Nov 4-5, 2013

Workshop on Day-to-Day Dynamical System Approach for Modeling Transportation Systems

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香港科技大學
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

HKSTS
香港交通研究學會

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Preamble

The dynamical system approach to modeling transportation systems has been around for at least two decades. But by far, the notion of equilibrium has been driving the majority of transportation analysis. Equilibrium analysis has its appeal, relatively simple and can be described by a set of well-defined mathematical expressions. Recently, there has been resurgence in the interest of developing a deeper understanding of the dynamical system approach for modeling transportation systems, perhaps motivated by studies that question the existence of equilibrium, its uniqueness, stability, and attraction domains, whereas others argue that understanding the process or trajectory toward equilibrium is just as important as it involves understanding the learning process and behavioral adaptations, and such an understanding is instrumental for transportation management. It suffices to say that many aspects simply cannot be answered by traditional equilibrium analysis.

This workshop is intended to be small, focusing on developing a deeper understanding of what we already know, or the current status, and what the emerging questions are in order to move this approach forward, or the future directions. The workshop is planned such that participants have plenty of time to interact and engage in in-depth discussions. The Organizing Committee includes Professors Giulio Cantarella, Martin Hazelton, Hong Lo, Mike Smith, and David Watling. Each speaker will preside on a topic relevant to his work, provide a review of past works, and present critical issues for future works, and invite other speakers to complement the discussion. The end result we hope is to formulate a proposal for the Croucher Foundation Advanced Study Institutes to expand the audience and widen the discussion topics to move this approach forward.

Organizing Committee
Giulio Cantarella
Martin Hazelton
Hong Lo (Chair)
Mike Smith
David Watling

Session Schedule

November 4, 2013 (Monday)

Venue: 4/F Seminar Room (Rm 4042), Institute for Advanced Study, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST

	Preparation
09:00 – 09:30	Preparation

09:30 – 10:00	Coffee and Refreshment

	Session A: Dynamical models with deterministic processes *Session Chair: Prof. Giulio E. CANTARELLA*
10:00 – 12:00	**Stability Analysis of Equilibrium Patterns in a Transportation Network** Giulio E. Cantarella **Physics of Network Flow Dynamics** Feng Xiao, Hai Yang, and Hongbo Ye

12:00 – 14:00	Lunch

	Session B: Dynamical models with stochastic processes *Session Chair: Prof. David WATLING*
14:00 – 16:00	**The Stochastic Process Approach to Transportation Systems** David Watling **Point queue models for a network of signalized intersections** Pravin Varaiya

16:00 – 16:20	Coffee Break

	Session C: Calibration and data issues for day to day dynamic models *Session Chair: Prof. Martin HAZELTON*
16:20 – 18:20	**An Overview of Statistical Inference for Day-to-Day Dynamic Traffic Models** Martin Hazelton **Understanding the Day-to-Day Traffic Evolution Process after the I-35W Bridge Collapse in Minnesota** Henry Liu

18:30 – 20:30	Workshop Dinner

November 5, 2013 (Tuesday)

Venue: 4/F Seminar Room (Rm 4042), Institute for Advanced Study, Lo Ka Chung Building, Lee Shau Kee Campus, HKUST

09:00 – 09:30	Coffee and Refreshment

	Session D: Dynamical interaction between traffic control and route (mode) choice *Session Chair: Prof. Mike SMITH*
9:30 – 12:00	**From Day to Day Models to Models Which Design Good Signal Timings** Mike Smith **Day-to-day Flow Dynamics and Congestion Control** Ren-Yong Guo, Hai Yang, Hai-Jun Huang, and Zhijia Tan **Signal Setting with Assignment Constraints: Equilibrium vs. Deterministic Process Approaches** Giulio E. Cantarella

12:00 – 14:00	Lunch

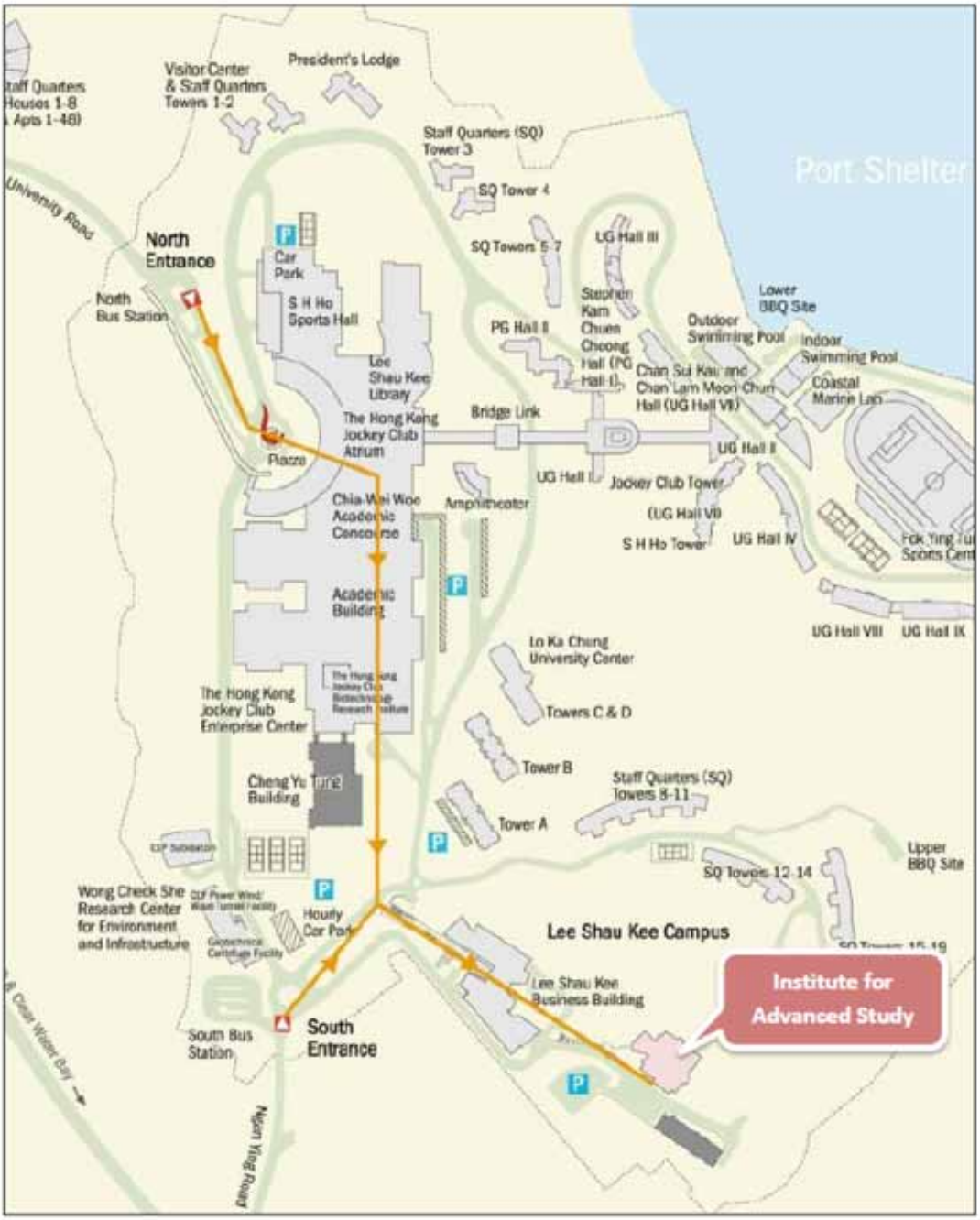
	Session E: Dynamical interaction between travel choice adjustment and information sharing *Session Chair: Prof. Hong K. LO*
14:00 – 16:00	**Influence of Social Network on Travel Choices** Hong K. Lo, Yu Xiao **Information transmission through a social network and its effect on discrete choice behaviour - some experimental / empirical trials** Takamasa Iryo

16:00 – 16:20	Coffee Break

16:20 – 18:20	ASI Workshop proposal preparation

18:30 – 20:30	Workshop Dinner

Walking Routes from Bus Stations to Institute for Advanced Study



Stability Analysis of Equilibrium Patterns in a Transportation Network

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Abstract

A general deterministic process models is described, for carrying out an equilibrium stability analysis, concerning both identification of attractors different from fixed-points and of bifurcations. Main goal of this paper is to show that stability of equilibrium cannot be given for granted, in other words the equilibrium approach to demand assignment may fail to describe the state of the system relevant to analysis and design.

Keywords: Stability analysis, Day-to-Day Dynamics

Physics of Network Flow Dynamics

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Abstract
This paper offers a new look at the network flow dynamics from the viewpoint of physics by demonstrating that the traffic system, in terms of the aggregate effects of human behaviors, may exhibit like a physical system. Specifically we look into the day-to-day evolution process of network flows that arise from travelers' learning behavior on perceived travel costs and route choices. We show that the flow dynamics can be characterized via a set of second-order non-homogeneous ordinary differential equations (ODEs) that is analogous to the damped oscillatory system in classical physics. The concept of energy, including the potential energy and kinetic energy, is introduced to analyze the system behavior. The potential energy, stored in each link, increases with the traffic flow on that link; the kinetic energy, generated by travelers' day-to-day route swapping, is proportional to the square of the path flow changing speed. The potential energy and kinetic energy are converted to each other throughout the dynamical process, and the total system energy keeps decreasing owing to the travelers' swapping behavior, which is analogous to the damping of a physical system. Finally the system will approach the static state with the minimum total potential energy and zero kinetic energy. We establish the stability of the flow dynamical system and provide numerical experiments to elucidate our interesting findings.

Keywords: Hysteresis, Network flow dynamics, Potential energy, Kinetic Energy

The Stochastic Process Approach to Transportation Systems: What is it, what do we know about it, what kinds of models can it encompass, and what are the limits of the phenomena it can represent?

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Abstract

The presentation builds on a recent paper, presented at DTA2012 and now published online (Watling & Cantarella 2013: http://link.springer.com/article/10.1007%2Fs11067-013-9198-2), which aimed at introducing the Stochastic Process approach in a way that was friendly to transport audiences, who are probably more familiar with deterministic things (this is also a tactful way of saying that a number of transportation papers, when mentioning this approach, have mistakenly described it). But also it was intended to show that it can be a unified way of representing many kinds of concept that are familiar in the transport networks arena, from simulation to RUM, DTA and even some more unusual models. One referee of this paper suggested that it was aiming to set out a 'complete protocol for transportation systems modelling', which is somewhat more ambitious than we had intended. On the other hand we did open up the question of how this approach could go in the respect of more widely representing other dimensions of transportation systems (e.g. land-use/transport interactions evolving over years?), as well as other phenomena which we see in real-life but often do not represent (e.g. economic recession, the 'Arab spring', …). The presentation will draw on the cited paper to give examples and discuss future directions.

*Draws heavily on work with Giulio Cantarella, but he is not responsible for any of the remarks above!

Point queue models for a network of signalized intersections

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Abstract
The evolution of traffic in a signalized road network is modeled as a network of queues, whose state is the vector of all queue lengths at all intersections. The signal control at any time permits certain simultaneous turn movements at each intersection at pre-specified saturation rates. Miller (1963) studies the queue for one approach at a single intersection modeled as

$$x(t+1) = x(t) - c(t) \wedge x(t) + d(t). \qquad (1)$$

Here $x(t)$ is the queue length at the beginning of period t, $c(t)$ is the number of vehicles that can potentially depart in period t when the signal is actuated, and $d(t)$ is the demand in period t. $c(t)$ and $d(t)$ are iid (independent, identically distributed) random variables with mean c and d vehicles per period, respectively. $y \wedge z = \min\{y, z\}$. The system (1) is stable if the mean queue length is bounded. This is the case if $d < c$, that is, the mean demand is smaller than the service rate. Under this condition, Miller (1963) estimates the mean and variance of the queue length in equilibrium.

The single-queue model (1) extends to a network of signalized intersections. For every approach k at an intersection the queue length $x_k(t)$ evolves according to

$$x_k(t+1) = x_k(t) - C_k(t+1)S_k(t) \wedge x_k(t) + \sum_l a_{k,l}(t) + d_k(t+1) \qquad (2)$$

Here $S_k(t)$ = 1 or 0, accordingly as the intersection signal control permits or forbids movement of vehicles from queue $x_k(t)$, $C_k(t+1)$ is the random number of vehicles that could depart in period t if $S_k(t)$ = 1, $\sum_l a_{k,l}(t)$ is the sum over all arrivals from other intersections in the network, and $d_k(t+1)$ is the sum of all arrivals from outside the network. The stochastic process described by (2) is a controlled Markov chain. It has not been analyzed in the literature, even for a fixed-time control. (A noteworthy exception is the approximate equilibrium analysis of the network model in Osorio and Bierlaire (2009).) In particular, it seems not to be known whether, with stochastic arrivals and service, a particular fixed-time control will stabilize the network, i.e., all queues have bounded mean.

This model is useful for theoretical analysis, simulation, and designing signal control strategies with guar- anteed performance Varaiya (2013).

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P. Varaiya. Max pressure control of a network of signalized intersections. Transportation Research, Part C, 2013. http://dx.doi.org/10.1016/j.trc.2013.08.014.

An Overview of Statistical Inference for Day-to-Day Dynamic Traffic Models

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Abstract
Effective practical application of day-to-day traffic models will require good estimates of model parameters. A major challenge is that available observations on the traffic system may provide only indirect information for such estimation, particularly when it comes to parameters describing the processes by which travellers adjust their behaviour from day-to-day.

I will start this talk by providing a review of recent progress on inference for day-to-day models, with a particular focus on parameter estimation from link count data alone. A recent breakthrough means that for the first time, maximum likelihood and Bayesian methods of estimation can be implemented reliably using Markov chain Monte Carlo algorithms. Nevertheless, there is certainly a ceiling on what can be learned from link counts alone, motivating the need to study statistically principled methods of inference for combined data sources. I will speculate on how this might be achieved.

The final part of my talk will address model assessment. Specifically, I will discuss the scope for using day-to-day observations on a traffic system to test the adequacy of any given model, and ask whether day-to-day models that incorporate detailed representations of traveller behaviour can hope to avoid the cut of Occam's razor.

Understanding the Day-to-Day Traffic Evolution Process after the I-35W Bridge Collapse in Minnesota

Henry Liu
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Abstract

Understanding the traffic evolution process after an unexpected network disruption is of great significance to traffic engineers who are responsible for traffic restoration. In this talk, we will discuss our findings on the day-to-day traffic equilibration process following the unexpected collapse and eventual reopening of the I-35W Bridge over the Mississippi River in Minneapolis. Following the I-35W Bridge collapse, drivers were observed to drastically avoid areas near the disruption site until the perceived congestion in that area gradually diminished. After the reopening of the disrupted link, despite a complete restoration of network topology, it was found that total demand restoration on that link did not occur, implying that a different traffic equilibrium was reached. Due to the rare occurrence of the network disruption event, such behaviour has not been reported in the literature and none of the existing day-to-day traffic assignment models are capable of explaining the empirical evidences. To fill in this gap, we developed a nonlinear dynamical system that is capable of describing the transient states of a disrupted network, answering questions related to the traffic evolution trajectory from a disequilibrium (due to a network disruption) toward an equilibrium. Our models are calibrated and validated using the data collected from the Twin Cities network after the bridge collapse and reopening. To the best of our knowledge, this is the first time that day-to-day traffic equilibration models have been constructed and validated with real world observations.

From Day to Day Models to Models Which Design Good Signal Timings

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Abstract
This talk will consider very simple example networks aiming to illustrate the ideas clearly and will also indicate how things work "in general" (under certain conditions).

The talk will begin with the specification of reasonable route-swapping algorithms which to some degree might represent real life non-equilibrium behaviour of car drivers and travellers as they seek over time the best route for themselves. The route swapping algorithms will all be modifications of the proportional adjustment process (PAP) where the rate of swapping from a more expensive route 1 to a less expensive route 2 is proportional to the flow on route 1 and the difference in cost between the two routes. See Smith (1984) and He et al (2010).

The talk then considers the original PAP route-flow adjustments, but now within a model, and augments these route-flow adjustments by adding artificial bottleneck delay adjustments also following PAP. This "represents" the change in the bottleneck delay as queues grow and shrink in the model. These two adjustments are then augmented again by adding signal green-time adjustments which again follows the PAP swapping rule; applied now to stage green-times and using the control policy P0 to provide the green-time swapping incentive (see Smith 1979a, b).

The talk shows that in a quasi-dynamic environment and under natural conditions the simultaneous operation of all the above adjustments becomes a dynamical system which is convergent to a non-empty set of consistent [route-flow, bottleneck delay, stage green-time] equilibria.

Further, the talk shows that (again under suitable conditions) the signal timings arising at any such consistent equilibrium maximises the capacity of the quasi-dynamic network. (It will also be shown that the model may also be used to calculate suitable prices.)

Early ideas behind this talk are in Smith et al (1987) and Smith (1987).

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Day-to-day Flow Dynamics and Congestion Control

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Abstract

In this paper, we propose a price-based congestion control scheme for traffic flow that evolves from day to day to achieve a given set of targets. The planner predetermines a set of upper bound of link flows for traffic restraint and congestion control. On each day, the drivers have to pay a cost selected from a feasible set. The cost is determined by the link flows and payment costs on the previous day and the upper bound of link flows. Several properties of the dynamical system model with the control scheme are analyzed, including the invariance of its evolutionary trajectories, the equivalence between its stationary state and user equilibrium under payment cost, the uniqueness of its stationary state, and the convergence of its evolutionary trajectories. A special case of the model and implementation of the control scheme for several targets are also given. Finally, application of the model to a traffic network is demonstrated using a numerical example. The study is helpful for better understanding the mechanism of congestion control under day-to-day traffic flow dynamics.

Keywords: Traffic dynamics; congestion control; user equilibrium; convergence

Signal Setting with Assignment Constraints: Equilibrium vs. Deterministic Process Approaches

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Abstract
This paper deals with traffic signal setting with assignment. All existing approaches are based on equilibrium assignment; whilst dynamic process models have been proposed for assignment only, assuming that signal setting (as well as transportation supply) is given. This paper reports some results of an undergoing research project on traffic signal setting with dynamic process assignment (assuming probabilistic path choice behaviour). This problem seems relevant since optimization of signal timings under equilibrium assumptions may not guarantee that an effective solution is obtained, because it may well be not an attractor of the evolution over time of the system. The main contribution regards a formal definition of such a problem, specifications of models and fixed-point stability conditions (for some simple specifications). This paper also reports results from an application to a toy network, supporting major theoretical findings.

Keywords: Signal Setting, Day-to-Day Dynamics, Assignment

Influence of Social Network on Travel Choices

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Abstract

With the prevalence of social networks, such as Facebook, Twitter, and Waze, more and more people begin to share their travel information to their friends. Compared with traditional traffic information, the information shared in social networks has many unique properties: up-to-date, user specific and more reliable. So a natural question arises: Whether and how this new kind of information would affect travel behavior? This presentation will focus on the influence of social network on traveler's dynamic decision-making process.

Existing research on travel behavior considering social networks could be mainly divided into two folds: one is investigating how the information shared on social networks could affect traveler's own decision-making, such as day-to-day departure time and route choice; the other is interesting in how the existence and evolution of social networks could influence people's joint social activities, such as shopping with friends. This presentation will review the models, approaches, and data in this field of research.

This presentation will then introduce one of our recent works which focuses on the departure time choice of commuters with information shared via their social networks. An online experiment was conducted to collect data. And the preliminary analysis shows that bad choices (with high travel cost) of friends may have significant influence on travelers, leading them to avoid the same choices or go to the opposite direction. Our further work will concentrate on the day-to-day learning process of travelers given this kind of additional information via the approach of Dynamic Bayesian Network (DBN).

Information transmission through a social network and its effect on discrete choice behaviour - some experimental/empirical trials

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Abstract

Travellers' discrete choices such as route choices and destination choices are affected by information that they can access. This implies that, if information is not perfectly provided to travellers, their choices may be biased depending on a distribution of information. One may consider that information would be perfectly distributed if speed of information transmission is sufficiently fast. However, it has been theoretically pointed out that a so-called 'lock-in' behaviour, which causes inefficient choices (i.e. selecting an inferior option) owing to a lack of information, can happen if information is transmitted very quickly. This presentation introduces a few experimental/empirical trial that intended to reveal whether such an phenomenon predicted by the theoretical model can exist in a real world.