Estimation of Network Reliability under Traffic Incidents for ITS Applications

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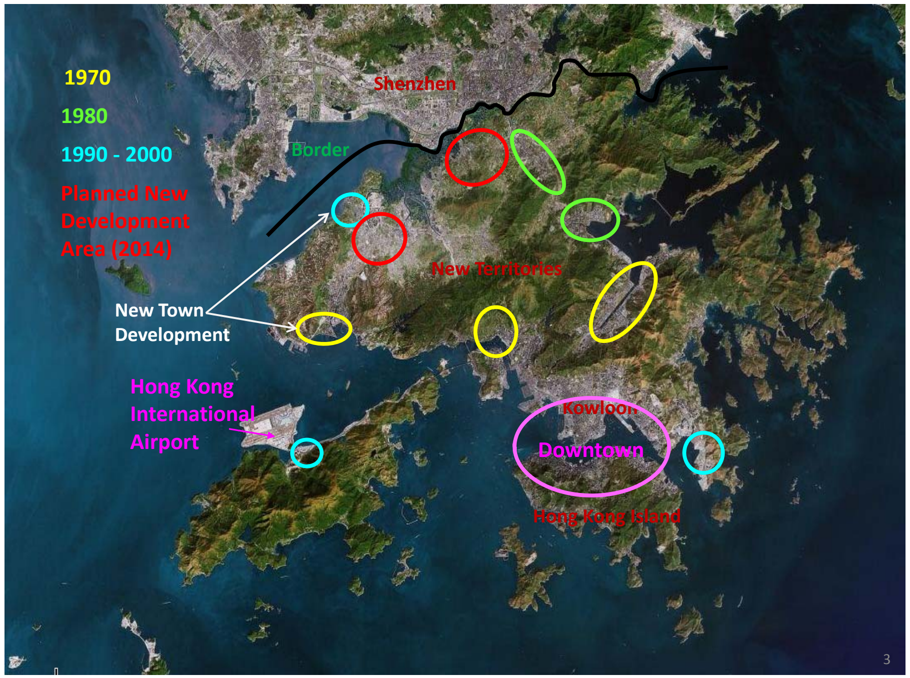
Background and Hong Kong Statistics



Background

- Population: Over 7.23 million
- Total area：1,104 km^2, about 24% land developed
- Car ownership: 75 per 1,000 people, about 10% of the US figure, despite a similar level of GDP
- Urban density: 27,000 persons/km^2 *(Developed land average)*
- In comparison: LA – 3,144;
  Taipei – 9,650; Tokyo – 7,100; Bangkok – 1,301
- **13 million** daily trips, ~**10%** of car trips
- *Road length = 2,090km*
- *No. of licensed vehicle = 700,600* (as at January 2015)
- *175,000 commercial vehicles out of 700,600 licensed vehicles in Hong Kong in January 2015.*

Hong Kong - *A high density populated city*

Within-day & Day-to-day
Recurrent and Non-Recurrent Congestion Problems

- There are **with-in day and day-to-day recurrent and non-recurrent traffic congestion problems** in densely populated cities such as Hong Kong. It has considerable impact on economic productivity, environment and safety.

- However, due to the topography of Hong Kong, there are hardly any feasible sites for further expansion of existing road network. To alleviate the **recurrent and non-recurrent traffic congestion problems** in Hong Kong, recent attention has been given to develop intelligent transportation systems (ITS).

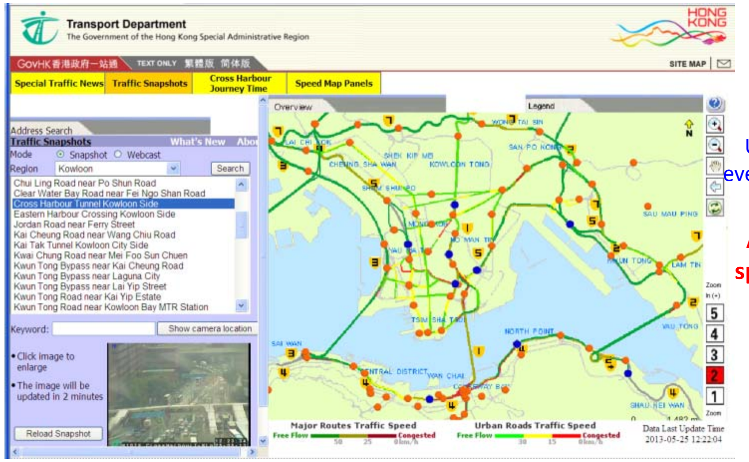
Better Use of New Technologies

Objective

" The use of new technologies will be encouraged to increase the efficiency of traffic management, improve the overall capacity of the road system, and enhance road safety . "

Recent ITS Development in Hong Kong

Real-time Traffic Information System (RTIS)



Update once every 5 minutes !

Accuracy of speed color is 90%

- Launched in Hong Kong Transport Department's website in January 2007;
- Recently updated in May 2010 with use of the latest road network in Hong Kong

http://tis.td.gov.hk/rtis/ttis/index/main_partial.jsp

Tam M.L. and Lam W.H.K. (2008) Using Automatic Vehicle Identification Data for Travel Time Estimation in Hong Kong. Transportmetrica, 4(3), 179-194.

Hong Kong eRouting

- Deterministic travel time
- Single criterion
  - Shortest time
  - Lowest toll
  - Shortest distance

Launched in Hong Kong Transport Department's website in mid-2010
http://hkerouting.gov.hk/drss/index.php?lang=EN

Journey Time Indication System (JTIS)

Launched on the major routes of Hong Kong Island in mid-2009 and of Kowloon area in mid-2010

Update once every 2 minutes !

Accuracy of the computed journey time is within +/- 20% errors with a compliance of 95%

Tam M.L. and Lam W.H.K. (2011) Validation of Instantaneous Journey Time Estimates: A Journey Time Indication System in Hong Kong. Proceedings of the 9th International Conference of Eastern Asia Society for Transportation Studies, Vol. 8, 20-23 June 2011, Jeju, Korea.

Speed Map Panels (SMP) in the New Territories of Hong Kong

Launched in January 2013

Update once every 2 minutes !

Accuracy of the computed journey time and speed range (in form of color) is within +/- 20% errors with a compliance of 95%

Tam M.L. and Lam W.H.K. (2013) Validation of ATIS Journey Time and Traffic Speed Estimates by Floating Car Survey. Journal of the Eastern Asia Society for Transportation Studies, 10, 131-146.

Real-time Traffic Data Collection Technologies adopted in Hong Kong

Radio Frequency Identification (RFID) Reader

Automatic License Plate Recognition (ALPR) Detector

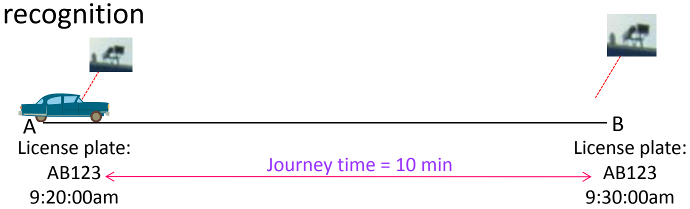
There is a need to make use of all different types of detector data!!!

Video Detector

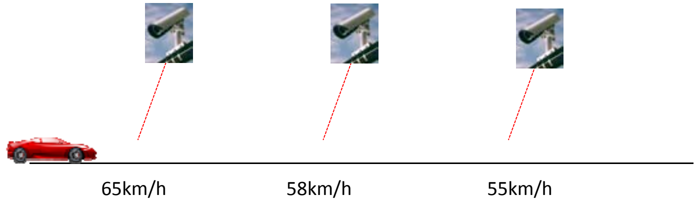
Loop Detector

Two Types of Traffic Detectors Adopted in SMP

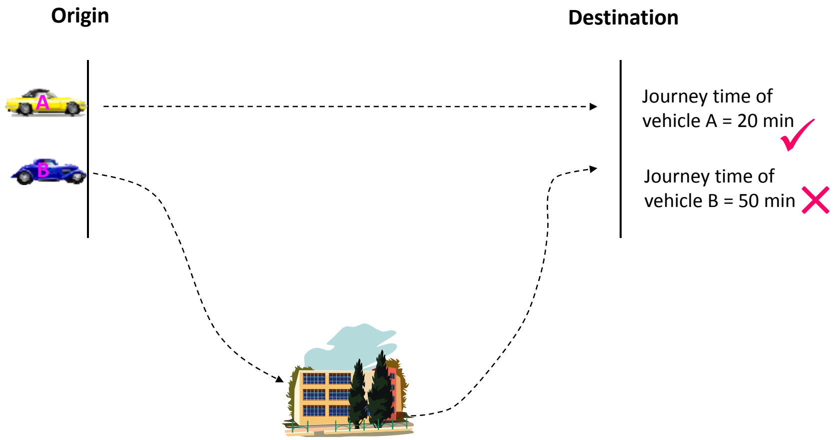
- **Link speed detector (LSD)** by automatic license plate recognition



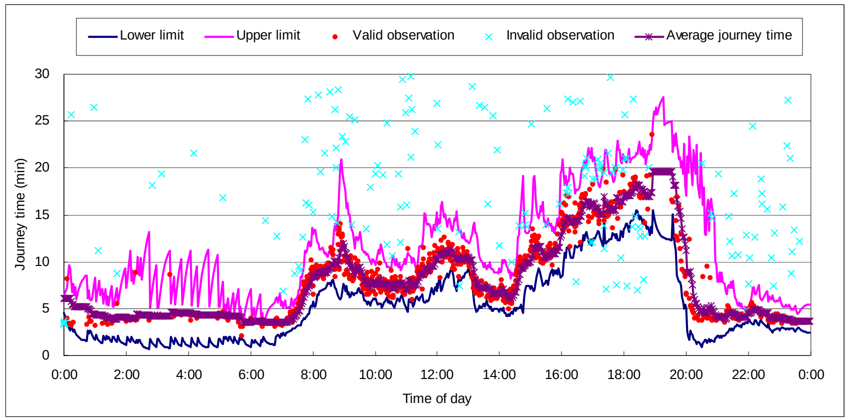
- **Spot speed detector (SSD)** by video image processing



Filtering of Automatic Vehicle Identification (AVI) Data Captured by LSD



Data Filtering Method for Generating Stochastic Journey Time Windows (at 2-min intervals)

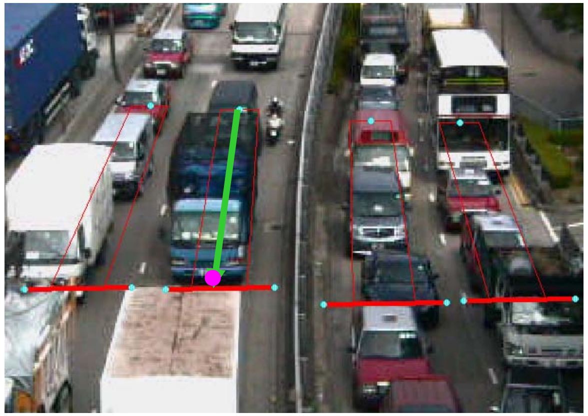


Journey times on a selected path in Hong Kong (11 May 2009)

Autoscope Speed Data

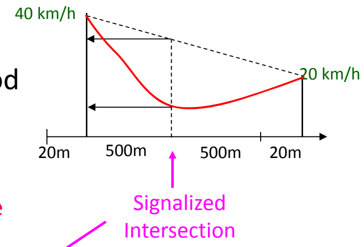
Time mean speed

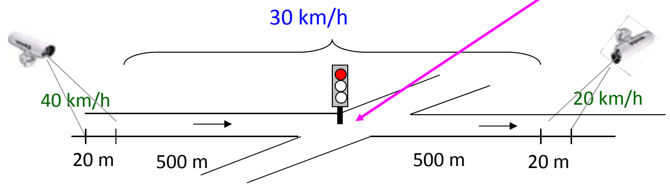
Space mean speed



Speed-based Method for Estimating Journey Time

- Average speed method
- Piecewise linear speed based method
- **Piecewise non-linear speed based method** (with consideration of covariance relationship of link travel times/speeds)

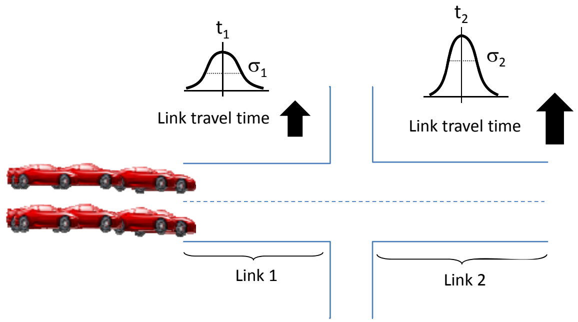




Offline Travel Time Estimates

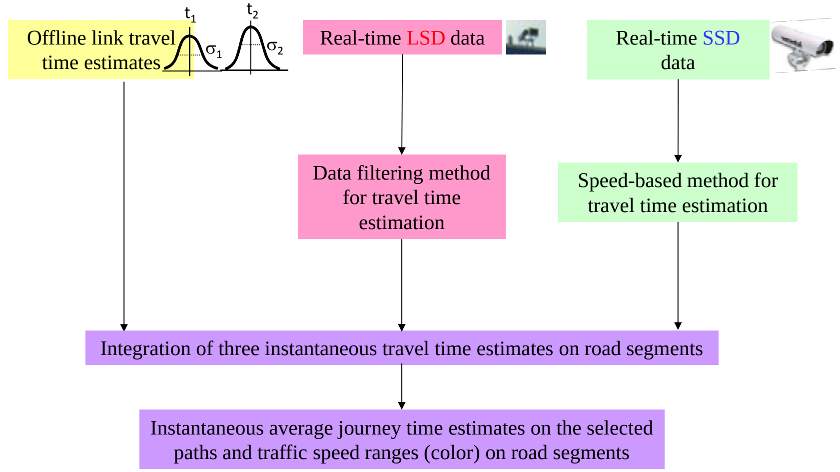
- ❖ Average link travel time estimates (t_1, t_2)
- ❖ Spatial variance (σ_1^2, σ_2^2) and covariance ($\sigma_1\sigma_2$) relationships of link travel times

Real-time Travel Information System (RTIS)
http://tis.td.gov.hk/rtis/ttis/index/main_partial.jsp



Lam W.H.K., Chan K.S. and Shi J.W.Z (2002) A Traffic Flow Simulator for Short-term Travel Time Forecasting. Journal of Advanced Transportation, 36(3), 265-291.

Integrated Algorithm for Estimation of Instantaneous Average Journey Times and Traffic Speed Ranges

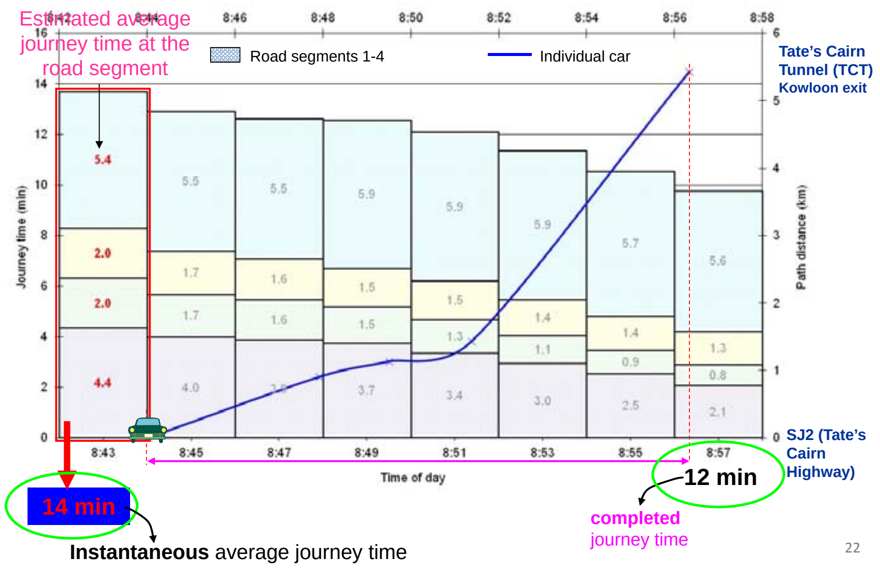


Tam M.L. and Lam W.H.K. (2008) Using Automatic Vehicle Identification Data for Travel Time Estimation in Hong Kong. Transportmetrica, 4(3), 179-194.

Validation Method

- Floating car method
- Observed average instantaneous journey times by test cars vs. instantaneous journey time estimates on each selected path for each two-minute interval during survey period.
- The targeted accuracy level of the computed journey time is within +/- 20% errors with a compliance of 95%.

Instantaneous Average Journey Time vs. Completed Journey Time of Test Vehicle



Sample Sizes for Validation of the Instantaneous Average Journey Times Provided by SMP

$$N \ge \left(\frac{z_{\alpha/2} s}{e}\right)^2$$

α = 0.05; Standard deviation; Permitted error (20%)

No.	Selected path	Path distance (km)	No. of samples used for validation			Minimum samples required within two survey days (*N*)
			Weekday	Weekend	Overall two survey days	
1	SJ1-LRT	7.53	92	88	180	60
2	SJ1-TSCA	8.43	95	83	178	130
3	SJ1-SMT	7.68	76	64	140	56
4	SJ2-TCT	5.43	58	58	116	54
5	SJ2-LRT	7.06	94	87	181	45
6	SJ2-TSCA	9.68	89	79	168	88
7	SJ3-TCT	10.17	63	72	135	70
8	SJ3-LRT	11.04	92	84	176	61
9	SJ3-TSCA	11.94	56	71	127	118
10	S4-TKTL	12.02	56	59	115	66
11	S4-TKTM	26.86	88	67	155	53
12	S5-TWTM	16.87	100	74	174	56
13	S5-TWCP	17.26	52	41	93	56
-	Total	-	1011	927	**1938**	**913**

Validation Results of the Instantaneous Average Journey Times Provided by SMP

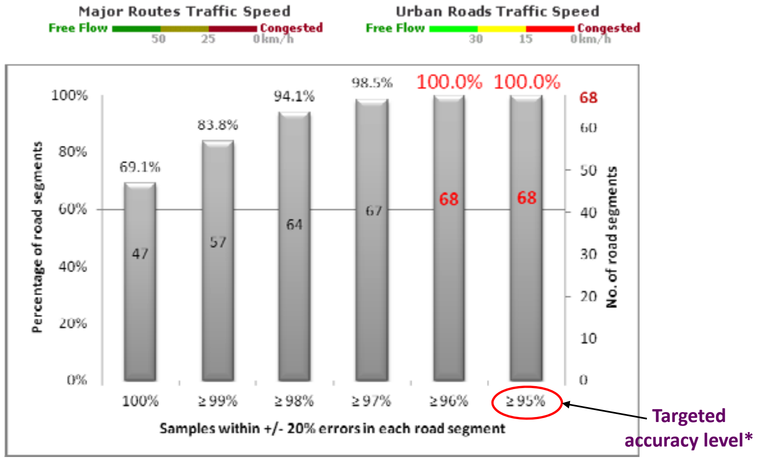
No.	Selected path	Percentages of samples within ± 20% errors		
		Weekday	Weekend	Overall two survey days
1	SJ1-LRT	100%	100%	100%
2	SJ1-TSCA	96.8%	100%	98.3%
3	SJ1-SMT	100%	100%	100%
4	SJ2-TCT	100%	100%	100%
5	SJ2-LRT	100%	100%	100%
6	SJ2-TSCA#	100%	98.7%	99.4%
7	SJ3-TCT	100%	100%	100%
8	SJ3-LRT	100%	100%	100%
9	SJ3-TSCA	96.4%	100%	98.4%
10	S4-TKTL	100%	100%	100%
11	S4-TKTM	100%	100%	100%
12	S5-TWTM	100%	100%	100%
13	S5-TWCP#	100%	100%	100%

The requirement of the targeted accuracy level is **achieved**.

***The targeted accuracy level of the computed journey time is within +/- 20% errors with a compliance of 95%.**

#The selected path with traffic signals and roundabouts.

Validation Results of Traffic Speed Range (Color) Provided by SMP



*The targeted accuracy level of the computed speed range (color) is to be fallen within +/- 20% with a compliance of 95%.

Recent ITS Research Works Conducted by Hong Kong Polytechnic University

Sources of Network Uncertainty

Supply and Demand Uncertainties

Multiple sources, which can be broadly divided into two categories, contribute to network uncertainty.

Classification	Supply uncertainty		Demand uncertainty
Specified form	Adverse weather conditions, road works, etc. (*Predictable*)	Traffic accidents, vehicle breakdown, etc. (*Less predictable*)	Travel demand fluctuations between a specified origin - destination pair

Non-recurrent conditions

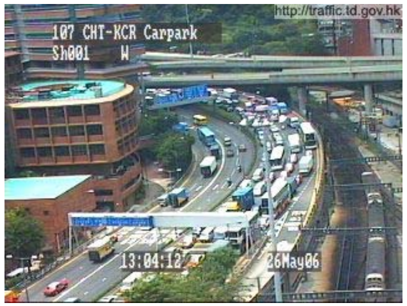
Recurrent conditions

11:20 am 19 Nov 2008 (Wed)

8:04 am 24 Feb 2006 (Fri)

8:04 am 25 Feb 2006 (Sat)

Network Uncertainty under Adverse Weather (Non-recurrent conditions)

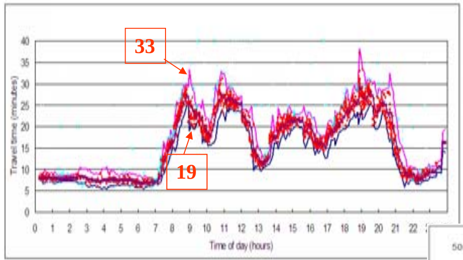


1:04pm 26 May 2006 (Fri, no rain)

1:04pm 29 May 2006 (Mon, raining)

Adverse weather in Hong Kong: Three levels of warning signals by the levels of rainfall expected:- **AMBER** rainstorm signal (>30 mm/hour), **RED** rainstorm signal (>50 mm/hour) and **BLACK** rainstorm signal (>70 mm/hour).

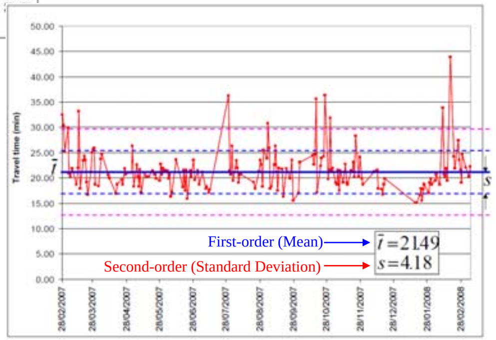
Traffic Dynamics – Stochastic Effects



Within-day travel time variations

Within-day
vs.
Day-to-day Dynamics

The first-order (Mean) and **second-order (Standard Deviation)** statistical properties of the traffic data should be considered for capturing the stochastic effects over time.



Day-to-day travel time variations

Stochastic Journey Time Estimation in Road Network with Uncertainty

- The second-order statistical property (standard deviation) of the observed data is used to estimate the journey time of each path in the territory-wide road network. It has the potential to provide traffic information for the whole network.

- Different types of observed data (link flow data and journey time data) are jointly used in the proposed modeling approach.


Transportation Research Part C

Journey time estimator for assessment of road network performance under demand uncertainty

Hu Shao, William H.K. Lam, Agachai Sumalee, Anthony Chen

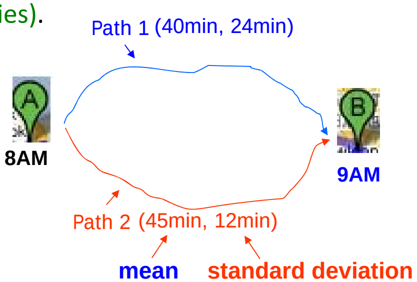
Shao H., Lam W.H.K., Sumalee A. and Chen A. (2013) Journey Time Estimator for Assessment of Road Network Performance under Demand Uncertainty. Transportation Research Part C, 35, 244-262.

Travel Time Reliability in Network with Uncertainties

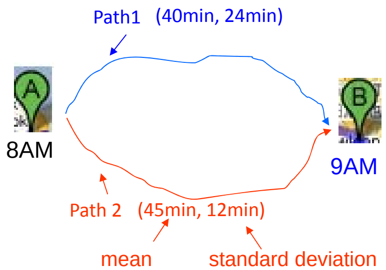
- A new concept of travel time reliability is introduced for capturing the *stochastic* effects over time, in which the **first-order** and **second-order** statistical properties of the traffic data are considered.

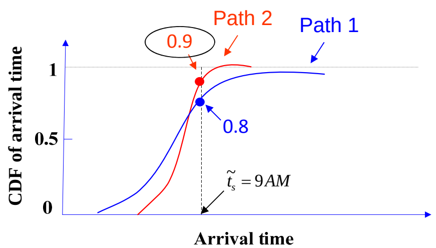
- Travel time reliability is defined as the probability that a traveler can arrive at a destination within a given travel time threshold (i.e. on-time arrival probabilities).

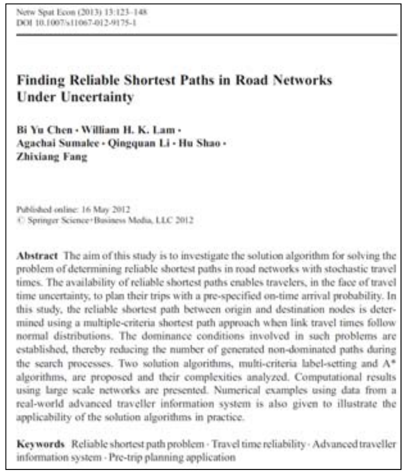
Deterministic
vs.
Stochastic



New concept of Travel Time Reliability: Probability of on-time arrival






Netw Spat Econ (2013) 13:123–148
DOI 10.1007/s11067-012-9175-1

Finding Reliable Shortest Paths in Road Networks Under Uncertainty

Bi Yu Chen · William H. K. Lam · Agachai Sumalee · Qingquan Li · Hu Shao · Zhixiang Fang

Published online: 16 May 2012
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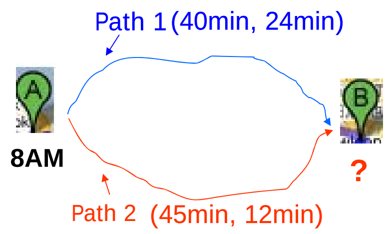
Abstract The aim of this study is to investigate the solution algorithm for solving the problem of determining reliable shortest paths in road networks with stochastic travel times. The availability of reliable shortest paths enables travelers, in the face of travel time uncertainty, to plan their trips with a pre-specified on-time arrival probability. In this study, the reliable shortest path between origin and destination nodes is determined using a multiple-criteria shortest path approach when link travel times follow normal distributions. The dominance conditions involved in such problems are established, thereby reducing the number of generated non-dominated paths during the search processes. Two solution algorithms, multi-criteria label-setting and A* algorithms, are proposed and their complexities analyzed. Computational results using large scale networks are presented. Numerical examples using data from a real-world advanced traveller information system is also given to illustrate the applicability of the solution algorithms in practice.

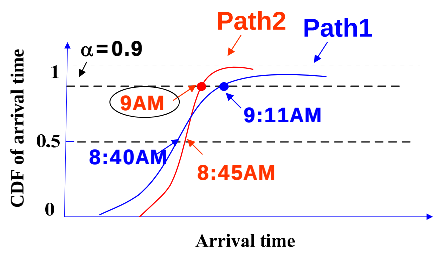
Keywords Reliable shortest path problem · Travel time reliability · Advanced traveller information system · Pre-trip planning application

*Chen B.Y., **Lam W.H.K.**, Sumalee A., Li Q.Q., Shao H. and Fang Z.X. (2013) Finding Reliable Shortest Paths in Road Networks under Uncertainty. Networks & Spatial Economics, 13(2), 123-148.*

Reliable Shortest Path Problem (RSPP) (1)

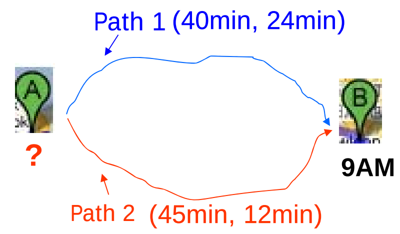
Given departure time t_r, to find earliest arrival time and the optimal path required to satisfy pre-specified probability of on-time arrival α





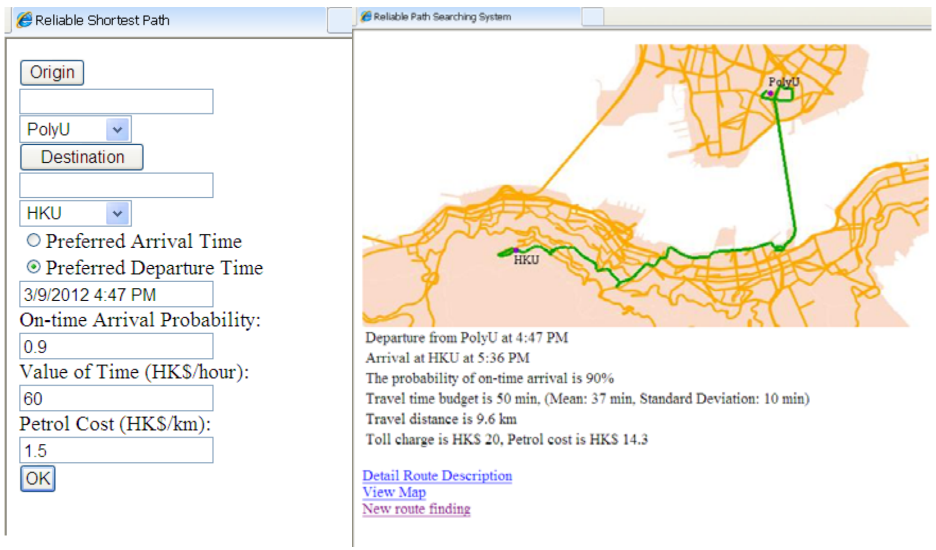
Reliable Shortest Path Problem (RSPP) (2)

Given preferred arrival time $\tilde{t}_s$, to find latest departure time and the reliable shortest path required to satisfy pre-specified probability of on-time arrival α



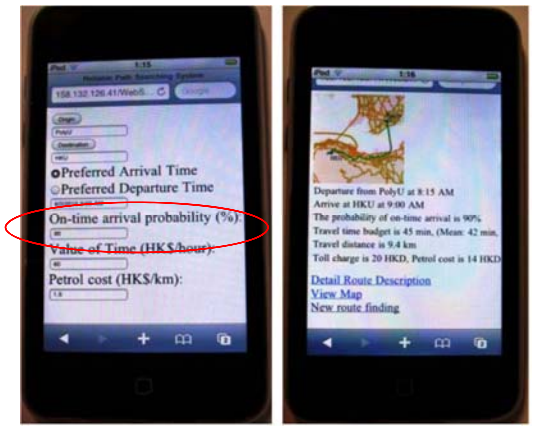
A New Concept of Travel Time Reliability is introduced, in which the first-order and second-order statistical properties of the traffic data are considered.

Reliable Route Searching System



Route Guidance

- Reliable routing service with on-time arrival probability:



Chen B.Y., Lam W.H.K., Sumalee A. and Li Z.L. (2012) Reliable Shortest Path Findings in Stochastic Networks with Spatial Correlated Link Travel Times. International Journal of Geographical Information Science, 26(2), 365-386.

Feasibility Study on Deploying Advanced Technologies in Incident Management

- Executive Summary

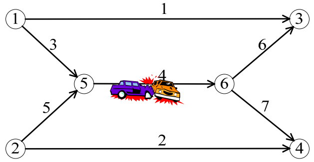
February 2010

http://www.td.gov.hk/filemanager/en/publication/executive%20summary_english.pdf

Impact of Traffic Accident on Network Reliability

11:20 am on 19 November 2008

Dynamic Impact of Traffic Incident on Network Reliability (On-time Arrival Probability)



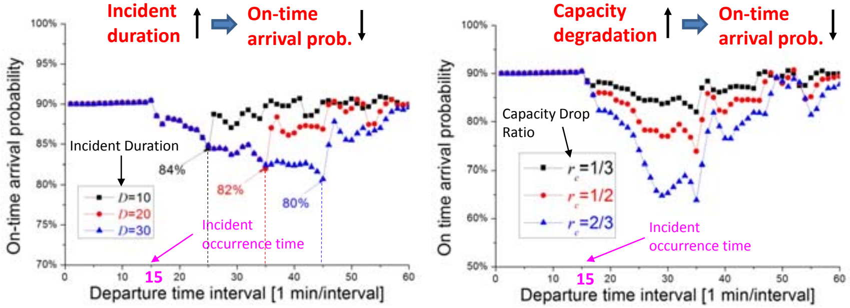
Route described by links
Route 1:1
Route 2:3-4-6
Route 3:5-4-7
Route 4:2

The capacity drop ratio is defined as the ratio of the dropped capacity to the original capacity.

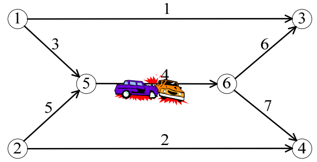
$$\text{Capacity Drop Ratio} = \frac{\text{Dropped Capacity}}{\text{Original Capacity}}$$

Incident duration ↑ ➡ On-time arrival prob. ↓

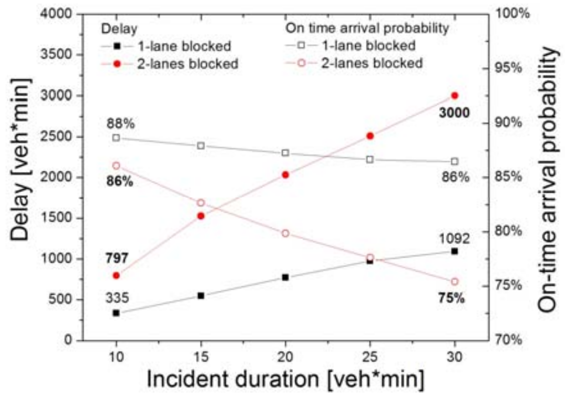
Capacity degradation ↑ ➡ On-time arrival prob. ↓



Impact of Traffic Incident on Network Performance



Route described by links
Route 1:1
Route 2:3-4-6
Route 3:5-4-7
Route 4:2



Incident duration ↑ ➡ Traffic delay ↑

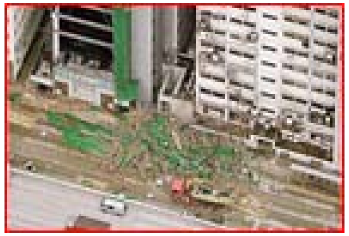
➡ On-time arrival prob. ↓

Capacity degradation (2-lanes blocked) ↑ ➡ Traffic delay ↑

➡ On-time arrival prob. ↓

Network with Non-recurrent Uncertainty

Within-day traffic congestion due to incidents and adverse weather in Kowloon, Hong Kong on 9 May 2005 (Mon).



There is a need to examine the Travel Time Reliability (in term of on-time arrival probabilities) posed by non-recurrent uncertainties (due to rainfall and traffic accidents) to understand their impacts on travel choice behaviors and network performance context.

Network with Day-to-day Recurrent & Non-recurrent Uncertainties

Before 28 September 2014 (Sun)

After 28 September 2014 (Sun) due to Occupy Central

Day-to-day Traffic Conditions at Causeway Bay, **Hong Kong urban area**

There is a need to explore new avenues of research for development of reliability-based ITS applications in road-based multi-modal transportation networks with taking account network uncertainties under recurrent and non-recurrent uncertainties due to **demand fluctuations**.

Further Study

Need for Further Study

Based on the rainfall data (annual averages for 30-year period) from the World Weather Information Services (http://www.worldweather.org/), that Hong Kong has the **highest average annual rainfall** of all the major Pacific Rim cities.

Further study is required to explore **new avenues of research** for development of Intelligent Transportation Systems (ITS) in Asian cities with relatively high annual rainfall intensities and/or high traffic accident rates.

Note: Rainfall intensity is based on annual averages for the 30-year period (as at September 2011). (http://www.worldweather.org)

Hong Kong in Year 2014

Month	Total Rainfall (mm)	Number of Rain Days (Daily rainfall ≥ 0.1mm)
Jan	0.0	0
Feb	39.5	7
Mar	207.6	12
Apr	132.4	12
May	687.3	23
Jun	436.6	19
Jul	260.5	20
Aug	548.2	17
Sep	140.6	13
Oct	109.8	7
Nov	31.1	7
Dec	44.7	15
Total	**2638.3 mm**	**152 days**

Future Works

- To examine the **Travel Time Reliability** (in term of on-time arrival probabilities) posed by recurrent and non-recurrent uncertainties (due to rainfall and traffic accidents) to understand their impacts on travel choice behaviors and network performance context.
- To explore **new avenues of research** for development of **reliability-based ITS** applications in road-based multi-modal transportation networks with taking account **network uncertainties** due to recurrent and non-recurrent congestion.
- To develop **reliability-based Dynamic Traffic Assignment (DTA)** model for assessing network degradability due to adverse weather and incidents.

ACKNOWLEDGEMENTS
This work was jointly supported by research grants from the Research Grant Council of the Hong Kong Special Administrative Region (Project No. PolyU 5242/12E) and from RISUD of PolyU (Project Nos. 1-ZVBZ).

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-THE END-

The 20th HKSTS International Conference
12-14 December 2015, Hong Kong
http://www.hksts.org