

APPLICATION OF INFORMATION TECHNOLOGIES FOR DEVELOPMENT OF REAL-TIME TRAVELER INFORMATION SYSTEM IN HONG KONG

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ABSTRACT

This paper presents a real-time traveler information system (RTIS) for Hong Kong. It is a robust on-line updating platform for advanced traveler information system in practice, in which the real-time travel time estimates for Hong Kong road network can be extracted easily. In the RTIS, the on-line travel times are estimated by the real-time traffic data, the off-line travel time forecasts and their variance-covariance relationships between road links. The real-time traffic data consists of Autotoll tag data and Journey Time Indication System data, while the off-line travel time forecasts and their variance-covariance matrices are obtained by the traffic flow simulator. On the basis of these real-time and off-line traffic data, the current traffic conditions on Hong Kong major roads can be updated once every 5 minutes. In this paper, a case study for major roads on Hong Kong Island is presented to illustrate the performance of RTIS in real life.

KEY WORDS

real-time traveler information system, on-line travel time forecasts, real-time traffic data, Hong Kong.

INTRODUCTION

With the rapid development of Intelligent Transportation Systems (ITS) and electronic information and communication technologies, there is great potential for the application of advanced technologies to alleviate traffic congestion, particularly for large Asian cities like Hong Kong. Advanced Traveler Information System (ATIS) is one of the options that are being adopted in many western countries. In the ATIS, detectors are located at some sections of the road network to collect historical and real-time data such as traffic flow. Based on these partial detected data, the link flows and travel times within the network can be estimated and delivered to drivers by various means, such as variable message signs, mobile phones and internet (Lam and Chan 2001; Eisele and Rilett 2002; Chien and Kuchipudi

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2003). The drivers will then make their route choice decision based on the estimated travel times and their own driving experience.

In Hong Kong, a prototype of the ATIS so-called the Journey Time Indication System (JTIS) has been introduced in mid-2003. It is basically a system of providing current traffic conditions in term of travel times via displays at gantry signs nearby the major roads along the harbour of Hong Kong. Figure 1 shows the Journey Time Indication System which can provide drivers the current estimated journey times of different cross-harbour routes between Hong Kong Island and Kowloon urban areas. The displays are refreshed once every five minutes. Real-time closed-circuit television (CCTV) images and videos at major roads in Hong Kong are also available on the website of Hong Kong Transport Department (<http://traffic.td.gov.hk/snapshots/eng/index.htm>). There are a total of 117 CCTV cameras installed in Hong Kong territory and the CCTV images are updated once every two minutes. From these updated CCTV images, people can know the current traffic conditions on major roads in Hong Kong, in terms of traffic density. However, the limited number of CCTV cameras cannot be sufficient to capture the traffic conditions for the whole territory. Moreover, digital information may be more useful and valuable than video images for most drivers. Therefore, there is a need to collect and make use of additional real-time traffic data for development of the territory-wide real-time traveler information system in Hong Kong.

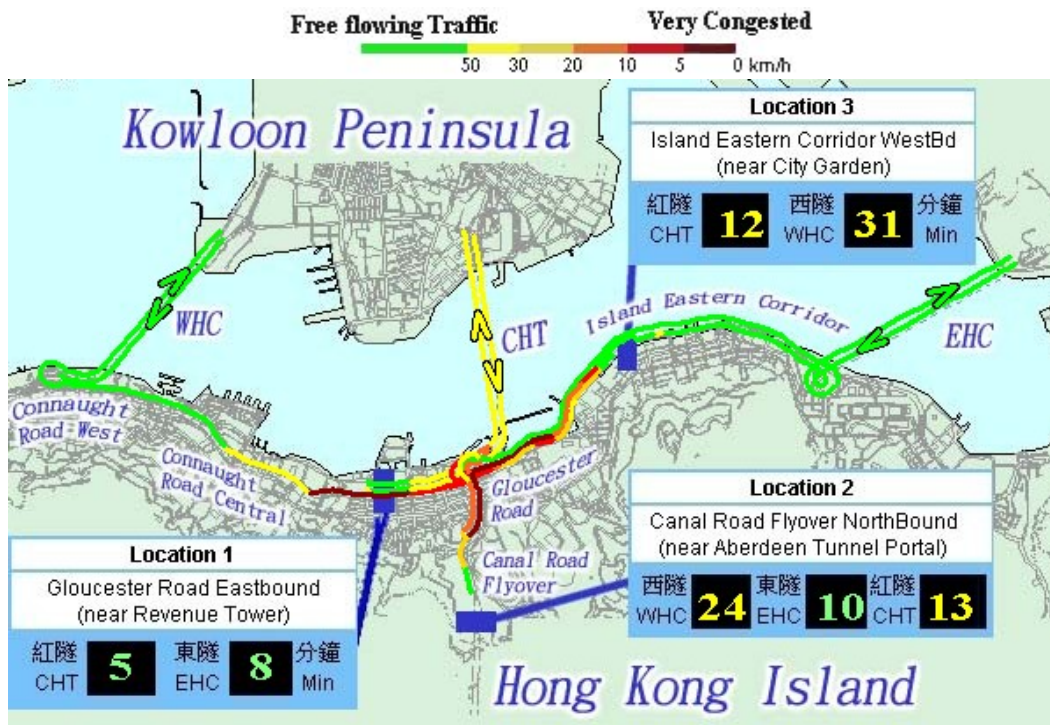


Figure 1: Journey Time Information System (JTIS)

An off-line short-term traffic forecasting platform with Geographic Information System (GIS) functions has been developed for ATIS applications in Hong Kong (Lam et al. 2005). In this system, a Traffic Flow Simulator (TFS) was calibrated for short-term forecasting of travel

times by making use of the Hong Kong Annual Traffic Census (ATC) data (Lam et al. 2002). The models for short-term prediction of the hourly traffic flows at ATC detector locations have also been investigated by Lam et al. (2006). Based on these short-term traffic forecasting results at ATC detector locations, the TFS can be used to estimate the off-line short-term travel time forecasts and the variance-covariance relationships between road links for the whole territory of Hong Kong. The off-line system is useful to travelers for their pre-trip planning. However, the real-time traffic conditions have yet been incorporated in the off-line system and hence the en-route information cannot be disseminated to drivers on real-time basis. Therefore, an extension of the off-line system to a real-time traveler information system (RTIS) is required.

In this paper, a GIS-based on-line travel time forecasting system is developed for Hong Kong. The TFS for off-line travel time forecasting system is extended to on-line travel time forecasting system. The on-line updating procedures include: (1) the use of the real-time traffic data which consist of Autotoll tag data and JTIS data; (2) the updating of variance-covariance matrices by real-time traffic data; and (3) the on-line travel time estimation by the updated variance-covariance matrices. In this paper, a case study for major road network on Hong Kong Island is used to demonstrate the performance of the RTIS.

The structure of the paper is organized as follows. The framework of the RTIS is given in the next section. It follows with the model formulation of the TFS. The on-line updating procedures are then described. A case study on Hong Kong Island network is presented together with validation results. Finally, conclusions are drawn and recommendations for further study are given.

FRAMEWORK OF RTIS

Figure 2 shows the framework of the RTIS which consists of both the off-line and on-line travel time forecasting components. In the off-line component, likely realizations of Origin-Destination (O-D) demand are obtained on the basis of the historical (prior) O-D demand and the Hong Kong ATC traffic data. The off-line solution includes the estimated link flows, travel times and the variance-covariance matrices. In the on-line component, the off-line solution and the real-time Autotoll tag data and JTIS data are integrated for the on-line travel time forecasting. Note that the Autotoll tag data are collected at the toll gates of the 10 tunnels/links in Hong Kong, where the locations of these tunnels/links are shown in Figure 3. The times of vehicles passing through the toll gates of tunnels/links are automatically recorded and stored in a database together with the identification information of these vehicles. Based on the Autotoll tag records, the travel time of a vehicle passing between any two of these 10 tunnels/links can be extracted in 5-minute interval. On the other hand, the JTIS data consists of the journey times from the three indicators to the three harbour crossings in Hong Kong that are also estimated in every five minutes. With making use of these two types of real-time traffic data, the off-line travel time forecasts and the variance-covariance matrices can be updated in every 5-minute intervals. The deliverables of the RTIS are on-line travel times, shortest path by selected origin and destination and speed map which can be displayed in website and/or 3-G mobile phones.

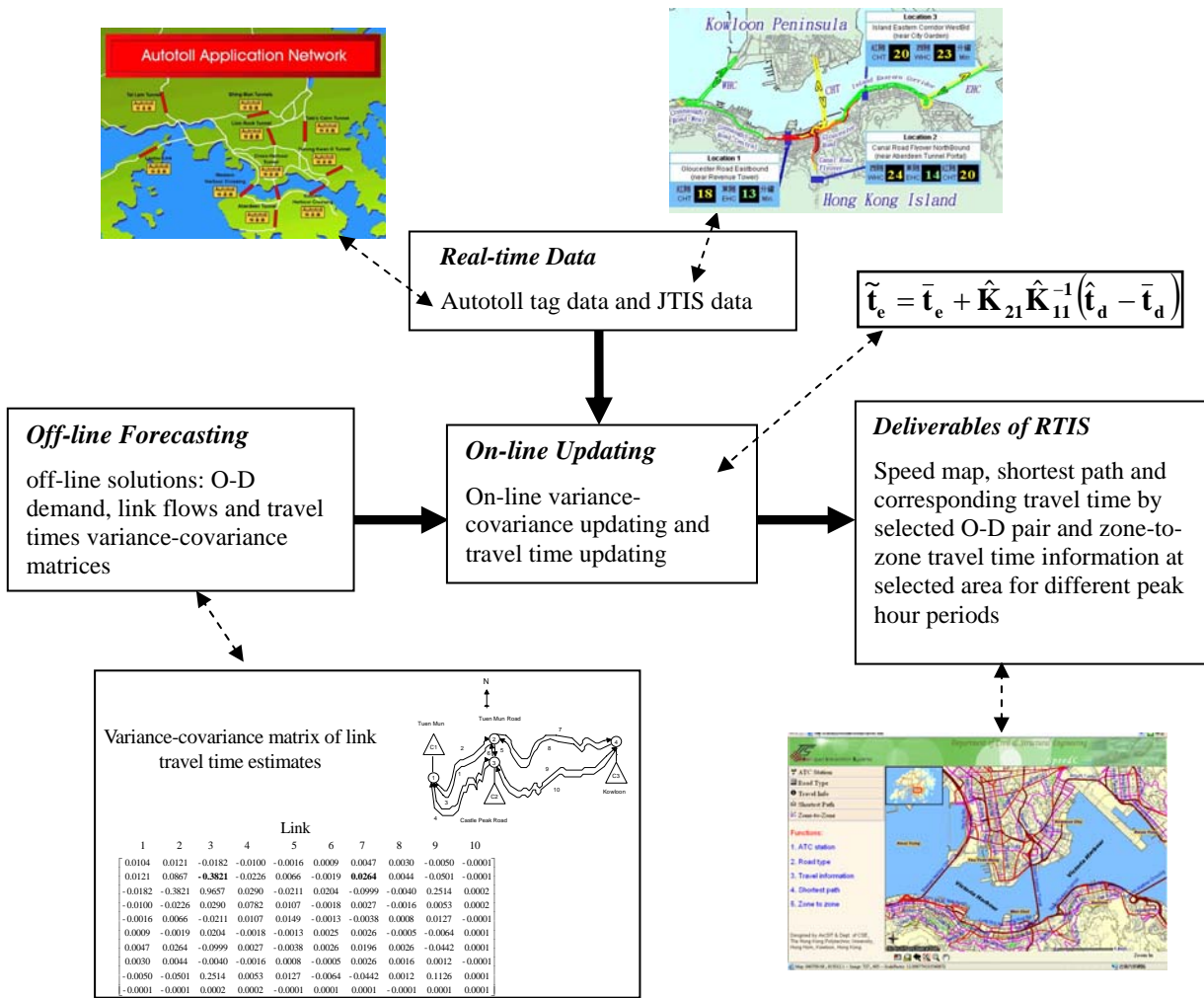


Figure 2: Framework of the Real-time Traveler Information System (RTIS)

MODEL FORMULATION OF TFS

In practice, the average link travel times can be estimated by the function of BPR (Bureau of Public Roads 1964) on the basis of the link flows and/or path flows. The link flows are usually estimated by using a conventional traffic assignment model that takes the prior O-D matrix as input. Whereas the link flows can be easily measured, it is however difficult to determine the actual O-D demand in practice. Therefore, many O-D estimators have been developed on the basis of partial link flow data collected by detectors and the prior O-D matrix used for strategic planning, which can provide additional information for more reliable estimation of the updated O-D matrix.

Different methods have been employed for the O-D matrix estimation. These methods can be generally formulated as

$$\text{Min}_{\mathbf{v}, \mathbf{q}} F_1(\mathbf{q}, \bar{\mathbf{q}}) + F_2(\mathbf{v}, \bar{\mathbf{v}}) \quad (1)$$

$$\text{s.t.} \quad \mathbf{v} = M(\mathbf{q}) \quad (2)$$

where $\bar{\mathbf{q}}$ is the prior O-D matrix, $\bar{\mathbf{v}}$ is the traffic count vector, $M(\mathbf{q})$ is the assignment map and/or link choice proportion which relates the link flows \mathbf{v} with the O-D matrix \mathbf{q} by the following relationship.

$$\mathbf{v} = \mathbf{P}\mathbf{q} \quad (3)$$

where \mathbf{P} is the proportion of trips using a particular road link by O-D pair and is considered to be constant. The O-D estimation models with the linear constraint (3) have the advantage of efficient computation, but are disadvantaged by inconsistencies between the predetermined link choice proportion and the estimated link choice proportion when assigning the estimated O-D matrix onto the road network using the user equilibrium (UE) approach.



Figure 3: Locations of Tunnels/Links with Autotoll System in Hong Kong

To overcome the inconsistency of link choice proportions, previous researches have focused on formulation of a bi-level programming problem for the O-D estimation in road network with partial traffic count data. Therefore, the bi-level programming approach, in which the lower-level problem is a UE assignment and the upper-level problem is a generalized least squares estimation, is used to ensure consistency in the link choice proportions. However, the bi-level programming approach is disadvantaged by intensive computation and the

assumption adopted in the UE assignment that all drivers have perfect knowledge of the network traffic conditions.

In view of this, a probit-type stochastic user equilibrium (SUE) assignment has been adopted in the TFS (Lam and Xu 1999) so as to offer a more realistic description of macroscopic path choice behaviours in road network with variation in travel time. It is because the SUE assignment does consider the error of travel time perceived by road users for their travel. Maher et al. (2001) presented a bi-level programming approach for the O-D estimation problems with the use of the SUE assignment. Based on their heuristic iterative algorithm, a solution algorithm has been developed for solving the bi-level programming problem of TFS. The formulation of the TFS is expressed as follows.

Upper-level Problem:

$$\text{Min}_{v,q} \quad \mu_d \sum_d (v_d - \hat{v}_d)^2 + \mu_e \sum_e (v_e - \tilde{v}_e)^2 + \mu_q \sum_{rs} (q_{rs} - \hat{q}_{rs})^2 \quad (4)$$

$$\text{s.t.} \quad \tilde{\mathbf{v}}_e = \mathbf{v}_e + \mathbf{B}_{21} \mathbf{B}_{11}^{-1} (\hat{\mathbf{v}}_d - \mathbf{v}_d), \quad \forall d \in L_d, e \in L_e \quad (5)$$

$$(1 - \rho) \hat{v}_d \leq v_d \leq (1 + \rho) \hat{v}_d, \quad \forall d \in L_d \quad (6)$$

$$(1 - \delta) \hat{q}_{rs} \leq q_{rs} \leq (1 + \delta) \hat{q}_{rs}, \quad \forall rs \in W \quad (7)$$

$$\mu_d + \mu_e + \mu_q = 1 \quad (8)$$

Lower-level Problem:

$$\text{Min}_v \quad - \sum_{rs} q_{rs} S_{rs}(v) + \sum_d v_d t_d + \sum_e v_e t_e - \sum_d \int_0^{v_d} t_d(w) dw - \sum_e \int_0^{v_e} t_e(w) dw \quad (9)$$

$$\text{s.t.} \quad v_d \geq 0, v_e \geq 0, \quad \forall d \in L_d, e \in L_e \quad (10)$$

In the upper-level problem, L_d is the set of links with detector data while L_e is the set of links without detector data. \hat{v}_d is the partial traffic counts and v_d is the assigned flows on detected link d , \tilde{v}_e is the estimated flows and v_e is the assigned flows on undetected link e . W is the set of O-D pairs. For each O-D pair rs , q_{rs} is the updated O-D demand and \hat{q}_{rs} is the prior O-D demand. ρ and δ are tolerance constants. μ_d , μ_e and μ_q are weighting factors for traffic counts, estimated link flows by link flow covariance matrix and prior O-D demand, respectively. \mathbf{B}_{11} and \mathbf{B}_{21} are partitions of the link flow variance-covariance matrix \mathbf{B} . \mathbf{B}_{11} is referred to as the variance of the flows on the links with detector data, whereas \mathbf{B}_{21} is the covariance of the flows on the links without and with detector data. In the lower-level problem, t_d and t_e are the mean travel times on detected and undetected links corresponding to flows of v_d and v_e , while S_{rs} is the expected minimal travel time between O-D pair rs . Similar to Equation (5), the estimated travel times on the links without detector data can also be calculated (see Equation (11) below) on the basis of the link travel time variance-covariance matrix \mathbf{K} generated in the lower level of the TFS.

In summary, the TFS integrates the O-D matrix estimation problem with the probit-type SUE assignment using a bi-level programming approach, in which the variation of perceived travel time errors and the fluctuations of O-D demand are considered explicitly (Lam and Xu 1999). A unique feature of the TFS is the use of the variance-covariance information of link travel times and traffic flows in the estimation process. On the basis of prior O-D demand and partial historical traffic count data, the TFS can estimate link travel times and flows for

the whole study network and update the O-D matrix simultaneously. As the results in terms of link traffic flows, travel times, O-D demand and variance-covariance matrices are static and so called the off-line solutions.

ON-LINE UPDATING PROCEDURES

In the proposed RTIS, the real-time traffic information will be updated on the basis of the off-line solutions and the real-time traffic data. The on-line updating procedures of the RTIS are outlined as follows:

Step 1: From the real-time traffic data, it can obtain

- (a) the mean travel time on the links with real-time data $\hat{\mathbf{t}}_d$; and
- (b) the updated link travel time variance $\hat{\mathbf{K}}_{11}$ and covariance $\hat{\mathbf{K}}_{12}$ and $\hat{\mathbf{K}}_{21}$ are used to replace the off-line variance-covariance matrix of link travel times $\mathbf{K} = \begin{bmatrix} \mathbf{K}_{11} & \mathbf{K}_{12} \\ \mathbf{K}_{21} & \mathbf{K}_{22} \end{bmatrix}$ with the updated variance-covariance matrix of link travel times $\hat{\mathbf{K}} = \begin{bmatrix} \hat{\mathbf{K}}_{11} & \hat{\mathbf{K}}_{12} \\ \hat{\mathbf{K}}_{21} & \mathbf{K}_{22} \end{bmatrix}$.

It should be noted that, in off-line forecasting system, $\mathbf{t} = \begin{bmatrix} \mathbf{t}_d \\ \mathbf{t}_e \end{bmatrix} \sim \text{MVN} \left(\begin{bmatrix} \bar{\mathbf{t}}_d \\ \bar{\mathbf{t}}_e \end{bmatrix}, \begin{bmatrix} \mathbf{K}_{11} & \mathbf{K}_{12} \\ \mathbf{K}_{21} & \mathbf{K}_{22} \end{bmatrix} \right)$

where \mathbf{t}_d and \mathbf{t}_e are the link travel times with respect to the links with and without detector data, \mathbf{K} is the link travel time variance-covariance matrix which is corresponding to the link flow variance-covariance matrix \mathbf{B} in TFS. Note that \mathbf{K}_{11} and \mathbf{K}_{22} are the variance of the travel times corresponding to the links with and without detector data respectively, whereas \mathbf{K}_{21} and \mathbf{K}_{12} are the travel time covariance of the links without and with detector data.

Step 2: On-line travel time updating:

Based on the partial real-time data and the updated variance-covariance matrices of link travel times, the mean travel times on the links without real-time data $\tilde{\mathbf{t}}_e$ are estimated by Equation (11),

$$\tilde{\mathbf{t}}_e = \bar{\mathbf{t}}_e + \hat{\mathbf{K}}_{21} \hat{\mathbf{K}}_{11}^{-1} (\hat{\mathbf{t}}_d - \bar{\mathbf{t}}_d) \quad (11)$$

where $\bar{\mathbf{t}}_e$ and $\bar{\mathbf{t}}_d$ are the mean link travel times obtained in the off-line system with respect to the locations without and with real-time data.

Step 3: Regenerate the on-line link flows based on the mean travel times $\hat{\mathbf{t}}_d$, $\tilde{\mathbf{t}}_e$ and the updated variance-covariance matrix of link travel times $\hat{\mathbf{K}} = \begin{bmatrix} \hat{\mathbf{K}}_{11} & \hat{\mathbf{K}}_{12} \\ \hat{\mathbf{K}}_{21} & \mathbf{K}_{22} \end{bmatrix}$.

CASE STUDY

In this paper, the Hong Kong Island (HKI) road network is used as a study network to demonstrate the performance of the proposed RTIS. For illustration, travel times are estimated in every 5-minute in the morning peak period (7:30 - 9:30) of a typical weekday in November 2005 for the case study network. Real-time traffic data available on major roads in the HKI network are illustrated in Figure 4. Given that these real-time traffic data include the Autotoll tag data of six tunnel pairs and seven sets of JTIS data. However, the paths from Aberdeen Tunnel or Canal Road Flyover to the three harbour crossings are totally overlapped. As such, either one set of these data is used in the on-line updating process. The real-time Autotoll tag data for the travel from Aberdeen Tunnel to the three harbour crossings are chosen to input to the on-line forecasting system, as the tag data are automatically recorded by the Autotoll system whereas the JTIS data are extracted from their own system. In order to check the accuracy of the travel time estimates of RTIS, some JTIS real-time data should be used for validation. In this case study, the paths from Gloucester Road to Cross Harbour Tunnel and from Island Eastern Corridor to Cross Harbour Tunnel are chosen for validation of their journey times while the remaining two sets of JTIS real-time data are used for the on-line updating together with real-time Autotoll tag data. The paths from Gloucester Road and Island Eastern Corridor to the Cross Harbour Tunnel are shown in Figure 1.

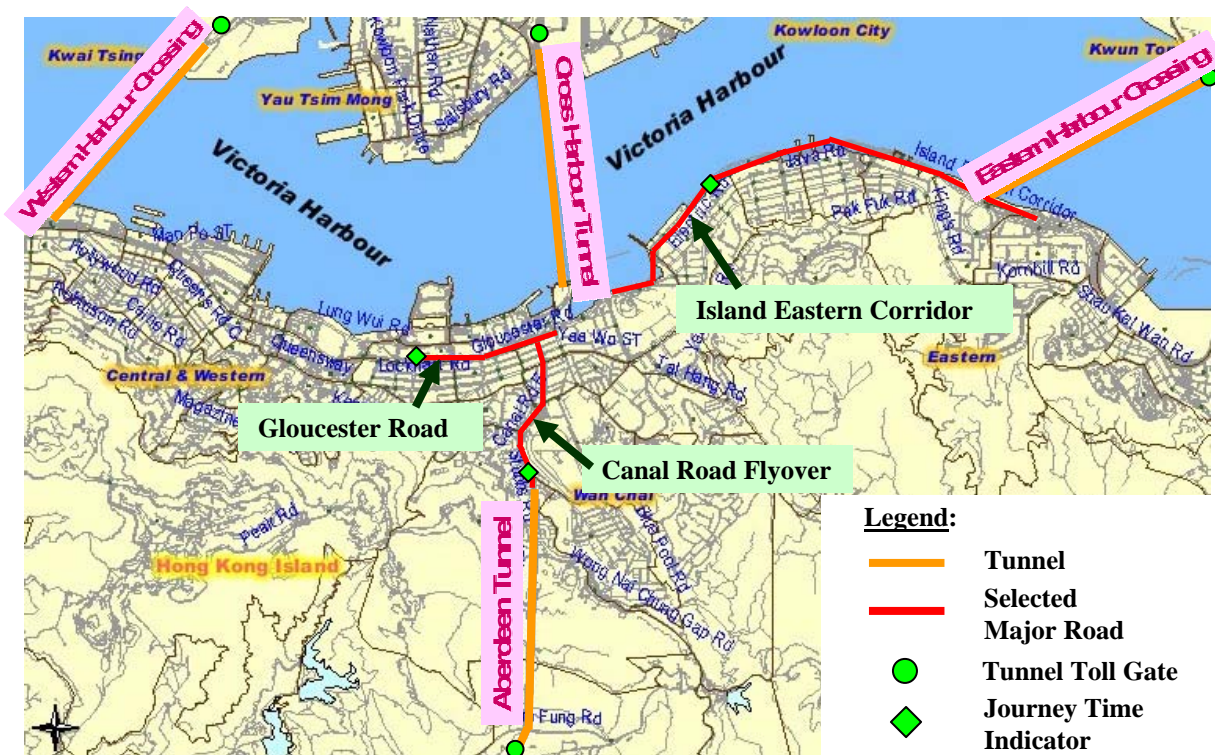


Figure 4: Locations of the Major Roads with Real-time Traffic Data

By following the on-line updating procedures, both the Autotoll and JTIS real-time traffic data are input into the system to calibrate the mean travel times and variances of the road

links in the study network. The travel times for the road links without real-time data are then estimated by the travel times on the links with real-time data and the updated variance-covariance matrices using Equation (11). The results of the estimated journey times from Gloucester Road to Cross Harbour Tunnel and from Island Eastern Corridor to Cross Harbour Tunnel are compared with that from the JTIS real-time data for model validation purpose. It is because the JTIS results are expected within 10% errors as they have been validated with observation data.

Figure 5 displays the journey times of the two chosen paths estimated by RTIS against those estimated by JTIS together with the R^2 (coefficient of determination) value. R^2 is a measure to reflect the accuracy of the journey time estimation by RTIS against that by JTIS. The nearer the R^2 value to 1.0, the higher the estimation accuracy. It can be seen in Figure 5 that 82% of journey times estimated by RTIS closes to the JTIS travel time estimates on the paths of Gloucester Road and Island Eastern Corridor to Cross Harbour Tunnel during AM peak period. The results of the model validation are acceptable; however, the accuracy and the reliability of the travel time estimates by RTIS should be further enhanced by improving the updating procedures and making use of more real-time traffic data.

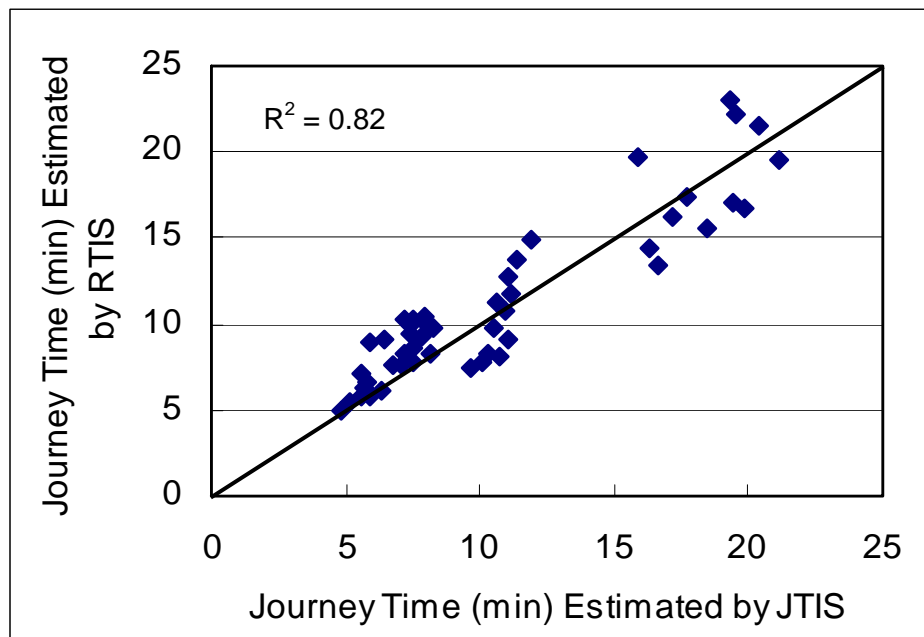


Figure 5: Estimated Journey Times from Gloucester Road and Island Eastern Corridor to Cross Harbour Tunnel during AM Peak (7:30 am - 9:30 am)

CONCLUSIONS

In this paper, a real-time traveler information system (RTIS) for Hong Kong has been presented. This RTIS was developed on the basis of the off-line solutions of the Traffic Flow Simulator (TFS) and the real-time traffic data including the real-time Autotoll tag data and Journey Time Indication System (JTIS) data. They are the major inputs for the on-line travel time forecasting. On-line updating procedures have been proposed to update the variance-

covariance matrices and link travel times. A case study for Hong Kong Island network has been carried out together with validation of the estimated travel times on selected major roads during the morning peak period of a typical weekday in November 2005. Although the validation results are acceptable, the accuracy and the reliability of the travel time forecasts should be further improved.

Further work can be carried out to enhance the accuracy of the travel time estimation by improving the on-line updating procedures and by making use of more real-time data, such as Global Positioning System (GPS) data and closed-circuit television (CCTV) data. Test car surveys will also be conducted to collect the journey times on various paths for extensive validation. The real-time traffic estimates will be fed into an on-line platform with Geographic Information System (GIS) functions for ATIS applications in Hong Kong.

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