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**Advances in Modeling Network Dynamics Incorporating Behavioral Considerations**

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1. **Background**

The workshop was attended by about 25 participants and the discussion during the workshop was enabled by two resource papers. The first resource paper titled “Agent-based traffic assignment: going from trips to behavioral travelers” by Nagel and Flötteröd (2012) reviews the current state of dynamic traffic assignment models and sheds light on some of the limitations of these models with respect to the traveler’s behavior representation. This resource paper presents an approach (implemented in the software MATSim) to extend the static or dynamic traffic assignment models to include additional behavioral dimensions often missing from standard assignment models. The author also discusses the associated simulation and computer implementation issues. The second resource paper by Peeta (2009) entitled “Advances in Modeling Network Traffic Flow Dynamics Incorporating Behavioral Considerations” provides a motivation and preliminaries linking network dynamics and traveler behavior and a historical perspective of network modeling developments. Further, the paper identifies some modeling research needs and presents some recent work by the author in the field of Behavior-Consistent Models of Route Guidance that pertains to systematically incorporating traveler behavior in network models. The following section provides a summary of the workshop discussion followed by a section identifying topics for future research.

1. **Summary**

The discussion during the workshop was mainly centered around the following eight themes.

**2.1 Type of Model**

The type of the model and the scale of analysis were among one of the first points that were raised during the discussion. In the context, the discussion was also closely tied with the data availability. What kind of models should one use for a particular policy analysis – descriptive, predictive, or normative incorporating welfare measures? What should be the scale of analysis? If it is a short term policy analysis, one should use a microsimulation approach and if it is a long term policy analysis, then one should use a meso or macroscopic approach.

The descriptive, predictive and normative analyses are not independent, and more research needs to be devoted to better understand their connections.

**2.2 Data**

An important topic that was raised during the workshop discussion was with respect to the data. The data availability partially determines the spatial and temporal scale at which the analysis will be conducted. In the context of data, the following questions were raised and suggestions provided:

**Spatial and temporal resolution of analysis**

What kind of data exists and what kind of data will exist in the future for model estimation, calibration and validation?

What should be the spatial and temporal resolution at which policy analysis is conducted?

**Validation**

How should one validate the time-dependent outputs from DTA models and at what spatial and temporal resolution? The spatial correlations issues have to be addressed using rather sophisticated econometric models.

**Data availability**

Sometime data have been collected and the researcher should try to have access to them, while in other occasions, data collection is needed. More and more systems (telephone, GPS, web, etc.) naturally collect huge amount of information searching for adequate models.

**2.3 Gap between Theory and Practice**

There is a gap in the sense that advanced models are not always used by practitioners to conduct analyses even though they may be more appropriate than traditional models. Part of the reason for not employing advanced models is because practitioners are not always knowledgeable about the theoretical foundations and limitations of these models. There is a need for disseminating information about the theoretical foundations of these models. Additionally, practitioners can be unaware of the limitations of the model systems. Documentation should provide guidance on when to use advanced model systems versus traditional models, and clearly point out the limitations and shortcomings of the model systems. The large amount of disaggregate outputs provided by the advanced models can be overwhelming at times to practitioners and hence is sometimes a deterrent for their use in policy analysis. Another reason for not employing advanced dynamic models is because of instability of the results generated by advanced models. A static moel can be better behaved numerically, but also wrong, or at least unable to be used for predictions.

**2.4 Model Properties**

Dynamic Traffic Assignment (DTA) models suffer from not having a unique solution and there is also, so far, no real proof of convergence. Under certain unrealistic assumptions one can show uniqueness and convergence. However, the actual DTA problem is non-linear and non-convex in nature and therefore does not have necessarily a unique solution. Therefore, the solution from the original DTA model may not be not unique. However, it is desirable that the solution from the DTA model be stable i.e., that it does not vary too much to moderate changes in the network conditions. It is also important that the model be parsimonious. However, it is possible to develop dynamic planning models which add very few parameters, compared to static models. However, micro-simulation models add many parameters.

**2.5 Choice Sets**

Relevant choice sets are generated for individual agents as opposed to using the entire universe of choices, to keep the models computationally tractable. Choice sets are generated for modeling the location choice, route choice dimensions etc. Choice set generation is very difficult with many tradeoffs (computation time, variability across iterations, and econometric estimations). Most of the workshop participants agreed that we do not have a good understanding of the process underlying the generation of choice sets across individuals and that we make simplifying assumptions to make the analysis computationally tractable. Therefore, there is need for a systematic approach to generating choice sets that is founded on sound behavioral assumptions. In this context, further work needs to be done to explore the implications of including irrelevant choices during calibration, and of using different choice sets during estimation and calibration etc.

**2.6 Heterogeneity**

An important component of incorporating the behavioral considerations in modeling the network dynamics is to accurately represent the heterogeneity across agents. For accurately capturing the traveler behavior, researchers need to go beyond basic variables such as income categories, gender etc. for defining types of agents. There is a rich body of literature in the fields of demography and economics that deals with incorporating heterogeneity in microsimulation models. The methodologies may not be directly applicable to modeling the network flows because of the lack of interaction between agents in these fields. However, it would behoove the field of transportation to learn from the methodologies employed in other fields to incorporate heterogeneity across agents in the model system.

**2.7 Travel Behavior**

This was the most important topic that was discussed during the workshop as is also suggested by the title of the workshop. The complexity and realism of the traveler behavior in the network models is a major concern. Network models should be developed such that systematic approaches are employed to incorporate traveler behavior. Modeling paradigms discussed for improving the behavioral representation include the use of analytical methods and then improving the behavioral realism or use of agent-based models which already incorporate traveler behavior. In addition to the modeling paradigms there was a discussion on the need for disaggregate data on driver behavior and characteristics. The availability of such data is not without issues because of privacy concerns, hardware costs etc. Researchers in transportation have also started to analyze the behavior of drivers via some laboratory experiments.

**2.8 Calibration**

Calibration and validation are two of the important exercises in the application of any model system. In this context, the scale at which calibration is to be carried out was a central theme of the discussion. At what scale should calibration be carried out? Can aggregate data be used to calibrate outputs from disaggregate models? A mixed level of calibration was also considered wherein some sub-models are calibrated at the disaggregate level and other are calibrated at the aggregate level. In some case, also, it is possible to estimate the parameters, that is, to obtain some statistical properties on the unknown parameters. When estimations are not feasible, a robustness analysis is required.

1. **Future Directions**

During the workshop several research directions were identified, which need to be pursued in the coming years to advance models of network dynamics and to enhance the behavioral representation in these models. Many economic issues are discussed in de Palma, *et al*, (2011).

First, studies need to be conducted to understand the type of model (descriptive model, predictive model, normative model incorporating welfare measures) to be used.

Second, with the availability of additional data at finer spatial and temporal scales from sources such as Google real time traffic data, mobile phone data etc., studies should be aimed at exploring the potential advantages of modeling, calibrating and validating at a finer spatial and temporal resolution and the associated trade-offs with a finer representation of space and time. In addition to understanding the advantages of a finer spatial and temporal representation, studies should also be aimed at improving our understanding the appropriate scale (spatial and temporal) of analysis for evaluating short term and long term policies and alternatives.

Third, more efforts should be aimed at educating practitioners of the underlying theories and limitations of the model systems and in disbursing information on when to use a simple macroscopic model versus a counterpart based on microsimulation approaches. Also, parsimony in model systems is important for easy interpretation and application.

Four, the field would benefit from enhancing our understanding about the properties of network models including uniqueness, convergence, stability.

Five, there is a need to focus on the theories underlying the generation of choice sets for individual travelers. Other topics with respect to choice set generation that command attention includes the inclusion of suboptimal alternatives for calibration, generating different choice sets during estimation and calibration, issues related to the storage and computational tractability etc.

Six, it is important to incorporate more heterogeneity in our models. There is a rich body of literature in the fields of demography and economics dealing with microsimulation modeling. However, these are much simpler systems with no interactions to be considered but interactions do exist in traffic flow. None the less the field of transportation can learn from these successful implementations to incorporate heterogeneity in the model systems.

Seven, there is a need to enhance the traveler behavior representation in model systems by focusing more on the underlying behavioral theories and dynamics. Eight, studies should be aimed at understanding the right scale at which models should be calibrated.

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