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Towards process validation for complex transport models: A sensitivity analysis of a social network-enhanced activity-travel model

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ABSTRACT

Model validation is a significant issue for the modelling of social network-based transportation models because of the many interacting components (the individuals, the environment, and now the network) in the model.
In this paper we focus on a sensitivity analysis for such a model, which is part of a larger validation approach known as process validation. This approach investigates both the structure and behaviour of the model, to evaluate whether the model can be used for prediction.
The paper draws on a novel set of experiments with an agent-based model which was developed to explore the effects of social networks on activity and travel behaviour. Several versions of the model were created, beginning with a single day model with no interaction, and then adding in multi-day runs with interactions, in order to demonstrate the validation process.
The paper argues that testing the model at different levels of complexity increases confidence in the model and makes it easier to locate components or functionality that require improvement. It concludes by suggesting that this approach to sensitivity testing should be adopted for validation of complex transportation models.

1. Introduction

Model validation is a significant issue for the modelling of social network-based transportation models because of the many interacting components (the individuals, the environment, and now the social network) in the model. For example, as one's social network grows, the number of activities and potential travel required to keep in touch with each member of the network may increase. Certain life events (e.g., moving house, changing jobs, a change in family composition) may also affect one's networks and travel patterns (Sharmeen, Arentze, & Timmermans, 2010).

Due to the interacting components within the system, agent-based modelling is a sensible approach to take. Agent-based models "consist of a system of agents and the relationships between them" (Bonabeau, 2002). The agents perceive their environment and other agents, make decisions following some rules, and act, possibly changing the environment in the process. Agents can also evolve over time, learning about their past experiences. Modelling at such a low level is sometimes more "natural" than attempting to, for example, create flow equations.

However, this then introduces more complexity into the validation of the model, that is, determining how it can be used and in which situations. In this paper we focus on a sensitivity analysis for such a model, which is part of a larger validation approach described in Ronald, Arentze, and Timmermans (2010). This overall approach investigates both the structure and behaviour of the model, to evaluate whether the model can be used for prediction. For our sensitivity analysis, several versions of the model were created, beginning with a single day model with no interaction, and then adding in multi-day runs with interactions, in order to demonstrate the validation process.

These results build on earlier work with an uncalibrated version of the model, demonstrating initial results (Ronald, Arentze, & Timmermans, 2012) and experimenting with different interaction protocols (Ronald, Arentze, & Timmermans, 2011) and different social network topologies (Ronald, Dignum, Jonker, Arentze, & Timmermans, 2012). However, the version described in this paper is still a proof-of-concept. Although it was calibrated on real-world social networks and activity diaries, we do not have enough data at this stage to validate completely.

The paper argues that testing the model at different levels of complexity increases confidence in the model or makes it easier to locate components or functionality that require improvement. It concludes by suggesting that this approach to sensitivity testing should be adopted for validation of complex transportation models.

2. Related work and theory

Models of transport and activity behaviour focus on adding "why" people are travelling to the existing "when" and "where" are they travelling. "Who with" is a recent area of interest (Axhausen, 2008b), in particular travel and activities with non-household members.

It is theorised that social activities could place constraints on other activities. However, at present, social activities tend to be modelled

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with a random time and location (Arentze & Timmermans, 2004), neglecting the preferences of the other travellers or activity participants. Recently, research towards overcoming this limitation was undertaken by Illenberger (2012).

Incorporating social networks into activity-travel models is therefore important to understand the full extent of social and spatial interaction for joint and non-joint activities.

However, this raises another issue: how do we collect the data on social networks? In most cases, survey participants complete an activity diary, similar to existing household travel survey methodologies, but with more details about the people they travelled with and undertook activities with. A second stage also collects information about their general social network, which may bring other individuals to light who were not part of the participant's interactions during the survey days. With this data, a number of statistical models have been developed, investigating relationships between social network properties and activity frequency (Carrasco & Miller, 2009) and exploring whether social activities are routine or spontaneous (van den Berg, Arentze, & Timmermans, 2010). A summary of work in this area, focusing on data collections in Canada, Switzerland, The Netherlands, and Chile, can be found in Kowald et al. (2012).

Other influences in this area of research are investigating the formation of social capital and social network geography (Axhausen, 2008a), the impact of information and communication technologies (ICT) on leisure activities, in particular the amount of substitution and complementarity and other changes (Mokhtarian, Salomon, & Handy, 2006), the collection of social network data and activities (Carrasco & Miller, 2009), the generation of social networks (Arentze, van den Berg, & Timmermans, 2012; Illenberger, Flötteröd, Kowald, & Nagel, 2009), and modelling influence (Sunitiyoso & Matsumoto, 2009).

Some attempts have been made in modelling social networks and activities. Hackney and Marchal (2009) developed a microsimulation of daily activities, adding a social network on top. The simulated individuals exchange information, about both friends and locations of interest. Their system did not permit scheduling collaborative activities.

Our system does include collaboration, which adds another layer of interactions to validate. The aim of validation is to describe what the model is capable of doing, and then the user can determine whether it is suitable for its purpose (Amblard, Bommel, & Rouchier, 2007). Empirical validation has traditionally been dominant in transport modelling, where model outputs are compared to real-world data. However, these statistical techniques are not always applicable to agent-based models due to lack of data and possible chaotic/non-linear behaviour in the system (Klügl, 2008). Despite this, several methodologies have been proposed, which include a combination of face and empirical validation tests. The processes within the model are also inspected as well as the model outputs.

Barlas (1996) presents process validation, which is focussed on structural validity. There are several types of tests described:

- Direct structure tests: the structure of the model is compared with knowledge about the real system structure. Tests include comparing with information gathered from the system being modelled (qualitative and quantitative) and from theory, comparing equations with knowledge, and extreme value testing on individual equations with a comparison with the real world.
- Structure-oriented behaviour tests: the structure is indirectly testing by looking at behaviour. Tests include extreme condition testing (is the real world also sensitive to the same parameters?), relationships between variables (phases), and modified testing (if a real system can be modified in some way and data collected, does the model change in the same way?).
- Behaviour pattern tests: moving on from the structure, are the outputs sensible? In particular, patterns (periods, frequencies, trends etc.) are more important than replicating data points. This can be done statistically (means, variances, etc.) or visually.

From a transportation perspective, Donnelly, Thompson, and Wigan (2012)) outlined how process validation could be used for freight models. They found that the more involved process permitted the use of numerous data sources and led to "more transparent and trustworthy models, fewer defects, and greater confidence in the outcomes".

The main technique used in structure-oriented behavioural testing is sensitivity analysis, by which we want to determine the effects of different parameter values and inputs. It can be undertaken before calibration, in order to determine if any parameters are insignificant enough to be removed, or afterwards, in order to explore the effects of policy changes.

Sensitivity analysis can take the form of either altering parameters given a "base scenario" (i.e., systematically changing the value of one or more inputs) or providing different scenarios (e.g., increase in car ownership, which requires one or more parameters to specific values, based on data or understanding of the scenario). For our model, different parameters, such as thresholds for utility functions and input matrices, can be altered to see the effects. Extreme values or bounds are also of interest.

In terms of validation approaches for other transport models incorporating social behaviour, very few have described how their model was verified or validated. As shown in Hackney and Marchal (2009), sensitivity analysis can be undertaken. Four types of inputs were varied: the starting social network (none, a random graph, and a random graph with addition and deletion of links), social interactions (none or sharing one location with a friend per time step), utility function, and replanning (varying proportions of changing route, changing activity time, changing locations based on agent knowledge or the whole environment).

3. Case study overview

The aim of the model is to simulate the decision-making processes of people planning an activity together. This is done by agents interacting with each other to determine a choice set and then individually evaluating activities to determine their preferences. In this section, the modules within the model are described: the environment, the population and how individuals communicate with each other, the schedule, and how decisions are made. A note on implementation is also included. This is a summary of the model described in Ronald (2012), to which the reader is referred if interested in further details.

3.1. Environment

The global network is stored as a graph with links and nodes; some of the nodes contain location details. Each link has a distance and possibly certain modes associated with it. Each mode has an associated cost per kilometre, which will be used to calculate travel costs, and an indication of speed per kilometre plus an error term, which will be used to calculate the duration of trips.

The locations contain properties that are global to the system, such as opening times and name. Individuals have a separate object which stores their personal information about a location that they know about, such as the distance from their home, their preferred mode, and their error value for that location.

3.2. Population

The population module contains the individuals and the social network details. It also contains the communication module.

The agent architecture is shown in Fig. 1. The colours represent the functionality that will be added step-by-step in the experimentation.

An interaction protocol consists of a Protocol object, which specifies the possible messages, and a Behaviour object, which specifies the behaviours on receipt of messages. At this stage, all individuals have the same behaviour, however this can be altered in future versions. Note