Estimation of Network Reliability under Traffic Incidents for ITS Applications

Ir Prof. William H.K. Lam
Chair Professor of Civil & Transportation Engineering and Head
Department of Civil & Environmental Engineering
The Hong Kong Polytechnic University
E-mail: william.lam@polyu.edu.hk
Website: www.cee.polyu.edu.hk/~cehklam

Background

• Population: Over 7.23 million
• Total area: 1,104 km², 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/km² (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 within-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)**

- 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
- Update once every 5 minutes!
- Accuracy of speed color is 90%


**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

**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%


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

- Launch 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%

Real-time Traffic Data Collection Technologies adopted in Hong Kong

Automatic License Plate Recognition (ALPR) Detector

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

Radio Frequency Identification (RFID) Reader

Loop Detector

Video Detector

Two Types of Traffic Detectors Adopted in SMP

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

  License plate: AB123
  9:20:00am

  Journey time = 10 min

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

  65km/h 58km/h 55km/h

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

Journey time of vehicle A = 20 min

Journey time of vehicle B = 50 min

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 ($\sigma_1^2$, $\sigma_2^2$) and covariance ($\sigma_1\sigma_2$) relationships of link travel times

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

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


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%.

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

<table>
<thead>
<tr>
<th>No.</th>
<th>Selected path</th>
<th>Path distance (km)</th>
<th>No. of samples used for validation</th>
<th>Minimum samples required within two survey days (N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SJ1-LRT</td>
<td>7.53</td>
<td>92 88</td>
<td>180</td>
</tr>
<tr>
<td>2</td>
<td>SJ1-TSCA</td>
<td>8.43</td>
<td>95 83</td>
<td>178</td>
</tr>
<tr>
<td>3</td>
<td>SJ1-SMT</td>
<td>7.68</td>
<td>76 64</td>
<td>140</td>
</tr>
<tr>
<td>4</td>
<td>SJ2-TCT</td>
<td>5.43</td>
<td>58 58</td>
<td>116</td>
</tr>
<tr>
<td>5</td>
<td>SJ2-LRT</td>
<td>7.06</td>
<td>94 87</td>
<td>182</td>
</tr>
<tr>
<td>6</td>
<td>SJ2-TSCA</td>
<td>9.68</td>
<td>89 79</td>
<td>168</td>
</tr>
<tr>
<td>7</td>
<td>SJ3-TCT</td>
<td>10.17</td>
<td>63 72</td>
<td>135</td>
</tr>
<tr>
<td>8</td>
<td>SJ3-LRT</td>
<td>11.04</td>
<td>92 84</td>
<td>176</td>
</tr>
<tr>
<td>9</td>
<td>SJ3-TSCA</td>
<td>11.94</td>
<td>56 71</td>
<td>127</td>
</tr>
<tr>
<td>10</td>
<td>S4-TKTL</td>
<td>12.02</td>
<td>56 59</td>
<td>115</td>
</tr>
<tr>
<td>11</td>
<td>S4-TKTM</td>
<td>26.86</td>
<td>88 67</td>
<td>155</td>
</tr>
<tr>
<td>12</td>
<td>SS-TWTM</td>
<td>16.87</td>
<td>100 74</td>
<td>174</td>
</tr>
<tr>
<td>13</td>
<td>SS-TWCP</td>
<td>17.26</td>
<td>52 41</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1011</td>
<td>927</td>
<td>1938</td>
</tr>
</tbody>
</table>

Validation Results of the Instantaneous Average Journey Times Provided by SMP

<table>
<thead>
<tr>
<th>No.</th>
<th>Selected path</th>
<th>Percentages of samples within +/- 20% errors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SJ1-LRT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>2</td>
<td>SJ1-TSCA</td>
<td>96.6% Weekday, 100% Weekend, 98.3% Overall</td>
</tr>
<tr>
<td>3</td>
<td>SJ1-SMT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>4</td>
<td>SJ2-TCT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>5</td>
<td>SJ2-LRT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>6</td>
<td>SJ2-TSCA#</td>
<td>100% Weekday, 100% Weekend, 99.4% Overall</td>
</tr>
<tr>
<td>7</td>
<td>SJ3-TCT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>8</td>
<td>SJ3-LRT</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>9</td>
<td>SJ3-TSCA#</td>
<td>96.4% Weekday, 100% Weekend, 98.4% Overall</td>
</tr>
<tr>
<td>10</td>
<td>S4-TKTL</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>11</td>
<td>S4-TKTM</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>12</td>
<td>SS-TWTM</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
<tr>
<td>13</td>
<td>SS-TWCP#</td>
<td>100% Weekday, 100% Weekend, 100% Overall</td>
</tr>
</tbody>
</table>

*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%.

Sources of Network Uncertainty

Supply and Demand Uncertainties

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

<table>
<thead>
<tr>
<th>Classification</th>
<th>Supply uncertainty</th>
<th>Demand uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specified form</td>
<td>Adverse weather conditions, road works, etc. (Predictable)</td>
<td>Traffic accidents, vehicle breakdown, etc. (Less predictable)</td>
</tr>
<tr>
<td>Non-recurrent conditions</td>
<td>Recurrent conditions</td>
<td></td>
</tr>
</tbody>
</table>

Network Uncertainty under Adverse Weather (Non-recurrent conditions)

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 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.

**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).

**New concept of Travel Time Reliability:**

**Probability of on-time arrival**

![Graph showing CDF of arrival time](image)

- **Path 1**: (40min, 24min)
- **Path 2**: (45min, 12min)

- **Deterministic vs. Stochastic**

**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.


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 $\alpha$.

Path 1 (40min, 24min)  
Path 2 (45min, 12min)

Reliable Shortest Path Problem (RSPP) (2)

Given preferred arrival time $t_f$, to find latest departure time and the reliable shortest path required to satisfy pre-specified probability of on-time arrival $\alpha$.

Path 1 (40min, 24min)  
Path 2 (45min, 12min)

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:

Feasibility Study on Deploying Advanced Technologies in Incident Management
- Executive Summary

February 2010


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)

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 occurrence time

Traffic delay

On-time arrival prob.

On-time arrival probability (2-lanes blocked)

Incident duration

Traffic delay

On-time arrival prob.

On-time arrival probability (1-lane blocked)

On-time arrival probability (2-lanes blocked)

Incident duration

Capacity degradation

On-time arrival prob.

On-time arrival probability (1-lane blocked)

On-time arrival probability (2-lanes blocked)

Incident occurrence time

Traffic delay

On-time arrival prob.

Capacity degradation

On-time arrival probability (1-lane blocked)

On-time arrival probability (2-lanes blocked)
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

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.

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.

| Month | Total Rainfall (mm) | Number of Rain Days (Daily rainfall \(\geq 0.1\text{mm})
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan</td>
<td>0.0</td>
<td>0</td>
</tr>
<tr>
<td>Feb</td>
<td>39.5</td>
<td>7</td>
</tr>
<tr>
<td>Mar</td>
<td>207.6</td>
<td>12</td>
</tr>
<tr>
<td>Apr</td>
<td>132.4</td>
<td>12</td>
</tr>
<tr>
<td>May</td>
<td>687.3</td>
<td>23</td>
</tr>
<tr>
<td>Jun</td>
<td>436.6</td>
<td>19</td>
</tr>
<tr>
<td>Jul</td>
<td>200.5</td>
<td>20</td>
</tr>
<tr>
<td>Aug</td>
<td>548.2</td>
<td>17</td>
</tr>
<tr>
<td>Sep</td>
<td>140.6</td>
<td>13</td>
</tr>
<tr>
<td>Oct</td>
<td>109.8</td>
<td>7</td>
</tr>
<tr>
<td>Nov</td>
<td>31.1</td>
<td>7</td>
</tr>
<tr>
<td>Dec</td>
<td>44.7</td>
<td>15</td>
</tr>
<tr>
<td>Total</td>
<td>2638.3 mm</td>
<td>152 days</td>
</tr>
</tbody>
</table>

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