Incorporation of Travel Time Reliability in Integrated Demand and Network Simulation Models

Peter Vovsha, PhD,
Principal, Parsons Brinckerhoff (PB), New York, NY

This presentation summarizes the implemented synthesis of the research literature and testing of various methods to incorporate travel time reliability in operational travel models in the framework of SHRP 2 C04 and L04 Projects. The key members of the research team include Hani Mahmassani & Jiwon Kim (NU), Mark Bradley (MBRC), Bob Donnelly & Surabhi Gupta (PB), Yannis Stogious (Delcan) & Cen Kurry (Delcan). Incorporation of reliability is primarily considered in the overall framework of demand-network equilibrium with the demand side represented by an advanced Activity-Based Model (ABM) and the network simulation side represented by an advanced Dynamic Traffic Assignment (DTA).

FINDINGS AND RECOMMENDATIONS ON ABM-DTA INTEGRATION

There are several important aspects of ABM-DTA integration and associated feedback mechanisms that are essential and need to be addressed even before incorporation of travel time reliability measures. New methods of equilibration of ABM and DTA are substantiated, that include the following technical solutions to be applied in parallel:

- *Individual schedule consistency & temporal equilibrium*. Individual schedule consistency means that for each person, the daily schedule (i.e. a sequence of trips and activities) is formed without gaps or overlaps. This solution is based on the fact that a direct integration at the disaggregate level is possible along the temporal dimension if the other dimensions (number of trips, order of trips, and trip destinations) are fixed for each individual. Then, full advantage of the individual schedule constraints and corresponding effects can be taken. The inner loop of temporal equilibrium includes schedule adjustments in individual daily activity patterns, made as a result of congested travel times being different from planned travel times. This is very helpful in reaching the DTA convergence (internal loop) and is nested within the global system loop (when the entire ABM is rerun and demand is regenerated). The purpose of this feedback is to achieve consistency between generated activity schedules (activity start times, and times and durations) and trip trajectories (trip departure time, duration, and arrival time). This feedback is implemented as part of temporal equilibrium between ABM and DTA when all trip destinations and modes are fixed, but departure times are adjusted until a consistent schedule is built for each individual. In this way, any change in travel time would realistically affect activity durations and vice versa.

- *Pre-sampling of trip destinations*. The second solution is based on the fact that trip origins, destinations, and departure times can be pre-sampled and the DTA process only then is required to produce trajectories for a subset of origins, destinations, and departure times. In this case, the schedule consolidation is implemented though corrections of the departure and arrival times (based on the individually simulated travel times) and is employed as an inner loop. The outer loop includes a full regeneration of daily activity patterns and schedules, but with a sub-sample of locations for which many individual trajectories are available. For destinations where individual trajectories have not been generated at the previous iterations, conventional aggregate origin-destination skims are used. This method also can be interpreted as a learning or adaptation process for travelers with limited information.

- *Specific methods to ensure equilibration and convergence with individual microsimulation*. These include various enforcement and averaging strategies. Enforcement methods are specific to microsimulation and designed to ensure convergence of "crisp" individual choices by suppressing or avoiding Monte-Carlo variability. Averaging methods have been borrowed from conventional 4-step modeling techniques, but can be also used with microsimulation as long as they are applied to continuous outputs/inputs such as LOS variables and/or synthetic trip tables generated by the demand microsimulation process.

- *ABM improvements for better compatibility with DTA*. There are several important aspects of ABMs that can be improved to provide better inputs to DTA and avoid additional procedures that are currently applied to overcome some structural incompatibilities that exist between the two models (for example, randomly slicing trips by departure time). We discuss three related aspects: 1) enhanced temporal resolution in trip departure choice, 2) car occupancy and associated conversion of person trips into auto trips, 3) inclusion of route type choice as part of the mode choice tree.

- *Compatible user segmentation by preserving individual randomized Value of Time (VOT) and Value of Reliability (VOR)*. For a full compatibility between the demand model and network simulation model, the relevant individual parameters have to be transferred between these two models. Network simulations, and specifically route choice, are not directly influenced by travel purpose or income or car ownership, but these effects can instead be encapsulated in the VOT and VOR parameters. There are two principal ways to ensure the necessary compatibility between ABM and DTA: 1) preserving individual VOTs and VORs transferred from ABM to DTA with the corresponding list of trips to simulate; this is a preferred approach that can in future be extended to include additional parameters like driving style or car type, and 2) forming user classes with similar VOT and VOR to simplify path-building procedures that can be applied for each class; this is a more constrained approach that can be considered as a fallback if the first approach proved for some reason to be infeasible to implement.

FINDINGS AND RECOMMENDATIONS ON INCORPORATION OF RELIABILITY

Four main methods for the quantification of reliability and its impacts are identified and analyzed in detail:

- ***Perceived highway time*** *by congestion levels*. This concept is based on statistical evidence that travelers perceive each minute of travel time with a weights related to the level of in congestion.. Although segmented by congestion levels in this method, perceived highway time is not a direct measure of reliability, since only average travel time is considered,. It can serve, howver, as a good instrumental proxy for reliability since the perceived weight of each minute spent in congestion is in part a consequence of associated unreliability.

- ***Time variability distribution*** *measures (or mean-variance approach)*. This method that has received a considerable attention in recent years.abd is considered the most practical direct approach. It assumes that several independent measurements of travel time are known that allow for forming the travel time distribution and the calculation of derived measures such as buffer time. One important technical detail with respect to generation of travel time distributions is, that even if the link-level time variations are known, it is a non-trivial task to synthesize the OD-level time distribution (reliability "skims") because of the dependence of travel times across adjacent links due to a mutual traffic flow. This issue was specifically addressed in the course of the current project.

- ***Schedule delay cost.*** This approach has been adopted in many research works on individual behavior in academia. According to this concept, the direct impact of travel time unreliability is measured through cost functions (penalties in expressed in monetary terms) of being late (or early) compared to the planned schedule of the activity. This approach assumes that the desired schedule (preferred arrival time for each trip) is known for each person and activity in the course of the modeling. This assumption, however, is difficult to meet in a practical model setting.

- ***Loss of activity participation utility.*** This method can be thought of as a generalization of the schedule delay concept. It is assumed that each activity has a certain temporal utility profile and individuals plan their schedules to achieve maximum total utility over the modeled period (for example, day) taking into account expected (average) travel times. Then, any deviation from the expected travel time due to unreliability can be associated with a loss of participation in the corresponding activity (or gain if travel time proved to be shorter). Recently, this approach was adopted in several research works on DTA formulation integrated with activity scheduling analysis. Similar to the schedule delay concept, however, this approach suffers from data requirements that are difficult to meet in practice. The added complexity of estimation and calibration of all temporal utility profiles for all possible activities and person types is also significant. These concerns make it unrealistic to adopt this approach as the main concept in practice yet.

The presentation includes practical recommendations for inclusion of travel time reliability measures of the 1st and 2nd methods in travel demand models and network simulation tools. It also identifies research avenues for future with respect to the 3rd and 4th methods. The main features of the four approaches and associated features that have to be added to the demand model and network simulation model are summarized in **Table 1**.

Table 1: Summary of Methods for Incorporation of Reliability in Travel Models

Method	Demand model	Network simulation
Perceived highway time	Segmentation of highway time by congestion levels with differential weights; no significant modification of model structure required	Segmentation of highway time skims by congestion levels; no significant modification of model structure required
Mean-variance (time distribution measures)	Adding variance or standard deviation as LOS variable along with mean travel time and cost to mode choice and other travel choices	Adding variance or standard deviation to route generalized cost along with mean travel time and cost; employing path-based assignment and/or multiple-run framework; generation of route variance or standard deviation skims for demand model
Schedule delay cost	Specification of Preferred Arrival Time (PAT) for each trip exogenously or generation of PAT endogenously in time-of-day choice; calculation of schedule delay cost based on PAT and travel time distribution	Incorporation of schedule delay cost in joint route and departure time choice; generation of OD travel time distributions in single-run or multiple-run frameworks
Temporal activity profiles for participation in activity	Calculation of generalized cost including loss in activity participation based on travel time distribution	Incorporation of temporal activity profiles in joint route and departure time choice; generation of OD travel time distributions in single-run or multiple-run frameworks

The main focus of the SHRP L04 research is on making the 2nd method fully operational, when travel time reliability is measured by variance, standard deviation, or buffer time. Incorporation of reliability in a demand model has been fully explored in the SHRP C04 Project and the current project summarizes the main findings primarily on the practical implementation side. The incorporation of reliability in a network simulation model requires innovative approaches to generate the reliability measures that are fed into the demand model, to make route choice sensitive to reliability measures, and to ensure that a realistic correlation pattern is taken into account when route-level measures of reliability are constructed from link-level measures.

FINDINGS AND RECOMMENDATIONS ON IMPLEMENTATION FRAMEWORK

The corresponding technical solutions are broken into two groups – singe-run framework and multiple-run framework. Incorporation of reliability factors in the models can be done in either of these two principal ways:

- ***Implicitly in a single model run,*** in which travel time is implicitly treated as a random variable and its distribution, or some parameters of this distribution, such as mean and variance, are described analytically and used in the modeling process.
- ***Explicitly through multiple runs (scenarios),*** where the travel time distribution is not parameterized analytically, but is simulated directly or explicitly through multiple model runs with different input variables. One of significant efforts of the current project was to design and implement the Scenario Manager that is an essential tool to operationalize the multiple-run approach.

There are pros and cons associated with each method. The vision emerging from this research is that both methods are useful, and could be hybridized in order to account for different sources of travel time variation in the most adequate and computationally efficient way. In particular, we consider single-run analytical methods whenever possible, since they are generally preferable from the both a theoretical point of view, particularly for network equilibrium formulations, and in terms of a more efficient use of computational resources in application. Generally, the factors that can be described by means of analytical tools and probabilistic distributions relate to the baseline demand and capacity estimates, day-to-day variability in travel demand, impact of weather conditions, traffic control, route choice, meso effects associated with traffic flow physics, and individual driver behavior. Factors that can be better modeled through explicit scenarios, rather than captured by probabilistic distributions, mostly relate to special events, road works, and occurrence of incidents. Some of the factors -- like day-to-day fluctuations in demand, weather conditions, and traffic control -- can be modeled in both ways, and the best approach will be determined in the course of this research project.

RECOMMENDATIONS FOR FUTURE RESEARCH

Several important research directions have become clear in the course of the current project. Many of them relate to more advanced methods of incorporation of travel time reliability, specifically schedule delay cost and temporal activity profiles. However, improving travel demand models and network simulation tools in this direction is closely intertwined with a general improvement of individual microsimulation models. The following specific recommendations for future research are made:

- Continue research on advanced methods for incorporation of travel time reliability in demand models and network simulations tools, including the schedule delay cost approach and temporal utility profile (loss of activity participation) approach. As part of it, continue research and development of path-based assignment algorithms that incorporate travel time reliability and can generate a trip travel time distribution in addition to mean travel time.

- Continue research on schemes for the integration of advanced ABM and DTA that can ensure a full consistency of daily activity patterns and schedules at the individual level and behavioral realism of traveler responses. In this regard, enhancement of time-of-day choice, trip departure time choice, and activity scheduling components are essential to address. This relates to the conceptual structure of these models and their implementation with respect to temporal resolution.

- Encourage additional data collection on the supply side of activities and on scheduling constraints, including the distribution of jobs and workers by schedule flexibility, classification of maintenance and discretionary activities by schedule flexibility, as well as developing approaches to forecast related trends.

- Continue research and application of multiple-run model approaches and associated scenario formations, for both the demand and network supply sides. Our synthesis and research have shown that a conventional single-run framework is inherently too limited to incorporate some important reliability-related phenomena such as non-recurrent congestion due to a traffic incident, special event, or extreme weather condition.

- Incorporate travel time reliability in project evaluation and user benefit calculation. Restructure the output of travel models to support project evaluation and user benefit calculations with consideration of the impact of improved travel time reliability.