SMART – Future Urban Mobility

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Abstract
This paper presents an overview of the Future Urban Mobility programme of the Singapore-MIT Alliance for Research and Technology (SMART). Through this programme, MIT is establishing a research centre in Singapore with the mission to support sustainability and improve transportation system performance through innovations in infrastructure, technology, operations and policy.

Two key areas of research are discussed in more detail. The first is Networked Computing and Control, which utilises personal mobile computing and communication devices to provide high quality information about the state of the transportation network to users and system managers, functioning as data collectors and computing engines. The second is the development and evaluation of future scenarios through a new comprehensive urban mobility simulation system, known as SimMobility.

Introduction
The confluence of several fundamental developments presents significant opportunities for new research in urban mobility. These developments include: advances in computing, communications and sensing technologies; the growing awareness of environmental sustainability issues; the ageing of physical infrastructure in developed countries and the need for massive new infrastructure projects in less developed ones; and the recognition of the vast economic stimulus that can be generated by the modernisation and renewal of urban mobility systems worldwide.

The goal of the SMART (Singapore-MIT Alliance for Research and Technology) Future Urban Mobility Interdisciplinary Research Group (FM-IRG) is to develop a new paradigm for the planning, design and operation of future urban mobility systems. This new research centre is based on the premise that the advances in computing, communications and sensing technologies provide powerful capabilities to model, evaluate, realise and optimise next-generation urban mobility systems.

The FM-IRG, launched on 1 July 2010, is a five-year research programme with 10 MIT principal investigators. This paper discusses two areas that represent a subset of FM-IRG’s research: Networked Computing and Control (NCC) and its application to real-time traffic management; and SimMobility, the new comprehensive modelling platform for future scenario development and evaluation.
FM-IRG Overview

FM-IRG is a multidisciplinary centre structured around three pillars:

- Pillar 1: Networked computing and control (NCC) will enable next-generation urban mobility systems using technologies such as mobile mesh networking, mobile distributed computing, real-time data fusion and visualisation, and on-board automation.

- Pillar 2: Integrated modelling of mobility, land-use, environmental, and energy-use impacts will develop a suite of powerful demand estimation, performance prediction and optimisation tools, drawing on the availability of NCC-enabled information.

- Pillar 3: Performance assessment and implementation systems will enable meaningful evaluation of alternative mobility systems and the development of institutional, regulatory, and pricing mechanisms to support them.

Integration of the varied disciplines and facets of urban transportation and the urban environment are at the core of the approach. The main axiom for this integrated approach is the premise that urban demands, such as energy consumption and transportation flows, are derived from human needs. Hence, a behavioural model of human activities is pivotal to this approach. To test the impact of different policies or investments accurately, a model is framed that simulates individual behaviour (within the constructs of households and firms) in connection with the associated mobility and energy consumption patterns. The model predicts the impact of these patterns over the entire population to generate the overall effect of the tested policy and/or investment. Once a model run is completed, several indicators can be extracted from the model output to evaluate the tested policy and/or investment. This methodology captures the relationship between transportation and energy in a way that would be abstracted by traditional macro-level models. Furthermore, it permits the identification of the role of each specific variable on the aggregate results, thereby allowing the model to serve as a decision support tool for urban planners and policy makers.

The heart of the FM approach will be SimMobility, a simulation platform with an integrated model of human and commercial activities, land use, transportation, environmental impacts, and energy use. This modelling engine will be linked with a range of networked computing and control (NCC) technology-enabled mobility innovations, and with operations research-based decision models. This will allow FM-IRG to analyse the impacts of various novel concepts, including real-time information and management systems, and innovative mobility services such as...
“mobility-on-demand” and “green logistics”. We will link the behavioural models with state-of-the-art simulators to predict the impacts of mobility demands on transportation networks and services and on vehicular emissions. Similarly, land use models predict the evolution of urban real estate markets. These models also provide inputs to energy/material consumption models. Several challenges are evident, including the integration of heterogeneous populations of agents based on highly diverse data sources on households and firms, their activities, trips, real-estate and equipment purchases and energy consumption, and the design and application of methodologies to validate model performance. Integration will allow us to simulate the effects of a portfolio of technology, policy and investment options under alternative future scenarios.

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The SimMobility platform will be employed to derive and apply new evaluation frameworks for sustainable mobility; to evaluate and expand innovative portfolios of future urban mobility options; to develop and apply advanced scenario planning techniques to account for future uncertainties; to design and experiment with alternative institutional configurations and alternative physical urban designs enabled by NCC innovations; and to identify paths for “exporting”/“adapting” the Singapore FM model.

**Networked Computing and Control (NCC)**

The increased prevalence of smart phones, wireless connectivity and multiple sensors opens up new avenues of research and development. Personal mobile computing and communication devices can provide high quality information about the state of the transportation network to users and system managers by serving as data collectors and information providers. Coupled with other mobile devices, a resilient internet “cloud” can be formed to provide real-time information in a consistent and comprehensive manner.

The FM-IRG is working to build a framework to facilitate the creation and evolution of mesh networks (i.e. self-configuring networks of mobile devices connected by wireless links) that would connect mobile devices to each other and to the internet. Once built, these networks could be connected to enhance traffic and transit management, transportation planning, emergency management, and emergent applications. The information, however, will be massive, heterogeneous, and must be collected in an efficient and secure manner. The first challenge of this research is the data fusion required. The second challenge is the development of algorithms to use the real-time sensory information to plan, allocate, control, maintain and secure a complex urban transportation system. Fundamental questions include: how to best develop robust methods for transportation system management that
yield the desired global state and how to properly manage travel demand in the event of a natural or a man-made hazard? These are not purely technical questions; they require an understanding of behavioural choices and policy impacts.

**Real-time traffic and transit management system**

The purpose of a real-time system is to reconcile information from a variety of sources to generate predictions of the future system state. This prediction can then be used to produce information for travellers, such as, alternative mode or routes, travel time, etc. The reactions of travellers and traffic/transit managers to the prediction will have an effect on the future state of the network. The changes in the state of the network are reflected in the next set of measurements collected by the surveillance system. The real-time system is then recalibrated based on the new data and generates a new prediction (Ben-Akiva et al. 2002). Figure 1 shows the cycle of information dissemination, control, data collection and prediction.

The reaction to the predicted information disseminated from the real-time model presents a key challenge to the generation of such information. A non-represented reaction that influences the future state of the transportation network would invalidate the prediction of the model. Therefore, to be consistent, the real-time model needs to anticipate the reaction to the generated information through behavioural models. The point of convergence in this model would be where the real-time information generated matches the predicted network conditions (Figure 2). The consistent anticipatory information generated by the real-time model would be more reliable than the results of statistical models based on historical data (Bottom 2000). The following section introduces an example of a real-time traffic management system, DynaMIT.

**Real-time system: DynaMIT**

The Intelligent Transportation Systems (ITS) laboratory at MIT has developed a real-time traffic management software called DynaMIT (Dynamic Network Assignment for the Management of Information to Travelers).
DynaMIT generates consistent anticipatory information on the future state of a transportation network, as described above. To do so, DynaMIT includes, along with the typical supply model of network characteristics (links, transit network, operational characteristics of these services), a behavioural model of the travellers’ sensitivity to information.

The operation of DynaMIT is demonstrated in Figure 3, which displays the link-level network status and a timeline showing the calibration and prediction intervals. On the timeline at the bottom of Figure 3, the green interval is the calibration interval. Using the available real-time data for this interval, model outputs are calibrated to represent what has already happened on the network. The red interval is the prediction interval for which consistent anticipatory information is generated by simulating the network and anticipating behavioural reactions to network state and information. As the model runs, this time line moves forward, more data are collected from sensors in the network, the models are recalibrated and predictions are updated.

DynaMIT has been tested in several areas in the US and Europe. The next generation of DynaMIT will be developed and tested in Singapore through the FM-IRG. Among other enhancements, DynaMIT 2.0 will represent transit network performance so that consistent anticipatory information can be provided for multi-modal trips (Milkovits et al. 2010).

**Future Scenarios**

The second area of research is focused on the evaluation of future scenarios.

There are significant uncertainties surrounding the factors impacting urban transportation. These include the future of technology, the urban environment, security, energy prices, etc. Sampling from the distribution of uncertainties will create future scenarios. To reflect the complex challenges and responses of urban transportation and capture the interdependence of the factors, each future scenario will include several changes in the factors influencing urban transportation as well as new developments in NCC technologies. The scenarios can then be evaluated individually against multiple innovation portfolios. The bundle of options in each portfolio will include innovations in infrastructure investments, technological developments, as well as policy and management measures. Furthermore, a new evaluation framework is necessary to assess and rank each portfolio according to metrics of sustainable mobility and subjective well-being.
Integrated Simulation Platform – SimMobility

In order to explore and evaluate complicated future scenarios, we need to conduct experiments. Physical experiments can be conducted in order to understand how the different options work together on a small scale. For the entire urban area, however, a simulation model is the only viable option. SimMobility will integrate and link various mobility-sensitive simulation models to evaluate future urban transportation scenarios. It is designed according to the following principles:

- **Comprehensive**: to represent all options and potential reactions of the scenario portfolios
- **Modular**: to facilitate development and testing
- **Open source**: to provide a tool for the greater research community

SimMobility must include all the relevant decisions that people make in their everyday life that affect their well-being as well as their transportation demands. These decisions may be personal decisions of households or the commercial decisions of firms (Ben-Akiva et al. 1996). To support this level of representation, SimMobility is based on the concept of agent-based or micro-simulation. Representation of individuals as agents in the model is necessary to simulate how people will react in the future to new infrastructures, new technologies, innovations in system management and policy changes.

The decision process of the agents will be modelled by an activity-based approach. Activity-based modelling focuses not just on trips but also, and more importantly, on the activities that drive the demand for travel. Activities are in turn conducted to maintain or enhance subjective well-being (Abou-Zeid and Ben-Akiva 2010). Therefore, the model needs to represent what each agent does in their daily life, the activities they participate in, their well-being, and the impact on the transportation system (Ben-Akiva and Bowman 2001).

**Framework**

SimMobility is designed as three primary modules segmented according to timeframe. Figure 4 shows the timeframes in which we consider the behaviour of an urban system: long-term (year to year), medium-term (day to day), short-term (minute to minute). The short-term model is at the operational level; the medium term handles transportation demand; and the long-term model captures land use and economic activity.
In previous work, these models have not been fully integrated. While there is limited interaction of outputs, there is no internal coherence. SimMobility is unique in that the same pool of agents is used across all timeframes. Thus, these agents have a long-term behaviour already established when their behaviour is modelled in the medium-term simulation. This is the essence of the

**Figure 4: SimMobility Framework**

- Long Term
  - Agent characteristics
  - Demand for goods
  - Locations of HH/firms
  - Equipment of ownership
  - Accessibility

- Medium Term
  - Activity schedules
  - Performance parameters, e.g., capacities

- Short Term

**Figure 5: Examples of simulation models at different timeframes**

**Long-Term Model**

UrbanSim: Lisbon, Portugal

Evaluation of housing/employment location given zoning, transportation network and economic/population inputs

(Guevara-Cue 2010)

**Medium-Term Model**

DynaMIT-P: Beijing, China

Evaluation of network performance under congestion mitigation strategies

(Ben-Akiva et al. 2011)

**Short-Term Model**

MITSIMLab: London, United Kingdom

Assess the impacts of intervention on the network capacity

(Choudhury et al. 2009)
FM integration; the platform will integrate different types of modelling into a coherent agent-based micro-simulation.

*Figure 5* shows examples of previous work at the MIT ITS Lab for each of the timeframes. The simulators described have been applied and must be integrated in the SimMobility platform.

**Collaboration**

We are currently establishing relationships with local collaborators in Singapore. Government agencies, such as the LTA and the Urban Redevelopment Authority, are important supporters of this research. Other collaborators include Singaporean universities, including National University of Singapore (NUS) and Nanyang Technological University (NTU), to bring together professors and students who will participate in the FM research jointly with MIT researchers.

**Conclusion**

I introduced the MIT-Singapore FM-IRG and described two areas of research: NCC technology development and its application to systems like DynaMIT; and the development of future scenarios influenced by portfolios of future technologies and policy and their analyses using SimMobility. My colleagues and I are excited about the research that we will be doing during the next five years that we believe will lead to significant innovations in urban transportation.

**References**


Moshe E. Ben-Akiva is Edmund K. Turner Professor at the Department of Civil and Environmental Engineering of Massachusetts Institute of Technology (MIT), USA. He has co-authored two books, including the textbook *Discrete Choice Analysis*, published by MIT Press, and over 200 papers in refereed journals and conference proceedings. He also co-edited the book *Recent Developments in Transport Modeling: Lessons for the Freight Sector* published by Emerald. He directs the Intelligent Transportation Systems (ITS) Lab where two traffic simulators have been developed under his supervision: MITSIMLab, an open-source microscopic simulator; and DynaMIT, a mesoscopic simulator – which includes algorithms for dynamic traffic assignment, traffic predictions and route guidance. Professor Ben-Akiva has received honorary degrees from the University of the Aegean, the University of Antwerp, the Université Lumière Lyon and the Stockholm Royal Institute of Technology (KTH).