Presentation in “Ryuichi Kitmura Memorial Symposium”

Integration of Activity & Transport Network Equilibrium Models

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Outline

- Remembering of Ryuichi Kitamura
- The Challenge of the Changes
- Background (Objective & Motivation)
- Assumptions & definitions
- Model formulation & solution algorithm
- Numerical study
- Conclusions and future research

Remembering Ryuichi Kitamura

14th ARRB CONFERENCE
28 AUGUST — 2 SEPTEMBER 1988
CANBERRA, AUSTRALIAN CAPITAL TERRITORY

KITAMURA, R. **A dynamic model system of household car ownership, trip generation, and modal split: model development and simulation experiment**

LAM, W.H.K. **Development of probabilistic modal split model using both observed and synthetic generalised costs**

TOWARD THE NEXT GENERATION OF PASSENGER DEMAND FORECASTING MODELS

presented by

Professor Ryuichi Kitamura
and
Dr. William H.K. Lam

12 - 14 June 1995

Department of
Civil and Structural Engineering

The Hong Kong Polytechnic University

Short Biography of Professor Ryuichi Kitamura :

1972 : B.S., Department of Civil Engineering, Kyoto University
1974 : M.S., Department of Transportation Engineering, Kyoto University
1978 : Ph.D., the University Michigan
1978 : Assistant Professor, Department of Civil Engineering, University of California at Davis
1984 : Associate Professor, Department of Civil Engineering, University of California at Davis
1989 : Professor, Department of Civil Engineering, University of California of Davis
1993 : Professor, Department of Transportation Engineering, Kyoto University

Dr. Kitamura works in the areas of travel behavior analysis and demand forecasting. He is currently co-editor of the journal, *Transportation.* His professional activities have included : Chair, the Committee on Traveler Behavior and Values of the Transportation Research Board (TRB); President, International Association for Travel Behavior Research; Chair, Subcommittee on Activity and Travel Pattern Analysis, TRB; Editorial Advisory Board Member, *Transportation Research A;* Editorial Board Member, *JSCE Journal of Infrastructure Planning and Management*

Narrative Biography of Dr. William H.K. Lam :

Dr. William H.K. Lam received a B.Sc. in Civil Engineering and M.Sc. in Transportation Engineering from the University of Calgary in Canada, and a Ph.D. in Transportation Engineering from the University of Newcastle upon Tyne in U.K.

Dr. Lam is currently an Associate Professor in the Department of Civil and Structural Engineering at the Hong Kong Polytechnic University. He is a member of ICE, HKIE, CIT, ITE, a member of Editorial Advisory Board of the Journal of Advanced Transportation, and a Fellow of the Institution of Highways and Transportation (U.K.).

Dr. Lam has undertaken research projects and consultancy works in the fields of traffic management and transportation planning. He is completing a research project on "Co-ordination of Transport Pricing Polices" sponsored by the Research Grant Council of Hong Kong Government and being involved in "West kowloon Reclamation - Comprehensive Traffic Analysis Review and Environmental Impact Assessment" with Halcrow Fox.

Ryuichi Kitamura – Attendance of 2000 HKSTS conference in Hong Kong

Ryuichi Kitamura – Attendance of 2003 HKSTS conference in Hong Kong

Ryuichi Kitamura – Attendance of 2003 HKSTS conference in Hong Kong

Ryuichi Kitamura – Visit of Ryuichi's house by Hong Kong Group in 2006

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TRANSPORTMETRICA

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Editorial

We are delighted to announce that *Transportmetrica* is being published by the Taylor and Francis Group henceforth. We trust that this will strengthen journal circulation and worldwide distribution as well as enhance reader access.

With an internationally renowned editorial board, *Transportmetrica* was launched by the Hong Kong Society for Transportation Studies in 2005.[1] Its aim is to publish original papers in transportation research and development. To date, we have published 12 issues in 4 years. In fact, within only two years of the inaugural issue, we were informed by ISI Thomson that *Transportmetrica* had been selected for coverage in the Science Citation Index Expanded and the Social Sciences Citation Index, among other citation indices. Such an early inclusion in ISI indices attests to the remarkable quality of an upstart journal. As part of our continuing efforts to build up the journal's prestige, we look forward to your submission of high quality papers online.[2] We sincerely hope that *Transportmetrica* will serve as a vehicle that stimulates novel research initiatives.

As this issue was heading towards press, the news of Ryuichi Kitamura's untimely death on 19 February 2009 struck us with sadness and a profound sense of loss. A professor at Kyoto University, Ryuichi had given his unstinting support to *Transportmetrica* as Associate Editor. All of us who had the good fortune of having met him were often touched by his cheerfulness, kindness and generosity. His positive attitude and warmth endured even when he was suffering from a long illness.

Few of us undertaking transportation research have failed to be influenced by the breadth and depth of Ryuichi's scientific contributions to the literature. As a member of the International Scientific Committee of our annual conference, he was a staunch supporter of our activities – despite his hectic work and travel schedules – even in the early years when he was an Invited Speaker at the Society's 5th conference, for instance. Further, in our Society's short span of fourteen years of existence, he attended our Society's annual conferences no less than three times (in 2000, 2001 and 2003) before his deteriorating health curtailed his mobility. Over the years, he encouraged his colleagues and students to attend our annual conferences in Hong Kong and to submit high quality manuscripts to *Transportmetrica*. Indeed, he and a colleague published a highly cited paper, namely Kitamura and Susilo (2005), in the journal's inaugural issue. We are also grateful that Ryuichi, in his capacity as Chair of the International Conference on Travel Behavior Research (IATBR) held in Kyoto in 2006, chose some of the best papers on travel choice behavior presented there for publication in a Special Issue of Transportmetica (Lo and Lam, 2008). Being recognized as a leading figure in travel

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behavior research by the scientific community, Ryuichi was also keen on and instrumental in nurturing and inspiring young minds. He was a benevolent educator and mentor to many of us.

This issue of *Transportmetrica* is hereby devoted to the memory of Professor Ryuichi Kitamura, his admirable research stance and stellar contributions. We shall sorely miss his scholarship and friendship.

Editors-in-Chief

William H.K. Lam

S.C. Wong

Notes

1. http://www.hksts.org
2. http://mc.manuscriptcentral.com/transportmetrica

References

Kitamura, R. and Susilo, Y.O., 2005. Is travel demand insatiable? A study of changes in structural relationships underlying travel. *Transportmetrica*, 1 (1), 23–45.

Lo, H. and Lam, W.H.K., 2008. Recent advances in travel choice behavior modeling: editorial. *Transportmetrica*, 4 (2), 79–81.

Stimulated from his works

- Basic assumption
  - Travel is a derived demand from a need to conduct activities at different locations

- Purpose is to predict daily activity patterns
  - Which activities – work or non-work
  - For how long
  - When
  - Where
  - Transport mode used with & without HSR.
  - Chaining of trips – *e.g. Meeting at Guangzhou in the morning, work at office in Shenzhen, return home in Hong Kong on the same day with HSR.*

The Challenge of the Changes

- HSR as substitute for air over longer distances and road over shorter distances
- Ideal distance 400-600km
- Mode substitution and trip generation (induced demand)
- *Major changes*:
  - As competition to air transport – change of modes
  - The growth of longer distance commuting – change of demand (induced demand?)
  - The changes in activities of people in the region
  - The changes in economic activities and land use etc.

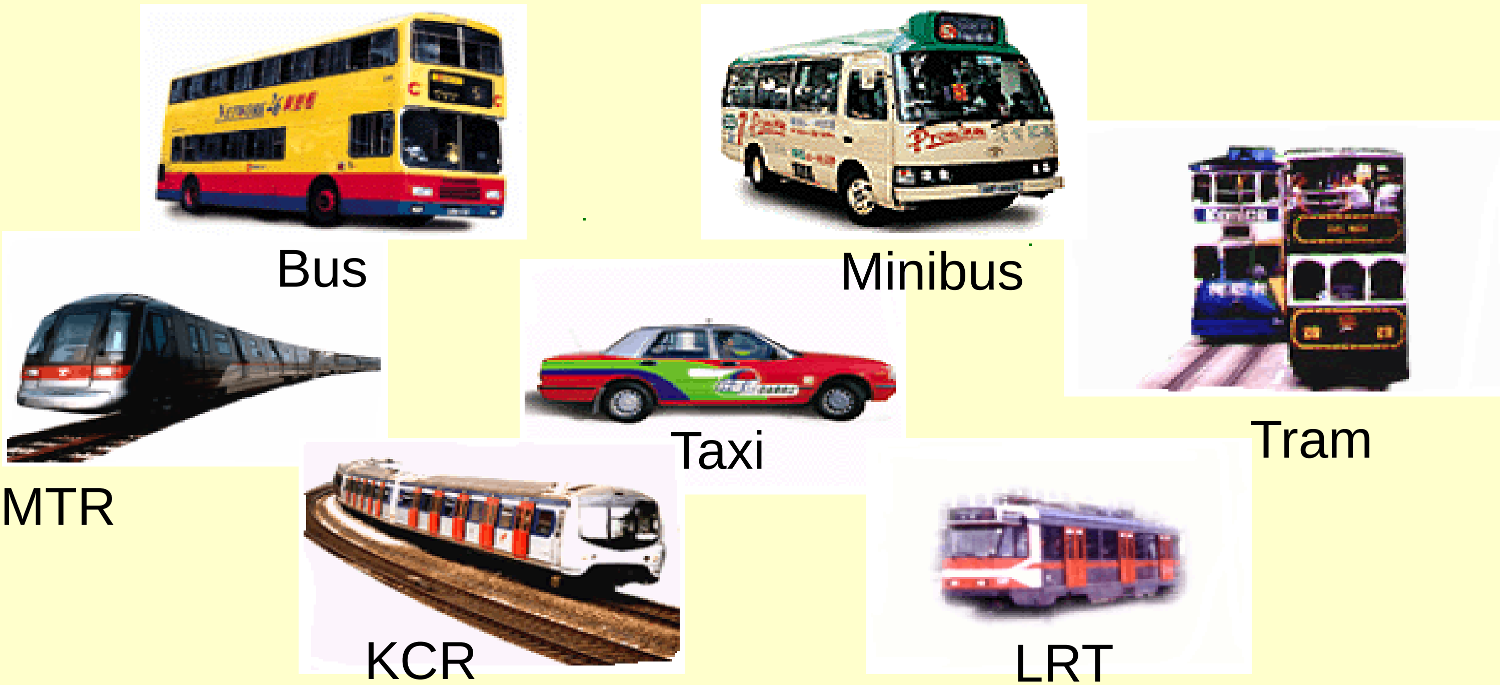
Need for research on activity-based transport network equilibrium models

1. "An Activity-based Time Dependent Traffic Assignment Model". **Transportation Research-B,** Vol. 35, No. 6, 2001, pp. 549-574. (**William H.K. Lam** and Y. Yin).
2. "A Combined Activity/Travel Choice Model for Congested Road Networks with Queues". **Transportation,** Vol. 29, No. 1, 2002, pp. 5-29. **(William H.K. Lam** and Hai-jun Huang).
3. "Combined Activity/Travel Choice Models: Time-Dependent and Dynamic Version". **Networks and Spatial Economics,** 2003, Vol. 3, pp. 323-347. (**William H.K. Lam** and Hai-jun Huang).
4. "A Stochastic Model for Combined Activity/Destination/Route Choice Problem". **Annals of Operations Research**, Vol. 135, 2005, pp. 111-125. (Hai-jun Huang and **William H.K. Lam**).
5. "A time-dependent activity and travel choice model with multiple parking options". **Transportation and Traffic Theory – Flow, Dynamics and Human Interaction**, Edited by Mahmassani, H.S., 2005, Elsevier, Oxford, pp. 717-739. (H.J. Huang, Z.C. Li, **William H.K. Lam** and S.C. Wong).
6. "Combined Location and Travel Choice Model - An Activity-based Approach". **Proceedings of the 88th Transportation Research Board Annual Meeting, 11-15 January 2009**, Washington D.C., U.S.A., Paper no. 09-3361. (CD-ROM) (L.Q. OuYang and **William H.K. Lam**).
7. "An activity-based land use and transportation optimization". **Journal of the Eastern Asia Society for Transportation Studies**, Vol. 8, 2009. (L.Q. OuYang and **William H.K. Lam**)

Part I

Background (Objective & Motivation)

Multi-modal transit modes in Hong Kong



Over **90%** of the 11 million daily person trips in Hong Kong are being served by the public transit modes.

Literature review on transit modeling

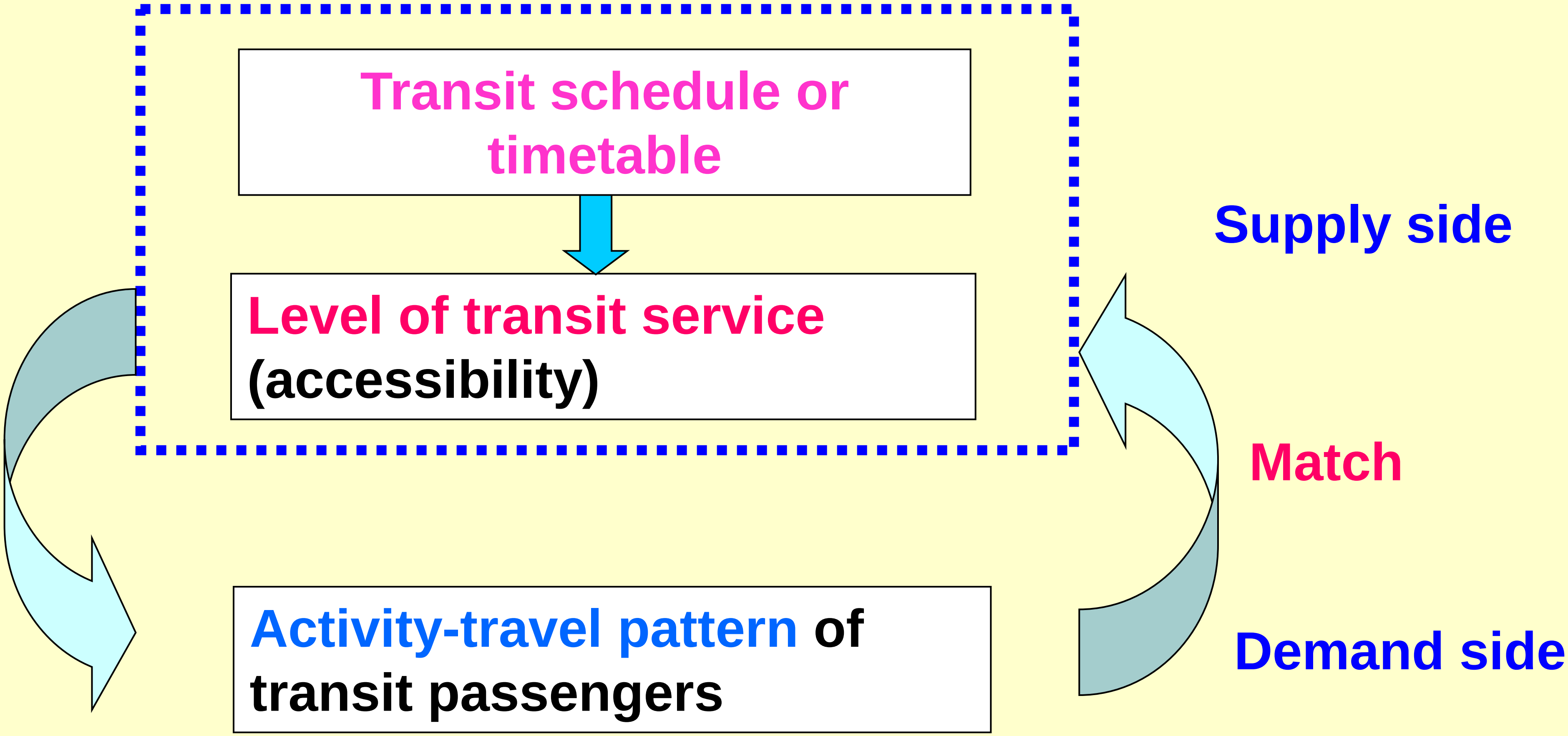
Modeling framework	Methodologies	Examples
Trip-based framework	**frequency-based approach**	Spiess and Florian (1989), De Cea and Fernandez (1993), Lam et al. (1999, 2002), Kurauchi et al. (2003), Uchida et al. (2005), Schmöcker et al. (2008)
	schedule-based approach	Wong and Tong (1998), Tong and Wong (1999), Tong et al. (2001), Nuzzolo et al. (2001)
Activity-based framework	mainly focus on road-based **auto networks** (Jones et al. 1990; Yamamoto et al. 2000; Lam and Yin 2001; Lam and Huang 2002; Huang et al. 2005); **For a comprehensive review, see Kitamura (1988); Timmermans (2005).** **Few studies** on **activity** scheduling behavior of **transit passengers**	

Related books:

Lam WHK and Bell MGH (2003) Advanced modeling for transit operations and service planning. Amsterdam: Pergamon.

Timmermans HJP (2005) Progress in activity-based analysis. Elsevier, Amsterdam.

Relationship between transit timetable and passenger activity schedule



Objectives

- Propose a **scheduling/timetabling model** of transit services in a multimodal transit network using an **activity-based approach**
- Develop **a heuristic solution algorithm** (Hooke-Jeeves method & a supply-demand equilibrium iterative method)
- **Model applications**

(1) Illustrate the **differences** between the activity-based model and the traditional trip-based model

(2) **Compare** the optimal timetables with even and uneven headways

Motivations

- Ascertain the **interaction** between transit **timetables** and **passenger activity-travel** choice behavior
- **Generate optimal timetables** for **short-term** transit **operations** and even for **long-term planning** of High-Speed Rail (HSR).

Research method

A bi-level modeling method

Transit timetabling problem

(Solution algorithm: Hooke-Jeeves method)

Upper level

Timetable ↓ ↑ **Path/link Flow**

Passenger activity-travel choice network equilibrium problem

(Solution algorithm: equilibrium iterative method)

Lower level

An activity-based + schedule-based method

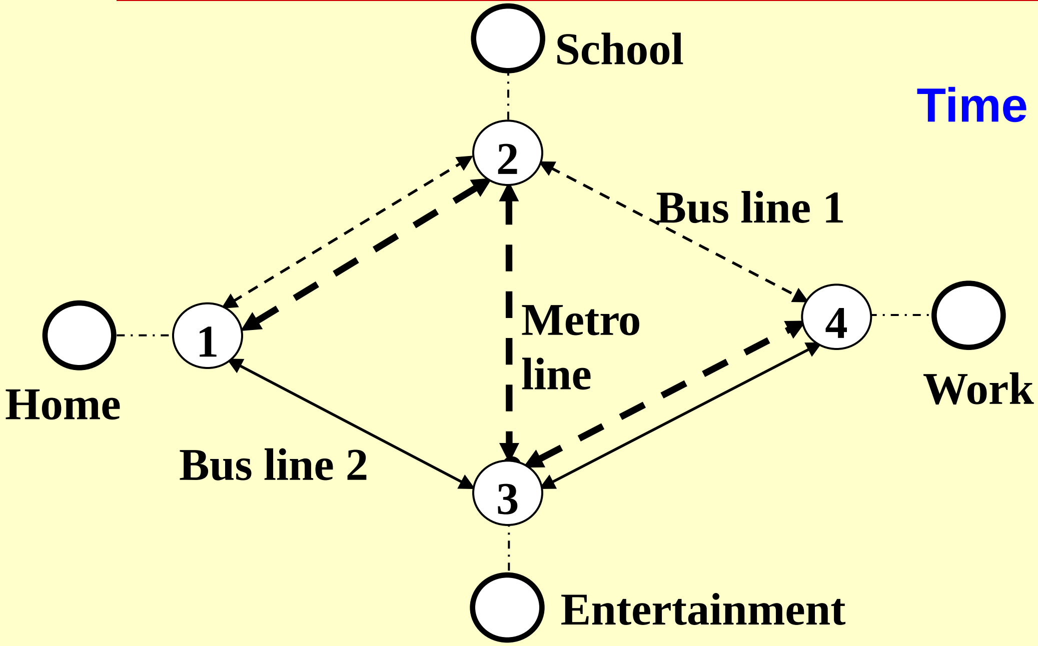
Part II

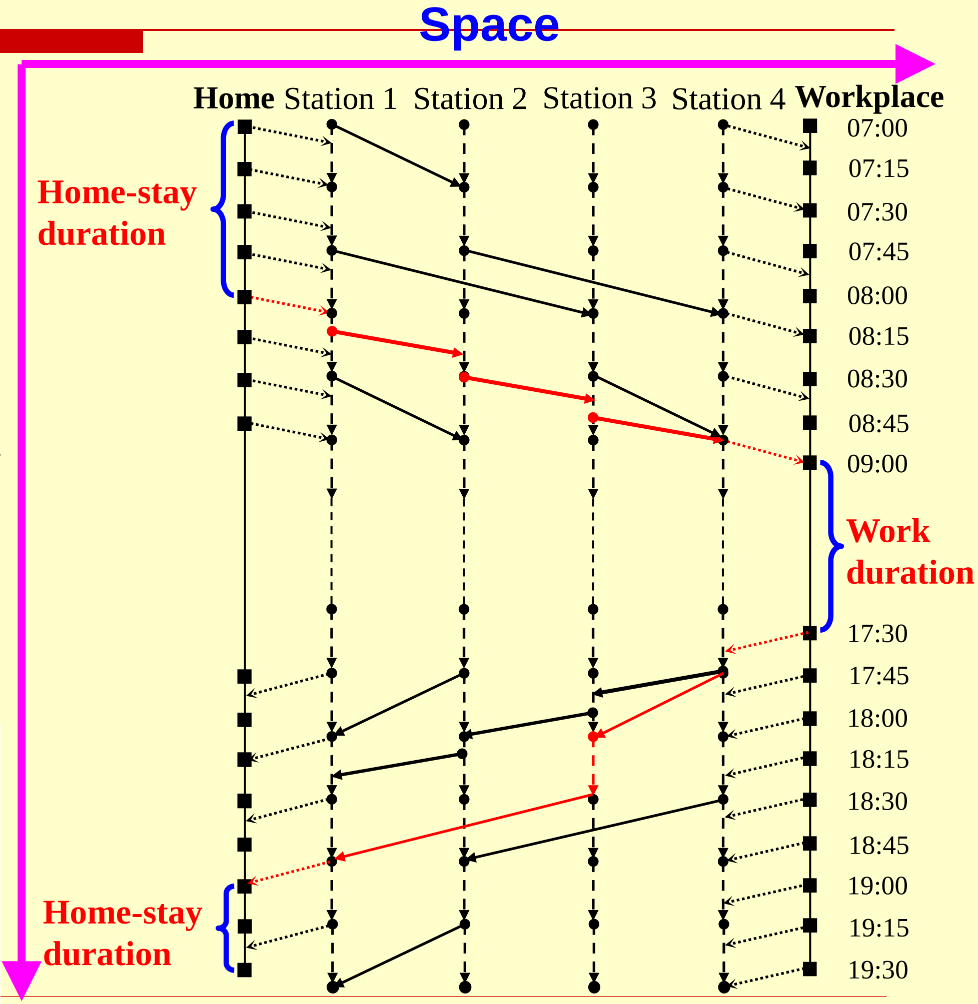
Assumptions and definitions

Assumptions

- **Transit vehicles** are assumed to fully **follow a scheduled timetable**
- The set of **feasible activity/trip chains** is assumed to be **pre-specified**
- Trip-makers base their decisions about activity and travel schedules on a **tradeoff** between the **utility** derived from activity participation at different locations and the **disutility** incurred by travel between activity locations
- **Transit fleet size** for each line is taken as **given and fixed** exogenously.
- The transit system operators choose **timetables** for each line that **maximize the total user net utility** in the system

Network representation





Set of activity-chains:

Home – work – home

Home – work – restaurant – home

Home – school – work – home

Home – school – work – entertainment – home

Passenger-flow time-space network

Path utility

Utility of a path = activity utility – travel disutility

$$U_{pc} = U_{pc}^{A} - U_{pc}^{T}, \quad \forall p \in P_c, c \in \Omega_r, r \in R$$

Travel disutility

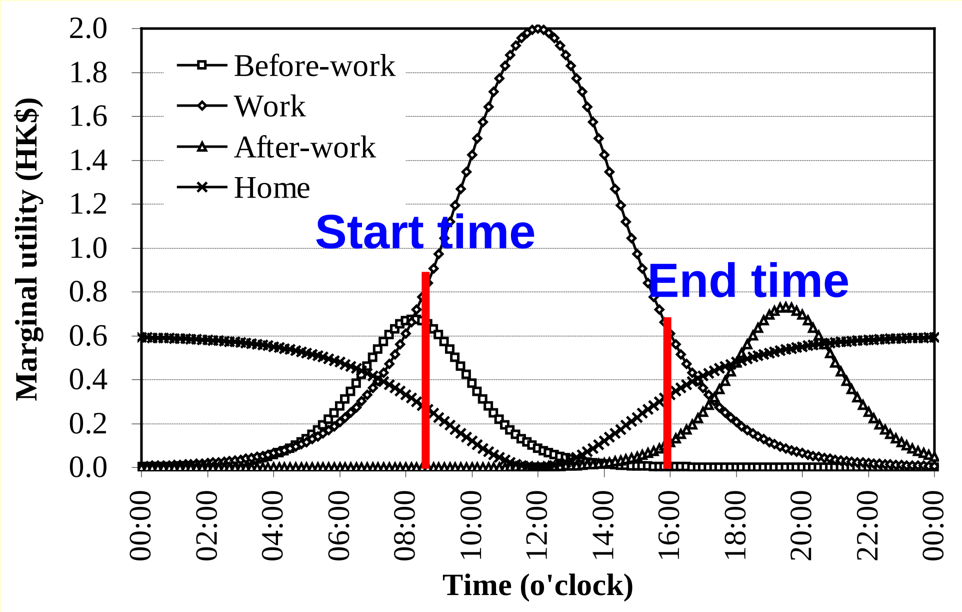
$$U_{pc}^{T} = \alpha_1 \varphi_{pc}^{1} + \alpha_2 \varphi_{pc}^{2} + \alpha_3 \varphi_{pc}^{3} + \alpha_4 \varphi_{pc}^{4} + \varphi_{pc}^{5} + \varphi_{pc}^{6}, \quad \forall p \in P_c, c \in \Omega_r, r \in R$$

- $\alpha_1 \varphi_{pc}^{1}$: **In-vehicle time with congestion effects**
- $\alpha_2 \varphi_{pc}^{2}$: **waiting time**
- $\alpha_3 \varphi_{pc}^{3}$: **walking time**
- $\alpha_4 \varphi_{pc}^{4}$: **line change penalty**
- φ_{pc}^{5}: **Schedule delay cost**
- φ_{pc}^{6}: **fare**

Activity utility

The utility of an activity depends on the **start time** of that activity and its **duration**.

$$MU_i(x) = U_i^0 + \frac{\sigma_i \lambda_i U_i^{\max}}{\exp\left[\sigma_i \left(x - \xi_i\right)\right]\left\{1 + \exp\left[-\sigma_i \left(x - \xi_i\right)\right]\right\}^{\lambda_i + 1}}$$



Marginal utility function

(For details, see Joh et al., 2002; Ettema and Timmermans 2003)

Part III

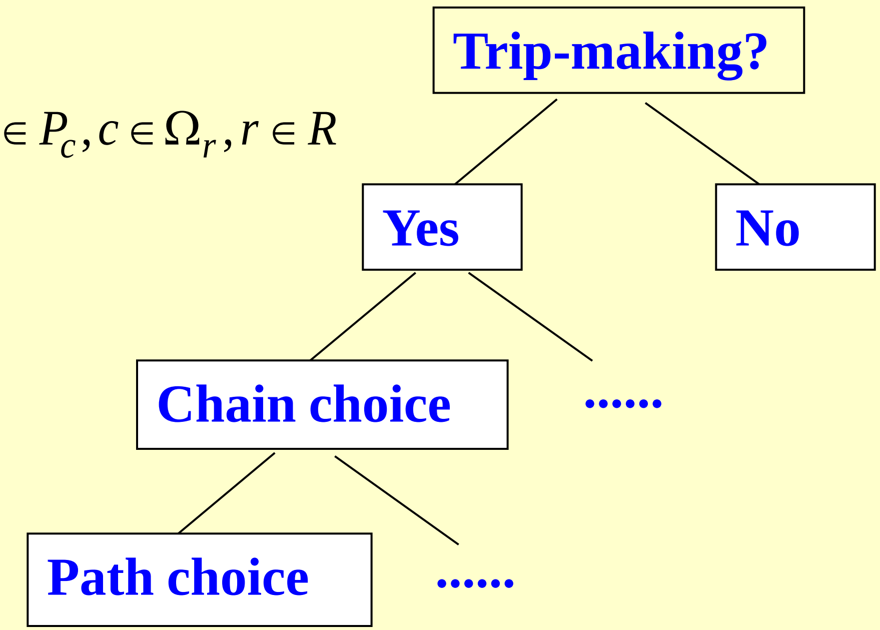
Model formulation

- Passenger activity-travel choice equilibrium
- Timetabling formulation

Passenger activity-travel choice equilibrium

The nested-logit based path and chain choices:

$$f_{pc} = q_r \Pr_{pc|r} = q_r \frac{\exp\left(\theta_2 U_c\right)}{\sum_{c\in\Omega_r} \exp\left(\theta_2 U_c\right)} \frac{\exp\left(\theta_1 U_{pc}\right)}{\sum_{p\in P_c} \exp\left(\theta_1 U_{pc}\right)}, \quad \forall p \in P_c, c \in \Omega_r, r \in R$$



Total number of trip-makers:

$$q_r = Q_r \frac{\exp(\theta_3 U_r^{\text{out}})}{\exp(\theta_3 U_r^{\text{out}}) + \exp(\theta_3 U_r^{\text{in}})}, \quad \forall r \in R$$

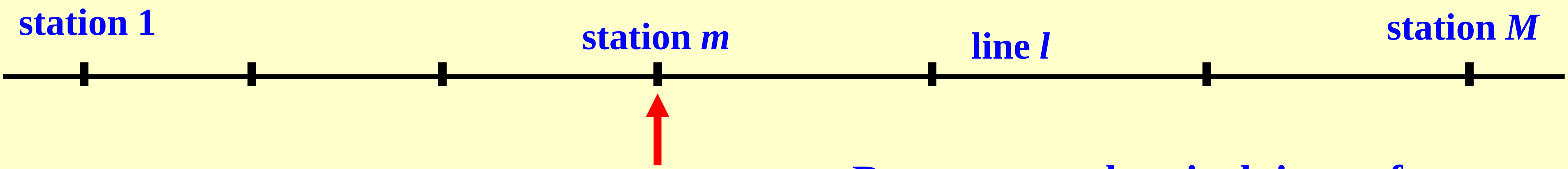
Fixed-point formulation:

$$\mathbf{f} = \mathbf{q} \cdot \mathbf{Pr}\left(\mathbf{U}\left(\ \left(\ \left(\ \right)\right)\right)\right)$$

The hierarchical choices of individuals

Timetabling problem

Problem description



$$\left((t_{\text{dep}})_{l,m}^{k},(t_{\text{arr}})_{l,m}^{k}\right)$$

Departure and arrival times of vehicle *k* from / at station *m*

$$(t_{\text{dep}})_{l,m}^{k}=(t_{\text{arr}})_{l,m}^{k}+(t_{\text{hold}})_{l,m}^{k}$$

Departure time = arrival time + holding time

Given the holding time, determination of <u>a round-trip timetable</u> for a line is equivalent to finding an <u>arrival timetable matrix:</u>

$$\left[(t_{\text{arr}})_{l,m}^{k}\right]_{K\times(2M-1)} \quad \textbf{or} \quad \left((t_{\text{arr}})_{l,1}^{k},(t_{\text{arr}})_{l,2}^{k},\cdots,(t_{\text{arr}})_{l,M}^{k},(t_{\text{arr}})_{l,(M+1)}^{k},\cdots,(t_{\text{arr}})_{l,(2M-1)}^{k}\right)$$

Timetabling model

<u>**Total user net utility maximization in the system**</u> (sum of utility of trip-makers and utility of non-trip-makers in the system)

$$\max \quad \mathrm{TUNU}(\mathbf{T}) = \sum_{r} \sum_{c} \sum_{p} f_{pc}(\mathbf{T}) U_{pc}(\mathbf{T}) + \sum_{r} \left(Q_r - q_r(\mathbf{T}) \right) U_r^{\mathrm{in}}$$

Subject to

$$\mathbf{f} = \mathbf{q} \cdot \mathbf{Pr}\left(\mathbf{U}\left(\quad \left(\quad \left(\quad \right) \right) \right) \right)$$

Passenger activity-travel choice equilibrium

$$(t_{\mathrm{arr}})_{l,m}^{k} - (t_{\mathrm{arr}})_{l,m}^{k-1} \geq h_{\min}^{l}, \quad \forall m, k$$

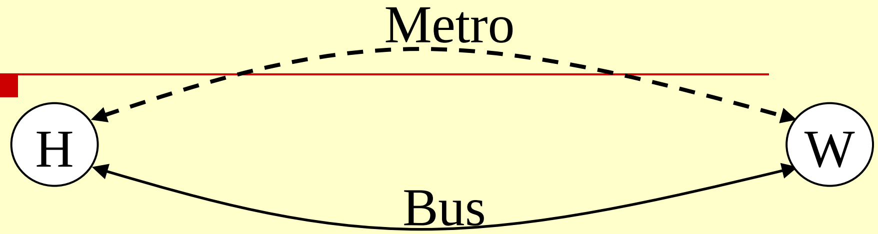
Minimum headway constraint

Solution procedure: <u>**Hooke-Jeeves based heuristic + MSA based equilibrium iterative method**</u>

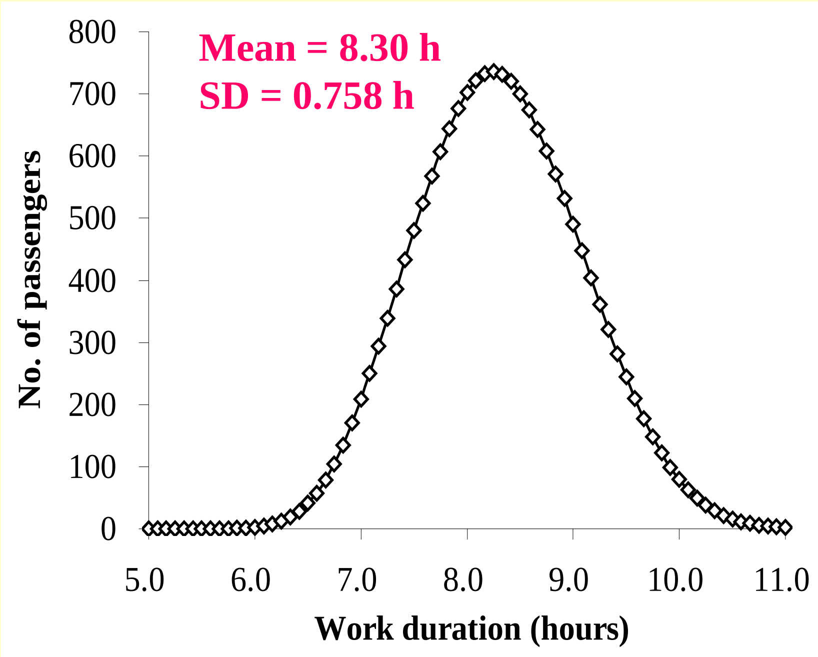
Part IV

Numerical study

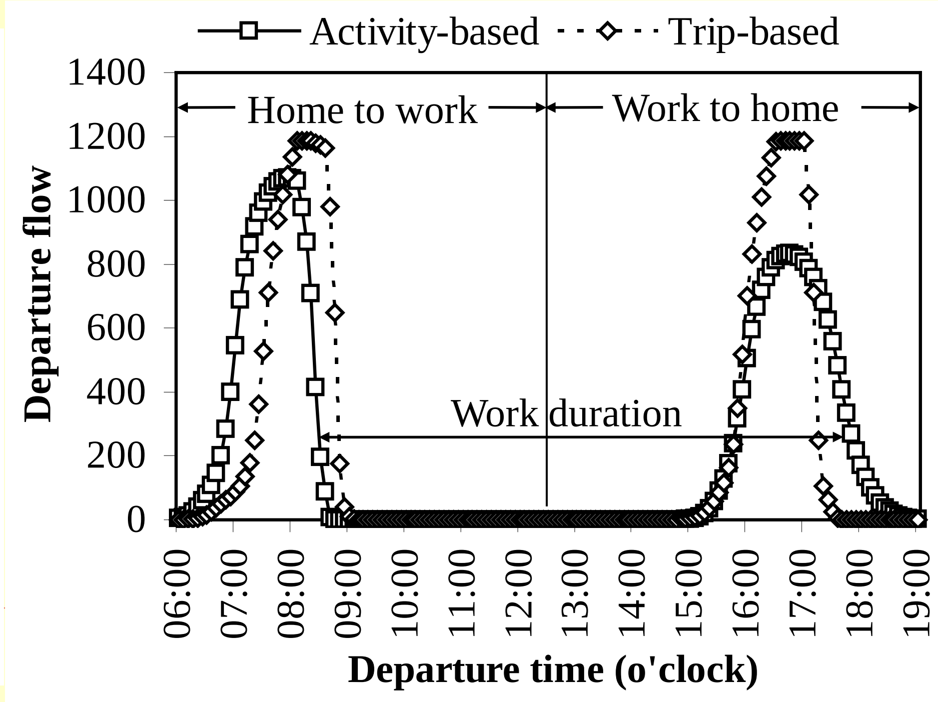
Example 1: Comparison of activity-based model and trip-based model



Distribution of work duration of commuters for the activity-based model



Departure flow patterns of the activity-based and trip-based models



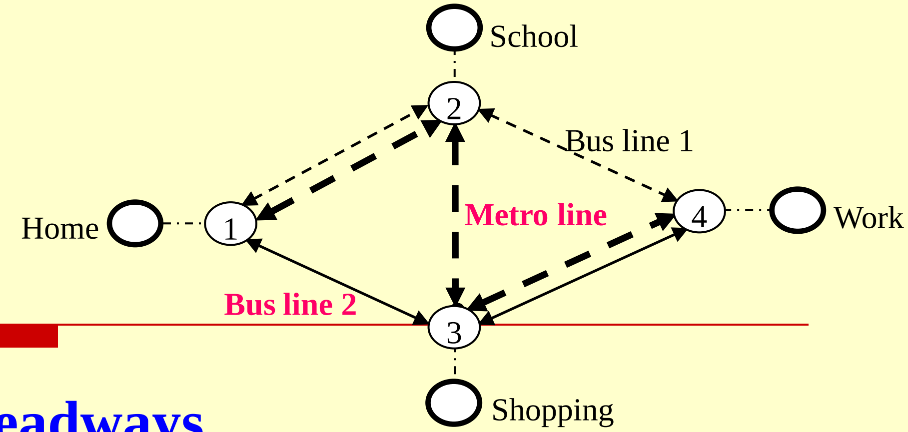
Example 1 (cont.)

Table 2 Effects of **train timetable changes** on the number of trip-makers and **time allocation** of in-home and out-of-home activities

	Number of trip-makers	Number of teleworkers	Average time spent for (hour)				
			Travel	**Walking**	**Waiting**	**Work**	**Home**
Base case (I)	17,777	2,223	0.74	0.48	0.17	8.30	14.31
Case (II)	17,338	2,662	0.80	0.46	0.30	8.48	13.96
Difference (II-I)	**-439**	**439**	**0.06**	**-0.02**	**0.13**	**0.18**	**-0.35**

Base case: train headway = **10** minute; **Case (II):** train headway = **20** minutes

Example 2: Illustration for optimization of timetables

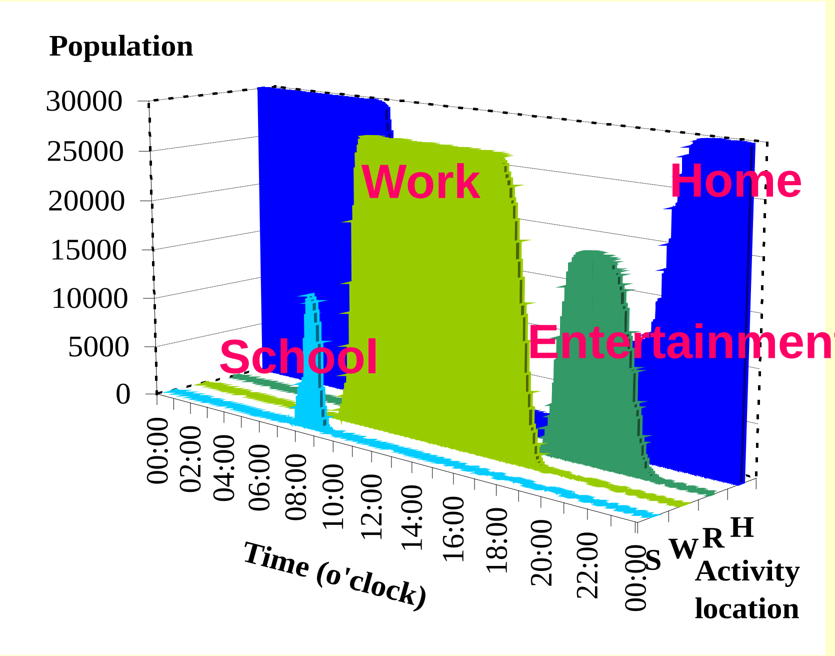


Optimal timetables with even and uneven headways

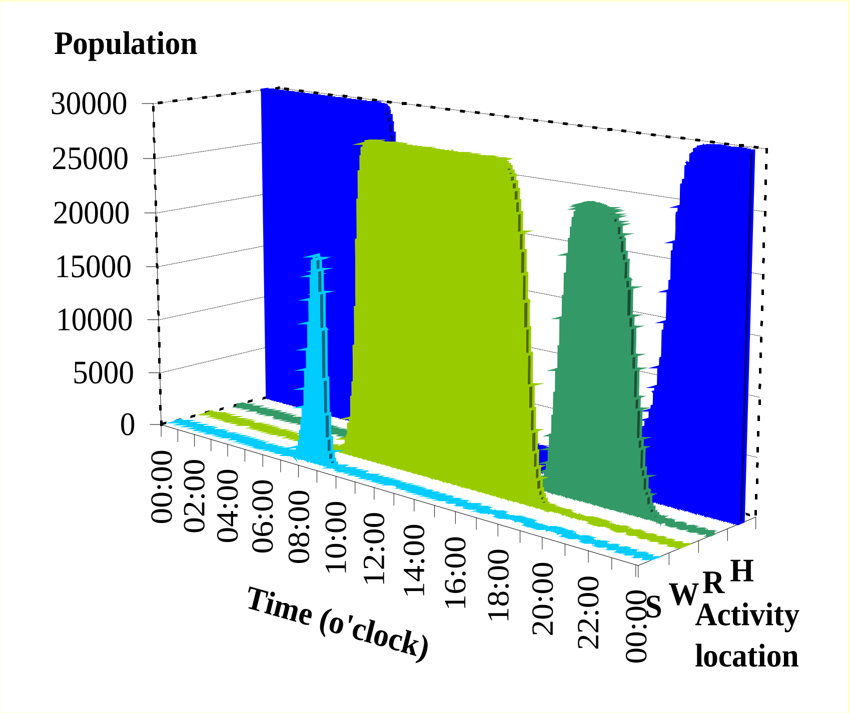
	Station	Arrival time of transit vehicles at station																			
Even	Metro line																				
	1	7:11	7:17	7:23	7:29	7:35	7:41	**7:47**	**7:53**	**7:59**	**8:05**	**8:11**	8:17	8:23	8:29	**8:35**	**8:41**	**8:47**	**8:53**	**8:59**	**9:05**
	2	7:16	7:22	7:28	7:34	7:40	7:46	7:52	7:58	8:04	8:10	8:16	8:22	8:28	8:34	8:40	8:46	8:52	8:58	9:04	9:10
	3	7:21	7:27	7:33	7:39	7:45	7:51	7:57	8:03	8:09	8:15	8:21	8:27	8:33	8:39	8:45	8:51	8:57	9:03	9:09	9:15
	4	7:26	7:32	7:38	7:44	7:50	7:56	8:02	8:08	8:14	8:20	8:26	8:32	8:38	8:44	8:50	8:56	9:02	9:08	9:14	9:20
	Bus line 2																				
	1	7:01	7:13	7:25	7:37	7:49	8:01	8:13	**8:25**	**8:37**	**8:49**	9:01	9:13	9:25	9:37	9:49					
	3	7:16	7:28	7:40	7:52	8:04	8:16	8:28	8:40	8:52	9:04	9:16	9:28	9:40	9:52	10:04					
	4	7:31	7:43	7:55	8:07	8:19	8:31	8:43	8:55	9:07	9:19	9:31	9:43	9:55	10:07	10:19					
Uneven	Metro line																				
	1	7:15	7:21	7:27	7:33	7:39	**7:45**	**7:52**	**7:58**	**8:04**	**8:09**	**8:15**	8:23	8:28	**8:35**	**8:40**	**8:45**	**8:52**	**8:58**	**9:05**	9:10
	2	7:20	7:26	7:32	7:38	7:44	7:50	7:57	8:03	8:09	8:14	8:20	8:28	8:33	8:40	8:45	8:50	8:57	9:03	9:10	9:15
	3	7:25	7:31	7:37	7:43	7:49	7:55	8:02	8:08	8:14	8:19	8:25	8:33	8:38	8:45	8:50	8:55	9:02	9:08	9:15	9:20
	4	7:30	7:36	7:42	7:48	7:54	8:00	8:07	8:13	8:19	8:24	8:30	8:38	8:43	8:50	8:55	9:00	9:07	9:13	9:20	9:25
	Bus line 2																				
	1	7:07	7:19	7:31	7:43	7:55	8:14	**8:25**	**8:35**	**8:45**	**8:55**	9:14	9:26	9:38	9:50	10:02					
	3	7:22	7:34	7:46	7:58	8:10	8:29	8:40	8:50	9:00	9:10	9:29	9:41	9:53	10:05	10:17					
	4	7:37	7:49	8:01	8:13	8:25	8:44	8:55	9:05	9:15	9:25	9:44	9:56	10:08	10:20	10:32					

Distributions of individuals at different activity locations

Even-headway timetable



Uneven-headway timetable



Performance of transit system with even and uneven headways

		Even headway	Uneven headway
Number of total trip-makers		28,012	28,155
Passenger demand of different activity chains	H – W – H	**6,777**	**2,002**
	H – S – W – H	**1,693**	**1,119**
	H – W – E – H	**6,874**	**6,467**
	H – S – W – E – H	**12,668**	**18,567**
Average duration of different activities (h)	S	**0.75**	**0.84**
	W	**8.33**	**8.46**
	E	**3.12**	**3.27**
	H	**11.80**	**11.43**
Average waiting time (min)		4.78	2.64
Average schedule delay cost (HK$)		11.61	4.53
Total operating revenue (10^6 HK$)		1.07	1.18
Total user net utility (10^6HK$)		31.02	31.59
Total system utility (10^6HK$)		**32.09**	**32.77**

H = Home, S = School, W = Work, E = Entertainment

Conclusions

- The trip-based model may lead to **a significant bias** in the estimation of the passenger activity-travel pattern compared to the activity-based model.
- The type of **transit headway** has a significant effect on the trip-makers' activity-travel schedules, and their use and allocation of activity time.
- **A demand-sensitive timetable** can offer greater benefits for both users and community than a fixed-headway timetable.

Future research

- Consider the **effects of uncertainty** in the supply and/or demand
- Incorporate **multiple transport modes** and **different user classes**
- Optimize the **transit fleet size**
- Further **validate** the proposed model **on large-scale transit networks** and **calibrate** the **marginal utility function**
- Extend the proposed model for determining the timetables of High-Speed Rail and long-distance buses
- Develop activity-based land use and transportation models etc.

The End

Thank You

The 15th HKSTS Conference
11-14 December, 2010, Hong Kong
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Thank you!

Q & A

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