ABSTRACT

This paper presents an overview of the research of the module Mobility and Transportation, one out of nine modules of the Future Cities Laboratory (FCL), the first interdisciplinary research group of the Singapore-ETH Center for Global Environmental Sustainability (SEC). The aim of the module is to advance research into the complexity of land transport, which derives from the demands of managing, planning and optimising the flow of people and goods at different time scales and in its interaction with all elements of the future city.

KEYWORDS

Medium and Long term modelling, activity-based transport demand modelling, MATSim

1. INTRODUCTION

This century will, for the first time, see over half the world’s population living in cities (UN, 2007). Making these urban structures environmentally, economically and socially sustainable and liveable is one of today’s great challenges. Due to the central importance of cities’ infrastructure and performance, one key element to meet this challenge is transportation infrastructure. Embedded in the Singapore National Research Foundation’s initiative Campus for Excellence and Technological Enterprise (CREATE) and with the objective to advance research into the complexity of land transport, the research outlined in this article addresses this challenge. The research is one of the nine modules of the Future Cities Laboratory, the first research programme of the Singapore-ETH Centre for Global Environmental Sustainability (SEC). The research is performed in close collaboration with the other FCL modules, the ETH Institute of Transport Planning and Systems based in Zurich and the Interdisciplinary Research Groups of the SMART MIT Future Mobility and TUM CREATE initiatives based in Singapore.

Figure 1. Research Framework

The goals of this research is to derive tools to manage, plan and optimise the flows of people and
goods at different time scales and in their interactions with all elements of the future city. The project has two perspectives: medium- and long-term (Figure 1). The medium term refers to the change across all degrees of freedom of the system (population, infrastructure, land use, regulation and pricing), but still taking the given situation as the starting point. The long-term processes over time make it possible to consider the changes required to achieve overarching policy goals and to account for their benefits and costs. Both perspectives will be developed in an integrated manner based on the same software framework and are presented in the following sections.

2. RESEARCH FRAMEWORK

2.1 Basis: Large-Scale, Multi-Agent, Activity-Based Transport Demand Model

The research framework is provided by the multi-agent-based travel demand simulation MATSim (MATSIM-T, 2011). Open-source MATSim is one of a group of agent-based models that have recently been developed to realise the potential of the activity-based approach in practice. In line with the activity-based approach (Jones et al., 1983), MATSim is based on the idea of the 24 hour daily activity schedule as the basic behavioural unit. In contrast to most other current agent-based models it fully integrates traffic flow simulation to calculate the generalised costs of travel implied by the schedule. In addition, MATSim is designed for speed and scale, which allows it to address large-scale and finely detailed scenarios. For example, the Switzerland implementation has 7.5 million agents, 1.0 million links and 1.0 million destinations (Figure 2), and is still able to find a steady state solution within acceptable computing time (Balmer et al., 2010). Besides Switzerland, MATSim has been successfully implemented in Toronto, Berlin and Tel-Aviv.

The research will be based on a calibrated and validated version of the multi-agent-based travel demand simulation MATSim for Singapore. This model will provide the simulation environment needed for both the medium-term and the long-term developments.

2.2 Medium Term

2.2.1 Weekly Activity Scheduling

Current activity-based models are generally one-day equilibrium-based models. This one-day restriction is becoming increasingly problematic, as many policies aim to reshape demand across longer time horizons; taking peak-spreading beyond a single day. Furthermore, it has been long recognised that this time horizon is too short, as at least a weekly rhythm is natural for the choices of many recurring activities.

One aim to overcome this constraint is to reformulate MATSim so that it can be run open-ended. This redesign has to consider factors such as the rhythms of the year, the rhythms of major events, the business cycle and long-term changes in the population and in the facilities (See below for the work on the agents and modules addressing the choices implied here).

The key design decision will be the choice of the learning mechanism with which the agents adapt their behaviour to the patterns they experience. While MATSim+ will not impose the strict maximiser implied by (stochastic) user equilibrium, it will still assume that the agents want to improve their daily experience.

Based on the idea of an ‘activity calendar’ of desired, but not yet undertaken activities, the project will develop an approach to schedule these activities over the course of a week (Axhausen, 2006). It will integrate the idea of a committed core schedule around which the travellers build their week. It will not adopt a fully continuous view of activity generation as arising out of an understanding of incremental need build-up. Still, the model will be rewritten to enable such an open architecture. This path-dependent MATSim will combine the weekly horizon with the ability to be integrated in the
longer-term considerations of a year and their development over time. The new processes to be added in the next element of the project will therefore have a suitable environment in which to age, move house, change jobs, etc.

2.2.2 Simulation Based Optimisation

In terms of transport demand management, an integration of an optimisation approach for ERP will be developed, which will be based on the information available from the simulation. In contrast to the agents added for the long-term horizon, this optimiser will have a definite time horizon of one day. Furthermore, and again based on information of the transport simulation, research on the optimisation of bus network design and operation will be conducted.

2.2.2.1 Optimising Traffic and Transport Demand Management Strategies

The derivation and evaluation of traffic and transport demand management strategies for urban road networks typically relies on the use of microscopic simulation tools that capture in detail the behaviour of drivers as well as their interaction with the network infrastructure.

Unfortunately, this degree of detail and realism comes at the cost of non-linear objective functions with no available closed form and potentially containing several local minima. To integrate these non-linear, stochastic and evaluation-expensive simulation models within an optimisation framework is a difficult and intricate task. In order to perform both fast and reliable simulation optimisation for congested networks, information from the simulation tool should be combined with information from a network model that analytically captures the structure of the underlying problem. The objective of this subproject is to derive efficient simulation-based optimisation methods for traffic and transport demand management.

New simulation-based optimisation algorithms for the generation of road pricing strategies and speed control will be developed, implemented, and tested. The algorithms are designed for offline operations on medium time scales. This work is likely to consist of the further development of research previously conducted at EPFL (Osorio, 2010) and TU Berlin (Lämmel and Flötteröd, 2009). Interfaces of the realised algorithms to the simulation system are implemented and tested.

2.2.2.2 Optimising Bus Systems

The optimisation of bus networks and its operation is a highly complex, multi-attribute problem. Besides dynamic demand it features a range of variables such as number and location of the bus stop, bus routes, service frequency, availability of bus lanes, integration with other modes of public transport and even fare collection method. Due to the complexity of the system, the problem will be decomposed into subproblems but all results will be evaluated based on the MATSim framework.

The network design problem will be based on earlier work by Daganzo (2010) which describe the network shapes and operating characteristics that allow an efficient transit system and by Fletterman (2008) which applies metaheuristics for network design. Special attention will be paid on the impact of separate bus lanes (Daganzo, 2006). Based on those pieces research, the city of Barcelona reorganised its bus network (Institute of Transportation Studies (ITS), 2010). However, it has not yet been tested within a multi-agent transport demand model, which allows further refinement of the approach.

In terms of bus operations, the research will build on earlier work proposing an adaptive control scheme to mitigate the problem of bus bunching (Daganzo, 2008). The MATSim simulation allows for integration of the proposed scheme which dynamically determines bus holding times at control points based on simulation-based, real-time headway information. Finally, the findings of Tirachini and Hensher (2011) on the influence of fare collection systems and optimal infrastructure investments will be incorporated and applied to the Singapore scenario.
2.3 Long Term

The urban system is constantly evolving. It is changing at different speeds and scales. Endogenous and exogenous agents and forces accelerate or delay these changes. Current urban land use and transport models focus their attention on the impact of accessibility changes arising from shifts, reductions or increases in the general transport cost surface. They do so by employing spatial aggregates or zones as their reference system. They assume many atomistic actors, who interact freely in an open land and housing market. So far, the first characteristic has been the result of data availability considerations and not of theoretical desirability. The second assumption reflects both American and European conditions, but is clearly untenable for other places such as China or Singapore, where land availability, land use and household capital availability are jointly regulated by the government. In Singapore, for example, the government controls land use, a vast share of the property market and pensions through instruments, such as government land sales, Housing and Development Board (HDB) or Central Provident Fund (CPF) and their various rules and regulations (Phang, 2001).

The microscopic adaptations of the residents and firms on exogenous planning scenarios will be the centre of the work the long-term part of the project, as they are generic in their methodology and transferable to other locations. The research is organised based on three main pillars (Figure 4), namely object fine location choice, service provider agents and social network geographies. The forecasting procedure is based on steps of one year. For each year, information on exogenous factors such as new property developments is feed in the loop whereupon the different agents react. Based on their reactions, a new state for year n+1 is computed which serves as basis for the next loop run.

![Figure 3. Overview of (L)ong Term Framework](image1)

![Figure 4. Residential locations of the respondents (Zurich only) and acquaintances as reported in Frei and Axhausen (2011b)](image2)

2.3.1 Advanced Location Choice Model

Current software systems such as MATSim and UrbanSim (UrbanSim, 2011), but the others as well, are moving from an aggregate description of the land use system to a parcel-based one. This has the advantage that all agents in the simulation correspond to individual entities: residents, their households and residences, firms and their branches, institutions and their locations, the associated vehicle fleets, transport firms and their services. This consistency in model resolution is not matched yet in some of the behavioural models, most importantly, residential location choice, activity location choice, location choice of firms and institutions.

The current choice models cannot fully characterise the individual alternatives, as central variables are missing. The construction of the very large choice sets is still computationally very expensive and therefore often not properly addressed. Previous work has served to highlight the shortcomings and
issues, but has not yet integrated the proposed solutions into a working system, which is the only way to verify if the parts work together or if other solutions have to be found.

The description of the alternatives will include the usual variables: attributes of the apartment, accessibility etc. for the case of residential location choice, and generalised cost elements for the given schedule (including parking variables), store size brand name, etc. for the activity and firm location choice. However, to address the issues of choice set size but also to take advantage of new available data sources, the description of the alternatives will have to be enriched by further elements such as capacity effects, quality of service, price levels, target markets and brand visibility.

A further strategy to control the size and actual relevance of the choice set will be based on existing approaches (Horni et al. (2009) and Scott (2006), to incorporate the time-space constraints of the schedules (Hägerstrand, 1970). Those approaches have improved the performance of the choice models. However, since they still lack a coherent way to estimate the appropriate endogenous size of the time-space prisms, the research will particularly focus on this problem.

The incorporation of social networks and analysis of its impact to location choice problems is a further aspect of the research and described in section 2.3.3.2.

2.3.2 Service Provider Agents

The agent-based models mentioned above do not model the choices of the suppliers of these services, so-called service provider agents i.e., retailers, car sharing companies, restaurant chains, banks, etc. For a long-term model of land use and transport at the parcel level it is not possible to ignore the moves of the firms in response to transport and land use policies.

The design of the agents will be developed based on a review of the existing literature about the strategies of the service providers, so that the scope of the capabilities is both realistic and appropriate. In case of retailers, the project can draw on initial work undertaken at ETH, where detailed interviews of retailers (Löchl, 2010) were undertaken (Arentze and Timmermans, 2007). The design phase will specify the internal model of agents, which will be used to adapt their network of locations, capacities and service/pricing levels. While formal optimisation techniques are a possibility, the preferred approach at this time is a guided adaptation (Ciari et al., 2008).

In addition to the literature review, the design phase needs to be complemented with local information. A series of qualitative interviews will be undertaken with service providers in the industries of interest. The interview results will detail the software design and provide initial estimates for the necessary parameters (e.g., minimum store sizes, minimum-maximum catchment areas, investment costs, labour pool preferences, etc.).

The software design of the service provider agent will be rather generic so that the concept can also be adapted for the medium term model. In that spirit, agents will be implemented to manage and optimize for example the taxi fleet. Following on the design phase, the agents will be implemented and tested in isolation to see that the code performs as designed. The capabilities will include the definition of chains, the addition and removal of locations, choice of service and price levels for each location of a chain. Once the software runs stable and delivers meaningful results, a joint test will be performed in order to understand the interactions better and various future scenarios will be tested.

2.3.3 Social Networks

As pointed out above, the second element missing for a destination choice at the parcel level is the understanding of the social network structures influencing these choices. In this context an original
survey will be undertaken in Singapore to capture the structure of local social networks and investigate the impact of social networks in joint decision-making.

The survey will feature a name generator as this methodology has a long history in sociology (Marsden, 1990). However, so far the geographic spread of the contacts has normally been omitted or downplayed (Frei and Axhausen, 2007) in such surveys. Recent work in transportation has three directions (Mok and Wellman (2007), Carrasco (2006), Frei and Axhausen (2011b)): building models of the dynamics of social networks, generating spatially distributed social networks in agent-based simulations and, finally, capturing the geography of the social networks (Figure 5). While Axhausen et al. (2006) had focussed on the interaction with the mobility biography, the survey planned here will combine the capture of the social network with the network of links and preferences to particular places and brands. Most work so far has centred the social networks on the contacts, which are relevant for joint leisure, but has omitted the fact that people also have attachments to particular places and firms.

The survey will be conducted as an ego-centric survey of contacts with whom the respondents spend their leisure time and fulfil the priority of obtaining a general and broad understanding of the network geographies. Special care will be taken to involve both citizens and foreign residents to get as complete an overview as possible.

The survey will give insights, as discussed above, in the number and geography of social networks of the Singapore residents and of the frequency of their interactions. The use of ‘clique’, an item tested in the current work at ETH Zurich (Kowald and Axhausen, 2010), will allow us to characterise the internal structure of the networks in a first approximation. The information about the place and firm attachments complements the social geography. Information about the mobility biography will place the current situation into the biographical context of the respondents.

The survey results will allow to do two things: a) Generalise the social networks to the population as a whole (Arentze and Timmermans (2006), Hackney and Marchal (2008), Frei and Axhausen (2011b), Arentze, Kowald and Axhausen, 2011) by linking the agents via a probabilistic model and b) establish new model structures to capture joint decision-making in destination choice (Frei and Axhausen, 2011a).

Based on the substantial literature on joint household decision-making in transport (see Zhang et al. (2007) for an overview) and on-going work within the SustainCity project (SustainCity, 2011), suitable model structures will be developed to capture the joint choice of locations within social networks, in particular, for leisure activities. The challenge will be to integrate this within the MATSim approach of modelling the whole daily schedule. The interaction of the joint choice on the then partially coordinated schedules will be the focus of the work. It is open at this point whether the most productive path will be a joint optimisation/satisfaction approach or an explicit discrete choice model. Both options will have to be explored and tested.

3. KEY IMPACTS AND OUTLOOK

The integration of the two time horizons, medium and long, is a significant methodological innovation that will enable a global analysis of complex issues related to mobility in the future, as the various modules of the system can be integrated as the issue concerned requires. Hence, this framework allows large-scale policy tests for various temporal dimensions. However, the system will be first explicitly tested for stability of the simulation results, multiple equilibria and heterogeneous demand- and supply-side agents.

From a medium-term horizon, the generalised costs of moving persons, goods and information can be derived from the new framework. Policymaking is interested in lowering these generalised costs of
movement as these induce more efficient labour and goods markets. Policymaking also requires a
detailed account of the winners and losers of any change in the supply, regulation and costs of
transport infrastructure and services. The proposed framework targets in this direction and allows, due
to the highly disaggregated approach, detailed analysis of winner and losers of changes, either in
infrastructure or policy.

For policymaking over time horizons of several years, an account of the daily flows and the form and
structure of the urban environment is needed. The development of a spatially detailed, path-oriented,
land-use aware transport model for Singapore will provide new insight into the possible risks and
benefits of different policies.

The project will publish its results through appropriate working papers on the Future Cities
Laboratory website (www.futurecities.ethz.ch), peer-reviewed journals, and supplement this with
papers and presentations at peer-reviewed as well as professional conferences. The code written will
be licensed as GNU public licence and where appropriate, it will become part of the then current
MATSim release.

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