A Multi-Level Modeling Framework for Route Choice Behavior

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Context and motivation The use of random utility models for route choice analysis involves challenges stemming from i) the high requirements in data, ii) the physical overlap of paths –resulting in complex correlation structures, and iii) the large size of the choice set. These factors significantly increase the complexity of route choice models. Given the revealed difficulty and complexity of route choice analysis, an emerging need is to move towards simplifying the models and rendering them applicable in large and dense networks. The modeling framework proposed in this paper aims at satisfying this need.

Within the proposed framework, the trade-off between complexity and realism can be explicitly controlled by the analyst, depending on the availability of data and the application. The innovation and the importance of the proposed approach lies in the potential to break down the combinatorial complexity of route choice models by replacing the current route *representation*, and subsequently modeling approach, which is based on paths corresponding to link-by-link sequences on the physical network, with an aggregate and more abstract representation. The key feature of the framework is the concept of the *Mental Representation Item* (MRI). This concept is employed to support the new approach for representing the routes.

The merits of the approach pertain to the flexibility of the model, the ability to tackle with the large size and latent nature of the choice set, and the reduction in the correlation among the alternatives. In addition, the afore mentioned approach is believed to be advantageous in comparison to the current approaches, by suggesting a way of modeling the routes which is directed towards the travelers' point of view, and hence being more behaviorally realistic.

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The scope of the present work is focused on car route choice, but we expect that the framework could be transferred to model pedestrian movements as well.

Methodology In route choice modeling the notion of path is used to represent and model the routes that travelers follow to go from their origin to their destination. As such, a path is defined as a chain of consecutive links in the network model, and there exist a huge number of alternative chains of links to go from a given origin to a given destination from which a traveler can choose. Drivers though, as planners and decision makers, do not actually use the concept of path.

Following the intuition and reasoning that travelers use abstract representations of their routes, path alternatives are constructed as (replaced by) sequences of geo-marked items. These items are structured in a hierarchy depending on varying levels of abstraction. The problem begins at the higher conceptual level and works down to the details (path on the physical network). The interest lies in capturing individual's decision in the various levels within the hierarchy, starting from the higher ones.

For the purpose of the current analysis the concept of *Mental Representation Item (MRI)* is used to denote the abstracted items and a hierarchical ordering of the MRIs is hypothesized. Within this framework, route choice can be approached and analyzed in each of the layers in the hierarchy. Each layer is characterized by a choice set $\mathcal{C}_\ell$ of MRI sequences with increasing level of detail from top to bottom layers, yet all referring to the same choice. For instance, starting from the top layer ℓ corresponding to choice set $\mathcal{C}_\ell$, the probability of choosing MRI sequence r given the set of MRI sequences $\mathcal{C}_\ell$ is:

$$P_\ell(r|\mathcal{C}_\ell;\beta^\ell) \tag{1}$$

where β is the vector of parameters to be estimated. Going one step down on layer $\ell+1$, additional detail is incorporated. The choice set in this layer is denoted as $\mathcal{C}_{\ell+1}$ and the probability of choosing MRI sequence r is then:

$$P_{\ell+1}(r|\mathcal{C}_{\ell+1};\beta^{\ell+1}) \tag{2}$$

This process can be repeated for all the layers up to the lower one –detailed path on the network– and route choice models can be estimated in each of the intermediate layers. Different types of route choice models (e.g. logit model to begin with), depending on the data availability and the level of complexity, can be used.

One issue is then how to underpin the links among these layers and how to ensure consistency with respect to the probabilities and the estimated parameters resulting from the various layers. Ensuring consistency is very important as the aim is to use the framework for prediction. Exploiting the hierarchy of the framework the choice probability in the top layer ℓ (see equation 1) can also be derived from (linked to) layer $\ell + 1$ as follows:

$$\bar{P}_\ell(r|\mathcal{C}_\ell;\beta^\ell) = \sum_{k\in\mathcal{C}_{\ell+1}} P(r|k,\mathcal{C}_\ell;\beta^\ell)P(k|\mathcal{C}_{\ell+1};\beta^{\ell+1}) \tag{3}$$

The consistency of the framework can be evaluated on the basis of the choice probabilities derived from the different layers.

Application In this paper we provide empirical evidence for the framework, obtained from simple case studies in the cities of Athens and Stockholm. Two qualitative examples are presented in an attempt to exemplify the ideas described above, acquire insights for the identification of the MRIs, and attain an initial verification of our hypothesis. These simple case studies, that take the form of questions where respondents are asked to give a description of the routes that they follow to go from home to work, or to a relative's place, showed that people use elements such as the *city center*, the *highway H*, the *neighborhood N* to describe their routes and identify alternatives. The attributes that in most cases they associate to the alternatives are in the form of longer but faster, with less traffic lights etc.

Furthermore, as an illustration of the model, we present a concrete example and provide estimation and forecasting results of the application of the framework in the Swedish city of Borlänge [1]. In this example, the choice set in the higher layer consists in three alternatives, that is i) avoid the city center, ii) go through the city center, or iii) go around the city center. Additional detail in the choice set of the following layer consists, for example, in identifying clockwise or counterclockwise route given that someone went around the city center.

We conclude the analysis with a comparison of the model with models presented in Frejinger and Bierlaire (2007).

Conclusion The prominent feature of the framework presented in this document consists in its flexibility to approach the choice decision from different levels of abstraction. The proposed structure aims at simplifying route choice models, ensures consistency, and offers adjustability of the framework in different contexts/ cities.

As the route choices can be modeled in a more abstract way, the requirements in data accuracy diminish. Several possible paths connecting the origin and destination on the physical network are bundled under MRIs while transferring from a lower to an upper layer, and hence the choice set size decreases and its composition is simplified. At the same time the correlation among the alternatives becomes simpler. These characteristics of the framework are important as they can render the

[1] We refer to Frejinger and Bierlaire (2007) and Axhausen et al. (2003) for a description of the Borlänge GPS dataset.

application in large networks operational.

Finally, concepts akin to the MRI –like anchor point, mental map, mental representation– have been researched and discussed before in disciplines such as cognitive science and geography [see for e.g. Tolman (1948); Lynch (1960); Suttles (1972); Chase (1983); Couclelis et al. (1987); Golledge (1999); Golledge and Gärling (2003); Arentze and Timmermans (2005); Hannes et al. (2008)], but never investigated or applied in route choice modeling.

References

Arentze, T. a. and Timmermans, H. J. P. (2005). Representing mental maps and cognitive learning in micro-simulation models of activity-travel choice dynamics, *Transportation* **32**(4): 321–340.

Axhausen, K., Schönfelder, S., Wolf, J., Oliveira, M. and Samaga, U. (2003). 80 weeks of GPS traces: Approaches to enriching the trip information., *Transportation Research Record: Journal of the Transportation Research Board* **1870**: 46–54.

Büchner, S. J. (2011). *Environmental Structure, Mental Representations and Path Choice Heuristics_Information Processing in Wayfinding*, PhD thesis, Albert-Ludwigs-Universität Freiburg.

Chase, W. G. (1983). *D. A. Rogers & J. A. Sloboda (Eds.), The acquisition of symbolic skills*, New York: Plenum, chapter Spatial representations of taxi drivers, pp. 391–405.

Couclelis, H., Golledge, R. G., Gale, N. and Tobler, W. (1987). Exploring the anchor point hypothesis of spatial cognition, *Journal of Environmental Psychology* **7**: 99–122.

Frejinger, E. and Bierlaire, M. (2007). Capturing correlation with subnetworks in route choice models, *Transportation Research Part B: Methodological* **41**(3): 363–378.

Golledge, R. G. (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*, Johns Hopkins University Press, Baltimore, MD.

Golledge, R. G. and Gärling, T. (2003). Cognitive Maps and Urban Travel, *University of California Transportation Center* .

Hannes, E., Janssens, D. and Wets, G. (2008). Destination Choice in Daily Activity Travel: Mental Map's Repertoire, *Transportation Research Record: Journal of the Transportation Research Board* **2054**: 20–27.

Lynch, K. (1960). *The Image of the City*, M.A.: MIT Press, Cambridge.

Suttles, G. (1972). *The Social Construction of Communities*, The University of Chicago Press, Chicago.

Tolman, E. C. (1948). Cognitive maps in rats and men, *Psychological Review* **55**: 189–208.