, the frequency of discretionary activity episodes may increase. In order to take advantage of HOV lanes, household members may decide to share rides to work. This not only affects mode choice, but also affects daily activity patterns, because of the coordination of patterns between household members. It may even lead to increased non-work joint activities.



To summarize our discussion so far and move to some operational models, there is a general tendency to improve the level of temporal resolution. Continuous duration models represent the best solution in this regard but they have their own limitations. We will discuss today some practical compromises that can be found in most applied activity-based models in practice that includes such aspects as:

- Time discretized with a reasonable level of resolution;
- Hybrid discrete-duration models mimic continuous models; and
- Activities, tours, and trips scheduled by priority and not necessarily in chronological order.



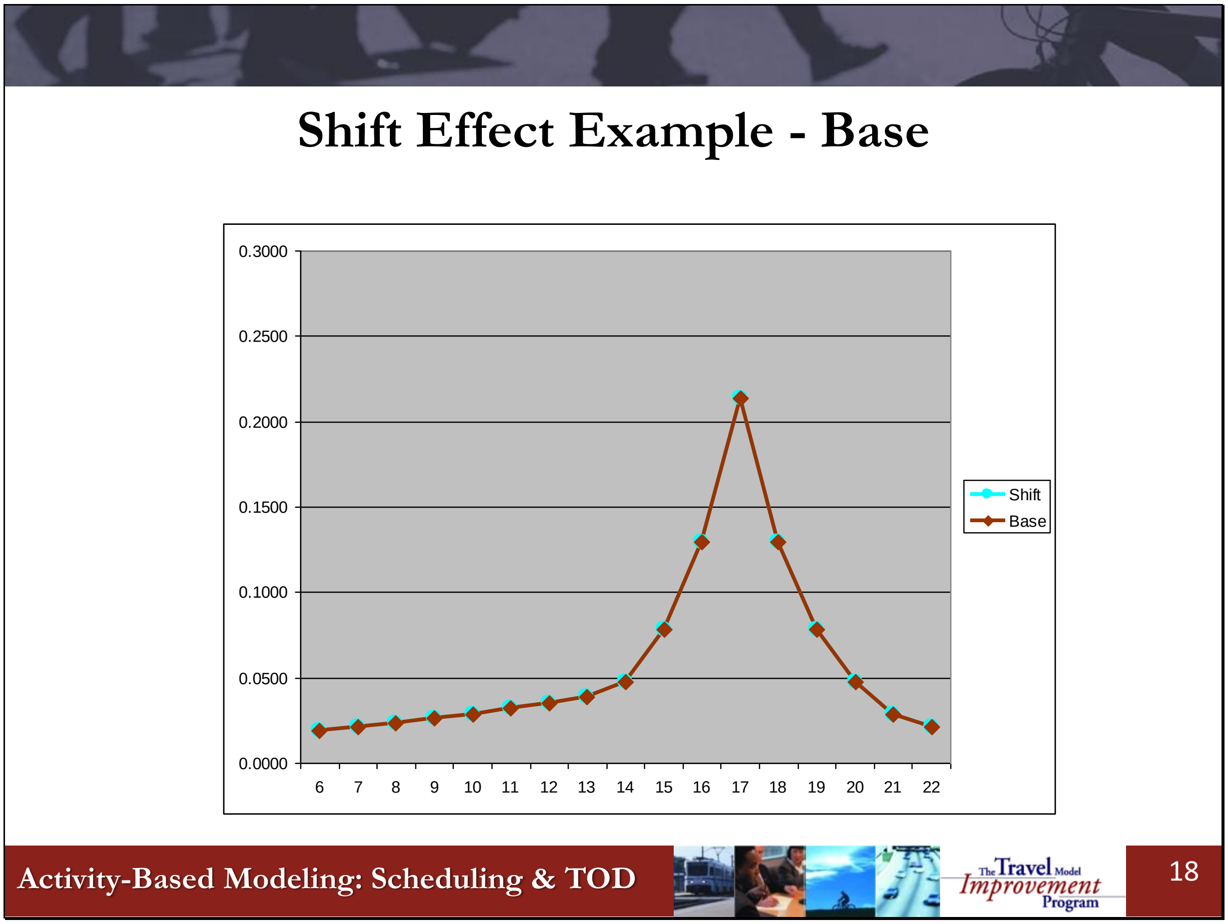
Resolution	Model	Entire day with the same resolution	Earlier than 5am and later than midnight collapsed
60 min	Trip departure	24	21
	Tour TOD	24×(24+1)/2 = 300	21×(21+1)/2=231
30 min	Trip departure	48	40
	Tour TOD	48×(48+1)/2 = 1,176	40×(40+1)/2 = 820
5 min	Trip departure	288	230
	Tour TOD	288×(288+1)/2 = 41,616	230×(230+1)/2 = 26,565
Continuous, 1 min	Trip departure	1,440	1,142
	Tour TOD	1,440×(1,440+1)/2 = 1,037,520	1,142×(1,142+1)/2 = 652,653

When we discretize time to apply choice models that are easy to incorporate in practice, we have to stop at a feasible level of temporal resolution. In the table shown above, the green areas correspond to feasible choice structures with fewer than 1,000 alternatives. The red areas are problematic for a discrete choice model. Some reasonable simplifications are applied in practice, for example, the night time can be collapsed into a single period since we do not have many trips there. This corresponds to the last column. You can see that both tour and trip time-of-day can be implemented with a 30-min temporal resolution (that is the prevailing state-of-the practice at the moment). Trip departure time choice can be implemented with even a finer level of temporal resolution.

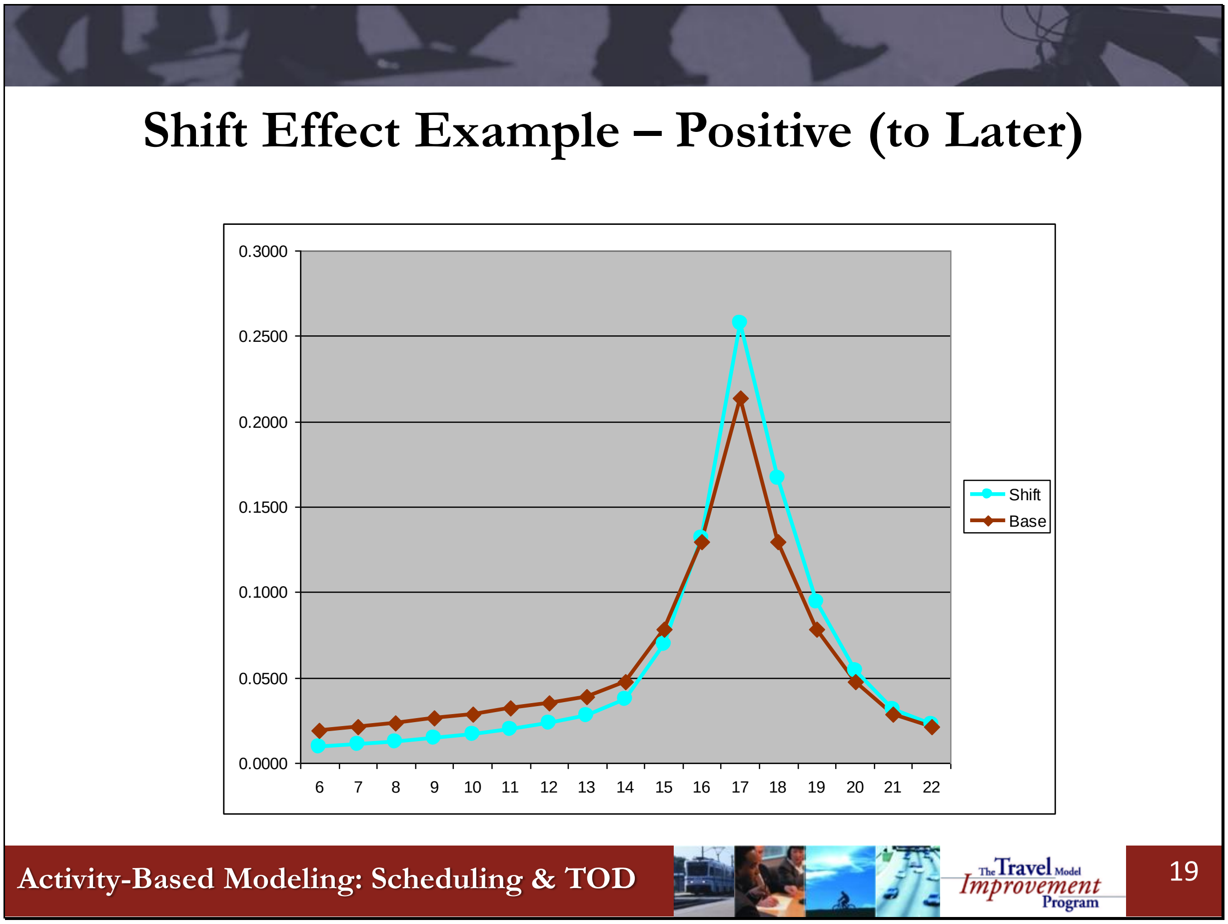
Core Utility Structure

- Consider 1-dimensional choice of duration in discrete space
  - 0 hours
  - 1 hour
  - 2 hours
  - …
- Consider a utility structure with a single linear "shift" variable X and coefficient C
  - U(0)=A(0)+0×X×C
  - U(1)=A(1)+1×X×C
  - U(2)=A(2)+2×X×C
  - ….

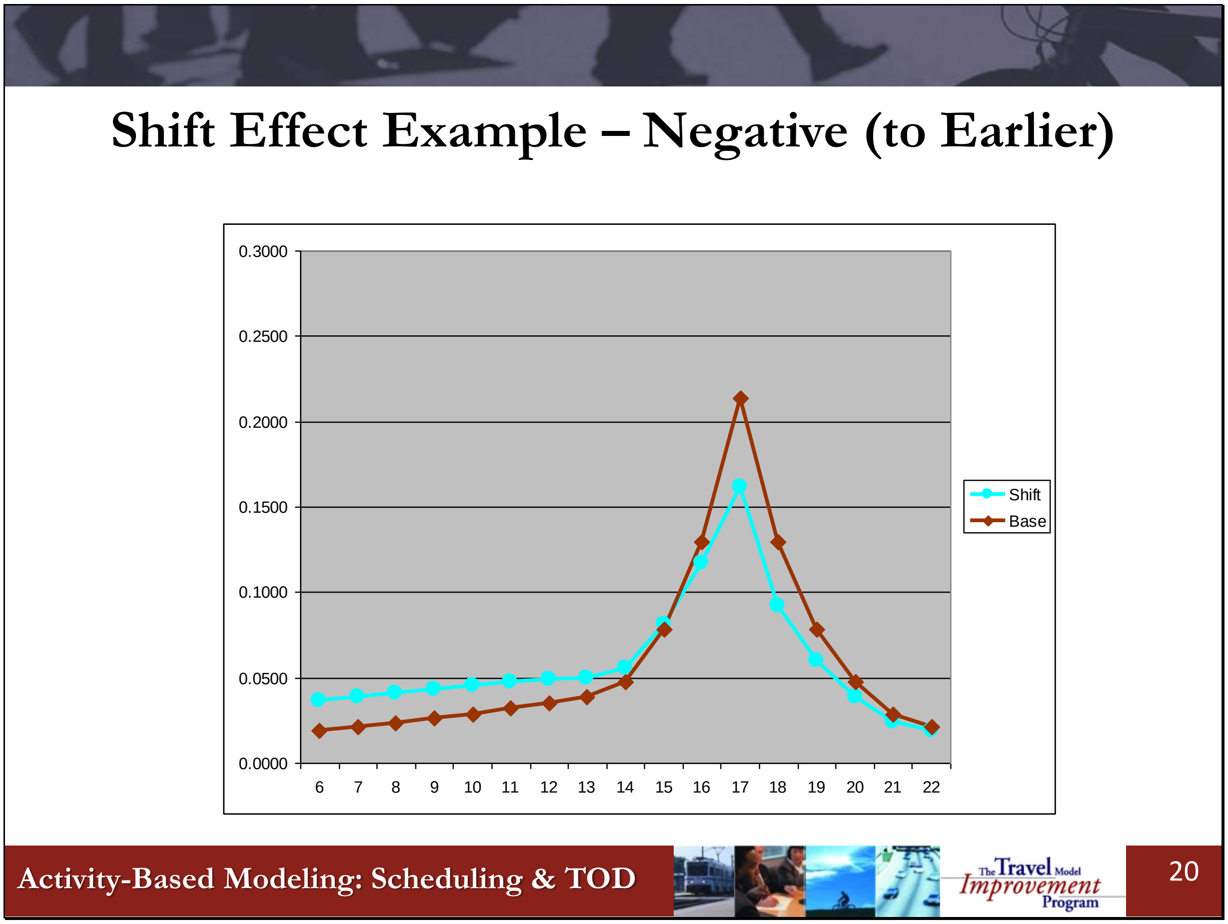
How does it really work and how can we form a choice model and corresponding utility when choosing a time bin? Do we have to form hundreds or thousands of unique utility expressions? This is not feasible. The key technical approach is to mimic a continuous duration model in discrete space by means of so-called shift variables. The main difference between a shift variable and ordinary variable as you can see on the slide is that a shift variable enters all utility expressions with the same coefficient but it is additionally multiplied by the time itself. This time-related multiplier creates a shifting effect that mimics a continuous duration model in discrete space.



This structure allows for a single variable to affect the entire temporal distribution. Let’s consider this distribution of, say, arrival back home from work. Let’s say we have a base case as shown on the slide.



If we add a shift variable that is positive (for example high income) it would shift the entire distribution to later hours.

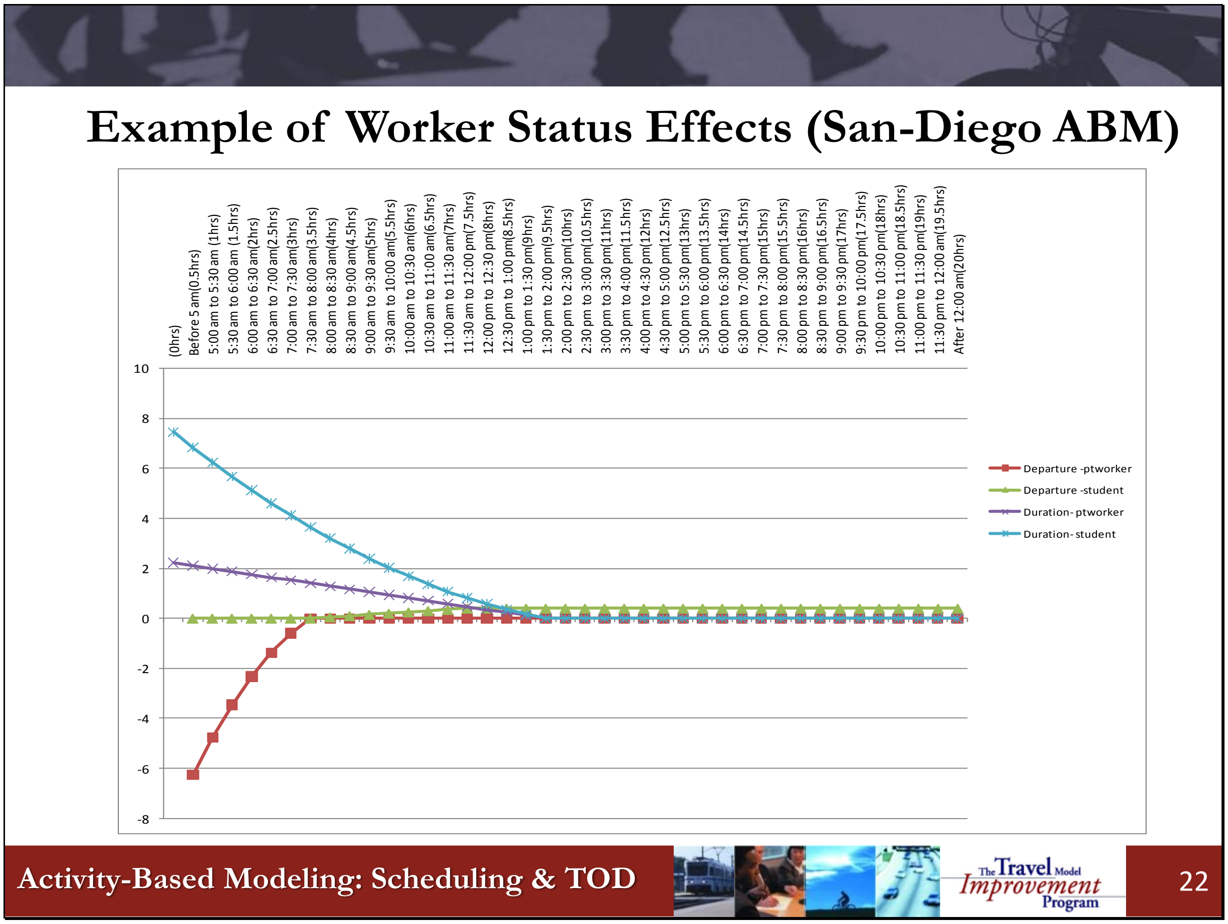


If we add a shift variable that is negative (for example part-time work) it would shift the entire distribution to earlier hours. This is a very powerful technique in practice that we widely apply.

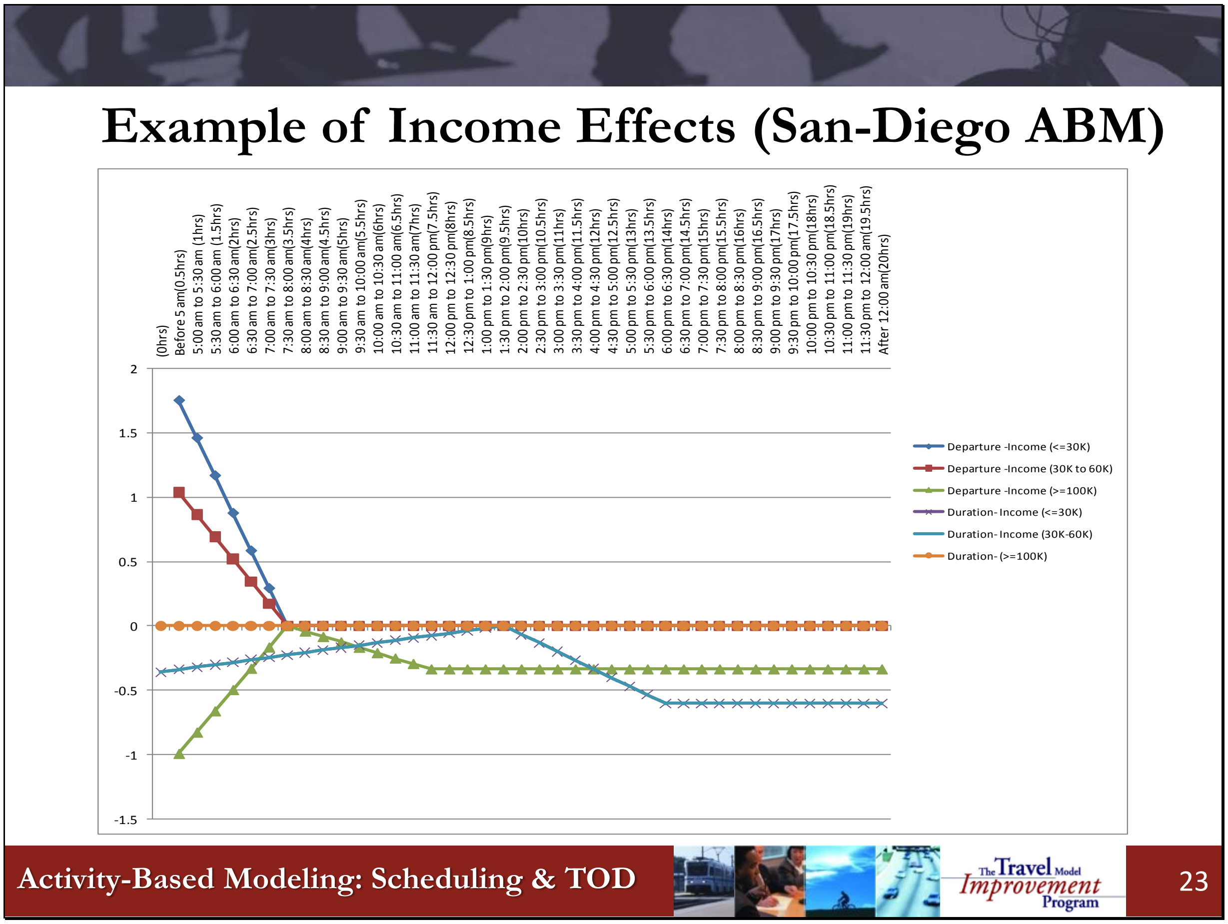
Non-Linear Shift Variables (CT-RAMP, DaySim)

- Consider a utility structure with a single polynomial "shift" variable X and coefficients B, C, D…
  - $U(0)=A(0)+0\times X\times B+0^2\times X\times C+0^3\times X\times D\ldots$
  - $U(1)=A(1)+1\times X\times B+1^2\times X\times C+1^3\times X\times D\ldots$
  - $U(2)=A(2)+2\times X\times B+2^2\times X\times C+2^3\times X\times D\ldots$
  - ….
- Further generalized to account for constrained intervals of impact, piece-wise functions, trigonometric functions, and referencing to a certain (peak) point
  - Every variable X is associated with a temporal profile:
  - $F(t)=t\times B+t^2\times C+\ldots$ or
  - $F(t)=\mathrm{Sin}(2\pi t/24)\times B+\mathrm{Sin}(4\pi t/24)\times C+\ldots$
  - Temporal profiles are convenient to analyze in graphical form (examples will be shown)

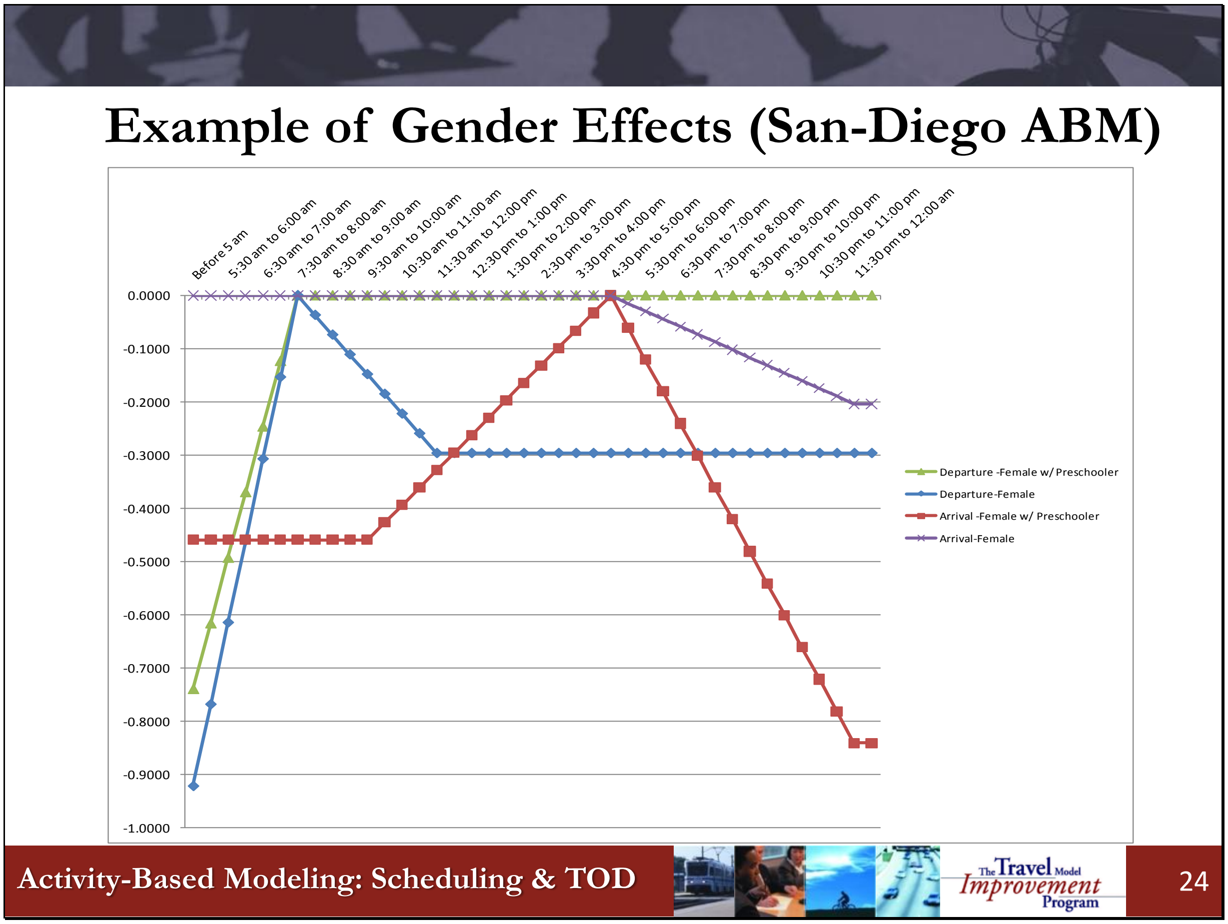
The technique of shift variables has been extended recently to accommodate more elaborate non-linear effects including polynomial functions, piece-wise functions, trigonometric functions, etc. In all these case the shift variable and coefficient are multiplied by a certain predetermined function of time. The product is called temporal profile that is a component of the time-of-day choice utility function. Temporal profiles are convenient to analyze in graphical form (examples will be shown).



As we discussed before, impact of shift variables can be illustrated in graphical from. For example, for part-time workers in the San Diego activity-based model, there is a logical tendency to avoid very early hours for departure from home (red line) and also a tendency to prefer shorter durations (violet line). It is quite logical since majority of part-time workers are females, frequently with children.



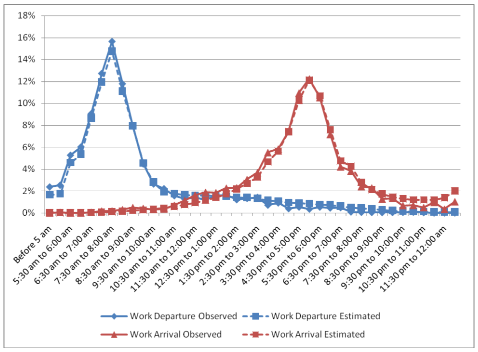
These are examples of income effects from the same activity-based model. It can be seen for example, that low-income workers (less than $30K, blue line with squares) tend to start much earlier compared to medium-income workers that serve as the base case. Interesting duration effect can be observed for medium-income workers (blue line with crosses). They most frequently prefer normal fixed-schedule workday (9-10 hours including commuting) compared to say high-income workers (orange line) show have more flexible schedules.

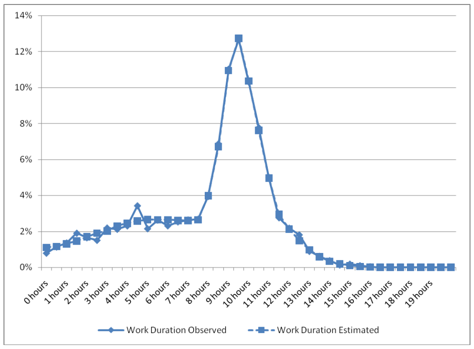


Another set of shifts correspond to gender effects. For example, you can see that arrival time back for female workers with a preschool child is (red line) highly concentrated around a relatively early hour (4:30pm). There are many other different shift effects incorporated in either departure, or arrival, or duration components.

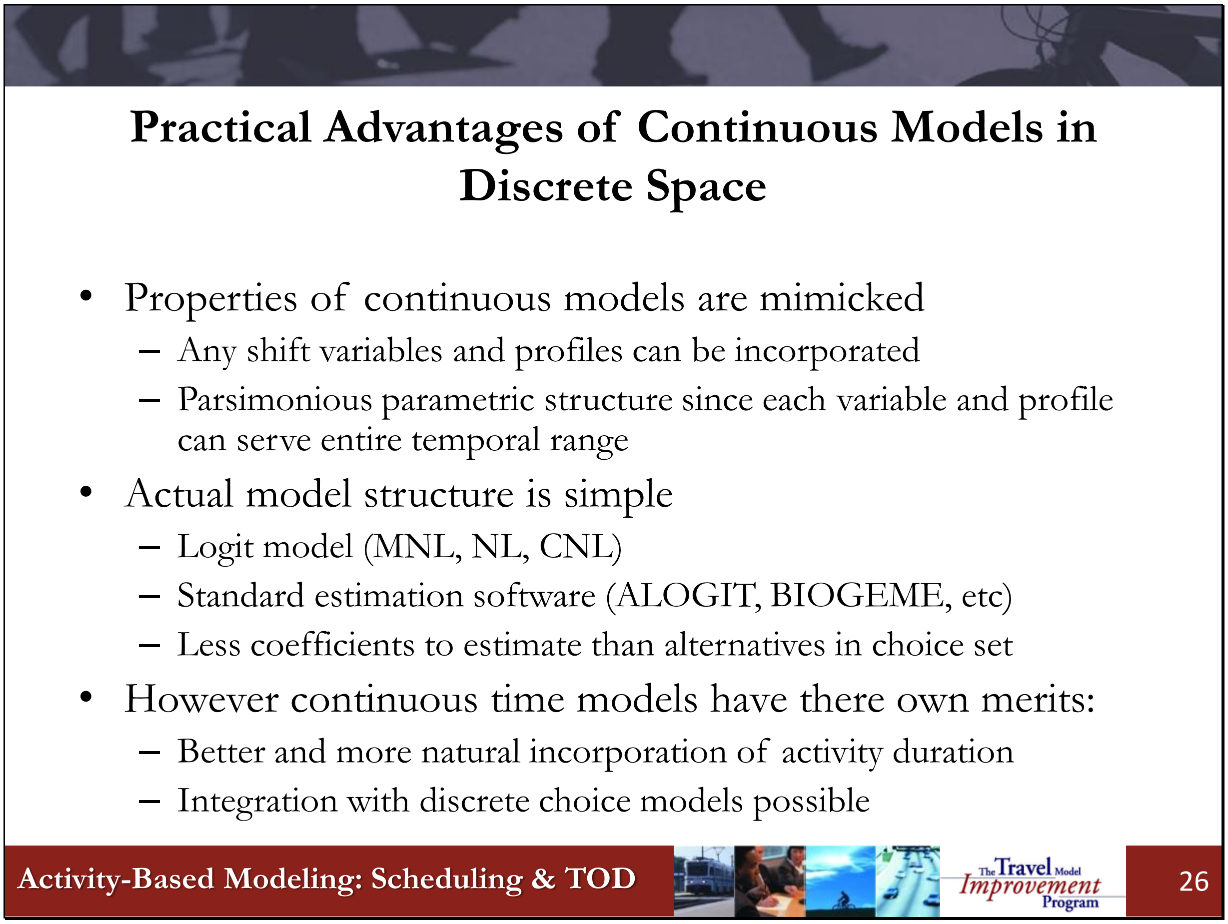
Resulted Temporal Profiles

- Temporal profiles modeled for each travel purpose and person type as a combination of multiple impacts and shifts
- They are compared to the observed distributions across multiple dimensions at the validations stage (see Part 2)





Temporal profiles modeled for each travel purpose and person type as a combination of multiple impacts and shifts. They are compared to the observed distributions across multiple dimensions at the validations stage. This will be discussed further in Part 2 of this session, with multiple examples.



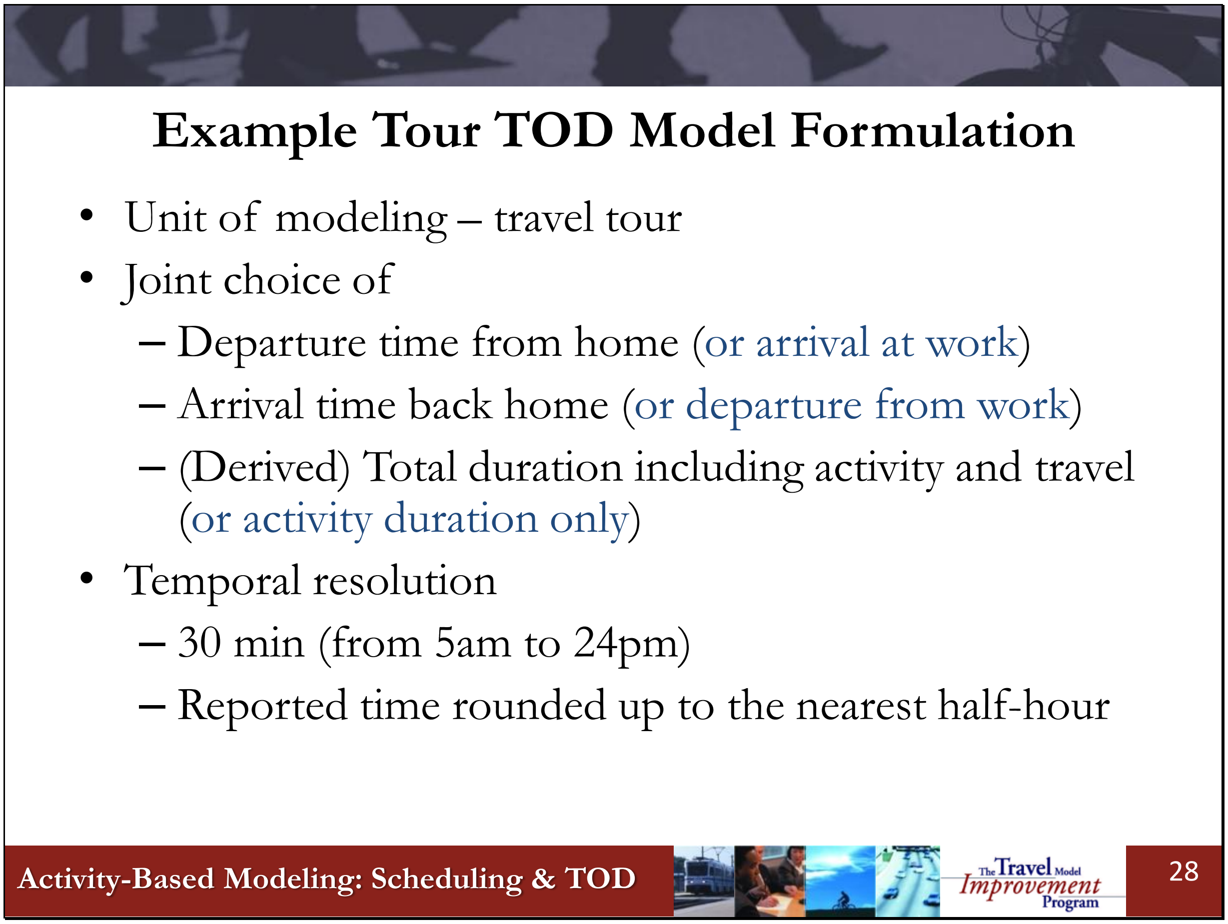
By applying continuous shift models in discrete space we mimic the good properties of continuous models such as variety of variables and corresponding profiles as well as quite a parsimonious structure with a few parameters to estimate. The statistical model structure is actually very simple. It is an ordinary choice model, most frequently logit. You can estimate it using a standard software package that you would use to estimate a mode choice model. The number of coefficients to estimate is less than the number of alternatives, thanks to the shift variables. However continuous time models have their own merits, such as better and more natural incorporation of activity duration as well as possible integration with discrete choice models.

TOD Choice and Assignments

- Ideally
  - TOD choice integrated with entire-day DTA
  - Trip tables and LOS variables generated by 5 min slices
- Practically
  - TOD choice integrated with SUE by 6-12 TOD periods (carrying over incomplete trips from period to period)
  - Trip tables and LOS variables aggregated by 6-12 TOD periods
  - HH, person, and zonal variables differentiate beyond TOD periods

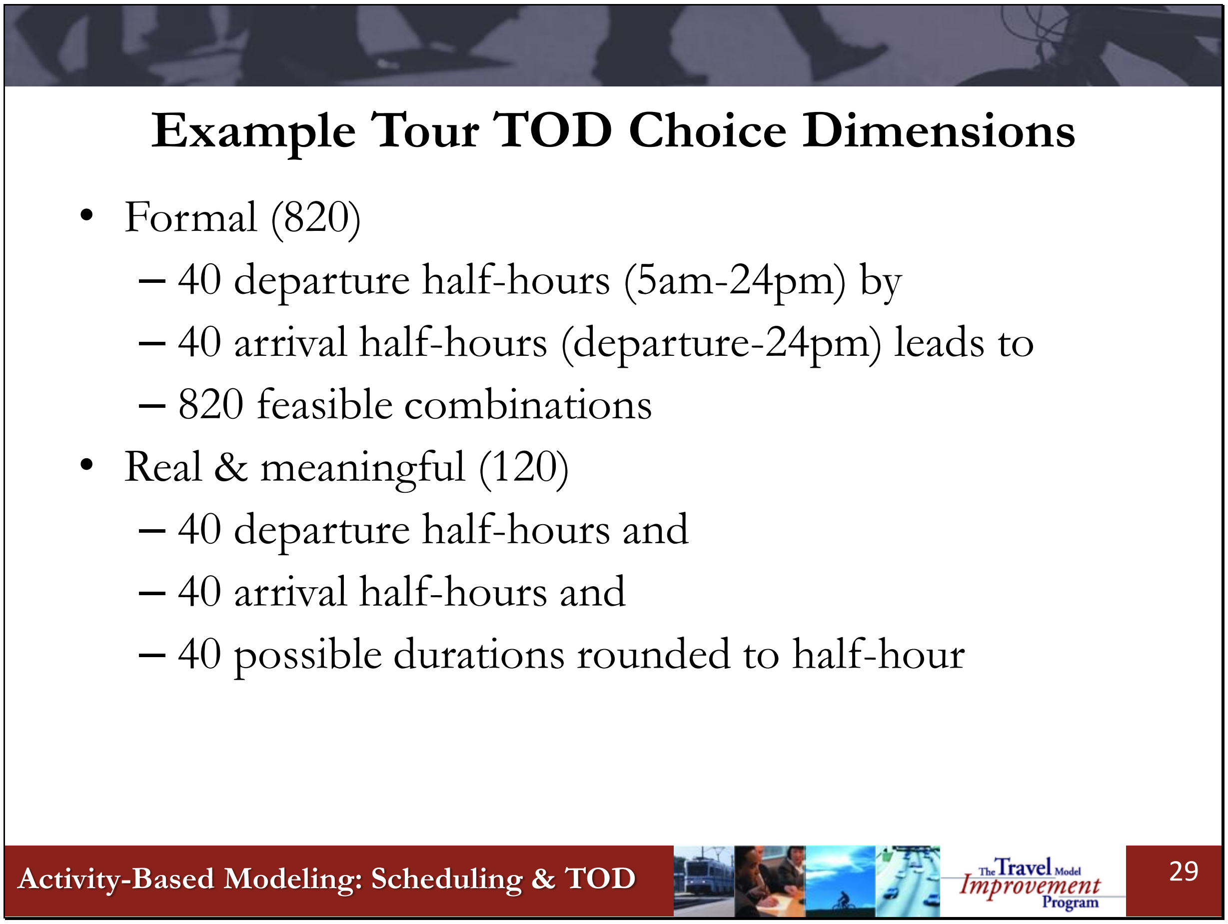
8 periods (Chicago ABM)
Night (7pm-6am)
Early AM shoulder (6am-7am)
AM peak (7am-9am)
Late AM shoulder (9am-10am)
Midday (10am-3pm)
Early PM shoulder (3pm-4pm)
PM peak (4pm-6pm)
PM late shoulder (6pm-7pm)

While the time-of-day choice operates with temporal resolution of 30 min or less we still have limitations on the network assignment side. It would be difficult to run 40 half-hour static assignments to match the activity-based model resolution. An ideal solution would be a full day DTA but this is still problematic for large regions. The compromise solution is to apply 5-8 static assignments that portray the main differences in time-of-day periods with respect to congestion and pricing as in the examples shown on the slide. These assignments can be run in parallel with distributed processing so that the run time will be equal to the single assignment run time. Distributed processing is possible with multiple computers or with multiple cores and threads on a single server.

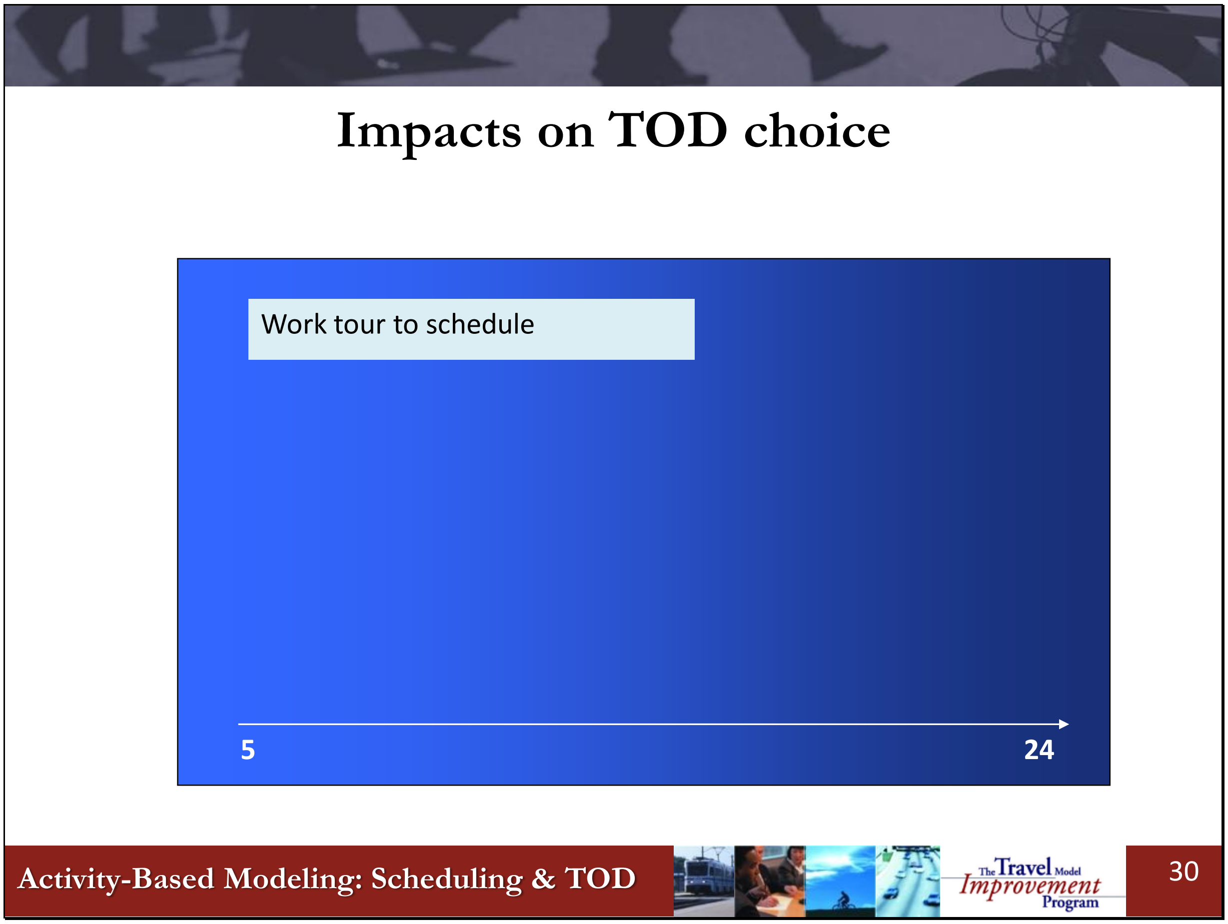


Now let’s consider details of the time-of-day choice model structure. We will focus on a single travel tour (for example work tour). We consider entire travel tour as unit of modeling. The model represents joint choice of:

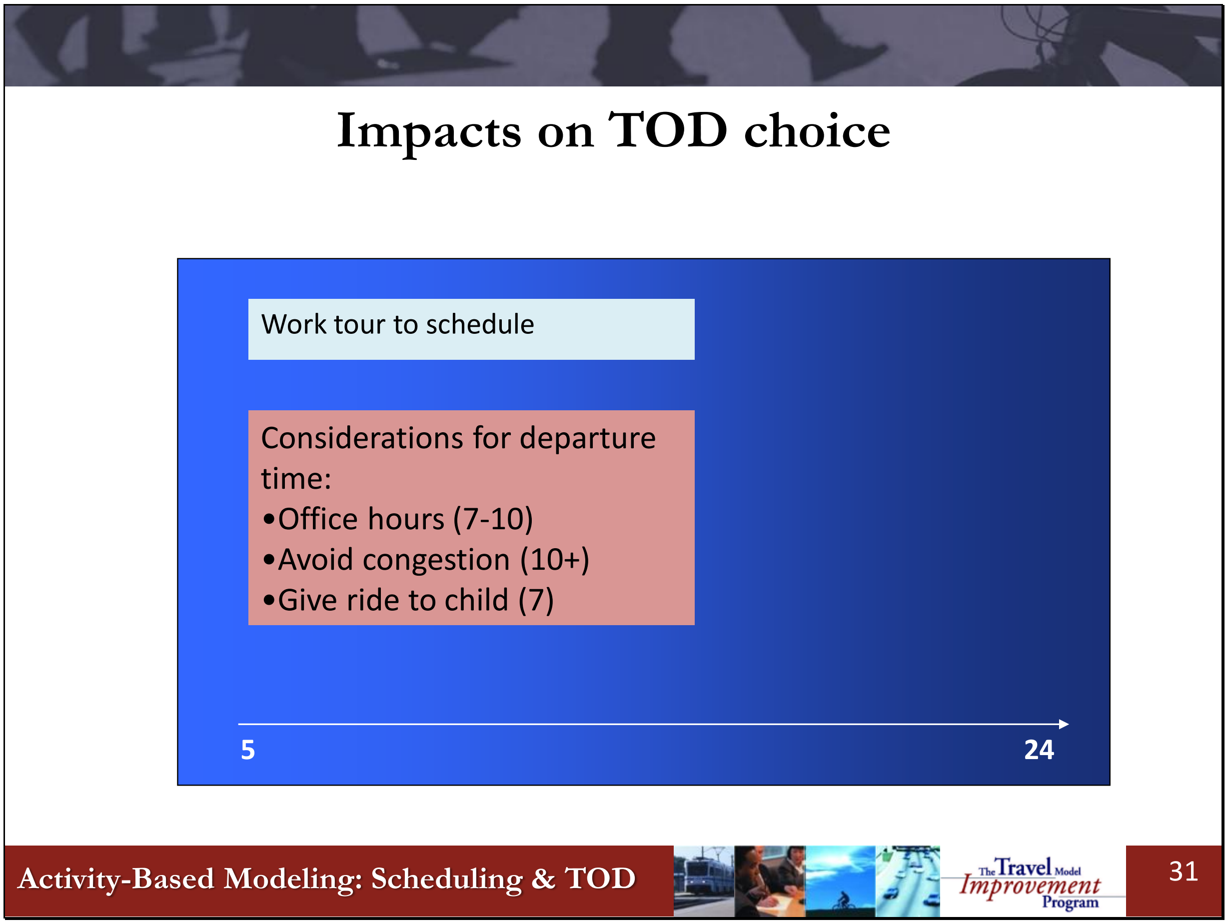
- Departure time from home;
- Arrival time back home;
- And total duration including activity and travel; and
- Temporal resolution is 30 min (from 5am to 24pm); thus reported time rounded up to the nearest half-hour.



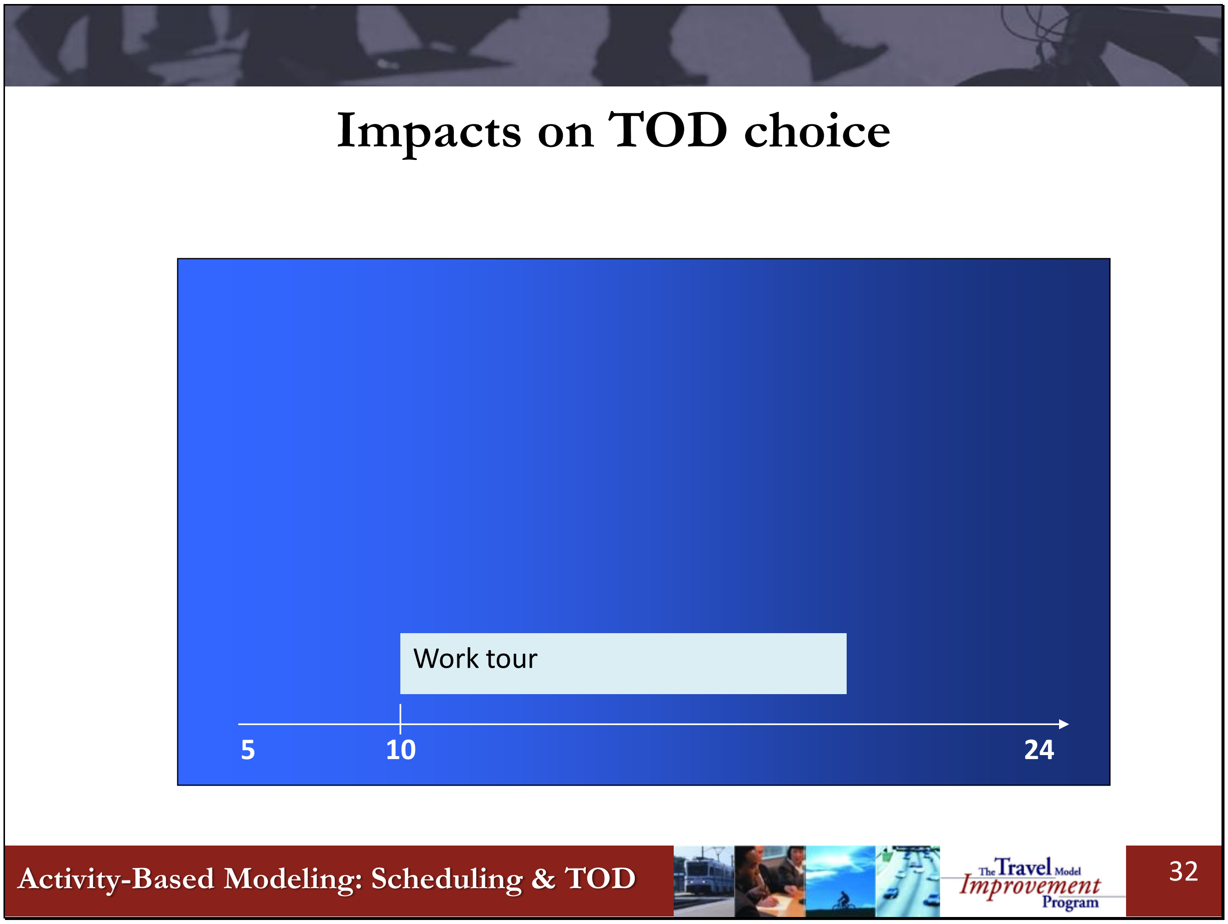
In this choice structure we have 820 choice alternatives that correspond to feasible combinations of the departure half-hour bins and arrival half-hour bins. Arrival back home cannot be earlier than departure from home. However we do not have to estimate and apply 820 unique utility expressions. That would be impossible. The advantage of this structure is that it can be decomposed into 120 meaningful dimensions for which we have to form utility components using shift variables. These components are further combined for each of the 820 alternatives. The first set of utility components corresponds to 40 departure time alternatives. The second set of utility components corresponds to 40 arrival time alternatives. The third set of utility components corresponds to 40 possible tour/activity durations. These combinations can be illustrated in the following way.



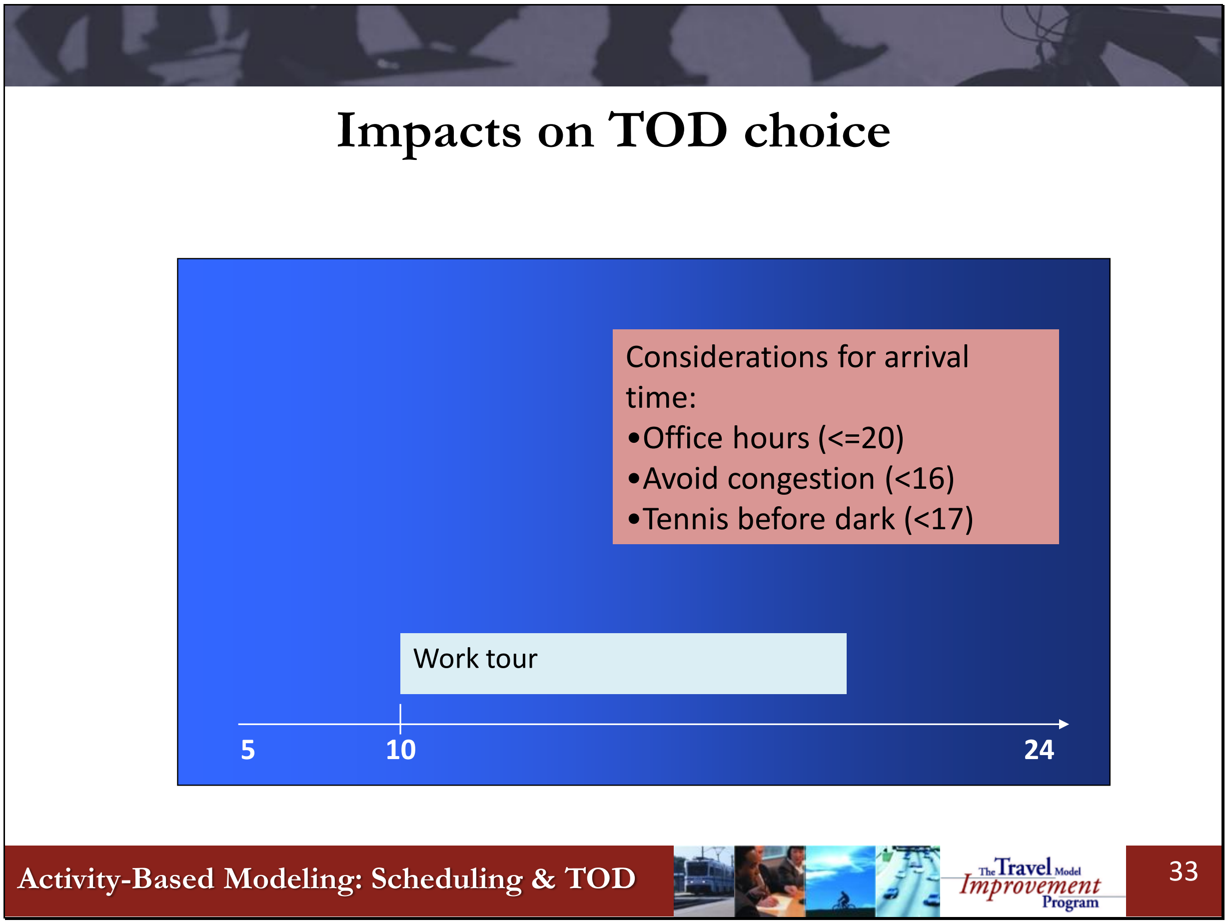
Consider a work tour that we want to predict for a given person. Currently the entire day window is open for the person and no other activities have been scheduled yet.



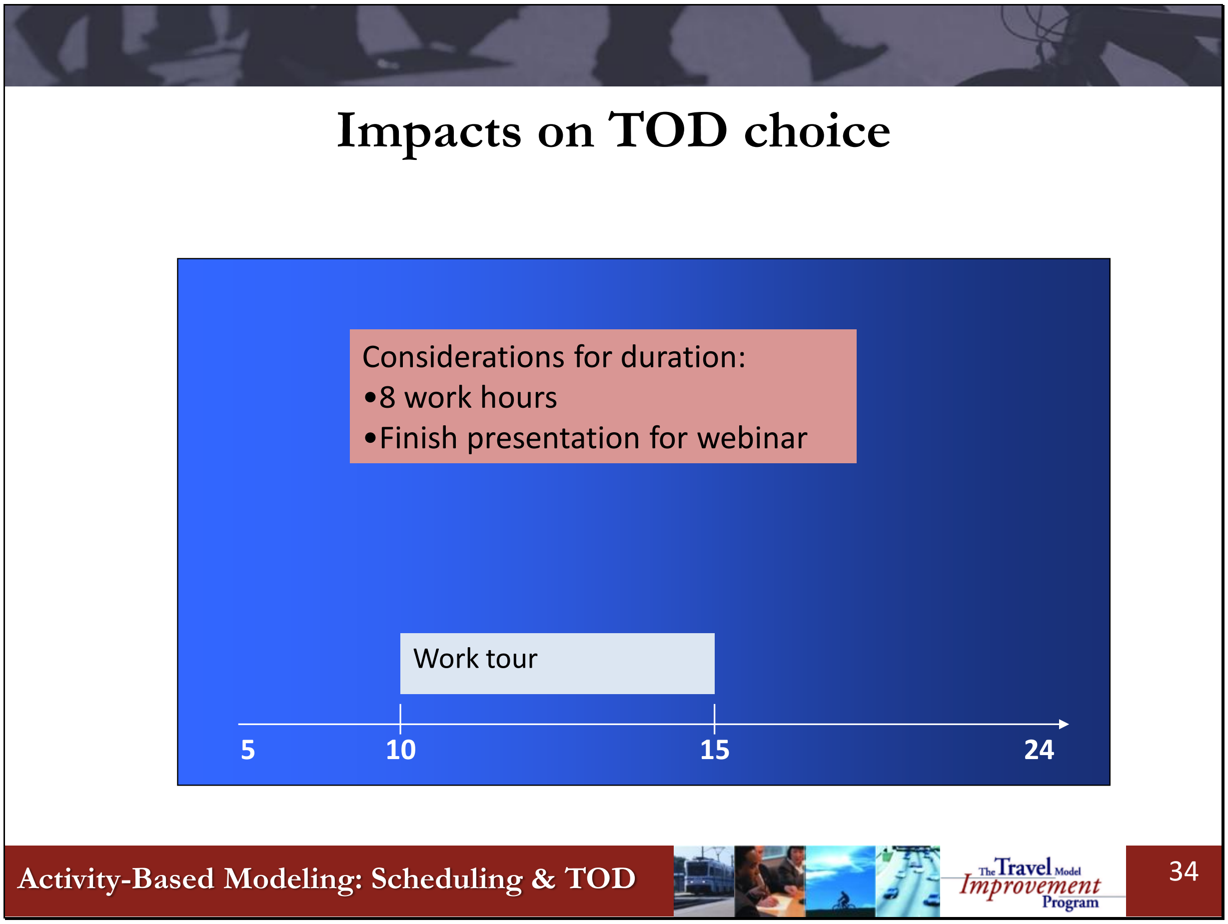
There are many factors and variables that affect the departure time from home for a work tour. These include office hours, the desire to avoid congestion and the potential need to provide rides to children. They are all included in the corresponding utility components.



Let’s say that based on the departure time utility component only the optimal time for this person to start work is 10am. This is the best utility so far.

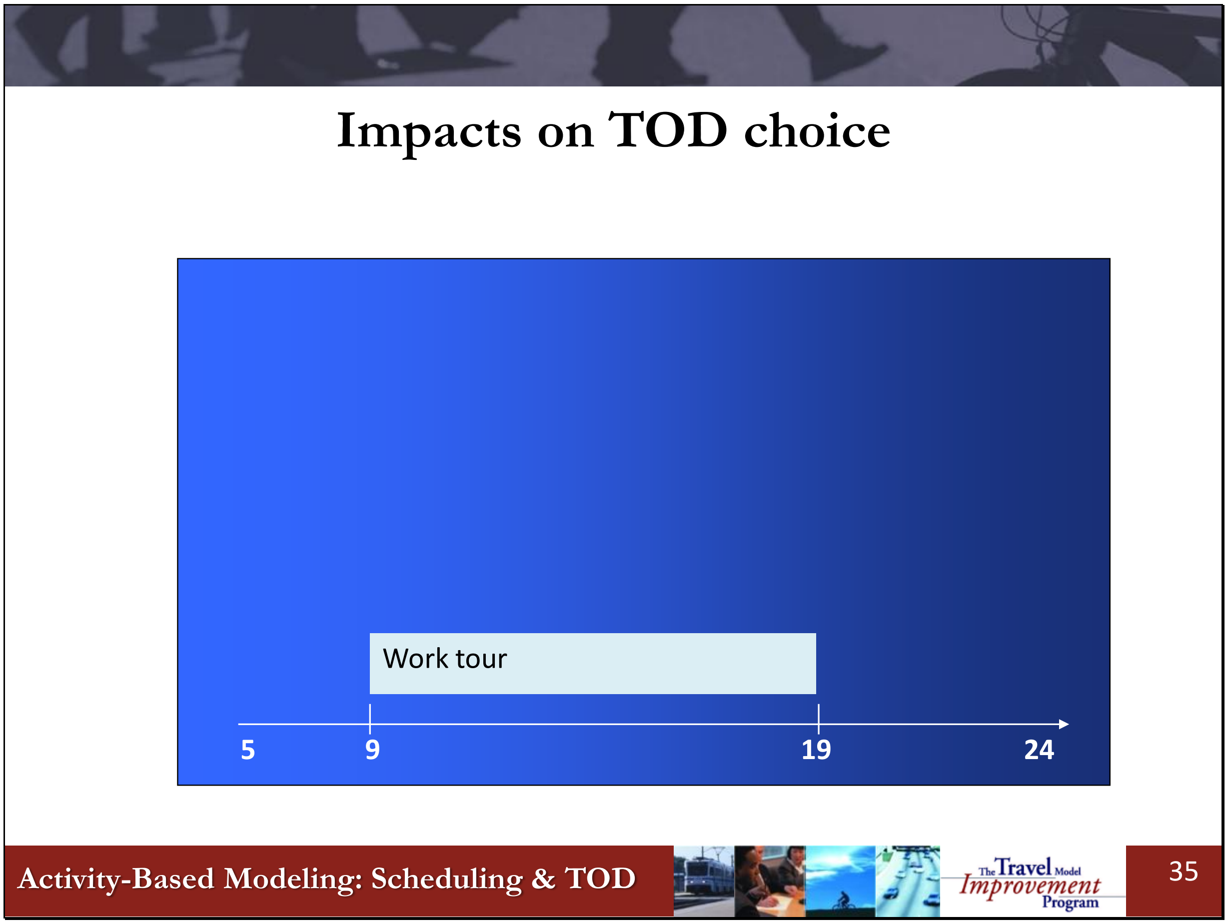


There are also many factors and variables affecting time of arrival back home. These include (again) office hours and the desire to avoid congestion, but in the particular example the individual may wan t to play tennis before it gets dark. These factors are incorporated in the second utility component for each alternative. Let’s say that from the perspective of arrival time back home we can find an optimal solution (i.e., the best utility).

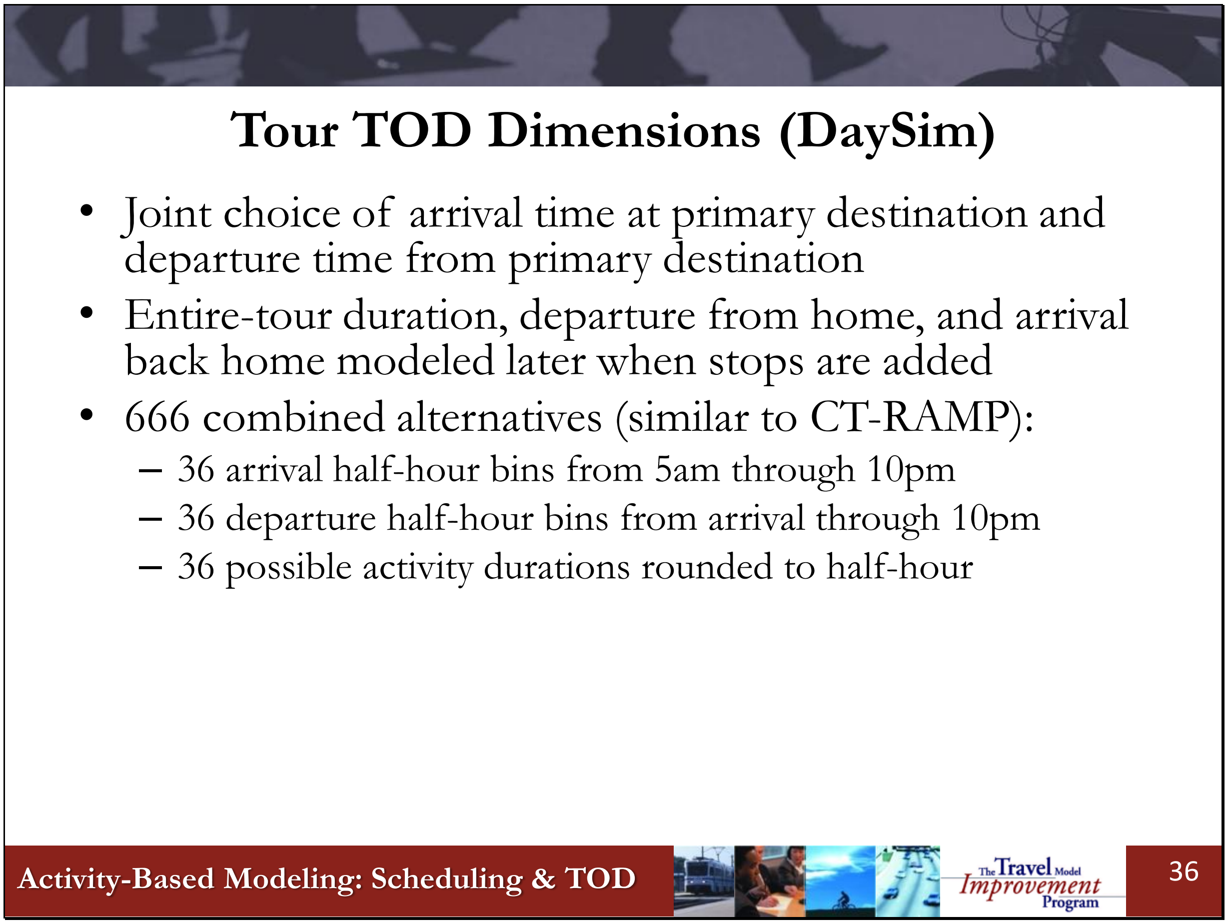


And this optimal solution will look like this. So far there is nothing in the choice structure that would prevent the choice model form generation a solution like this. Interestingly, this is not just a theoretical absurd. A 4-step trip-based framework where a time-of-day choice model is applied for each trip separately can easily generate a solution like this. However, in the tour-based framework we have a third set of factors and variables encapsulated in the duration component of the utility function (push button). These considerations would results in a more realistic solution where all three dimensions – departure, arrival, and duration would be integrated and the best compromise will be found.

One contrast between a 4-step model and an activity-based model would be their response to congestion pricing. A 4-step model in which outbound and inbound commuting trips are considered separately can shift the morning commuters to a later period and evening commuters to the earlier period, depending on the toll structure and schedule. However, this response is illogical since the overall balance between outbound and inbound time should be kept. This can only be achieved with an activity-based model that has an activity duration dimension explicitly.



This solution will look most probably like this, i.e. what we most frequently observe in reality. In this example we assume a 10-hour entire-tour span because it includes commuting time in addition to a normal 8-hour workday.



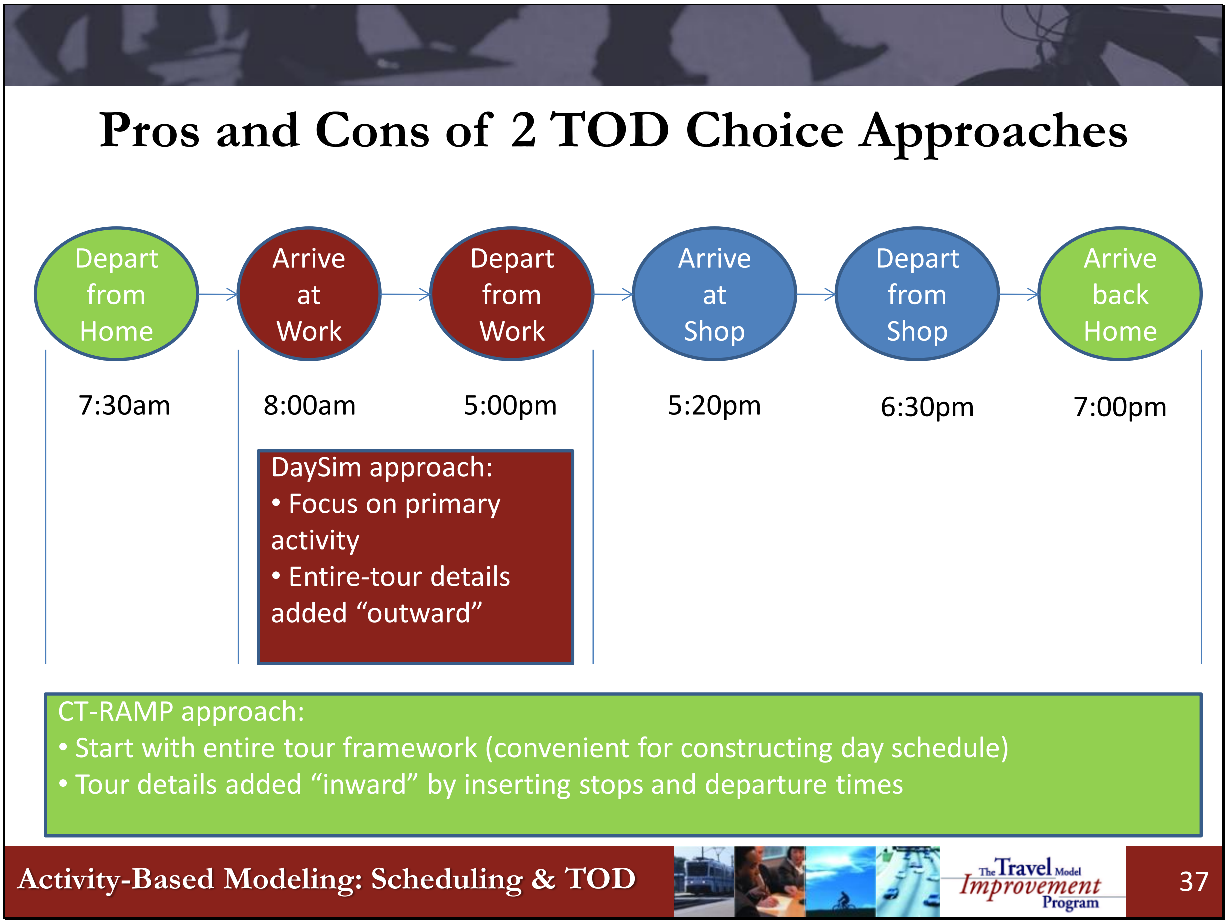
Similar logic is used in many other activity-based models. For example in the DaySim activity-based model the dimensions of tour are redefined in the following way:

- Joint choice of arrival time at primary destination and departure time from primary destination is modeled first.
- The entire tour's duration, departure time from home, and arrival time back home are modeled later after stops are added.

This results in 666 combined alternatives with 36 alternatives in each dimension:

- 36 arrival half-hour bins from 5am through 10pm
- 36 departure half-hour bins from arrival through 10pm
- 36 possible activity durations rounded to half-hour.

The number of alternatives is slightly less compared to CT-RAMP since the tour framework is limited to the primary activity only.



To summarize differences between two approaches let's consider a realistic tour structure as shown on the slide:

- Depart from home at 7:30am
- Arrive at work at 8:00am
- Depart from work at 5:00pm
- Arrive at shopping mall at 6:20pm
- Depart from shopping mall at 6:30pm
- Arrive back home at 7:00pm

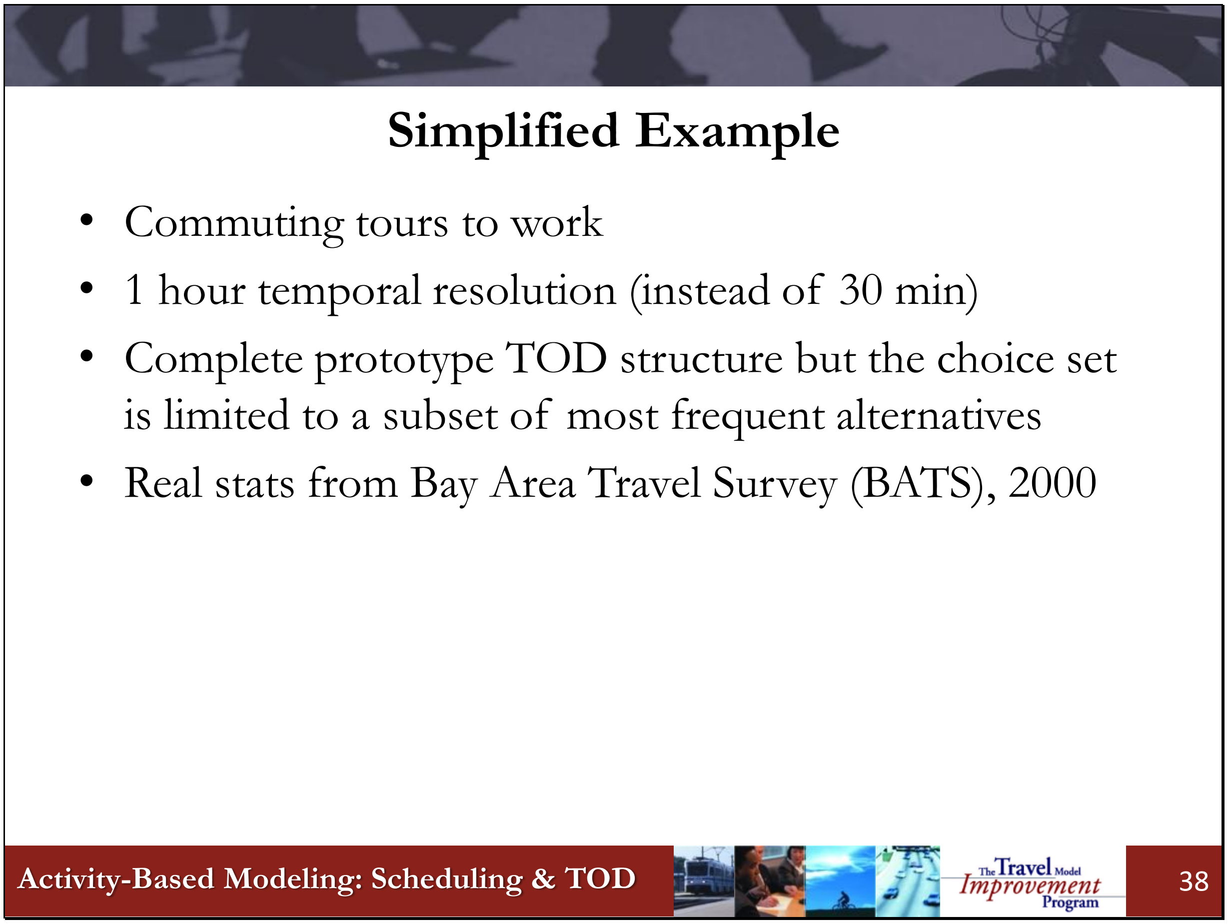
"Inward tour window partition" (CT-RAMP) is characterized by the following main features:

- Tour time-of-day modeled from departure from home until arrival back home; entire tour window constrains trip departure time
- Stops are sequentially inserted in a chronological order for each half-tour (outbound, inbound)

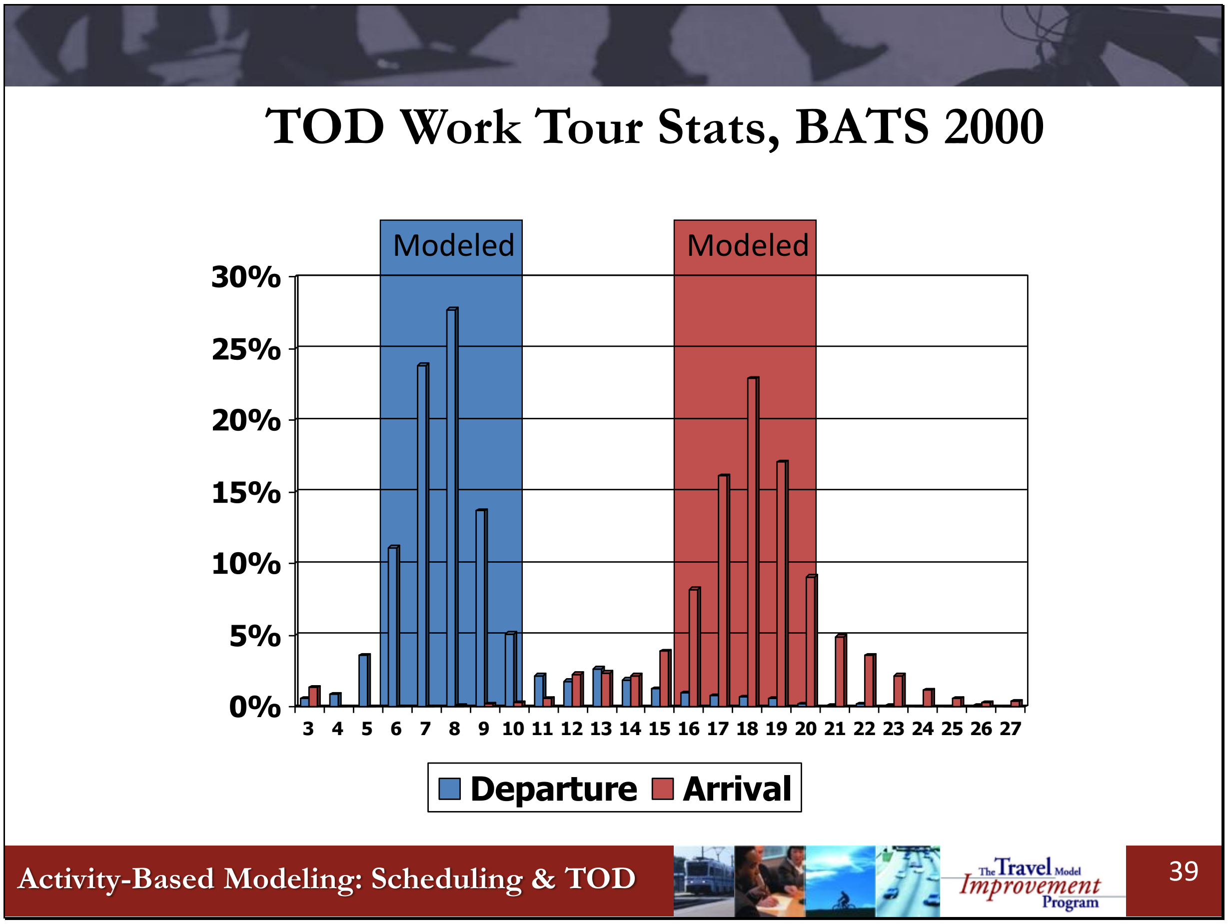
"Outward tour window extension" (DaySim) is characterized by the following main features:

- Primary tour activity time-of-day modeled from arrival at primary destination until departure from primary destination; primary activity window constrains trip departure time
- Stops are sequentially added in a chronological order for each half-tour (outbound, inbound)

Both approaches have their own merits and eventually provide all necessary tour details.



For you to have a better "feel" and more technical hand-on details we consider a simplified example of commuting tour. We will model it with a 1-hour resolution to reduce the number of alternatives. We will consider a complete prototype choice model structure but to further limit the choice set we will consider only a subset of most frequent alternatives. WE define them based on the real stats from the BATS survey.



The modeled areas cover majority of cases. They correspond to 5 morning hours for departure time and 5 afternoon hours for arrival time back home.

TOD Work Tour Stats, BATS 2000

Departure from home	Arrival back home				
	3-5	**6-10**	**11-15**	**16-20**	**21-27**
3-5	0.0%	0.1%	1.2%	3.4%	0.3%
6-10		0.6%	9.3%	62.9%	8.0%
11-15			1.0%	6.1%	2.7%
16-20				0.9%	2.0%
21-27					0.3%

If we single out tours that start in the first selected period and end in the second selected period we cover more than 60% of the observed tours. In the real time-of-day choice application we of course consider all possible combinations. But for now we will focus on the selected time periods for simplicity (and only to reduce the number of alternatives).

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Departure from home	Arrival back home	Duration	Alternative	Utility
6 (5:30-6:29 AM)	16 (15:30-16:29 PM)	10	1	DEP6 + ARR16 + DUR10
	17 (16:30-16:29 PM)	11	2	DEP6 + ARR17 + DUR11
	18 (17:30-16:29 PM)	12	3	DEP6 + ARR18 + DUR12
	19 (18:30-16:29 PM)	13	4	DEP6 + ARR19 + DUR13
	20 (19:30-16:29 PM)	14	5	DEP6 + ARR20 + DUR14
7 (6:30-7:29 AM)	16 (15:30-16:29 PM)	9	6	DEP7 + ARR16 + DUR9
	17 (16:30-16:29 PM)	10	7	DEP7 + ARR17 + DUR10
	18 (17:30-16:29 PM)	11	8	DEP7 + ARR18 + DUR11
	19 (18:30-16:29 PM)	12	9	DEP7 + ARR19 + DUR12
	20 (19:30-16:29 PM)	13	10	DEP7 + ARR20 + DUR13
8 (7:30-8:29 AM)	16 (15:30-16:29 PM)	8	11	DEP8 + ARR16 + DUR8
	17 (16:30-16:29 PM)	9	12	DEP8 + ARR17 + DUR9
	18 (17:30-16:29 PM)	10	13	DEP8 + ARR18 + DUR10
	19 (18:30-16:29 PM)	11	14	DEP8 + ARR19 + DUR11
	20 (19:30-16:29 PM)	12	15	DEP8 + ARR20 + DUR12
9 (8:30-9:29 AM)	16 (15:30-16:29 PM)	7	16	DEP9 + ARR16 + DUR7
	17 (16:30-16:29 PM)	8	17	DEP9 + ARR17 + DUR8
	18 (17:30-16:29 PM)	9	18	DEP9 + ARR18 + DUR9
	19 (18:30-16:29 PM)	10	19	DEP9 + ARR19 + DUR10
	20 (19:30-16:29 PM)	11	20	DEP9 + ARR20 + DUR11
10 (9:30-10:29 AM)	16 (15:30-16:29 PM)	6	21	DEP10 + ARR16 + DUR6
	17 (16:30-16:29 PM)	7	22	DEP10 + ARR17 + DUR7
	18 (17:30-16:29 PM)	8	23	DEP10 + ARR18 + DUR8
	19 (18:30-16:29 PM)	9	24	DEP10 + ARR19 + DUR9
	20 (19:30-16:29 PM)	10	25	DEP10 + ARR20 + DUR10

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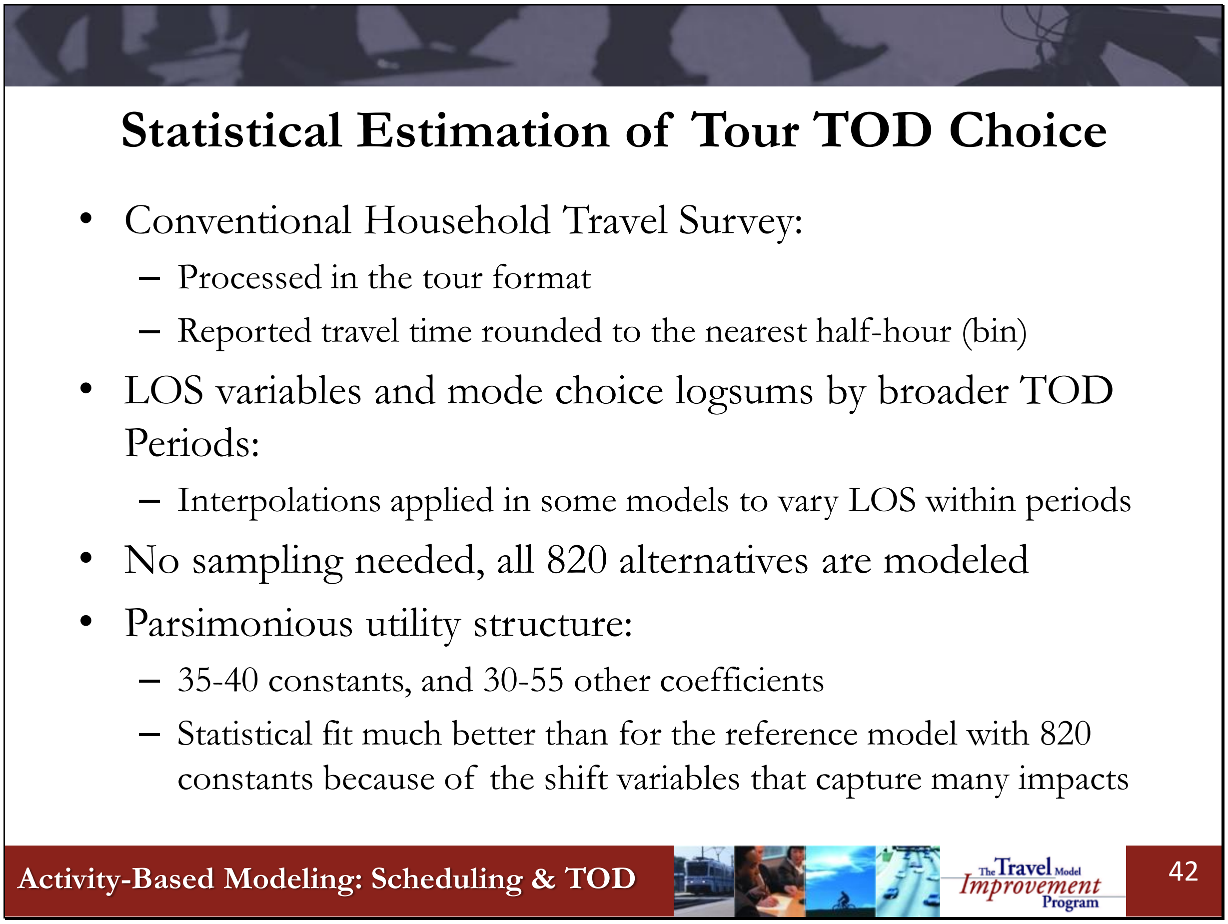
This results in 25 alternatives, as listed in the table. The choice set includes all combinations of 5 possible departure times and 5 possible arrival times. For each of the alternatives we have three utility components that describe the corresponding departure time, arrival time, and duration. Consider for example alternative number 6 (push the button). This alternative assumes departure from home at 7am, arrival back home at 4pm and total tour duration of 9 hours.



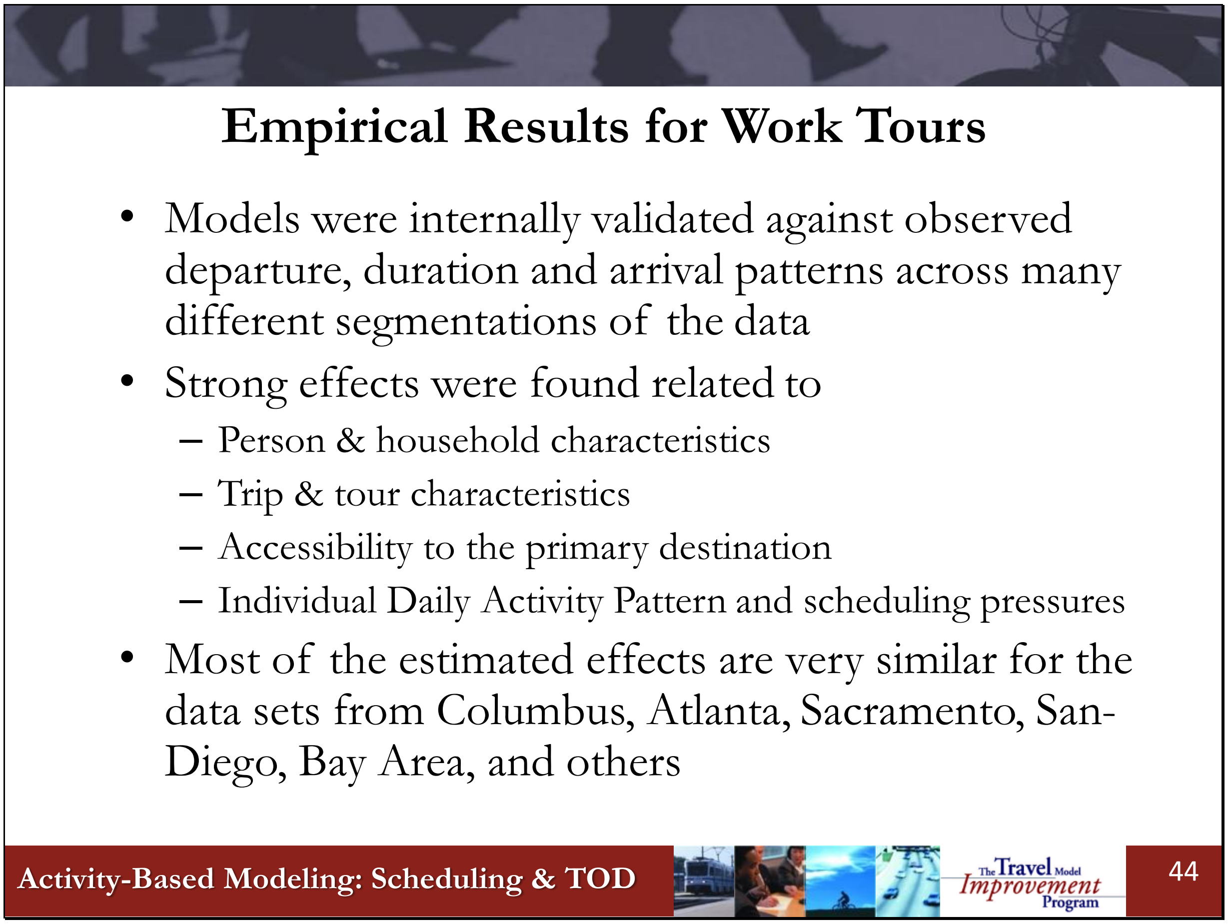
A model of this type is estimated based on the conventional Household Travel Survey It has to be processed in the tour format and reported travel time rounded to the nearest half-hour (bin). LOS variables and mode choice log-sums are specified by broader time-of-day Periods.

No sampling needed, all 820 alternatives are modeled. Parsimonious utility structure is applied with 35-40 constants and 30-55 other coefficients. Despite a limited number of parameters statistical fit is much better than for the reference model with 820 constants because of the shift variables that capture many impacts.

Questions and Answers

The Travel Model *Improvement* Program

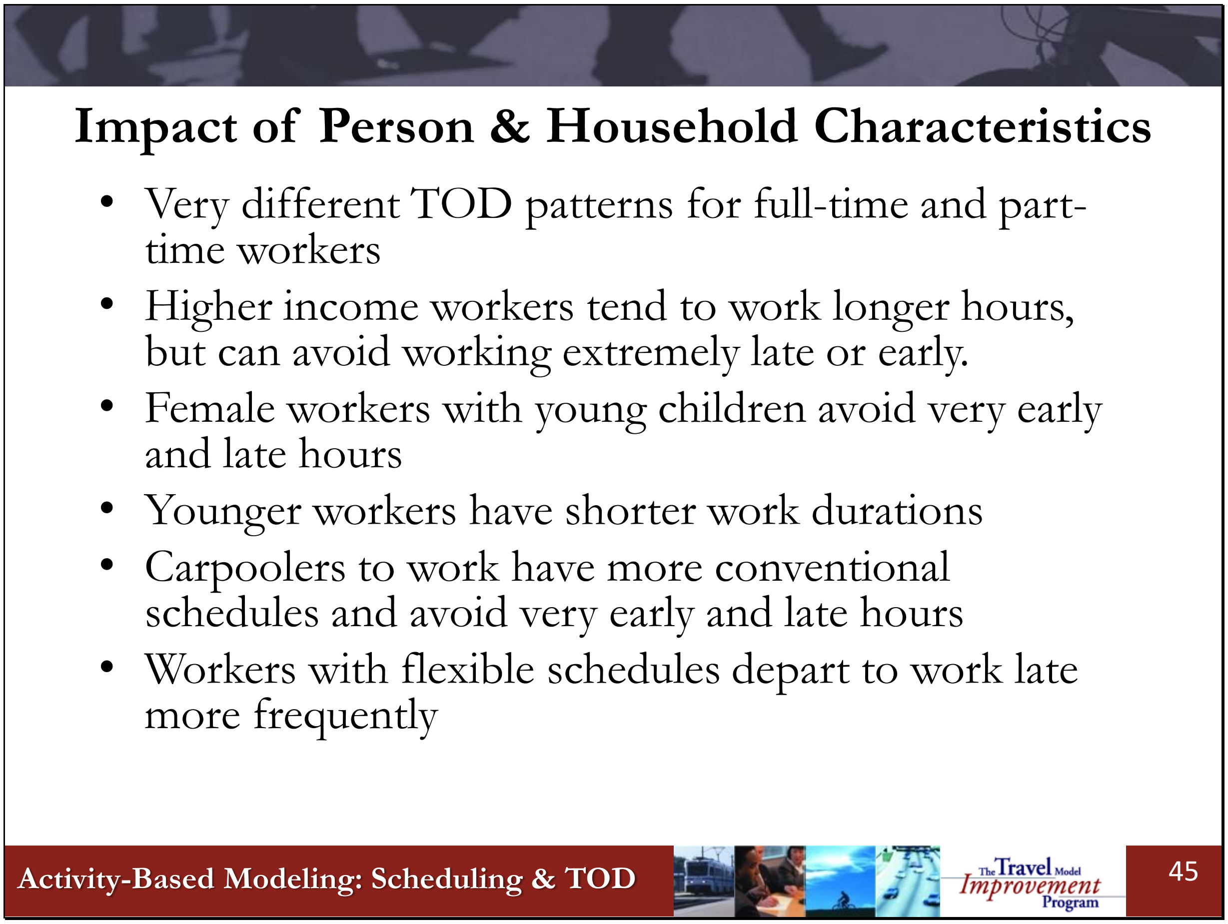
Speakers: Peter Vovsha & Maren Outwater



Models were internally validated against observed departure, duration and arrival patterns across different segmentations of the data. Strong effects were found related to:

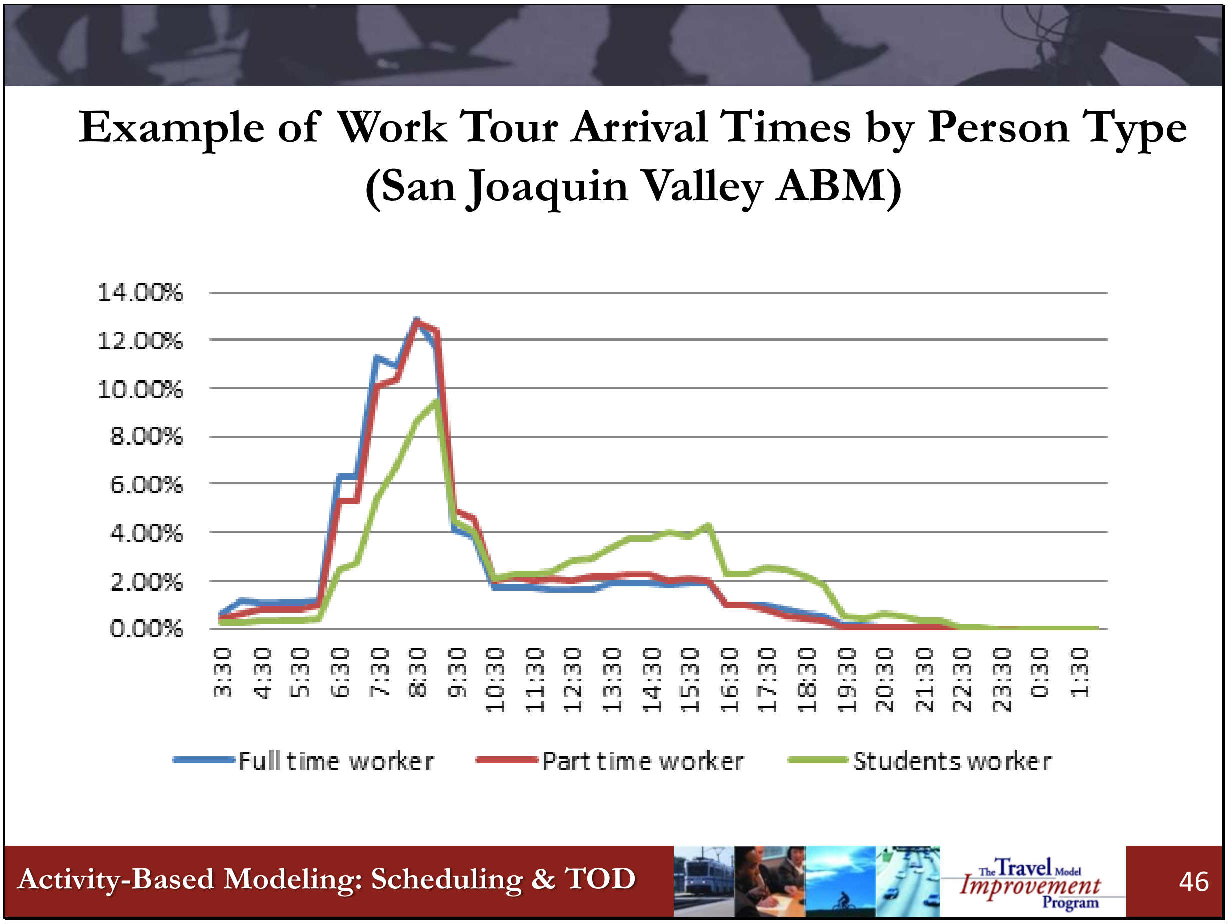
- Person & household characteristics
- Trip & tour characteristics
- Accessibility to the primary destination
- Individual Daily Activity Pattern and scheduling pressures

Most of the estimated effects are very similar for the data sets from Columbus, Atlanta, Sacramento, San-Diego, Bay Area, and others.

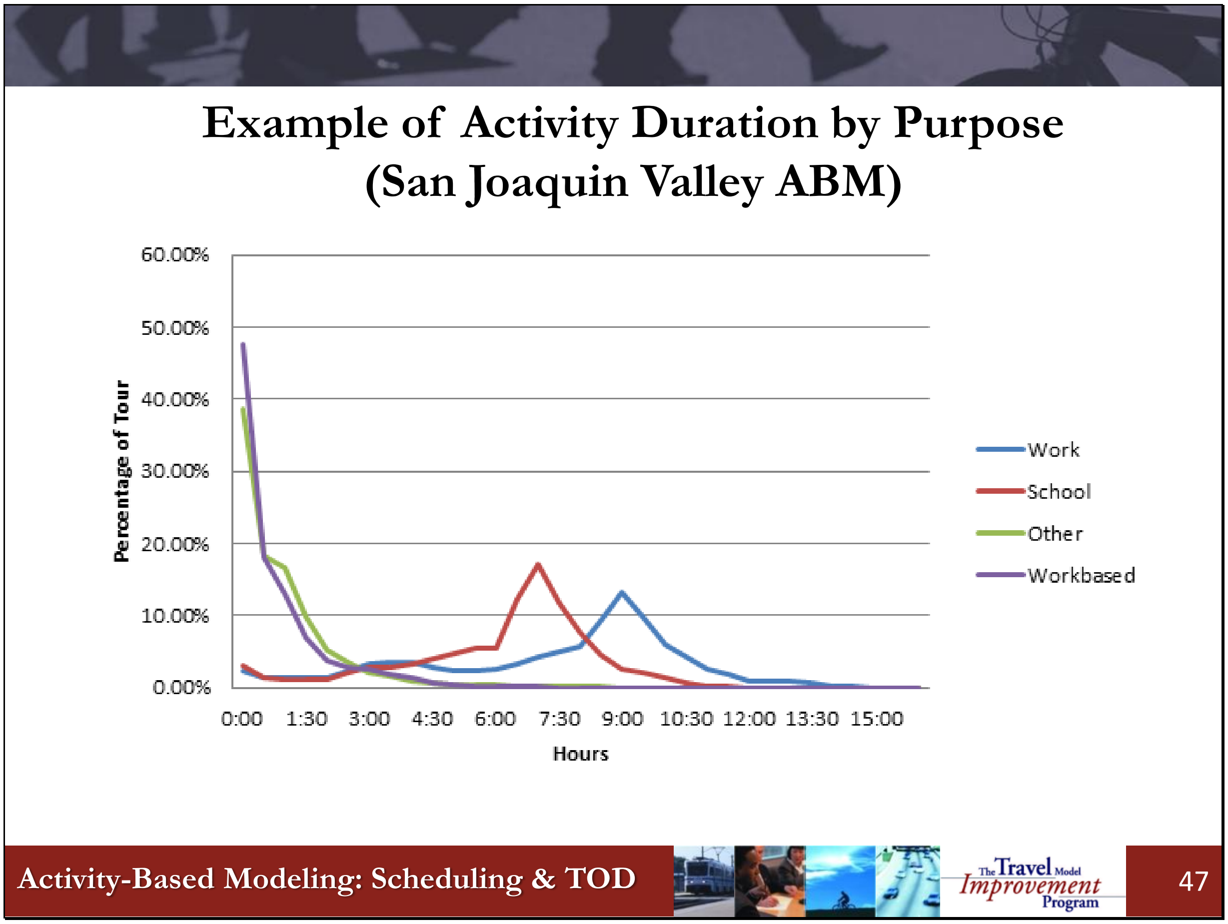


These are some of the stat findings with respect to impact of person and HH characteristics. They include the following main factors:

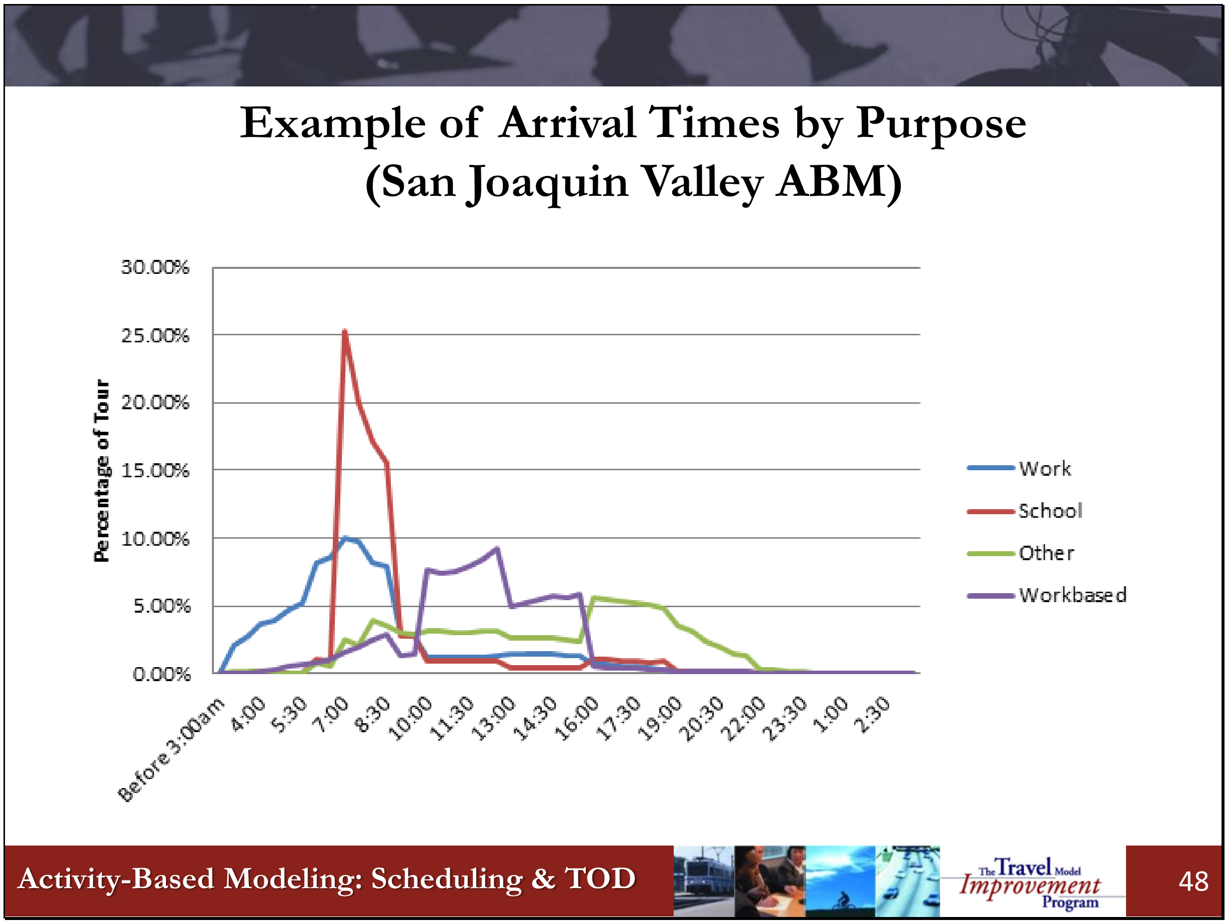
- Very different time-of-day patterns for full-time and part-time workers;
- Higher income workers tend to work longer hours, but can avoid working extremely late or early;
- Female workers with young children avoid very early and late hours;
- Younger workers have shorter work durations;
- Carpoolers to work have more conventional schedules and avoid very early and late hours; and
- Workers with flexible schedules depart to work late more frequently.



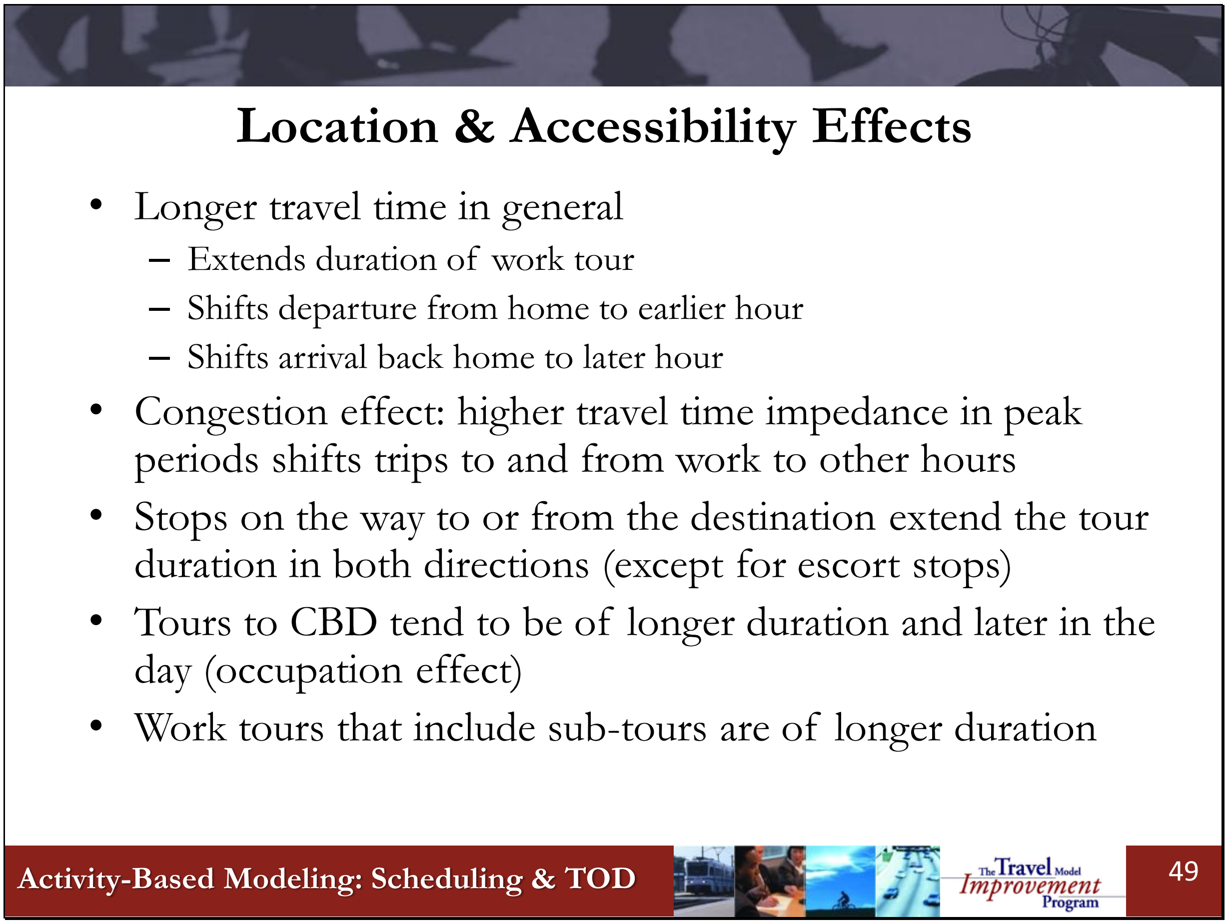
As we discussed before, impact of shift variables can be illustrated in graphical from. For example, work tour arrival times are similar for full-time and part-time workers, but student workers tend to start work later in the day. This example is derived from the 3-county activity-based model in San Joaquin, Stanislaus and Merced counties.



These are examples of activity duration by purpose from a 3-county activity-based model in the San Joaquin Valley. Work activities have the longest durations. The distribution peaks around 9 hours, and school activities are second, with peaks around 7 hours. Other activities and work-based activities are quite short in duration, peaking around 30 minutes.

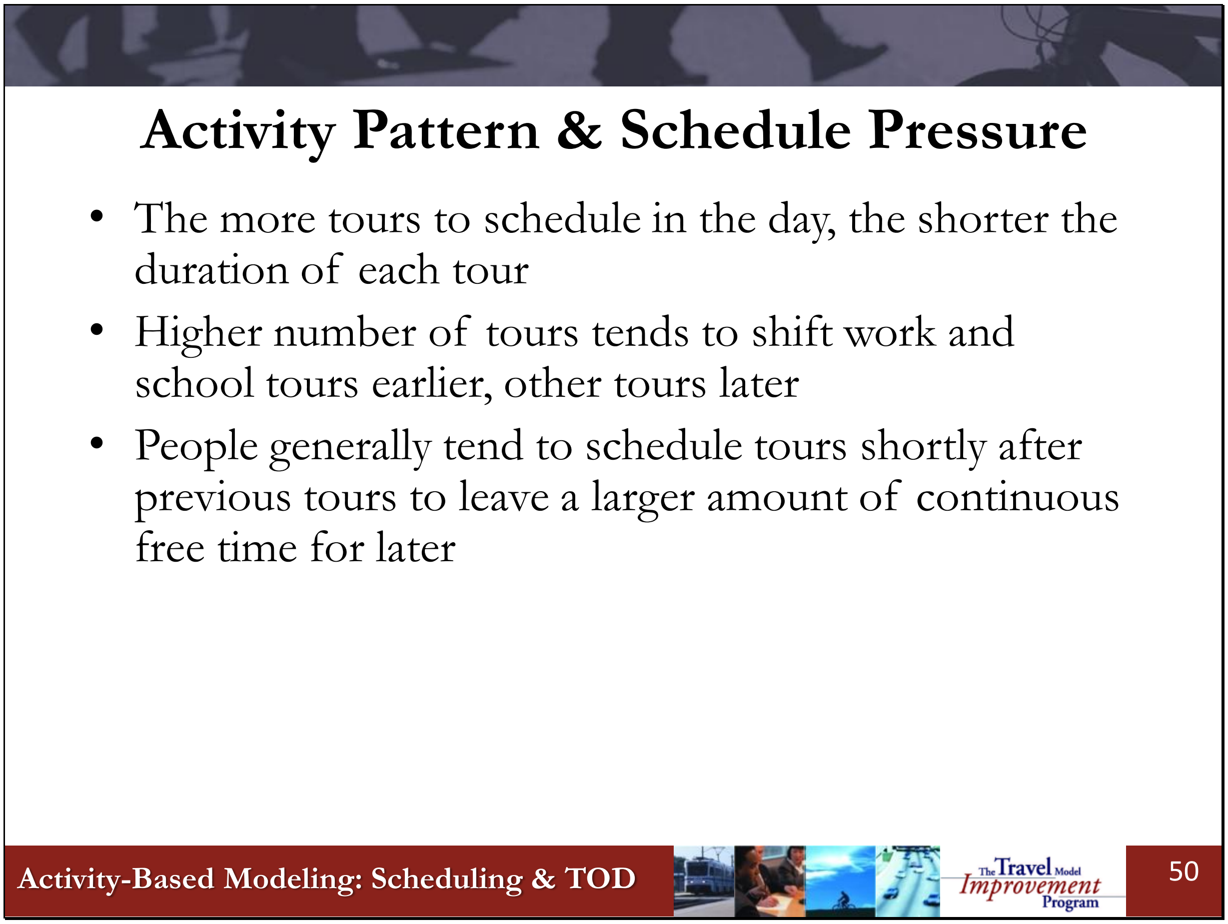


Arrival times by purpose follow expectations for different types of activities, as shown here in the arrival times by purpose from a 3-county activity-based model in the San Joaquin Valley. School activities have the highest peak, between 7-8am, with very few arrival times outside this window. Work activities are spread between 3-9am, with the majority occurring between 6-9am. Work-based activities are primarily in the middle of the day, between 10am and 4pm. Other activities tend to be in the evening, between 4-11pm.

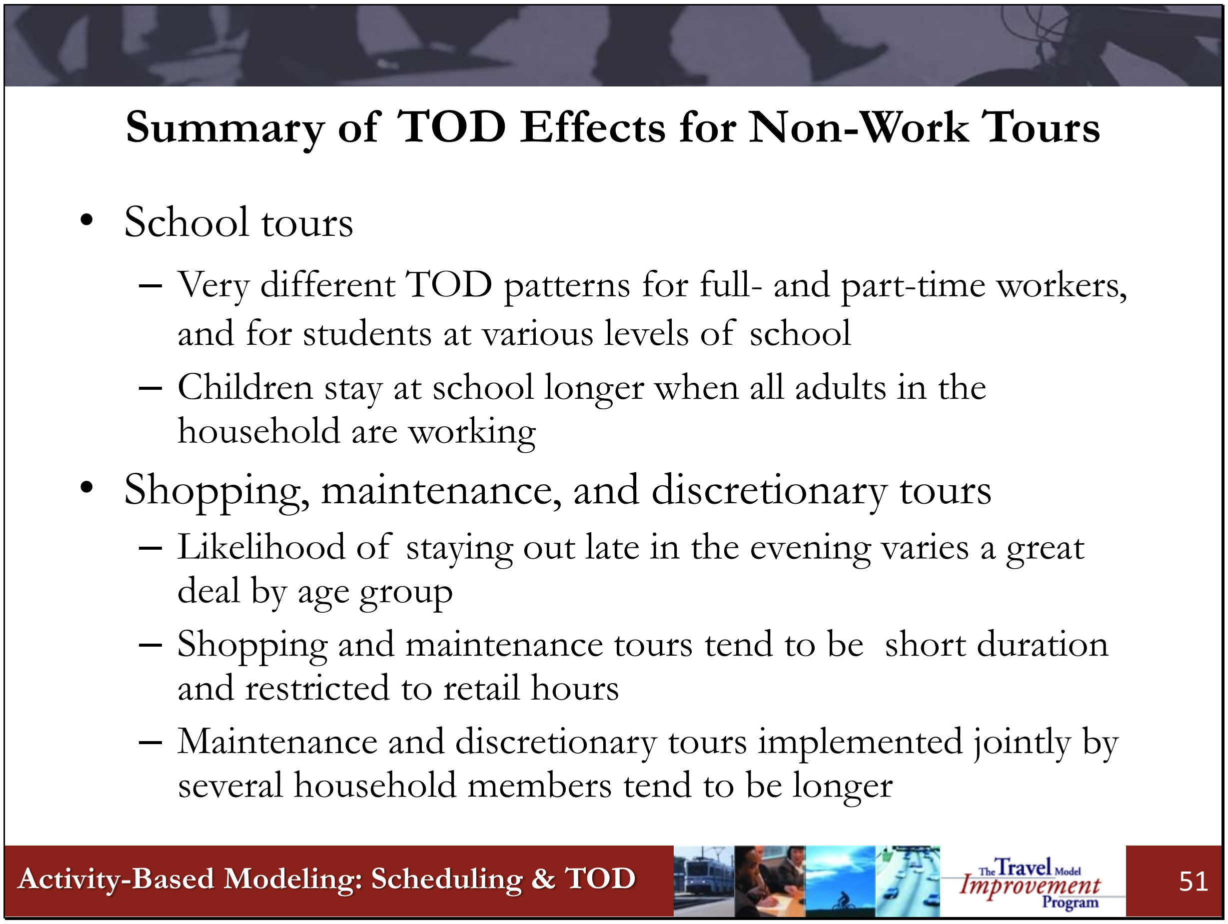


In addition to person and HH related effects time-of-day choice is strongly affected by location and accessibility effects. For example:

- Longer travel time in general Extends duration of work tour, Shifts departure from home to earlier hour, and Shifts arrival back home to later hour;
- There is a logical congestion effect: higher travel time impedance in peak periods shifts trips to and from work to other hours;
- Stops on the way to or from the destination extend the tour duration in both directions (except for escort stops);
- Tours to CBD tend to be of longer duration and later in the day (occupation effect); and
- Work tours that include sub-tours are of longer duration.

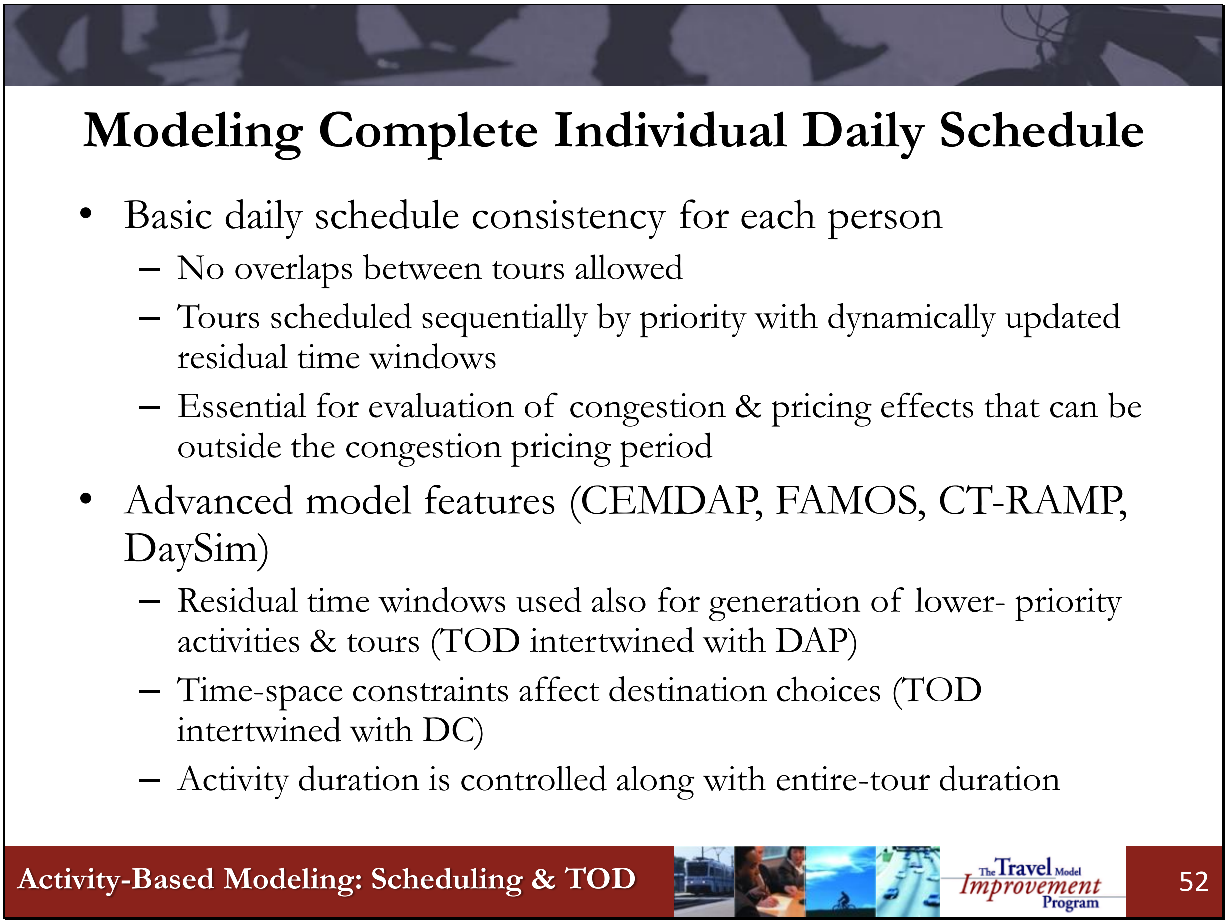


Additionally, the DAP of the person affects the time-of-day choice for each particular tour due to time-space constraints. In particular, the more tours to schedule in the day, the shorter the duration of each tour. Higher number of tours tends to shift work and school tours earlier, other tours later. People generally tend to schedule tours shortly after previous tours to leave a larger amount of continuous free time for later. All these effects are formalized trough the corresponding shift variables.



There are also certain effects pertinent to non-work tours. For school tours, there are very different time-of-day patterns for full- and part-time workers, and for students at various levels of school. Children stay at school longer when all adults in the household are working.

For shopping, maintenance, and discretionary tours, the likelihood of staying out late in the evening varies a great deal by age group. Shopping and maintenance tours tend to be of short duration and restricted to retail hours. Maintenance and discretionary tours implemented jointly by several household members tend to be longer, relative to those implemented independently. Again, all these effects are also formalized through the corresponding shift variables.

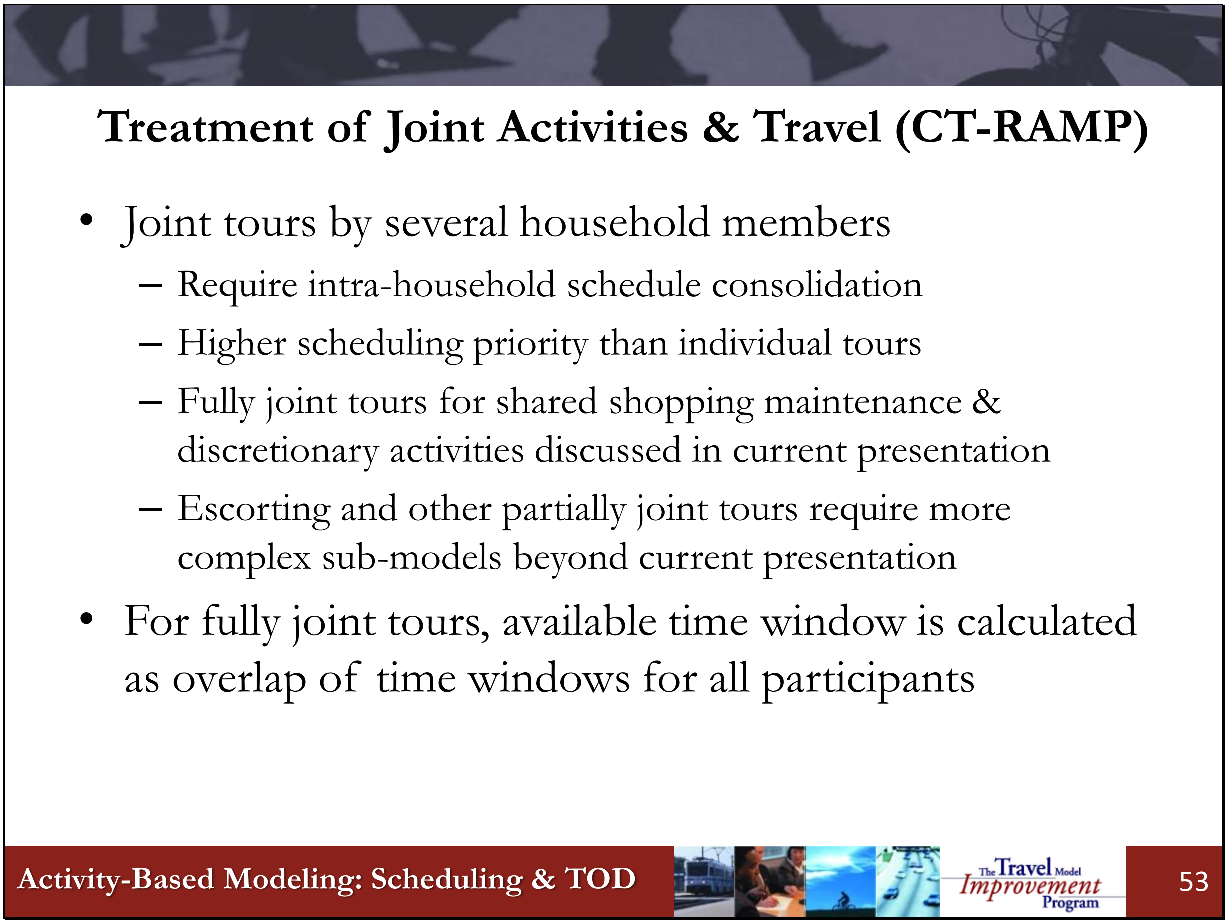


The micro-simulation activity-based model framework allows for tracking each person through time to ensure consistency of the generated individual schedule. This is one of the principal advantages of and activity-based model over 4-step. This feature means basic daily schedule consistency for each person that includes the following requirements:

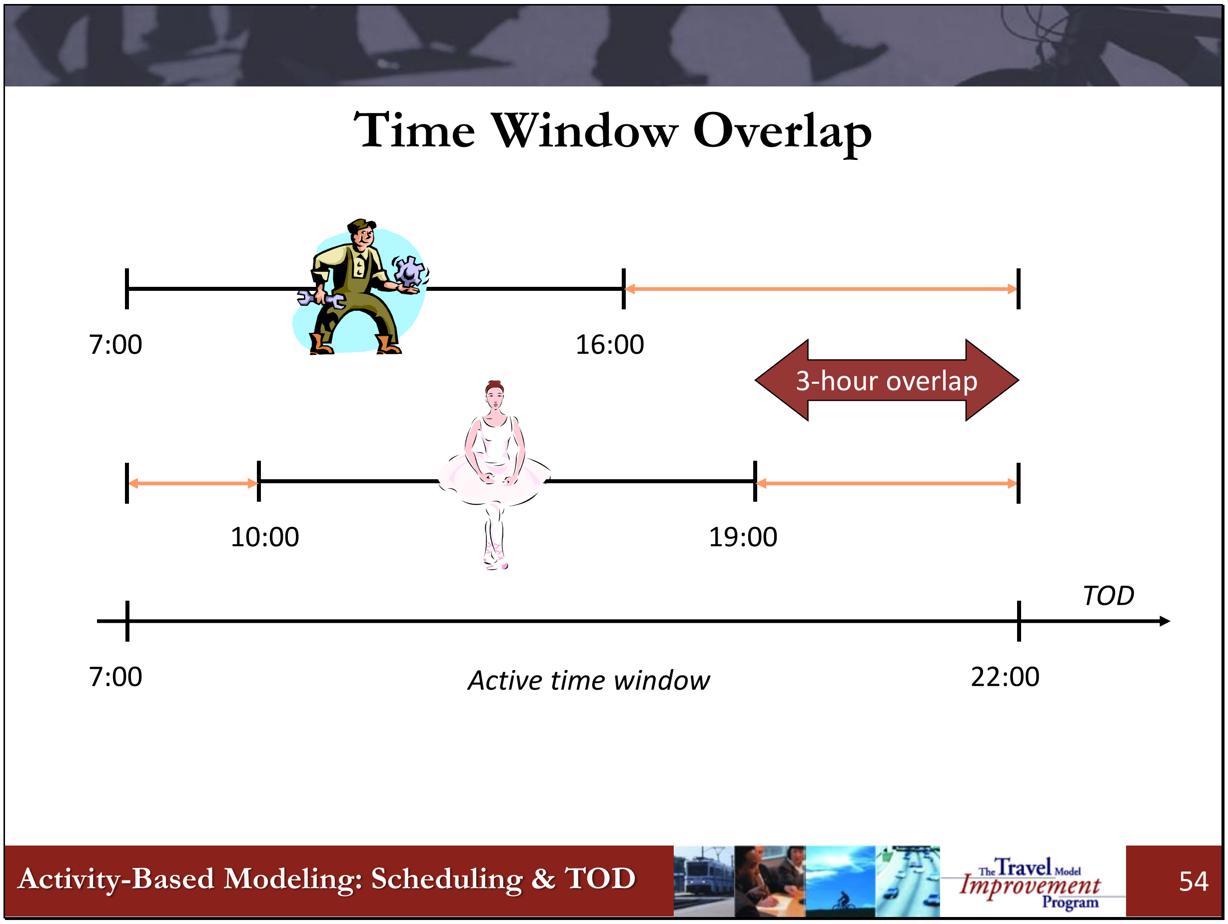
- No overlaps between tours are allowed;
- Tours are scheduled sequentially by priority with dynamically updated residual time windows.

These requirements are essential for evaluation of congestion and pricing effects that can be outside the congestion pricing period. In advanced activity-based models, some additional features were introduced:

- Residual time windows used also for generation of lower-priority activities and tours (time-of-day intertwined with DAP);
- Time-space constraints affect destination choices (time-of-day intertwined with Destination Choice); and
- Activity duration is controlled along with entire-tour duration.



An advanced activity-based model like CT-RAMP models joint activities and travel explicitly. When we model joint tour made by several HH members we have take into account the following factors … (read the first bullet). For a fully joint tour that involves several HH members we have to ensure that they are all available at the same time. In other words, their available time windows should have enough of overlap to implement the activity and associated travel.

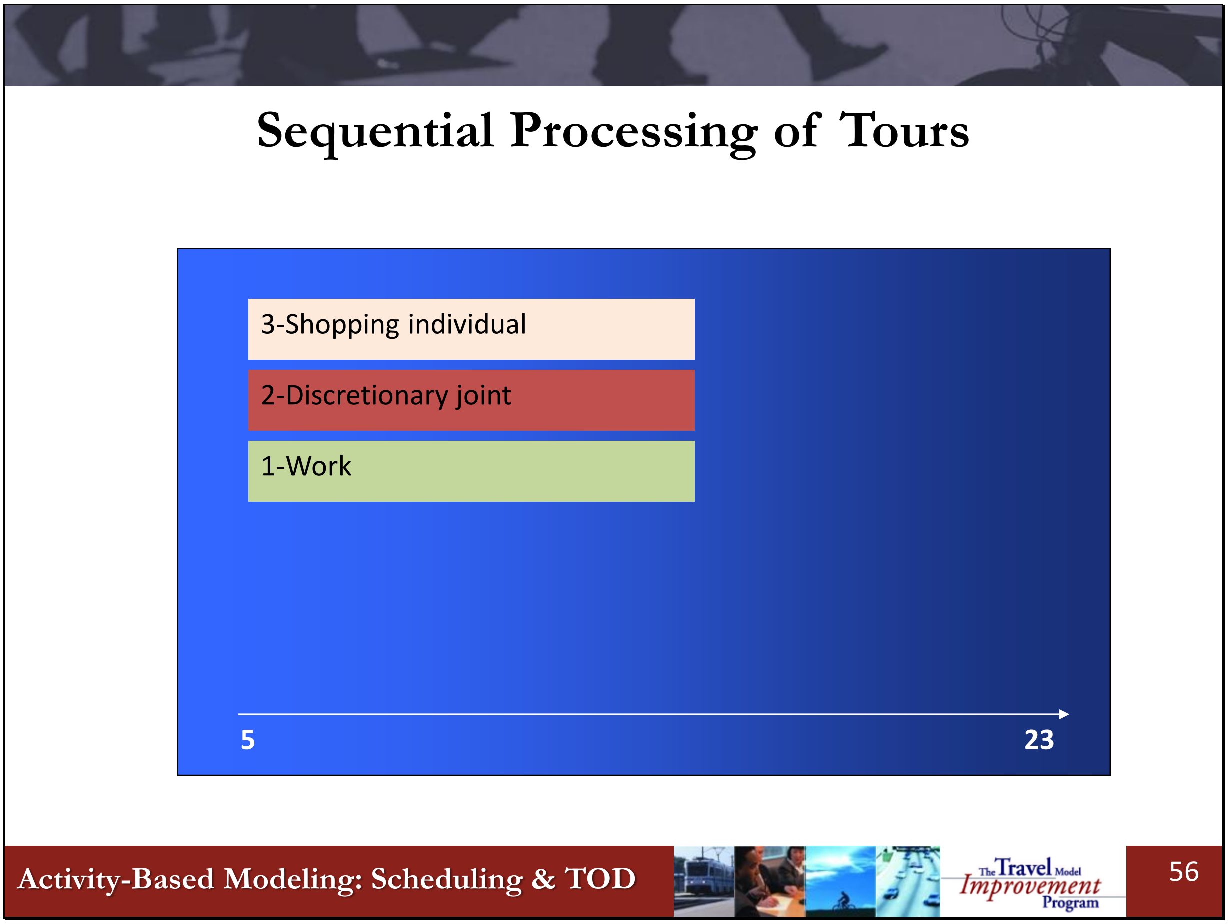


Consider example of a couple with the following fixed work schedules. He is only available after 4pm. She is available a couple hours in the morning and after 7pm in the evening. Essentially, they have only 3 hours to start a joint out-of-home activity. The probability for a joint non-mandatory activity to happen is basically proportional to the residual time window overlap.

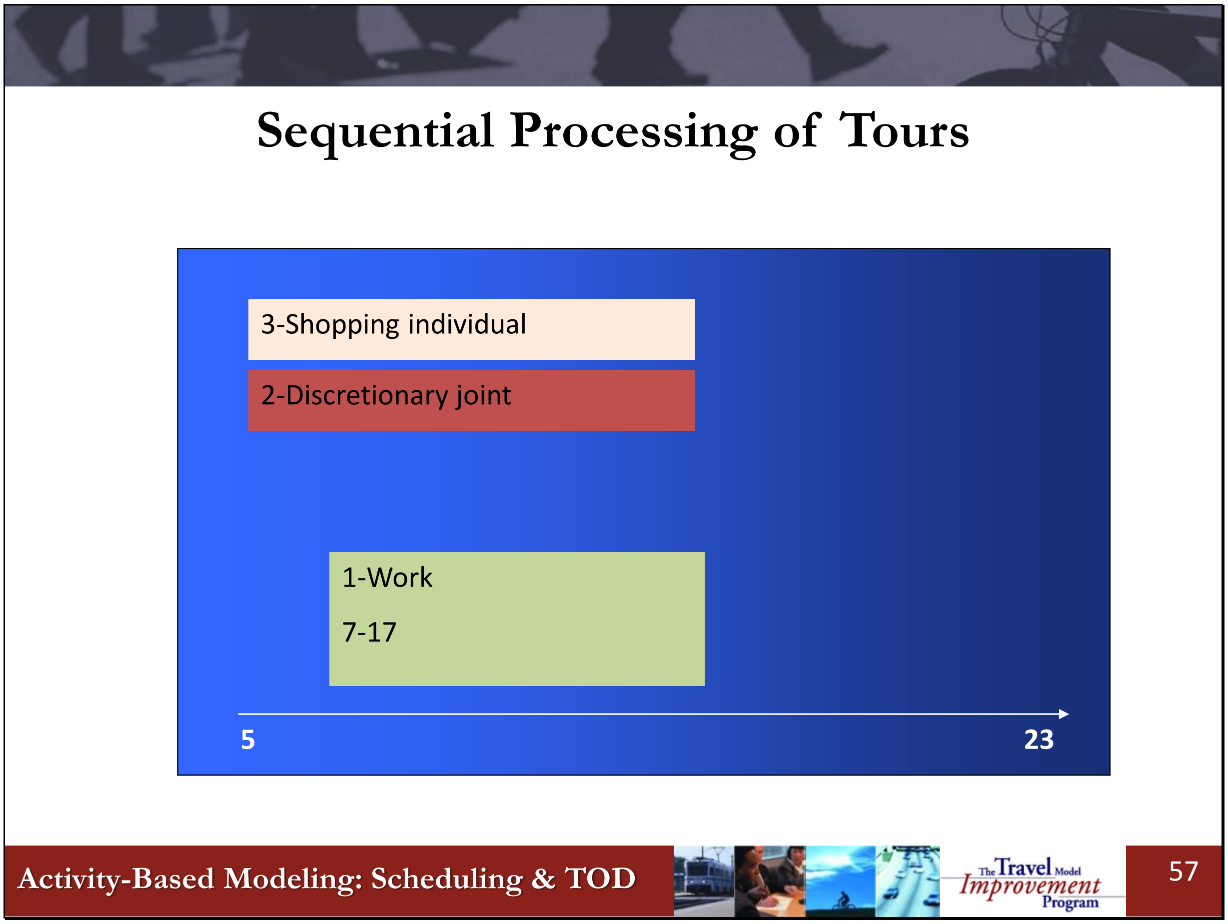
Tour Hierarchy for Scheduling

Priority	Workers / Non-workers	University students / School children
1	Work	University / School
2	University	Work
3	Maintenance joint	
4	Shopping joint	
5	Discretionary joint	
6	Eating-out joint	
7	Escorting	
8	Shopping individual	
9	Maintenance individual	
10	Discretionary individual	
11	Eating-out individual	

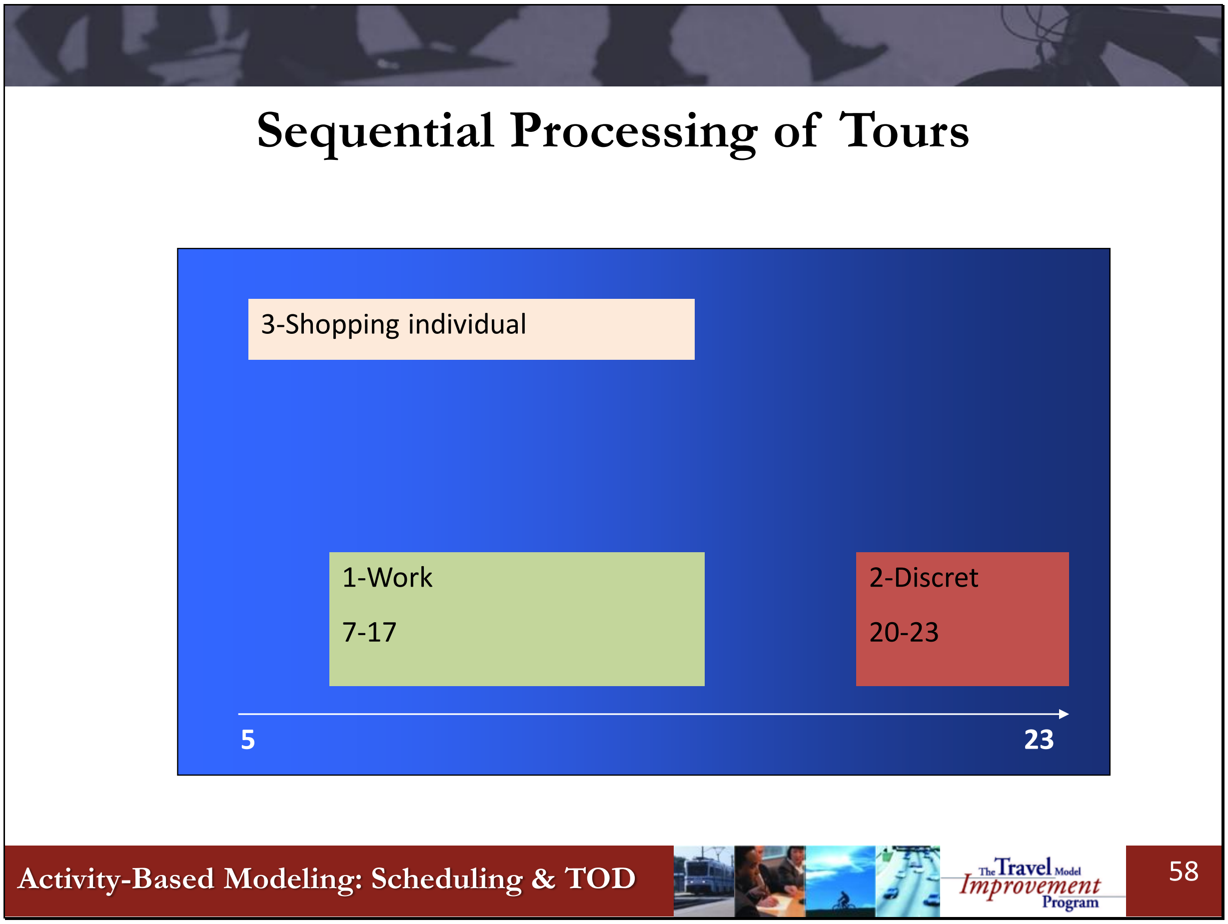
All tours including individual and joint are scheduled sequentially in a consistent way where each subsequent tour can be only scheduled in the residual time window left for this person after the higher priority tours have been scheduled. Mandatory activities scheduled first, followed by non-mandatory joint tours, and finally by non-mandatory individual tours. There are some variations in this order and rules from model to model. However, the basic idea is the same.



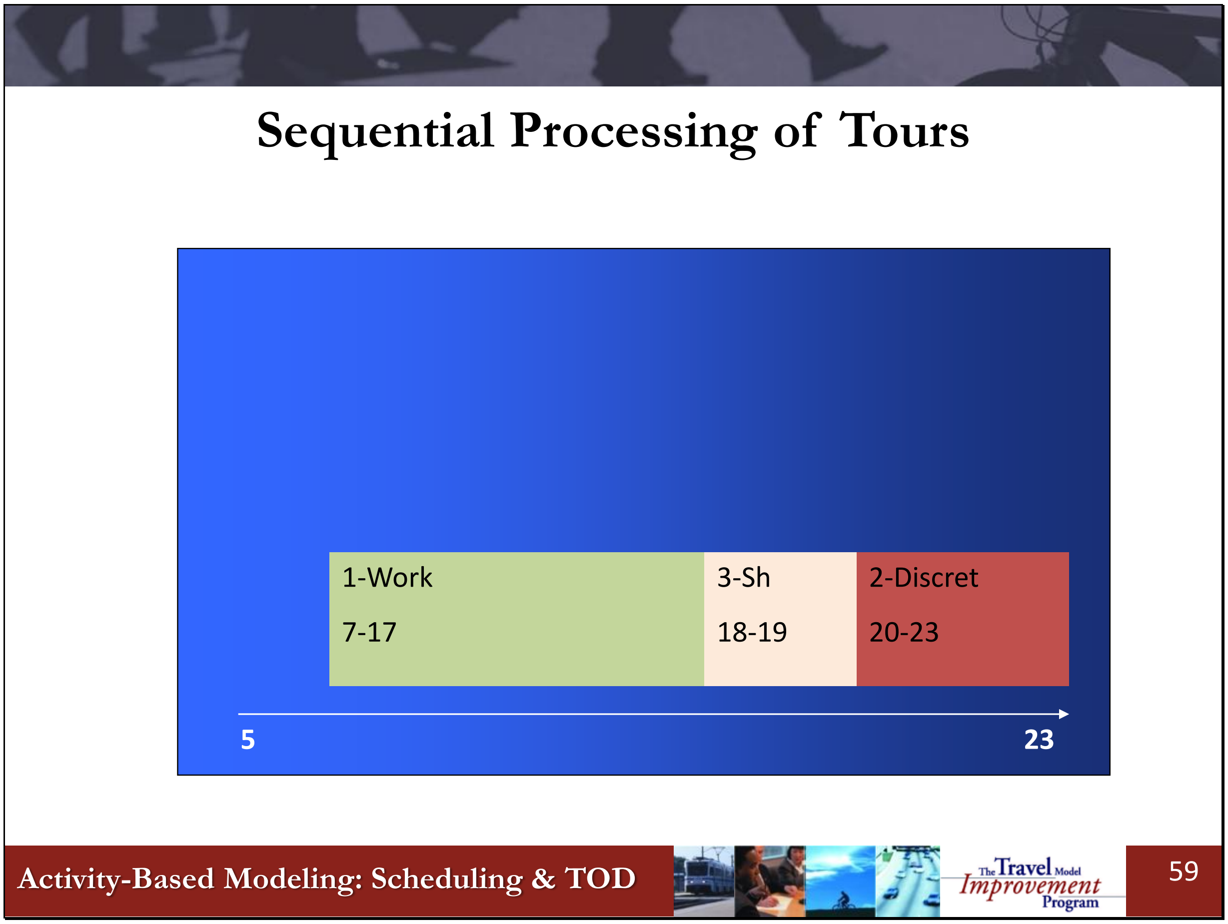
To illustrate this process of sequential scheduling and technique of residual windows, let's consider example of a person who plans three activities and tours on the given day.



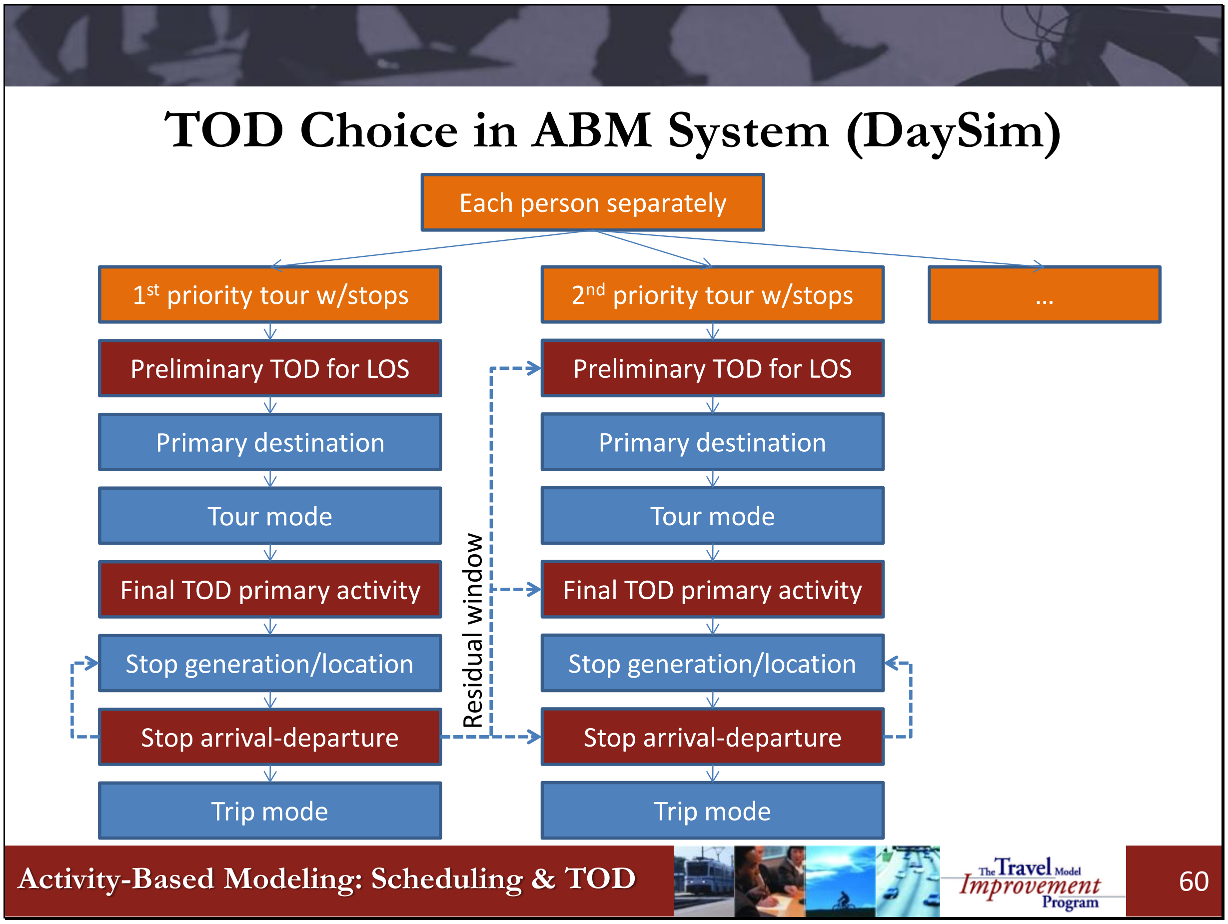
The work tour is scheduled first w/o scheduling constraints. Let's say it is a conventional schedule where the worker would leave home at 7 am and would arrive back home at 5 pm.



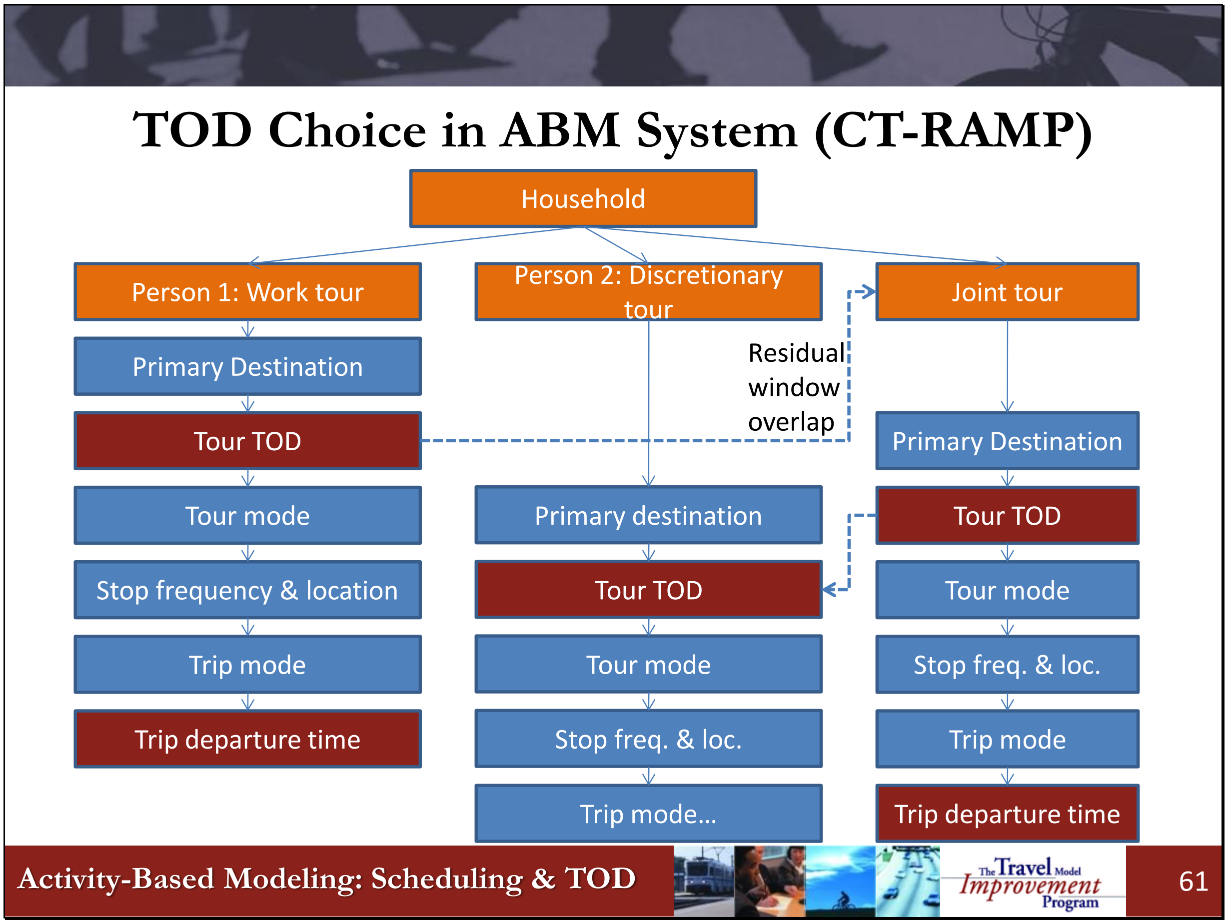
Now the second tour can go only into the residual time window. Let’s assume that this person scheduled a late discretionary activity like going to a theater between 8 pm and 11 pm.



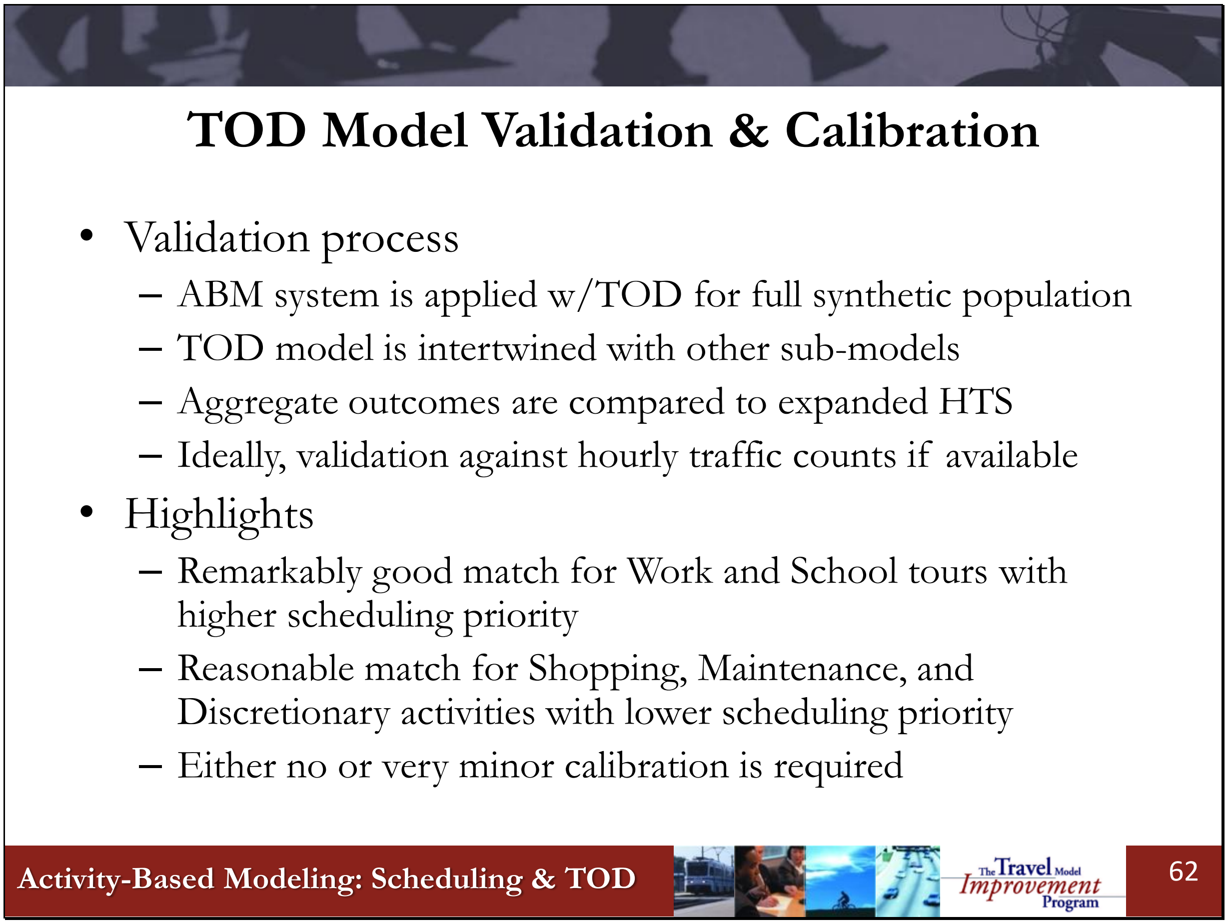
Now the third activity must go into the narrow residual window of two hours. Thus it cannot be a major shopping or distant destination. It is important to recognize and model these interdependencies because they create many scheduling constraints. Imagine how naïve and unrealistic would be a model that schedules each tour independently.



Now consider how the time-of-day choice model integrated in the activity-based model system with the other models. Consider first a DaySim type of activity-based model where each person is modeled separately. For each person, tours are generated by priority and each tour already has secondary stops generated by the IDAP procedure that we discussed in the previous webinar. For each tour, the following sequence of sub-models shown in the first column is applied. After the first tour has been processed, residual time windows are calculated and used as constraints for scheduling the second tour, etc. An interesting feature of DaySim is that tour time-of-day choice is applied twice. First, a preliminary time-of-day choice is applied to identify which LOS variables should be used for destination and mode choice. Secondly, a final tour time-of-day choice is applied conditional upon the chosen primary destination and tour mode.

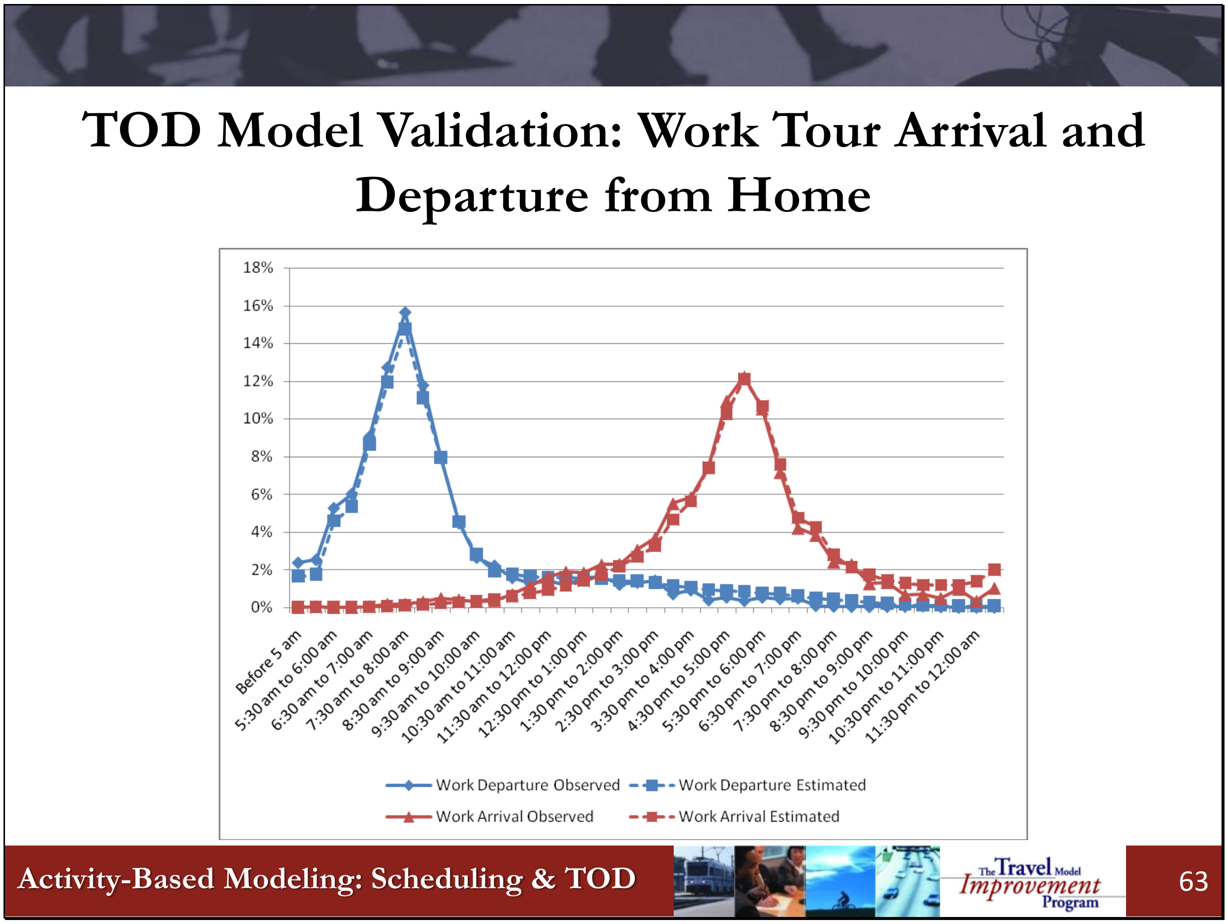


In the CT-RAMP system, the entire household is considered and the mandatory activities for workers and students modeled and scheduled first. For person 1 who has a work tour, the following sub-models shown in the left-most column will be applied. Person 2 does not have a mandatory activity. The next step involves scheduling of a joint tour that is conditional upon he residual time window overlap between persons 1 and 2. Finally, individual non-mandatory activity for person 2 is scheduled conditional upon the residual window left for person 2 after scheduling the joint tour.

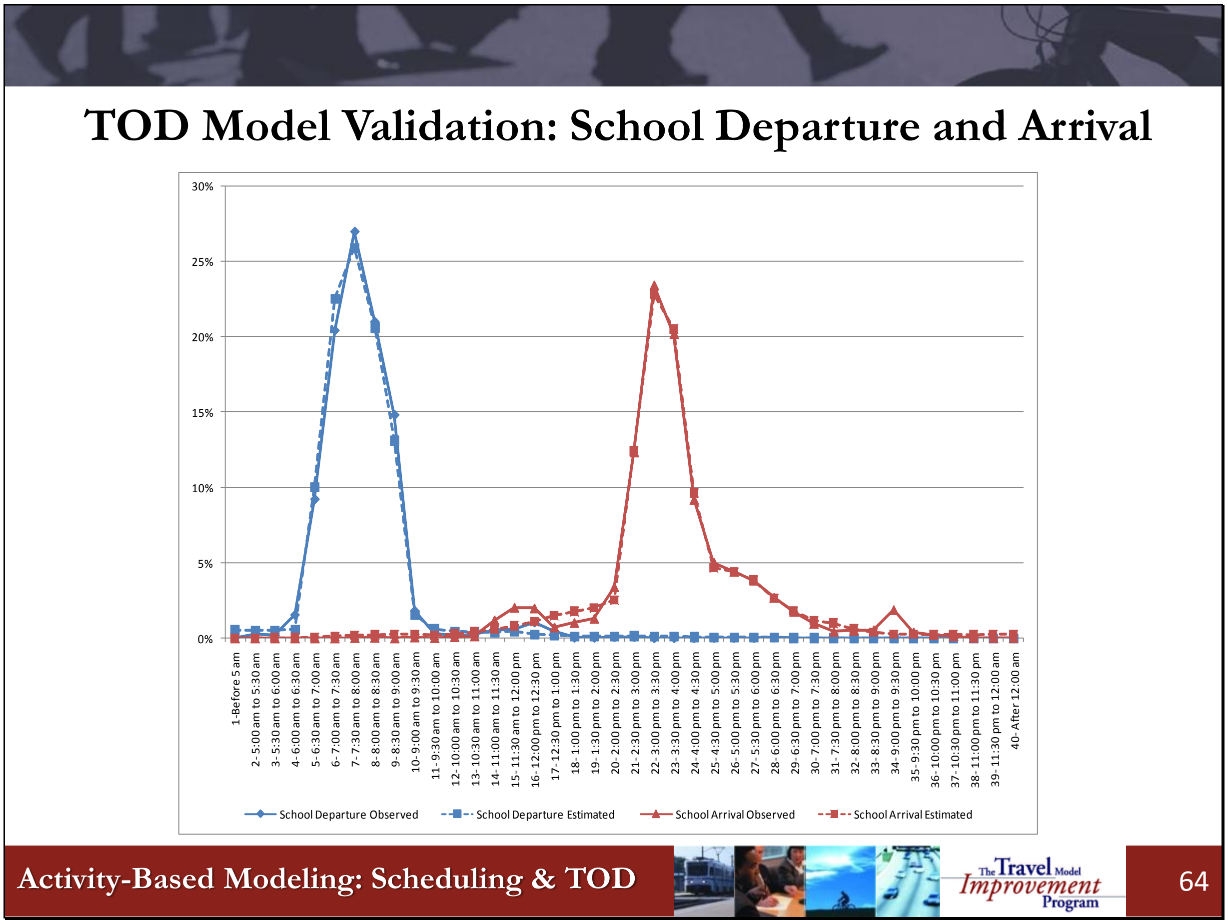


How can we validate the time-of-day choice model and prove this concept in practice? During the model validation process, the activity-based model is applied with time-of-day choice, aggregate outcomes are compared to an expanded household survey, and, ideally compared to hourly traffic counts.

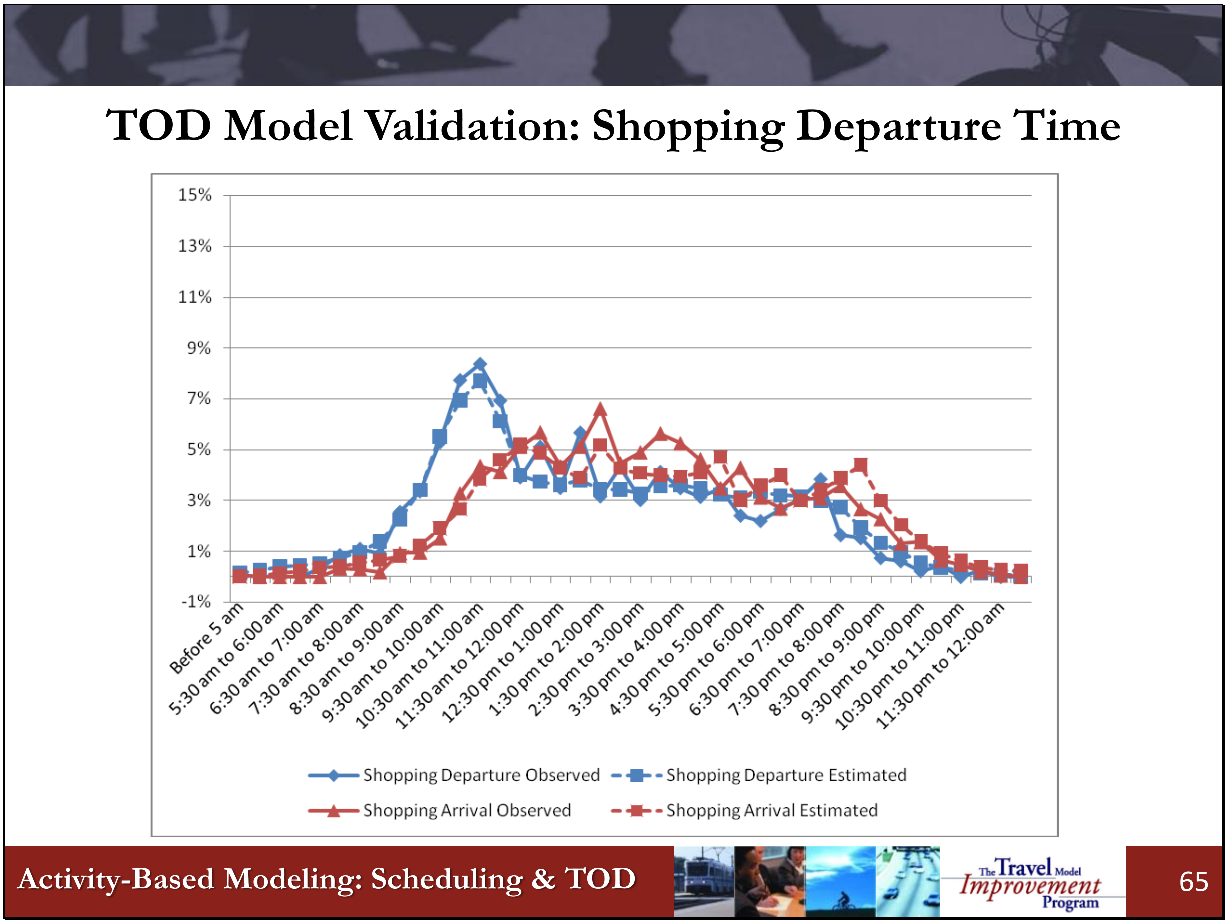
This usually results in a very good match to work and school tour times, with higher schedule priorities and more regularity. Matches to shopping, maintenance and other discretionary purposes are usually reasonable, but that is because these have lower scheduling priority. Often calibration of time-of-day choice models is necessary only if you are validating against traffic counts, since the adjustments to match counts will be needed to allow for differences between the observed data sources. Let’s see some examples from the activity-based models applied in practice.



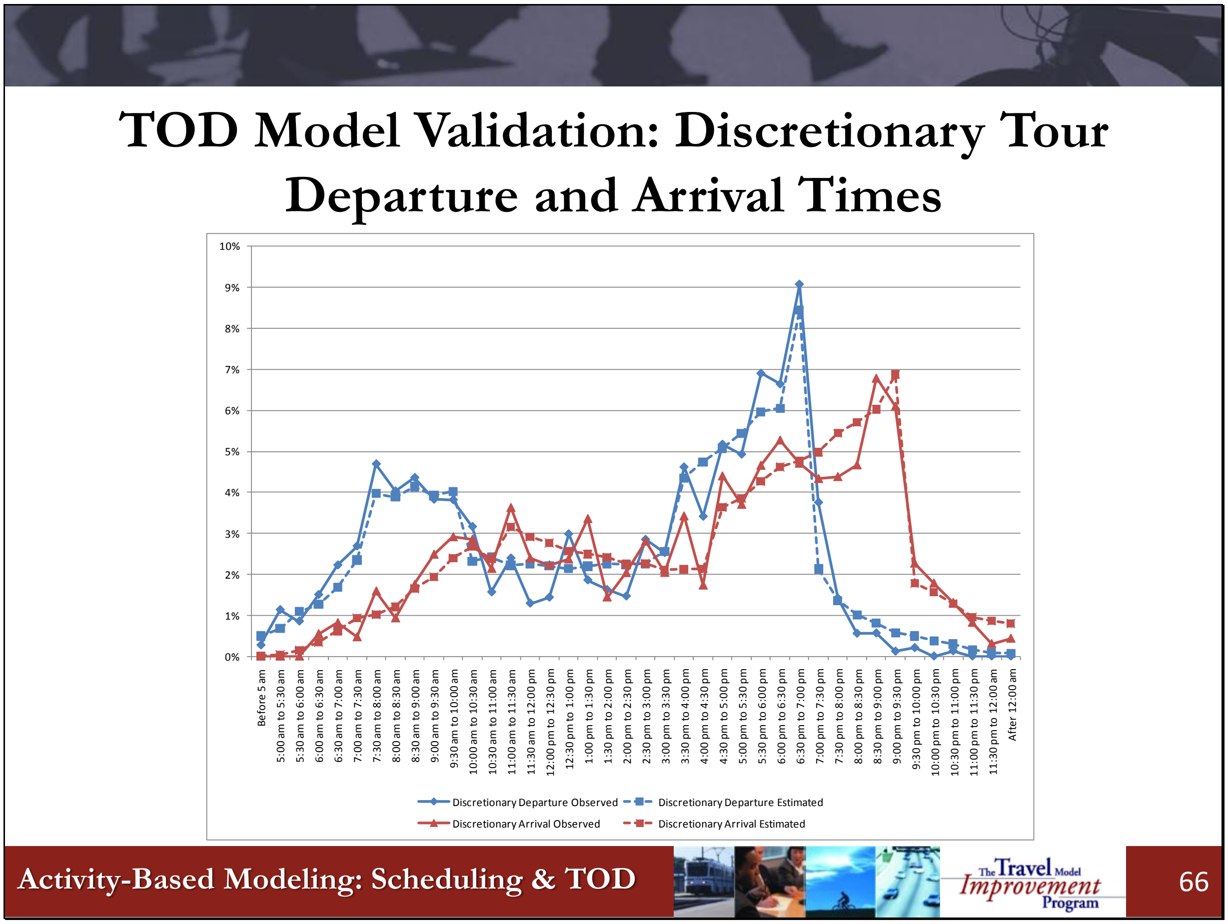
This is an example from the San Diego activity-based model for work tour departure-from-home and arrival-back-home stats. You would probably have a hard time to distinguish between the observed and modeled time-of-day choice. These distributions are typical. AM peak is a bit sharper than PM peak, and the model captures all these details quite accurately.



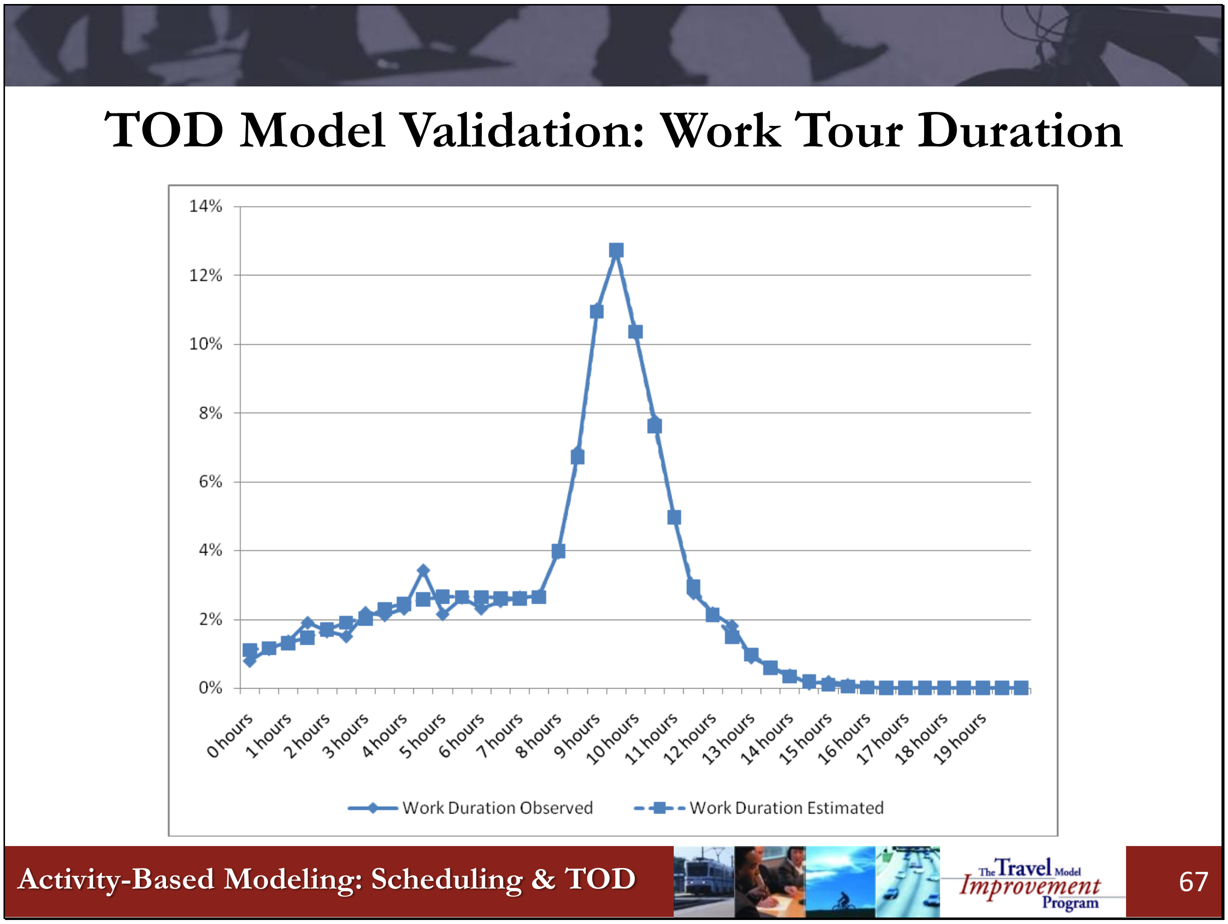
The same for school tours. School tours in the Chicago activity-based model are characterized but very sharp peaks in the morning departure from home and in the evening for arrival back home.



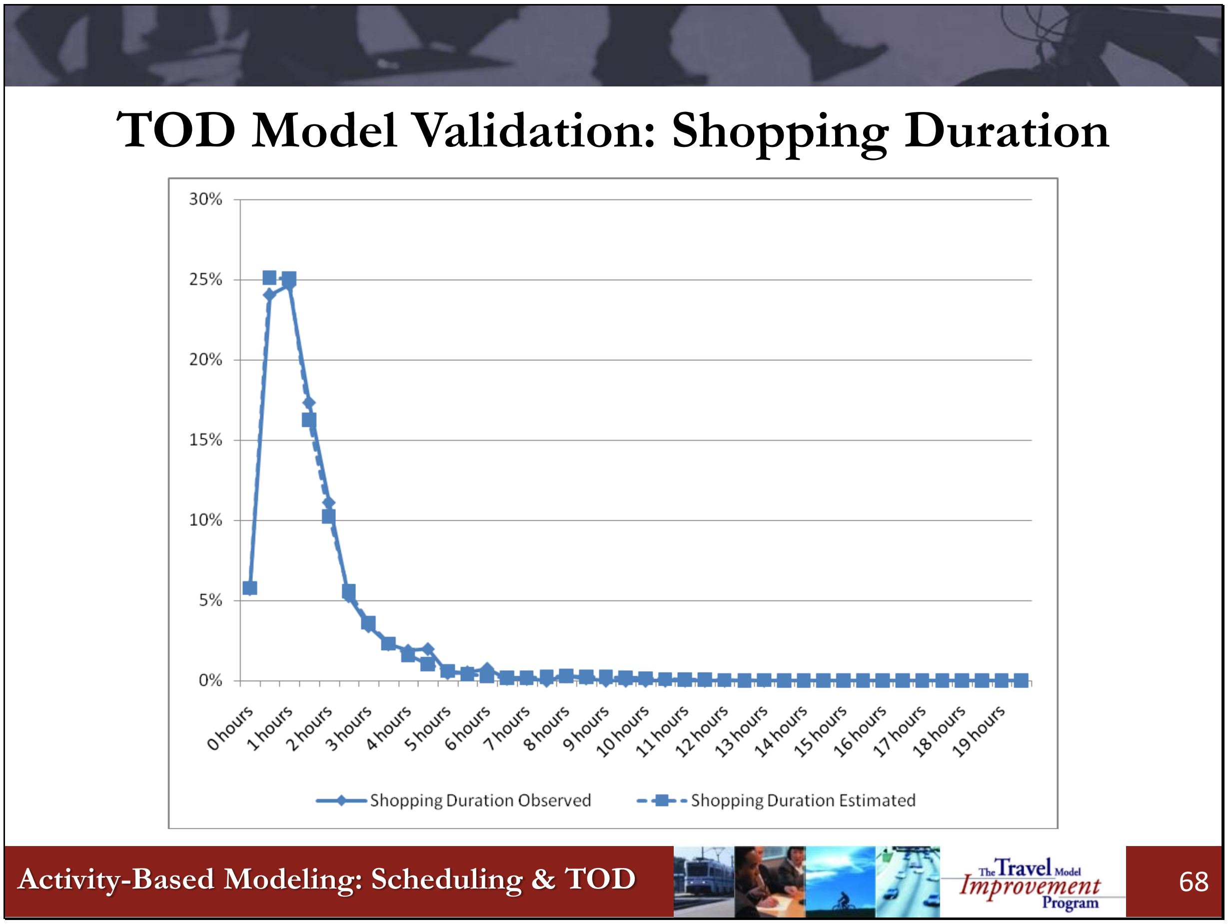
For shopping tours that is an example of a non-mandatory activity, we also have a good match but everything gets a bit fuzzier.



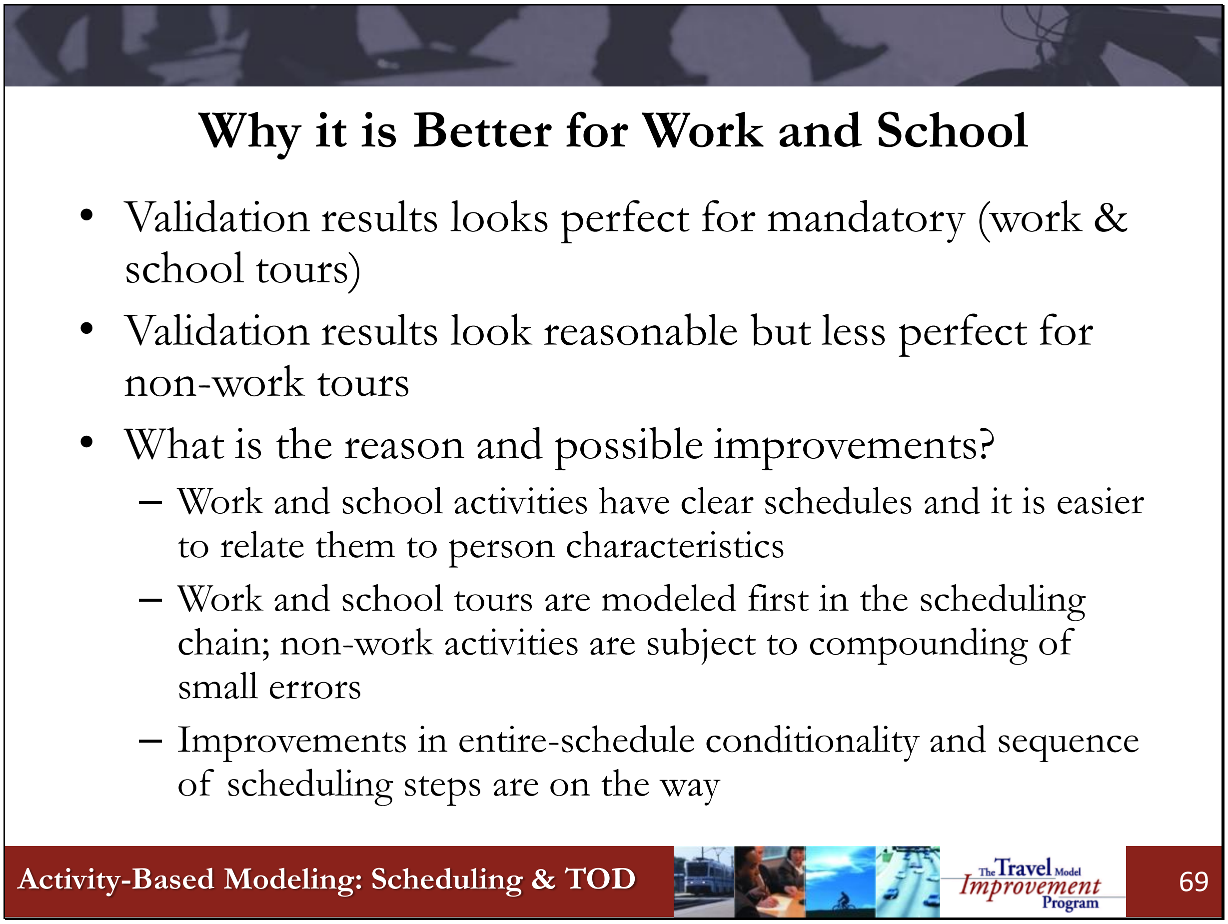
The validation results are also very reasonable for non-mandatory purposes, but not as perfect as for work and school. This is an example of the validation for discretionary tours with the San-Diego activity-based model.



Another important dimension is the tour duration. Again the San Diego model replicates the observed pattern almost exactly. The distribution is typical and looks similar in many other metropolitan regions. The mode duration is about 10.5 hours because is includes the entire tour and not only the work activity itself.

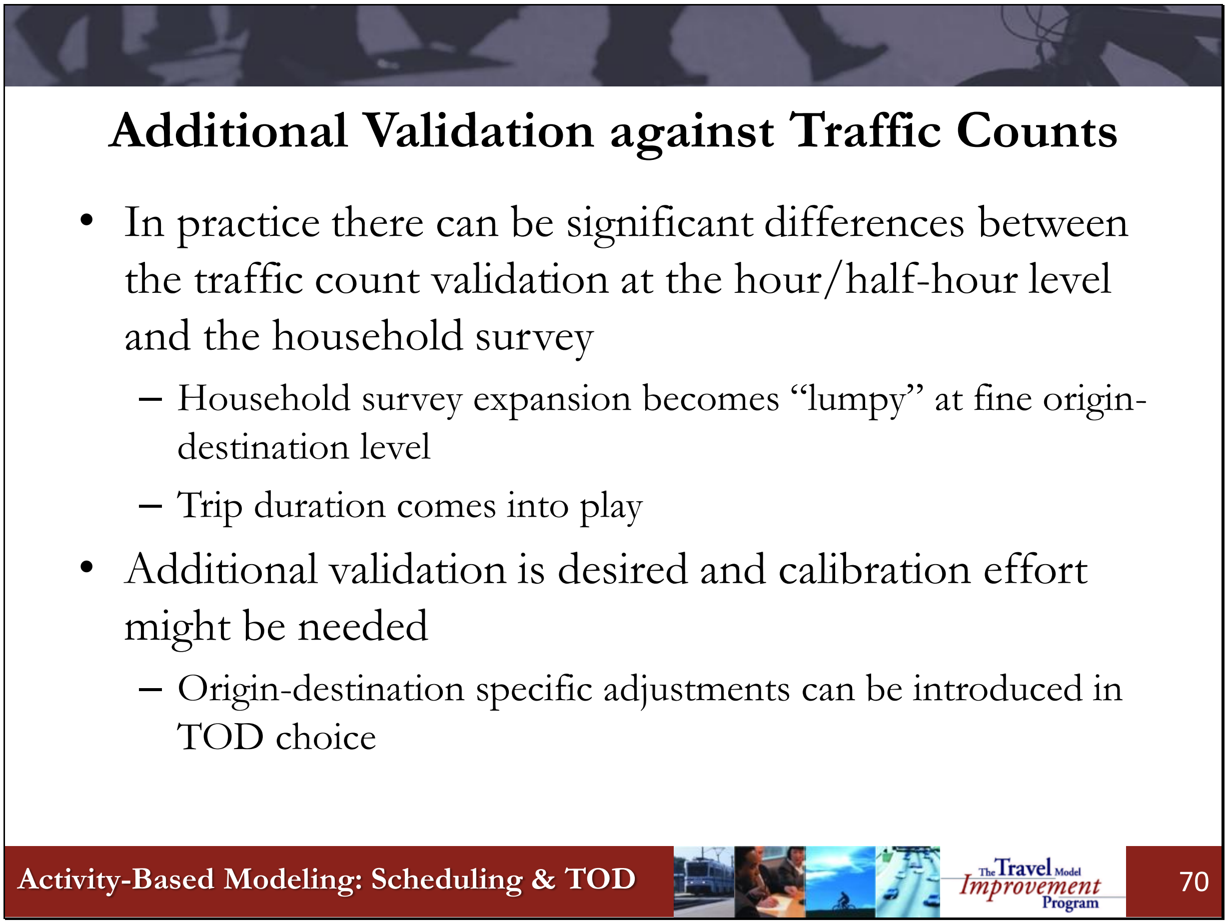


Shopping tour duration distribution from the San Diego activity-based model is also replicated very well. The average duration of shopping tour is of course much shorter (1.5-2 hours) and the distribution is much sharper compared to work tours.

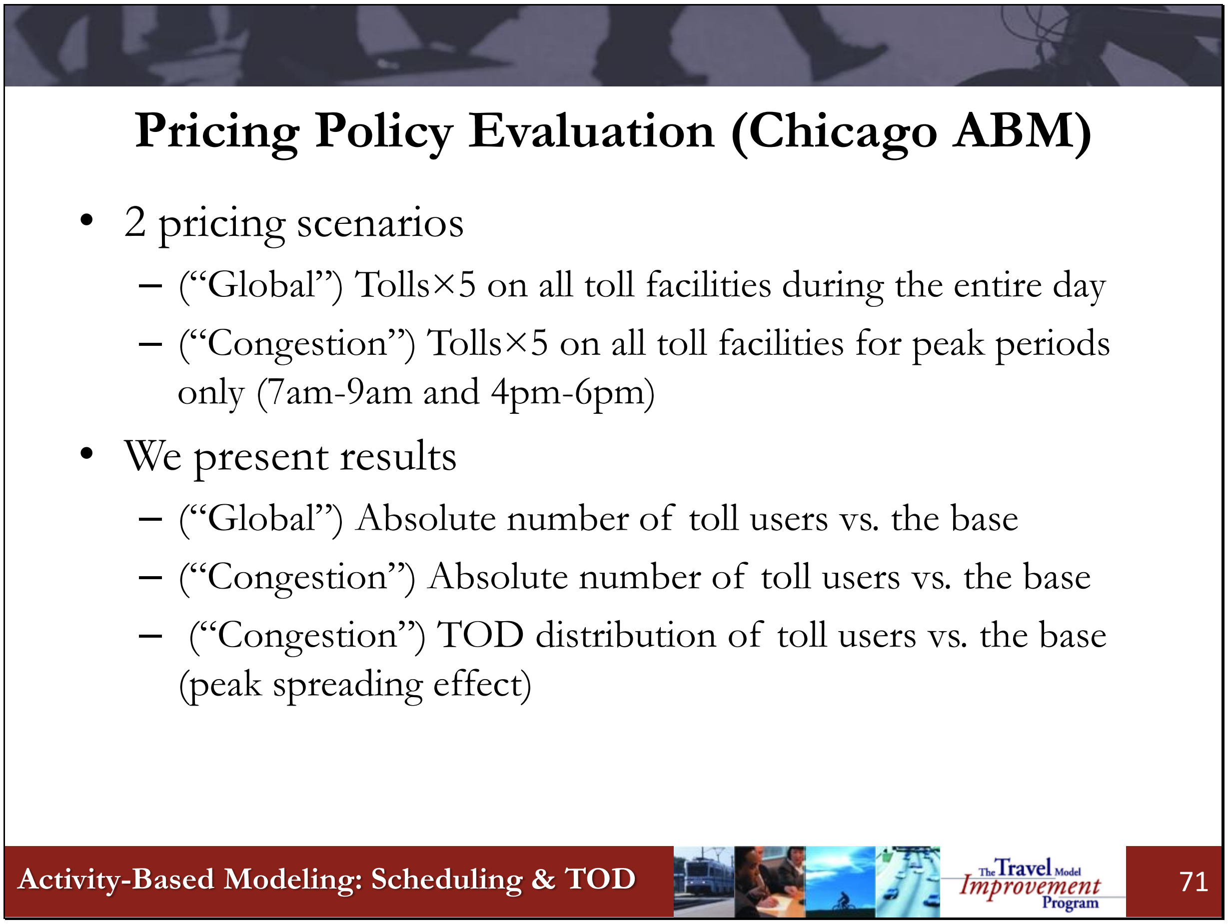


Why it is better for Work and School? There are several reasons for that:

- Work and school activities have clear schedules and it is easier to relate them to person characteristics;
- Work and school tours are modeled first in the scheduling chain; non-work activities are subject to compounding of small errors; and
- Improvements in entire-schedule conditionality and sequence of scheduling steps are on the way.



This additional level of validation is critical for time-of-day choice models, since there is likely to be a discrepancy between the traffic counts and the household survey at the half-hour or hour time periods. Household surveys can be lumpy, given humans tendency to round times to the nearest 5 or 15 minute increments. Also, expansion of household surveys can be lumpy at the specific origin and destination level. Traffic counts will include all vehicles, and at a minimum, trucks should be excluded so that the time-of-day choice model can be validated against autos. This will still include some commercial vehicles that are autos or light trucks, but the majority of the auto volumes will be for passenger movements.

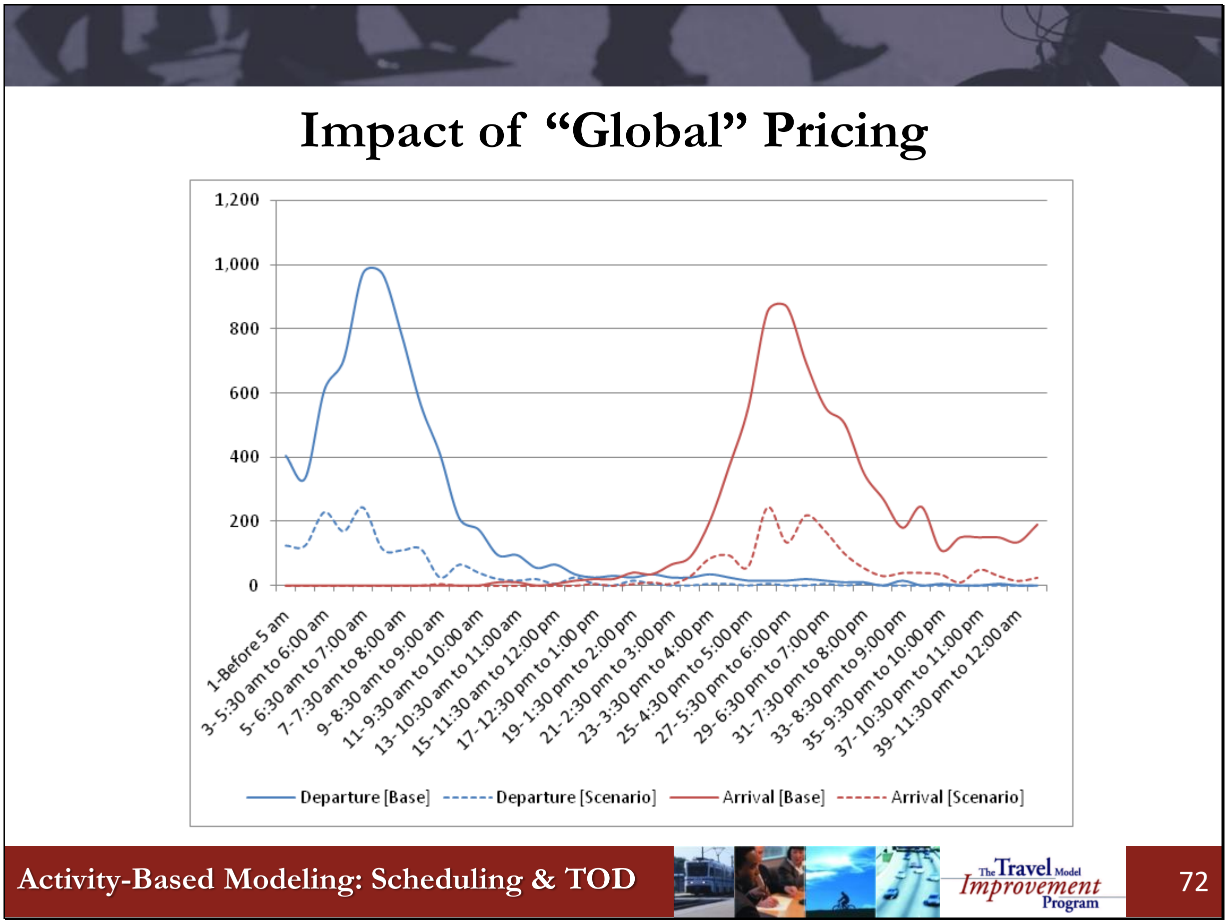


We would like to present the time-of-day choice model performance for pricing policies. These evaluations were implemented with the Chicago activity-based model, 2011. Two pricing scenarios were evaluated and compared to the base scenario:

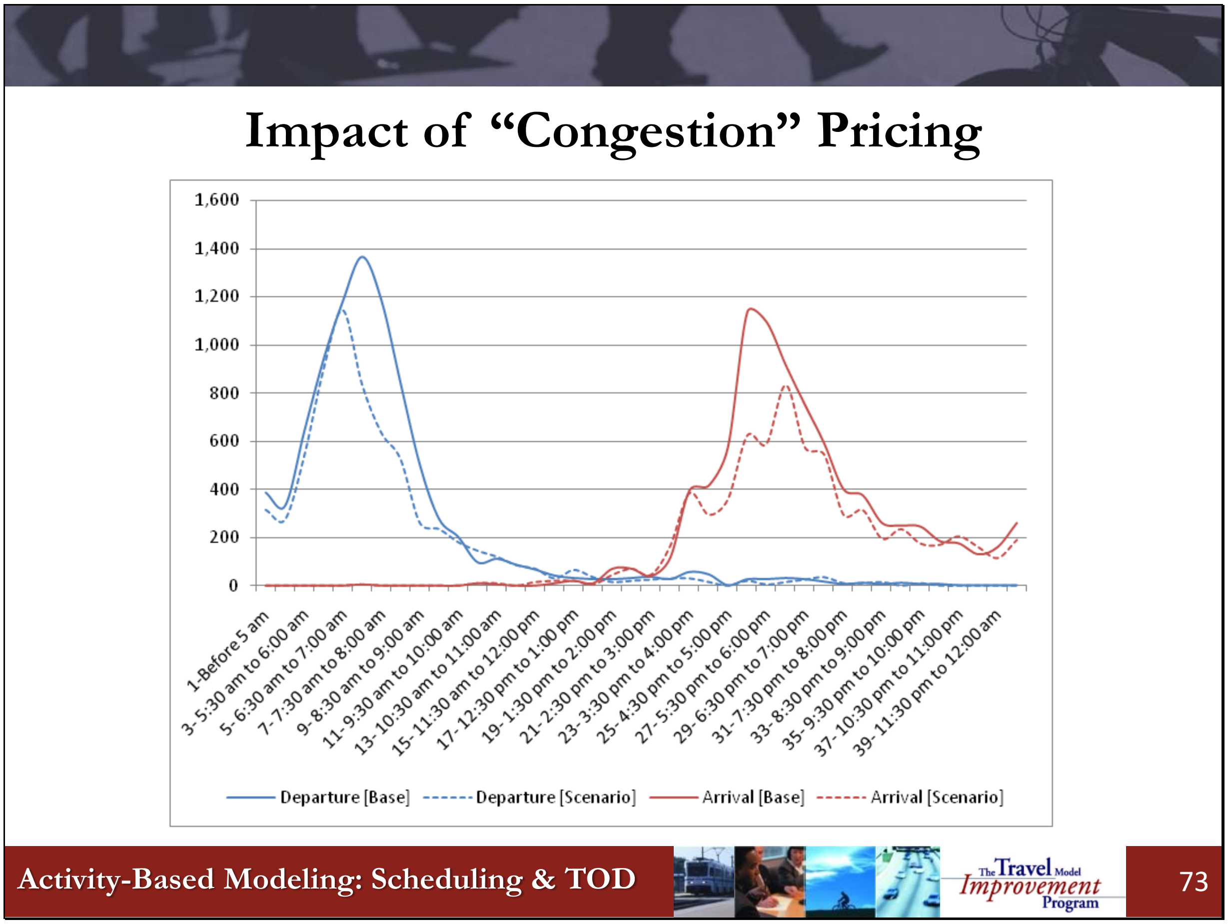
- A global pricing scenario in which current tolls are multiplied by a factor of five on all toll facilities during the entire day; and
- A congestion-based pricing scenario in which the tolls are increased by five times for only the 2-hour AM and PM peak periods.

We will also look at some particular outcomes:

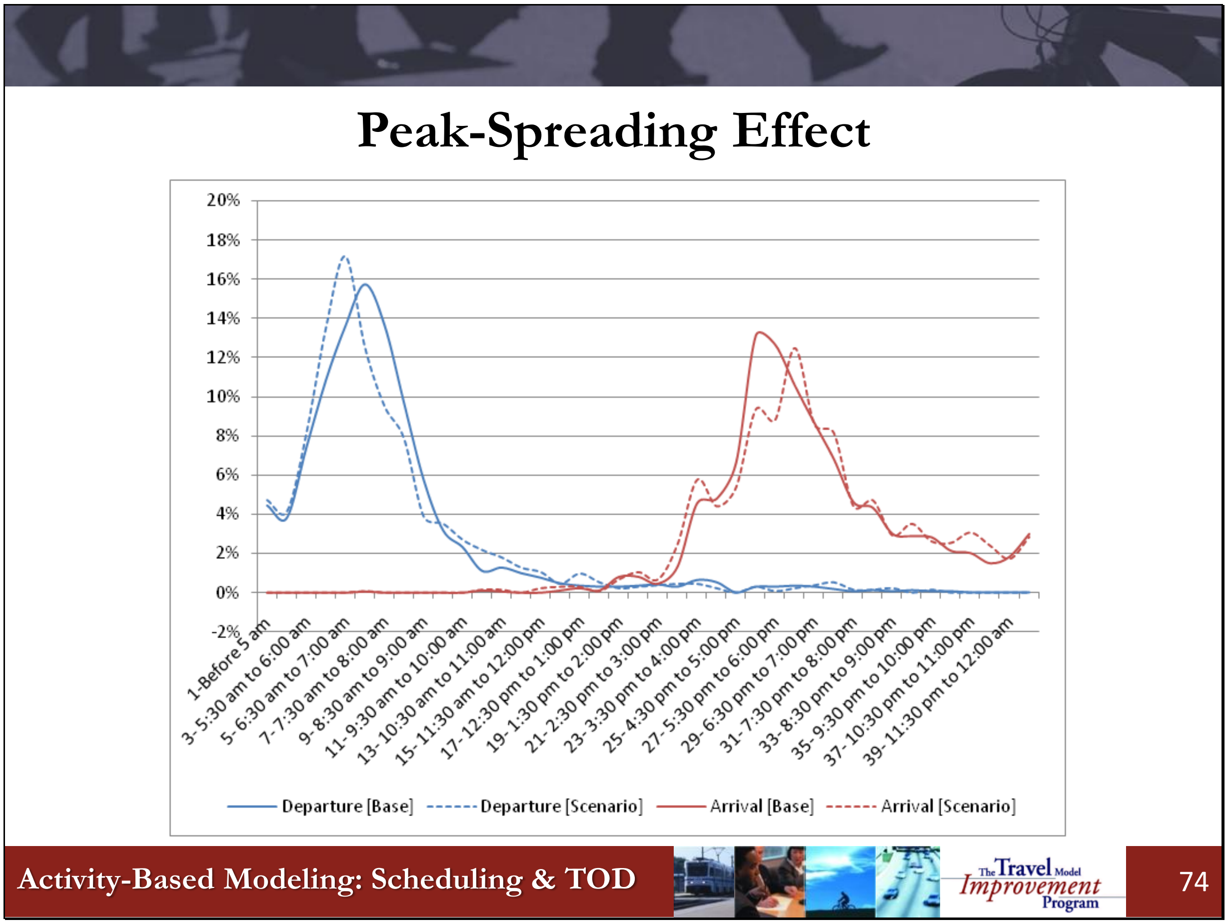
- For the global pricing scenario, we consider differences in the number of toll users; and
- For the congestion pricing scenario, we consider differences in the number of toll users overall, and by time period.



Global pricing with the radical rise of all tolls logically resulted in a significant reduction of toll users in the Chicago activity-based model. Only a few users with very high VOT continue using toll facilities. Please note also, that the existing toll users primarily use toll facilities in peak periods when the parallel facilities are congested.



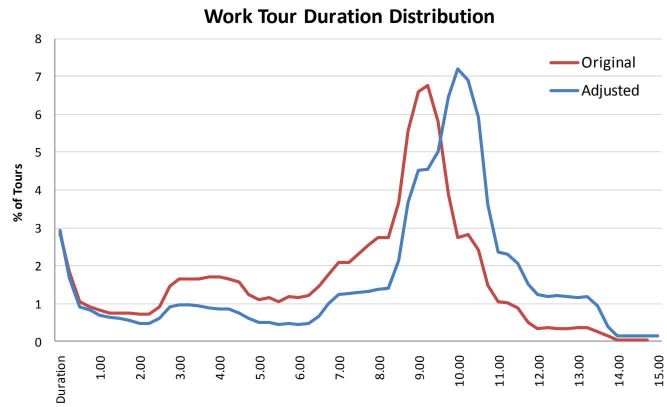
The congestion pricing scenario in the Chicago activity-based model yielded a very different outcome with the number of users affected primarily in the peak periods when tolls were raised. The number of toll users outside the peak periods barely changed.



If we compare temporal distribution of toll users in the Chicago activity-based model before and after rather than absolute numbers we can see an interesting peak-spreading effect where the morning peak was slightly shifted to earlier hours while the evening peak was slightly shifted to later hours. This is a consequence of the fact that high income (high VOT) users that stayed on the toll road after the tolls have been raised are characterized by a relatively longer work duration compared to low-income users who switched to non-toll roads or transit.

Travel Demand Management Evaluation (Burlington ABM)

- "Flexible Schedule" scenario
- Asserted assumptions about
  - Fewer individual work activities
  - Longer individual work durations
  - Aggregate work durations constant
- Target: Fulltime Workers



Activity-Based Modeling: Scheduling & TOD

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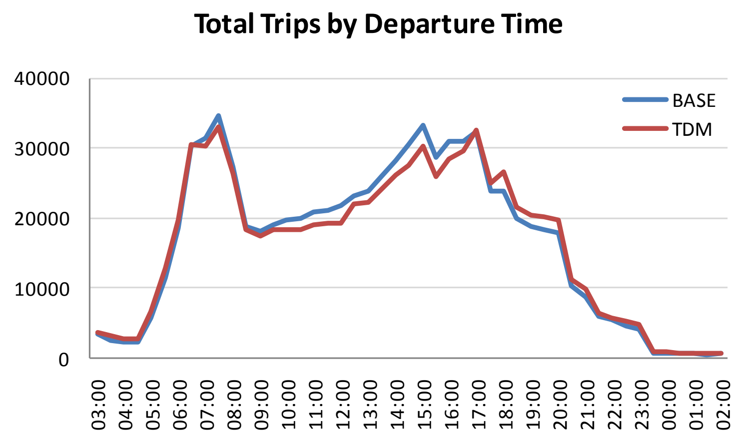
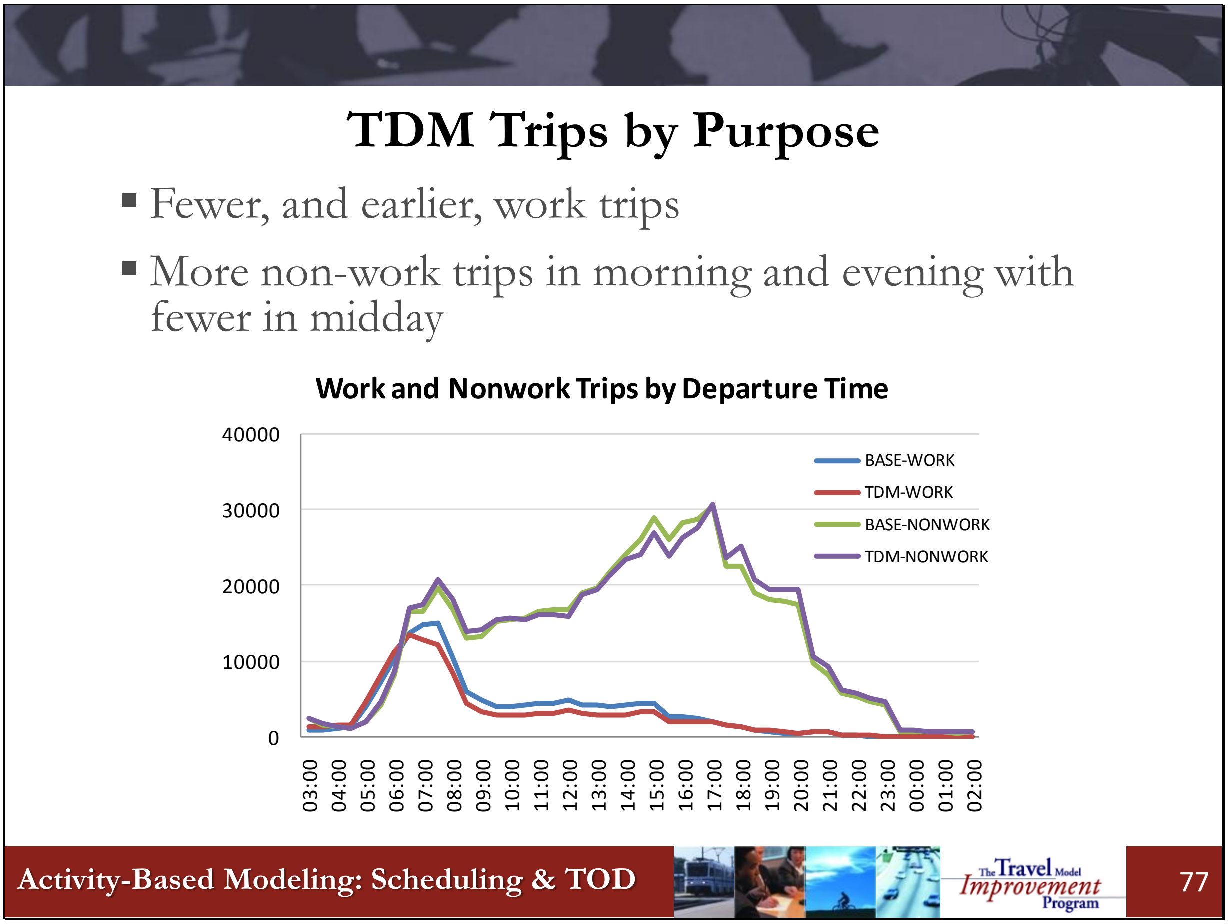
This is a travel demand management scenario for the Burlington (VT) activity-based model that was conducted as part of the SHRP 2 C10 research. This scenario demonstrates that when people are working under flexible schedules, then work durations are longer for full time workers.

TDM Total Trip Impacts

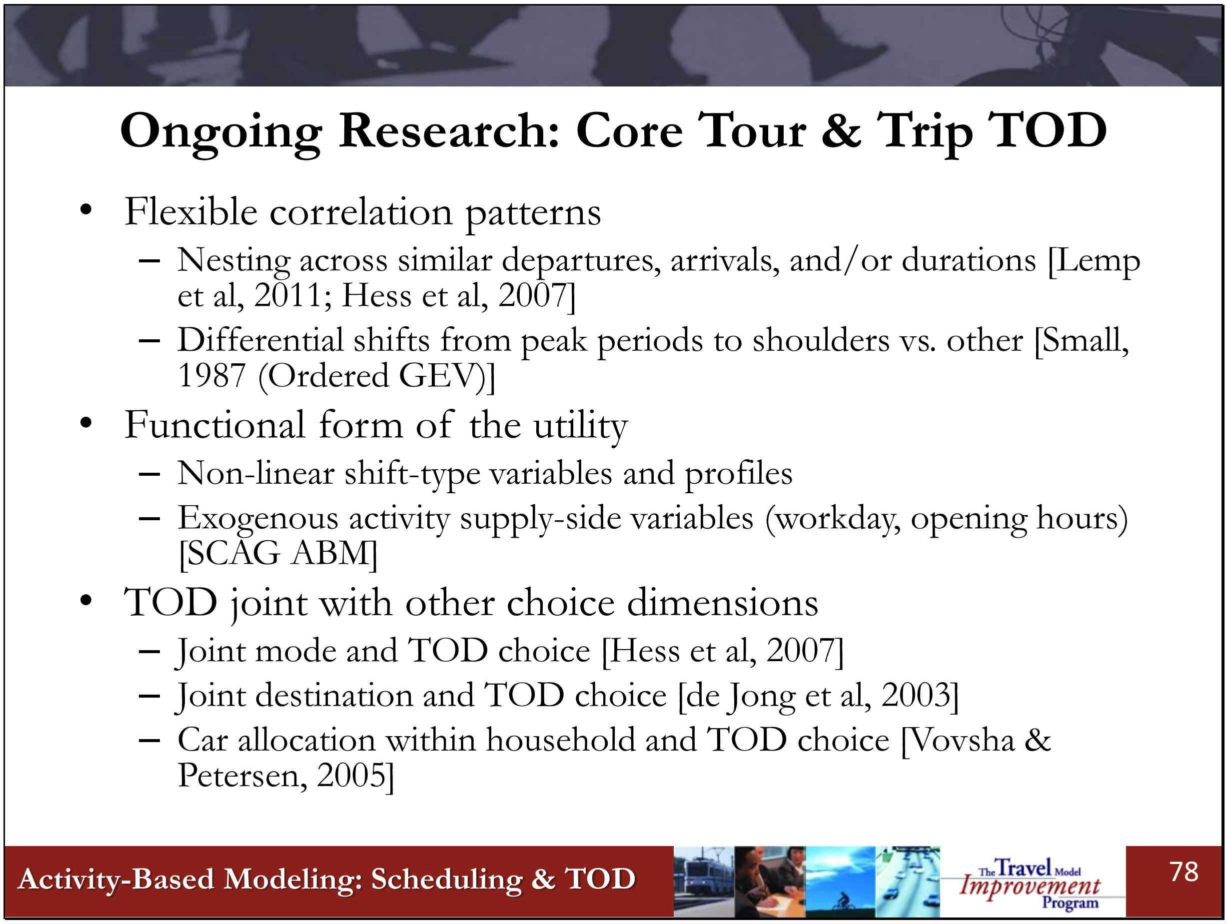
- Reduced peak period and midday travel
- Slightly more early AM travel
- Significantly more evening travel



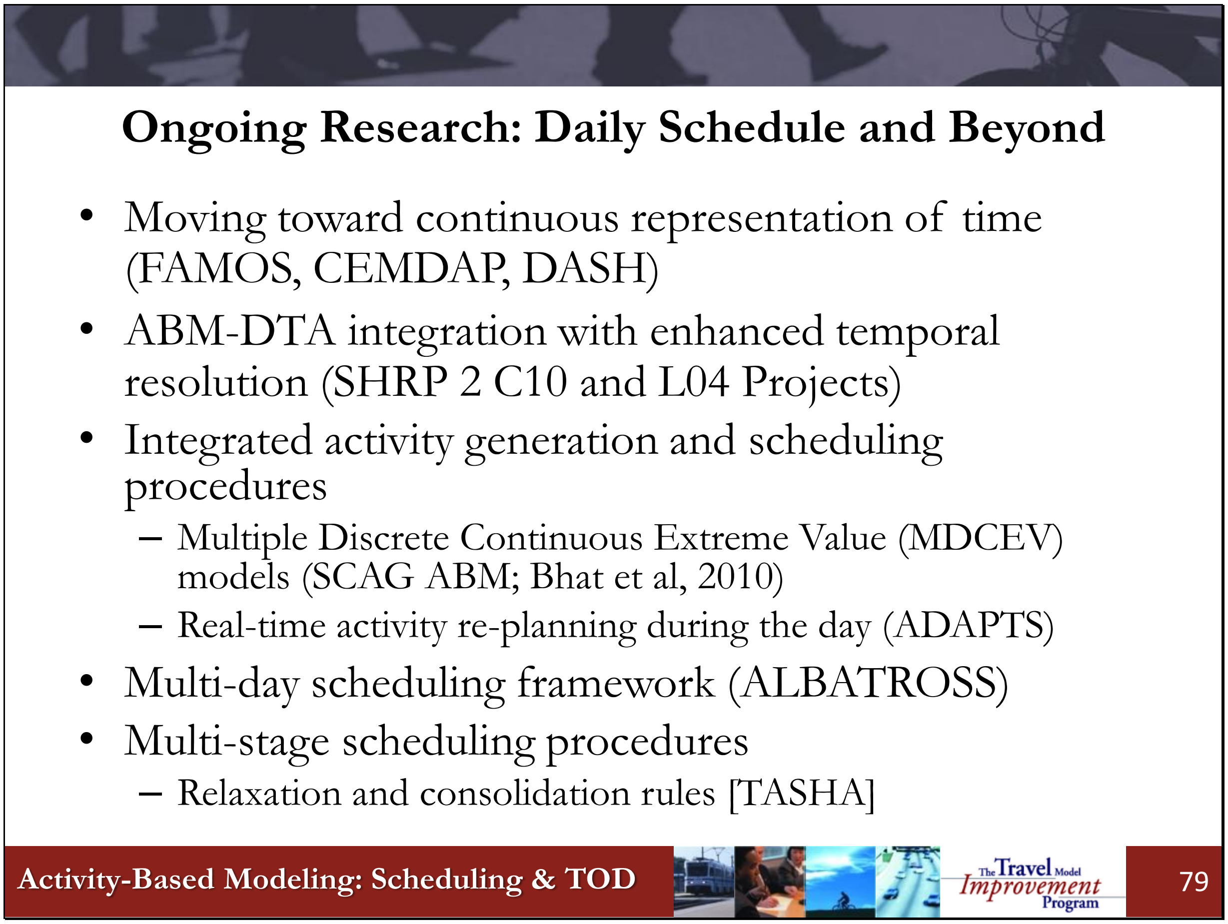
In addition, the Burlington activity-based model shows a reduction in peak period and midday travel, since flexible schedules often include 1-2 days off every 2 weeks. And, the start times are earlier as well as the time to return home from work in the evening.



This also translates into fewer overall work trips and allows for more non-work trips in the Burlington activity-based model, which are conducted on "days off" or in the morning or evening before or after work. There are fewer trips in the mid-day most likely because workers are going to work on fewer days over a two-week period.



Time-of-day choice and related activity scheduling is a very dynamic filed with many research directions pursued by different researches. To name just a few promising directions, there is ongoing development in terms of flexible correlation patterns that account for differential similarities across time-of-day alternatives, many suggestions to enrich the functional form of the utility, as well as many interesting attempts to integrate time-of-day choice with other choice dimensions such as mode, destination, car allocation, etc.



There are also many alternative ways to construct daily schedules and move towards a continuous representation of time, integration of activity-based model and DTA as part of the SHRP 2 program, integrated activity generation and scheduling (or time allocation) procedures, etc. Some researches go beyond the daily framework and consider entire week for modeling individual schedules. Some other researches pursue a multi-stage scheduling procedure with re-planning and consolidation rules.

Extending TOD Choice Framework: ALBATROSS

- Fundamental behavioral observation
  - People do not schedule and implement activities in one day
  - Some activities (special events) are scheduled many days in advance and come into daily schedule as pre-fixed
  - Some activities (shopping) occur periodically and can be shifted between days
  - Some activities (work, school) occur daily
- Modeling schedules requires longer time horizon (at least week)
  - Fixed events scheduled first
  - Daily activities are scheduled initially to assess time availability
  - Periodic activities are scheduled on certain days based on the "need" frequency function
  - Daily activities are adjusted if needed to accommodate periodic activities

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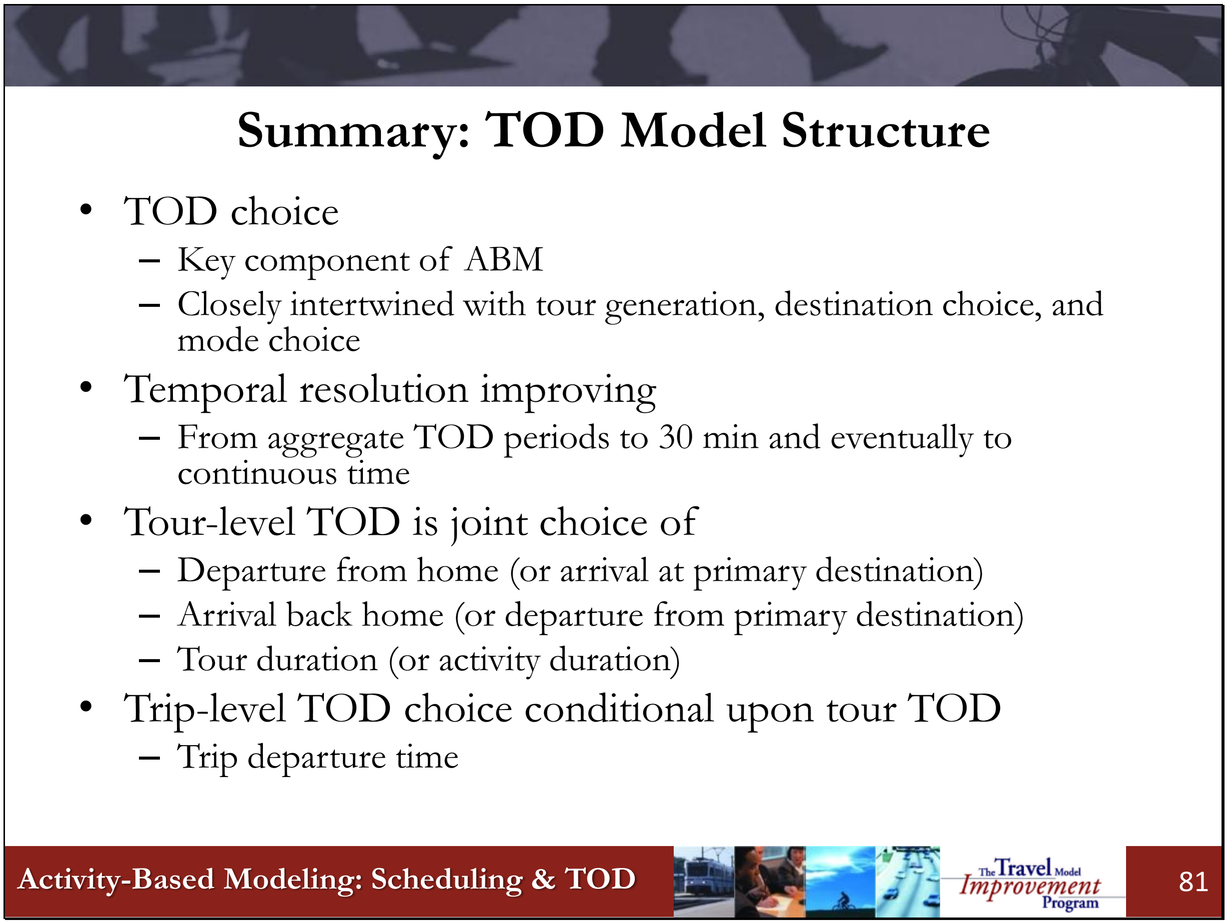
Let's take a look at and extended time-of-day choice framework. The ALBATROSS model provides a good example. It is based on a fundamental behavioral observation that people do not schedule and implement activities in one day. Some activities (special events) are scheduled many days in advance and come into daily schedule as pre-fixed. Some activities (shopping) occur periodically and can be shifted between days, whereas some activities (work, school) occur daily. Consequently, modeling schedules requires longer time horizon (at least one week) and follows a set of steps:

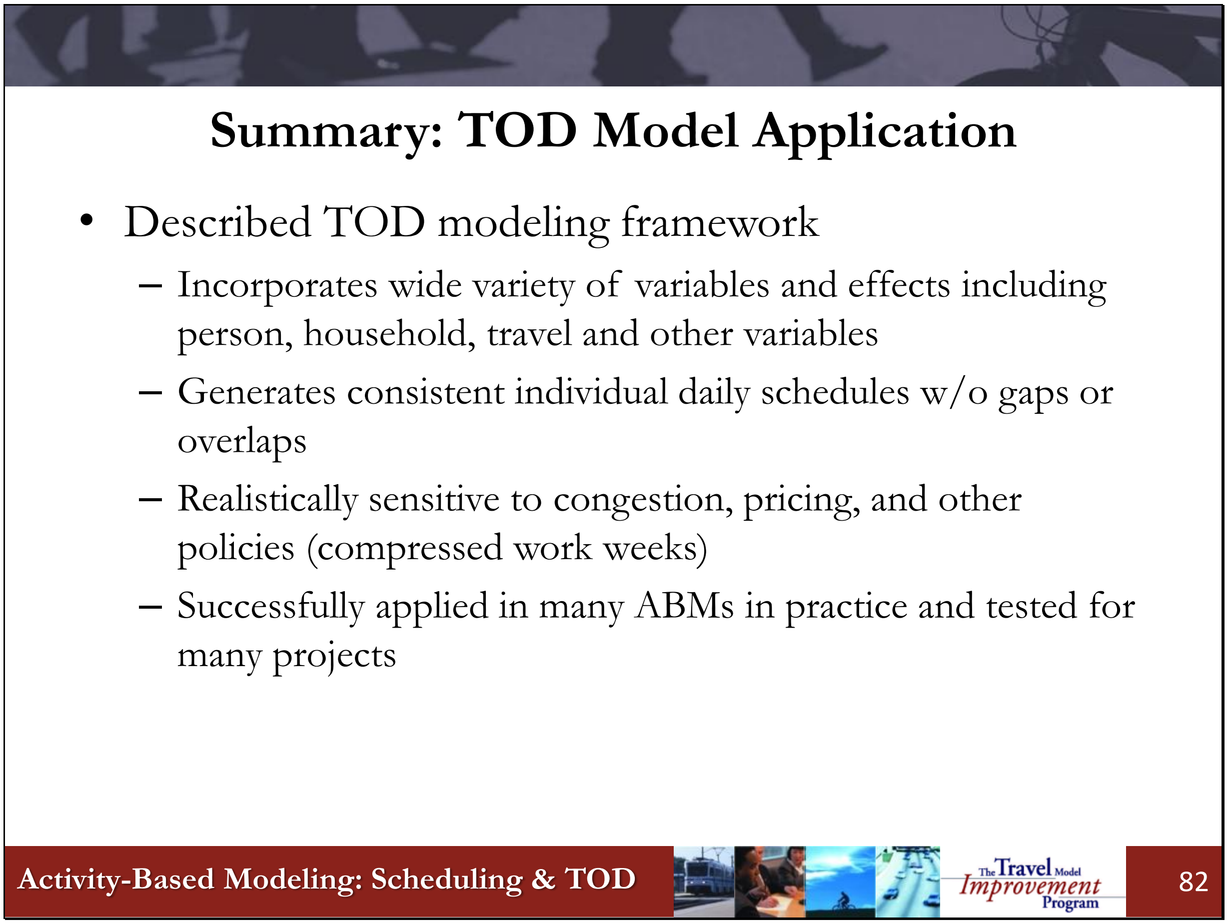
- Fixed events are scheduled first;
- Daily activities are scheduled initially to assess time availability;
- Periodic activities are scheduled based on a "need" frequency function; and
- Daily activities are adjusted if needed to accommodate periodic activities.



In summary we would like to mention the following key points. Time-of-day choice is a key component of activity-based modeling. It is closely intertwined with tour generation, destination choice, and mode choice. The temporal resolution of these models is improving, from aggregate time-of-day periods to 30 min and eventually to continuous time.

Tour-level time-of-day choice is actually the joint choice of departure from home (or arrival at primary destination) and arrival back home (or departure from primary destination). These choices imply tour duration (or activity duration). Trip-level time-of-day choice is conditional upon tour time-of-day and includes trip departure time.

The time-of-day modeling framework incorporates a wide variety of variables and effects that generate consistent individual daily schedules and are realistically sensitive to congestion and pricing. Such models have been successfully applied in many activity-based models in practice and tested for many policies.



To summarize, in this session we have described a time-of-day modeling framework that incorporates wide variety of variables and effects; that generates consistent individual daily schedules; that is realistically sensitive to congestion and pricing, and that has been successfully applied in many activity-based models in practice and tested for many policies.

Questions and Answers

The Travel Model Improvement Program

Speakers: Peter Vovsha & Maren Outwater

Next Webinar

Executive and Management Sessions	
Executive Perspective	February 2
Institutional Topics for Managers	February 23
Technical Issues for Managers	March 15
Technical Sessions	
Activity-Based Model Framework	April 5
Population Synthesis and Household Evolution	April 26
Accessibility and Treatment of Space	May 17
Long-Term and Medium Term Mobility Models	June 7
Activity Pattern Generation	June 28
Scheduling and Time of Day Choice	July 19
Tour and Trip Mode, Intermediate Stop Location	August 9
Network Integration	August 30
Forecasting, Performance Measures and Software	September 20

Session 9 Questions and Answers

Slide 70 suggests using traffic counts to provide validation for time-of-day choice. Has there been any transit work to validate time-of-day choice?

Maren: I am not aware of specific validation on the transit side. What I mean by that is looking at hour of day to see how they line up relative to results. Having said that, some activity-based models have been used in New Starts applications which are focused on transit, so it has been a component.

Peter: The New York activity-based model and MORPC (mid-Ohio) activity-based model were used for New Starts. There were validations and tried to look at transit by time-of-day. The problem is having good targets. Those validations revealed some problems. If your model looks very good overall, it doesn't mean it will represent transit peaks very well. Transit peaks may be very different from auto peaks. Overall we need to do a better job validating transit.

How are TDM strategies like compressed work week modeling? Seems you'd modify coefficients rather than explanatory variables.

Maren: Those are modeled by using assumptions about the number of people who participate in the program. You assume how many workplaces are offering the program and how many employees will participate. Currently, we have to make those assumptions at the beginning and they are not part of the model itself.

Time-of-day choices are impacted by the mode chosen, but this wasn't addressed in presentation.

Peter: Mode choice and time-of-day choice are closely intertwined. We can create time-of-day specific mode choice log-sums. This is very computationally taxing and there are numerous potential combinations. Time of day choice model is informed by any policy that impacts mode choice, and mode choice is determined by time-of-day.

Are all joint tours modeling as being home based? How is it modeled if two household members are at a different location when they have time to do a joint tour?

Peter: We distinguish between fully and partial joint tours. Currently, models only do fully joint tours. Only recently we extended framework to cover the partial joint tours. We started with the fully joint tours because they cover almost all joint tours.

How does choice of tour time-of-day affect congestion if mode has not been chosen yet?

Maren: This is the concept of estimating time-of-day twice. Before we know mode, we use mode choice log-sums to represent all possible modes and impact on time-of-day choice. Also, at beginning of process we have an idea of congestion effects from a previous year or a no-build scenario. That can be used as a starting point to influence time-of-day choice. That helps get an approximate time-of-day to start with. Once initial time-of-day is chosen, you can calculate mode and then actual time-of-day.

Regarding shifts, wouldn't one possible response be to shift a trip from beginning of day to end of day? How is that reflected in these paradigms?

Peter: Shifts can occur across entire range. Depending on structure, there may be longer shifts. This depends on the entire structure and other constraints. For example, a person with a very fixed schedule for work can implement shopping before or after work, since window for work activity is blocked. This is one of things possible to model with an activity-based model. You don't just see mode choice or time-of-day change. You see the change of entire day patterns.

In households with multiple children around the same age, do you model their time-of-day choice together or separately?

Peter: In both CT-RAMP and DaySim, every person is simulated, including small children. Each person has an individual record and activity schedule. This is applied to 70 year-olds and small children; however, patterns are different because young children cannot drive and are strongly linked to the activities of adults.

Is there any treatment, for example iteration, in activity-based models to make sure input hourly traffic costs are consistent with output hourly traffic costs?

Maren: Yes, the reason we do different iterations is to ensure at the end of the day there is some convergence. The treatment is something the modeler needs to do. It's not a built-in function, it's an idea that the iteration must converge and be checked.

Map-21 requires performance measures as a part of project evaluation. Would an activity-based model be able to do this better than traditional models?

Maren: activity-based models are more detailed spatially and temporally. We also have more detailed person characteristics. We can then aggregate better for performance measures that are segmented for different segments of the populations, for example, high- or low-income. This allows you to get better information about influence of your policies. A lot of people want to know if a particular policy is going to affect low-income households, for example, and that's possible with an activity-based model and would be much more difficult with a traditional model. Having said that, the performance measures that most MPOs are considering have started to expand to measures that are possible with activity-based models, but they still rely on the older performance measures, which activity-based models can still handle.

Peter: One of the new measures being extensively discussed is travel time reliability. There is a growing understanding that travel time reliability has a large impact on people's choices, and activity-based models can measure reliability very well.