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An agent-based framework for modelling social influence on travel behaviour

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Recent travel forecasting models have focussed upon the fact that travel is derived from the activities in which people participate, such as work, school, shopping, sport, leisure, and social events. Non-discretionary activities such as work and school may be explained by the traveller's sociodemographic characteristics and generalised travel costs, as well as long-term decisions such as a decision to move to a particular town.

Participation in social and leisure activities is determined by one's friends and the groups that one is a member of, i.e., their household, their workplace/school, sporting groups, voluntary organisations and clubs. These acquaintances form part of an individual's social network: a representation of the people one interacts with. This demonstrates a shift in the activity-travel modelling field from "where" to "what" and now towards "who with". On top of this, our changing use of ICT is influencing our activity and travel patterns, as some activities can now be replaced by online activities, and online activities can lead to actual travel.

Some researchers are already looking beyond households to the influence of social networks. However, we are not aware of any agent-based urban models considering activity-travel choice of individuals. Existing work is in the conceptual or early implementation phases. The aim of this project is to develop and validate a model combining social ("who with") and spatial ("where") networks for investigating and predicting social activities. In this paper, we describe the design of our model.

Agent-based modelling is a good fit for our model. Our system consists of different people, their relationships and interactions with each other, and their activities in and possible movement around the environment. The topology is not homogeneous and clusters may form. We have used a combination of the metamodels found in mature agent-oriented software engineering methodologies to design our model, focussing on system goals, the environment, acquaintances, roles, and services. The design successfully caters for the description of the environment, the nature of activities, and the dynamics of individuals and their networks.

The individuals in our model each have an agenda, and interact and negotiate with others to schedule social activities, in particular negotiating about the nature of the activity, participants, time, and location. Existing models do not capture the actual joint decision making process behind activity scheduling, and although some work on joint decisions has been undertaken, these models focus on outcomes of interactions within households and have not considered personal social networks at large. We use existing multi-issue negotiation theory to describe an interaction design, which is shown to satisfy a number of basic properties, such as termination, liveness, and safety.

Due to the current interest in predicting social activities and the changing nature of social activities due to our use of ICT, this type of model is of increasing importance to planners who need to be able to predict social activities and travel. The model is currently being implemented in Java, and will be validated using an extensive dataset of people's activity participation and personal networks, collected in Eindhoven, Netherlands. Future work includes more empirical experimentation with the protocols and implementation of and experimentation with the entire model.

Keywords: *activity-travel modelling, social networks, agent-based modelling*

1. INTRODUCTION

Travel is derived from the activities in which people participate, such as work, school, shopping, sport, leisure, and social events. Non-discretionary activities such as work and school can be partly explained by the traveller's sociodemographic characteristics and generalised travel costs (Hackney and Marchal, 2007), as well as long-term decisions such as a decision to move to a particular town. Participation in, and scheduling of, other activities is not as easily predicted. Social and leisure activities are the reported purpose for a large number of trips, ranging from 25 to 40% for various countries (Axhausen, 2006).

Interest in activity participation is also driven by our changing use of information communication technology. The use of the internet for activities, such as banking, shopping, and participating in online communities or conversations, may remove the need for physically visit places and therefore affect people's travel behaviour. As a result of receiving information via a mobile phone whilst travelling or participating in an activity outside the home, people could change their activity schedules and their transport plans on the fly.

Social networks are a graph representation of individuals and their relationships. Understanding the social network that lies on top of the spatial network (as seen in Figure 1) should lead to better predictions of social activity schedules and forecasts of travel patterns and demand for urban facilities, in particular those relating to social and leisure activities. This understanding could also influence the urban design of residential areas and public spaces, in order to encourage participation in social/leisure activities in local communities.

The consensus so far is that social activities are driven by the members of one's social network, in particular "determining trip destination, frequency, mode and scheduling" of leisure and "personal" activities (Hackney and Axhausen, 2006). Buliung and Kanaroglou (2007) state that some researchers are already looking beyond households to the influence of social networks. However, we are not aware of any agent-based urban models considering joint activity-travel choice of individuals. Existing work is in the conceptual or early implementation phases and concentrates on only one or two of the key concepts we have identified as important for these this type of models.

Our aim is to develop an agent-based simulation model to investigate the effects of social processes on activity and travel behaviour. We are interested in exploring the dynamics of the social network and how it affects individual choice sets of locations, activities, and participants. The core of our model is based on agents interacting with each other to schedule activities using cooperative interaction protocols. The decisions of agents will be utility-based, and therefore can determine, given some alternative plans in order to achieve a goal, which plan they prefer. This model will be an experimental tool that can be used by planners to explore the effects of different parameters on travel associated with social and leisure activities. Our spatial area of interest is interactions of residents within a particular city, including day-trips to neighbouring cities.

In this paper, we identify and describe requirements for models combining social and spatial networks. We also demonstrate how agent-based modelling can be used for the design of these models. Firstly, we present the conceptual model and a review of related models. We then follow with a demonstration of the design process, in particular focussing on the interaction design. The paper concludes with further work.

2. BACKGROUND

We have identified three issues that will be important in developing this model:

- the *selection* processes in the social network: how acquaintances are formed and deleted;
- the *influence* processes in the network: information exchange, social learning and social adaptation; and
- the *activity/travel generation* that emerges from the network: focussing on predicting the participants in, frequencies of, locations of, and transport modes used for social activities.

The *selection* processes in our system are based on the formation and deletion of connections. In the process of life events such as moving, starting a new job, or joining a club, connections are created. If people do not communicate with an acquaintance often enough, the connection may eventually fade and disappear.

Hackney and Axhausen (2006) claim that social networks can be generated using behavioural tendencies from sociology, including homophily, bridging social capital (where people are similar in one way but different in another), and placing limits on the number of relationships. The latter property is one of the principles used by Jin et. al. (2001) in their investigation into growing networks. Other principles included increased chances of meeting another person if you and they have a mutual friend, and tie strengths decaying over time.

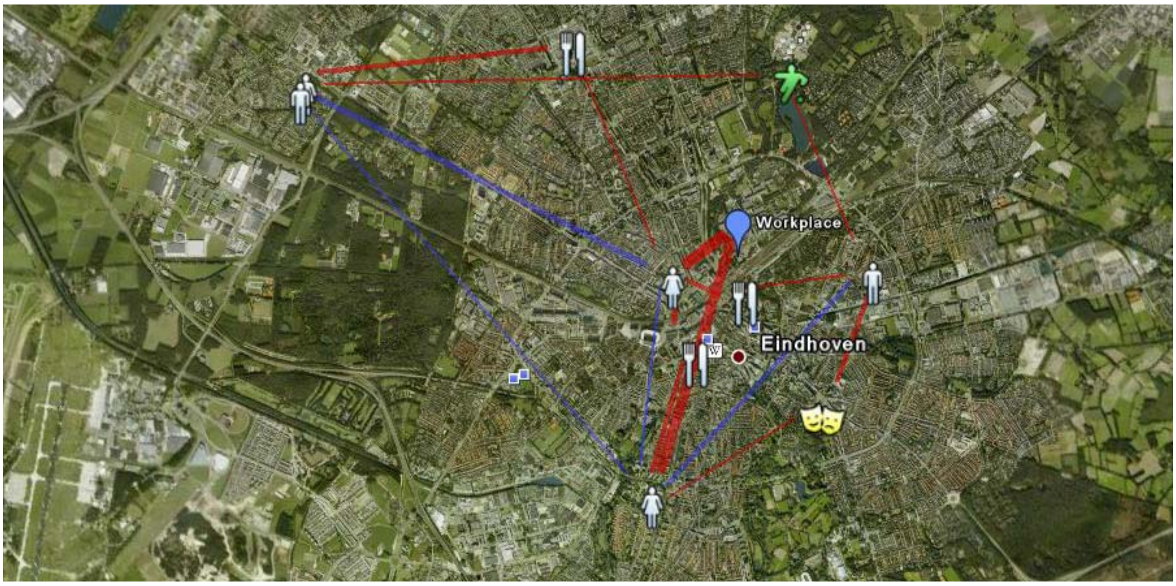

Figure 1 A social network (blue) and an activity network (red), overlaid onto a spatial network. The thicker the blue lines, the stronger the relationship between the two people. The thicker the red lines, the more often the person visits that location (which could be, for example, cafes, parks, theatres).

In their review of homophily, McPherson et. al. (2001) define homophily as the "principle that contact between similar people occurs at a higher rate than among dissimilar people". Some of the attributes that are used as similarity measures include gender, age, education, occupation, social class, behaviour, attitudes, abilities, beliefs, and aspirations.

Distance is also a key factor in the maintenance of relationships. McPherson et. al. (2001) claim that the most basic source of homophily is space as we "are more likely to have contact with those who are closer to us in geographic distance than those who are distant."

People *influence* each other by providing information or observing behaviour. For example, one of your acquaintances may inform you about a new restaurant they have recently discovered and you may wish to consider eating there in the future. Other indirect influences on travel behaviour include moving to be closer to work or family and choice of vehicle.

Much of the literature on influence relates to investigating the spread of epidemics or rumours, the diffusion of innovations, and determining which nodes or individuals in the network are "powerful". These can be divided into two different objectives: where the property being spread is undesirable and needs to be controlled or eradicated (epidemics etc.), and where the property being spread is desirable and should be spread quickly (rumours, new innovations etc.) (Boccaletti et. al., 2006), the latter of which is more interesting for us.

As Newman (2003) recognised, research has been slow in understanding the actual workings of networked systems and the focus has been on structural form and analysis. We are interested in the *activities* that emerge from the social and spatial networks. Activities are generated due to "physiological, psychological and economical needs" (Wen and Koppelman, 2000). The different activities can be categorised as subsistence (work-related), maintenance (keeping the household running), and leisure.

Some work has been done with trying to integrate the effects of social networks and interactions with activity patterns. This is very recent, as Axhausen (2006) notes that "transport research, but also sociological research has in the past not looked at the link between social networks, locational choices and travel". Currently, no model thoroughly incorporates all three concepts we have identified. Most models focus on one or two concepts and in most cases at a very basic level. For example, initial social networks usually follow a generic random graph model, which is not realistic. However, most of these models are described as preliminary or proof-of-concept.

Sunitiyoso has investigated influence, by exploring the spread of soft (or psychological) policy measures, such as environmental awareness and encouraging car-sharing, and in particular the influence of a minority influence group (Sunitiyoso et. al., 2006) and the spreading of mode choice behaviour (Sunitiyoso and Matsumoto, 2007).

In terms of activity generation, Carrasco and Miller (2007) developed a “proof-of-principle” model to look at including the social dimension in forecasting models. Their focus was on how social activities can be generated from a social network. A key idea from this work is that the “potential activity and travel” between two connected people is more relevant to predicting travel behaviour than the tie strength alone.

Incorporating both influence and selection, the model created by Marchal and Nagel (2005) investigates where “individuals perform activities such as shopping and leisure”. The essence of this model has been used as the basis for a recent extension for MATSim that allows for the inclusion of social network data into a large-scale model (Hackney and Marchal, 2007). In this model, individuals make visits to locations, alter the strength and existence of ties, exchange information with each other, and modify their plans by updating the location of secondary activities during each run. At the moment, the selection and influence strategies are simple, but more realistic behaviours could be incorporated.

With respect to simulation properties, both Marchal and Nagel (2005) and Hackney and Marchal (2007) report on the computational aspects of their models and make estimates of their computational complexity. Comments are also made on the usefulness and practicality of exploring social aspects and their effects (Ettema et. al. 2007, Hackney and Axhausen, 2006). Collection of more data will be required and it may be that simulations with more data input and more detail do not provide an improvement in forecasting. As a large amount of travel is now for social/leisure purposes, it seems reasonable that we attempt to understand the reasons behind it.

3. MODEL DESIGN

Agent-based modelling is frequently used for applications where the behaviour and intentions of heterogeneous individuals and interaction between individuals is required. Both Bonabeau (2002) and Macal and North (2006) present lists of attributes that systems should possess in order for agent-based modelling to be considered, including: agents have dynamic relationships with other agents; relationships form and dissolve; agents have a spatial component to their behaviours and interactions; and the topology of the interactions is heterogeneous and complex.

Our system consists of different individuals, their relationships and interactions with each other, and their activities in, and possible movement around, the environment. The topology is not homogeneous and clusters may form. Therefore agent-based modelling appears to be appropriate for our model, due to the complex relationships and interactions between individuals and the individuals' situatedness in an urban environment.

Several design methodologies have been developed for agent-oriented applications. Many elements are similar across methodologies. Most methodologies are developed for “real-life” applications, which are usually open, however the concepts are still useful for simulations. We have used a combination of the metamodels found in mature AOSE methodologies (for example, Gaia (Wooldridge et. al., 2000), ROADMAP (Juan, 2002), Prometheus (Padgham and Winikoff, 2004), and the reference meta-model described in Bernon et. al. (2005)) to design our model, focussing on system goals, the environment, acquaintances, roles, and services (i.e., the agent’s functions). Our interaction model is explained in more detail in Section 4.

3.1. System goals

The goals of the agents in the system are derived from the social needs of humans, which include interacting with, and gaining the respect and esteem of others. The system goals are therefore:

- making and maintaining (long-term) relationships with other agents;
- sharing experiences with other agents, in the form of joint activity participation;
- sharing (giving and gaining) information with other people; and
- learning individually about their local environment.

Levels of achievement are measured individually, i.e., each agent will have some level of satisfaction and will derive utility from sharing objectives. If they are not satisfied with their current situation, then they will try to change it. The same applies to how involved people will be in the community – it is dependent on their needs.

3.2. Environment

The environment has a network representation, derived from the actual road network. The links contain attributes for the actual distance, as well as some idea of the travel time for different modes. The nodes exist at a point in space, and most (if not all) nodes contain a location, which is a facility where (joint) activities can be undertaken. Each individual also has their own representation of this environment to account for limited knowledge and information.

There are several different types of location, and each type has a set of attributes. The major distinction is between private residences and public locations (e.g., restaurants/cafes, museums, theatres, parks, sport centres/gyms). For example, the latter will have opening hours.

3.3. Acquaintances and social structures

Each person has a set of acquaintances, which is defined by their personal social network. Each pair has a type of relationship (e.g., family, work, friend) and also know how long it has been since they last saw each other.

The model also contains groups and neighbourhoods. Groups are formal and informal clubs that the individual is a member of, such as sports clubs or special interest clubs, where the individual is effectively connected to many people. On leaving the club, some connections may remain, but as friends. The neighbourhood is based on the home location of the individual.

Using the ideas presented in Section 2, our friend selection model is based on the similarity between two people, the distance between them, and their friends in common. When considering proposing or participating in an activity, the agent's time availability, the time since they last saw the other agent, the social credit balance between the two agents, and their satisfaction from their last encounter are also taken into account.

3.4. Roles

Role models are used to define the roles present in the system, along with their permissions and responsibilities. In this model, individuals play roles only within interactions: each activity has a host and one or more respondents.

3.5. Services and tasks

The main task of an individual is to meet its goals discussed in Section 3.1. They will do this by initiating and participating in discussions about activities, as well as participating in the activity itself. Utility maximisation is used to determine the preferred activity choices.

The key service is the maintenance of an individual schedule, so that activities can be scheduled. The individuals in our model each have an agenda, and will interact and negotiate with others to schedule social activities, in particular negotiating about participants, time, and location. After participating in an activity, individuals update their state depending on their satisfaction with the activity.

Individuals will also meet new people as a result of activity participation, so another important service is the maintenance of a personal network. Just as their activities are influenced by their social network, their network is influenced by their activity participation.

As people participate in or discuss activities, they may visit or learn about new locations. The individuals will also keep track of the locations they are familiar with. They may share them with others, which is a form of influence.

4. INTERACTION DESIGN

Interactions between agents are an important component of agent-based applications. The agents in our model each have an agenda, and interact and negotiate with others to schedule social activities. In particular, they negotiate about the nature of the activity, participants, time, and location.

Current methods of modelling decision processes in activity-travel models in an individual manner will need to be revised to take into account that many decisions are made jointly. Joint activity decision making within households has been investigated, however existing models do not capture the actual mechanisms behind the decision making. Moreover, these models focus on interactions within households and have not considered personal social networks at large.

The different interactions we describe permit a more decentralised and collaborative approach to joint activity scheduling, which is better aligned with both the principles of agent-based modelling and decision making in reality than determining schedules individually.

Agent interactions have several components: the negotiation set (the possible proposals), a protocol, strategies, and a rule to determine that the interaction is complete (Wooldridge, 2002).

For the negotiation set, we have developed a list of activity patterns, including the activity purpose and location, as well as an indication of which acquaintances are likely to be involved and when (e.g., interacting socially with work colleagues is likely to be during the week, whereas visiting family is mostly a weekend activity).

The protocols we use are based on those developed by Wainer et. al. (2007) for agreeing on a meeting time. As these protocols are concerned with only one issue (time), elements from multi-issue negotiation need to be incorporated. Fatima et. al. (2006) explains three methods for dealing with issues in multi-issue negotiation: all issues are discussed together (package deal), issues are discussed separately and independently of each other (simultaneous), or issues are discussed one after the other (sequential). Although it has been shown that proposing complete deals at each step is computationally more complex, it has advantages such as Pareto optimality (Fatima et. al., 2006). In our model, it is too difficult to decide issues independently (for example, the activity may determine the time and location or vice versa) and also determine in which order they should be discussed (should we decide on the activity or the location first?), therefore we use the package deal method. However, the choice sets for certain issues are decided independently.

The protocol proceeds as follows:

- The host proposes an activity to one or more of its acquaintances (respondents). This could be incomplete, or could contain hard constraints for, e.g, time, location.
- The respondents respond with the possible days and times that they are available. The host creates an intersection of these times, so that only times when everyone is available are considered.
- The respondents then suggest locations. The host creates a union of these, so that all suggestions are considered.
- The host then sends a list of the potential activities. The respondents rank the potential activities using a utility function.
- The host determines the “best” activity based on everyone's rankings and notifies the respondents of the final details.

The protocol satisfies a number of basic properties, such as termination, liveness, and safety (e.g., all messages are handled, the protocol is unambiguous). It contains no loops and is completed in a constant number of rounds. All messages are sent from one role to another (either from host to respondent or vice versa) and the messages are unambiguous regarding the next step. Both roles proceed towards termination states, either when an activity has been scheduled, when a respondent cannot suggest any suitable times, or all parties cannot agree on options to negotiate about.

The agents’ decisions and strategies are determined by utility functions. A prototype of the interaction has been developed in Python, in order to experiment with parameters and choice sets.

5. CONCLUSIONS AND FURTHER WORK

This paper has outlined a framework and design for modelling the effects of social networks on travel behaviour. We show how this fits within the agent-based modelling paradigm. Due to the current interest in predicting social activities and the changing nature of social activities due to our use of ICT, this type of model is of increasing importance to planners who need to be able to predict social activities and travel.

Several existing transport models that incorporate social networks were described and related to our framework, however all are preliminary and concentrate on only one or two on the key concepts we have identified. The use of agent-based modelling appears to be a sensible approach for this model.

Many AOSE methodologies have been developed, but none specifically for agent-based modelling. We have combined features of several mature methodologies to produce a design. The design successfully caters for the description of the environment, the nature of activities, and the dynamics of individuals and their networks.

We also describe joint decision processes for scheduling social activities with many participants. Our use of interaction theory and processes is a novel way of realistically modelling social interactions involved in scheduling activities. We show that the protocols satisfy some basic properties, including termination, safety and liveness.

A model using this framework is currently being implemented in Java, and will be validated using an extensive dataset of people's activity participation and personal networks, collected in Eindhoven, Netherlands. Future work includes more empirical experimentation with the protocols and implementation of, and experimentation with, the entire model.

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