USING AUTOMATIC VEHICLE IDENTIFICATION
AND GLOBAL POSITIONING SYSTEM DATA
FOR TRAVEL TIME ESTIMATION IN HONG KONG

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Abstract: This paper presents a Real-time Traveler Information System (RTIS) for Hong Kong, in which a novel solution algorithm is proposed for estimating current travel times using automatic vehicle identification (AVI) and global positioning system (GPS) data. The proposed algorithm can deduce the travel times on road links either with or without real-time traffic data by integration of real-time and off-line traffic database together. The on-line travel times, in RTIS, are estimated and updated at five-minute intervals based on the real-time traffic data, the off-line travel time estimates, and the simulated and real-time updated variance-covariance relationships between road links. Observation surveys are carried out during different time periods at a selected path in Hong Kong urban area to validate the RTIS travel time estimates. The estimations of travel times on the road segments of the selected path have been conducted with and without using available real-time data. The validation results show that the performance of RTIS is satisfactory and acceptable for both cases.

Key Words: Real-time traveler information system, Automatic vehicle identification, Global positioning system

1. INTRODUCTION

On-line traffic information is one of the crucial components that affect road user’s travel decisions. By the provision of effective traffic information to road users, it is not only to assist drivers in making better travel decisions, but also enhance the effectiveness and efficiency of road traffic facilities. Particularly, in the event of traffic incidents, drivers might avoid traffic congestion and/or delays, through consulting means of traffic advisory devices such as variable message signs, cellular phones or the internet, in accessing relevant traffic incident and guidance information. Drivers are then able to make their route choice decisions based on a combination of the received estimated travel time/speed information and their own driving experience.

There are several techniques for real-time travel time data collection, including electronic distance-measuring instruments, electronic license plate matching, cellular phone tracking, automatic vehicle identification (AVI), automatic vehicle location (AVL), and video imaging techniques. Liu and Haines (1996) and Turner (1996) have compared different data collection techniques and summarized their advantages and disadvantages. It was found that, in general, AVI is a proven technology for providing area-wide real-time travel time data. The accuracy
of travel time and speed data is high and operating cost is low. The primary application of AVI is electronic toll collection; however, the use of AVI technology for real-time travel time estimation, monitoring and incident detection is gaining popularity (for example, Hellinga and Knapp, 2000; Hellinga, 2001; Dion and Rakha, 2006).

Besides AVI technology, AVL such as global positioning system (GPS) technology is also a proven technology for real-time data collection and route guidance. Several GPS-based technologies have been developed in recent years for travel time studies (Guo and Poling, 1995; Zito et al., 1995; Quiroga and Bullock, 1998). Moreover, a number of states in U.S. have tested the feasibility of using such system to measure vehicle speed (Wang and Nakamura, 2003). Using GPS technology, real-time travel information can be collected at frequent intervals and not limited to fixed route or checkpoints. However, AVL technique is generally based on a limited number of probe vehicles, which means that area wide coverage is limited.

In Hong Kong, real-time traffic information is available at website portal (http://traffic.td.gov.hk/selection_e.htm) in which images are provided from closed-circuit television (CCTV) cameras located at about 120 strategic roads and road junctions in the urban areas. Also, a prototype of advanced traveler information system, Journey Time Indication System (JTIS), was introduced in Hong Kong in mid-2003. This system provides current traffic conditions in terms of travel times via displays on three gantry signs near major roads along Hong Kong harbour side. The estimated journey times are calculated by using speed detection cameras, which capture spot speeds on routes, installed at the approach roads to the three cross-harbour tunnels and in-vehicle GPS receivers installed on buses. The JTIS displays are updated at five-minute intervals. However, the coverage of JTIS is limited to the major approach roads to the three cross-harbour tunnels in Hong Kong Island.

This paper presents a novel solution algorithm for a Real-time Traveler Information System (RTIS) to estimate the current travel times in Hong Kong with the use of both AVI and GPS data. The main contribution of the RTIS solution algorithm is to integrate both off-line travel times and real-time AVI and GPS data for provision of area-wide traffic information in the whole network of Hong Kong. Unlike the other existing AVI algorithms, the RTIS estimates the travel times on both road links either with or without real-time data available. The on-line travel times, in RTIS, are estimated and updated based on the real-time traffic data, the off-line travel time estimates and the simulated variance-covariance relationships between road links. Real-time Autotoll tag data, which are a kind of AVI data in Hong Kong, are adopted in the RTIS together with GPS data extracted from commercial vehicles. The travel time is estimated on the basis of the journey time of those vehicles equipped with electronic tags at tunnel toll-gates as well as the travel speed of the commercial vehicles equipped with GPS receivers. The advantages of making use of both AVI and GPS data are the large sample size of AVI data along the paths between tunnels in Hong Kong, whereas travel times on road segments can be updated by the GPS data. The off-line travel time estimates and the corresponding variance-covariance matrices are obtained by a traffic flow simulator (see Section 2 for description). On the basis of these real-time and off-line traffic data, the current traffic conditions on Hong Kong major roads can be updated in a geographic information system (GIS)-based RTIS website portal at five-minute intervals. Survey study for a major road network in Hong Kong urban area is presented in this paper to validate the RTIS travel time estimates.

The remainder of the paper is structured as follows. Background of the RTIS development is
presented in the next section. The framework of the RTIS is given in the third section. The proposed RTIS algorithm which consists of data filtering algorithm and on-line updating process is then described in the forth section. The fifth section presents a survey study for validation of the RTIS results. The GIS-based RTIS website portal is shown in the sixth section. Finally, conclusions are given together with recommendations for further study.

2. BACKGROUND

Lam et al. (2002) have developed an off-line traffic forecasting system for short-term travel time forecasting and empirical validation of the forecasting results has also been given (Lam et al., 2005). In this system, a traffic flow simulator (TFS) has been calibrated for short-term forecasting of travel times by making use of the Hong Kong Annual Traffic Census (ATC) data. The ATC is a collection of traffic-related data of the year at about 110 locations with permanent automatic traffic detectors. 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. Based on these short-term traffic forecasting results at ATC detector locations (Lam et al., 2006), the TFS can be used to estimate the off-line mean link travel times and the variance-covariance relationships between road links for the whole territory of Hong Kong.

The off-line short-term travel time forecasting system is useful to travelers for pre-trip planning. However, the real-time traffic conditions have not yet been incorporated in the off-line system and hence travelers are unable to access current traffic information on real-time basis whilst they are traveling on roads. Moreover, the Hong Kong JTIS only covers a limited number of roads along the harbour side in Hong Kong Island. Therefore, there is a need to provide update and reliable travel time/speed estimates for the whole Hong Kong territory. In view of this, an on-line traffic information system has been proposed specifically for Hong Kong, namely; Real-time Traveler Information System (RTIS).

The RTIS for Hong Kong has been recently developed by The Hong Kong Polytechnic University in collaboration with the Autotoll Limited (Tam and Lam, 2006a; 2006b). In their studies, real-time AVI data are the primary data for travel time estimation in Hong Kong. Moreover, a fixed threshold of travel time window was adopted for filtering the AVI data at the early stage of the system development. Enhancement of the RTIS is given in this paper, in which GPS data are incorporated in the system for real-time travel time estimation together with AVI data. Data filtering algorithm for AVI data is also improved in the RTIS in order to provide a dynamic travel time window for capturing both stable and unstable traffic conditions in Hong Kong. In addition, in the paper, not only the travel time estimates on the road links with real-time traffic data but also those on the road links without real-time data are validated by observation data in Hong Kong.

3. RTIS FRAMEWORK

The purposes of the RTIS are to provide update, reliable traffic information as well as to communicate the latest traffic information and advisories to the road users. Travel times/speeds are easily updated in RTIS once every five minutes, by making use of real-time traffic data and results of the off-line travel time forecasting system. The real-time traffic data are Autotoll tag records that are being used for electronic toll collection in Hong Kong and GPS data provided by the Autotoll Limited, whereas the off-line estimates are the mean travel
times by link and the link travel time variance-covariance matrices.

In Hong Kong, there are two types of toll-booths in the toll area of road tunnels. The first type of these toll-booths is Autotoll lanes which are mainly for vehicles installed with Autotoll tags, whereas the second type of toll-booths is manual toll lanes for other vehicles without Autotoll tags. There are about 559,000 licensed vehicles in Hong Kong since August 2007. Over 220,000 of these cars have been installed with Autotoll tags to enable toll charge payments at ten road tunnels or links in Hong Kong. The market penetration of Autotoll tags is around 40%. The locations of the tolled tunnels/links are shown in Figure 1. Autotoll tag data are collected at the toll-gates of these ten tunnels/links. The times of vehicles passing through the tunnels/links toll-gates are automatically recorded, processed and transmitted to the central computer system together with the identification information of these vehicles. Based on the Autotoll tag time records, the travel times of vehicles passing between consecutive tunnels/links are computed at five-minute intervals.

![Figure 1 Locations of tunnels/links with Autotoll system in Hong Kong](image)

The Autotoll tag data can provide the real-time path travel times of vehicles traveling from one tunnel to another tunnel, however, the travel times on the road segments along the routes may not be accurately estimated. Therefore, GPS data of commercial vehicles provided by the Autotoll Limited are adopted for updating the link travel times. Autotoll GPS service provides real-time tracking of commercial vehicle locations in order to monitor the vehicles performance. The tracking data include vehicle ID, record dates and time, local coordinates, traveling speed and vehicle direction, which are collected at regular sampling periods. GPS signals of a probe vehicle traveling on a route are shown in Figure 2. As the coordinates of the vehicle positions are known, the path of the vehicle together with its corresponding travel times can be traced from the data.

Figure 3 shows the framework of the proposed RTIS which consists of both off-line and on-line travel time estimation components. As Autotoll tag travel time data are collected from the vehicles passing through consecutive tunnels, it is necessary to filter out the outlier observations because vehicles may make stops or detour between two tunnels. The valid real-time AVI data, the GPS data and the offline estimates by TFS are then integrated for on-line travel time updating at five-minute intervals. The deliverables of RTIS are speed maps, the shortest path and corresponding travel time of a selected origin-destination pair, which can be displayed on website and/or 3-G cellular telephones.
Figure 2 GPS signals of a probe vehicle

Figure 3 Framework of RTIS

- Real-time Autotoll tag data (i.e. AVI data)
- Annual Traffic Census data and recent tunnel counts
- Traffic Flow Simulator (TFS)
- Off-line estimates

Data Filtering Algorithm for AVI Data

Valid real-time Autotoll tag data

On-line Updating Process

RTIS Website Portal (updated once every 5 minutes)

* Off-line results consist of the mean travel time by link and the link travel time variance-covariance matrices.
4. RTIS ALGORITHM FOR REAL-TIME TRAVEL TIME ESTIMATION

4.1 RTIS Data Filtering Algorithm for AVI Data
AVI tag readers provide time stamps at which vehicles pass successive monitoring stations or checkpoints. Data that are gathered by these readers require some form of filtering in order to remove outlier observations. The outlier observations may be due to stops or detour takings by vehicles. Since these vehicles would experience a travel time that is atypical, these observations should therefore be removed from the data set of valid observations to avoid producing erroneous travel time estimates. The current state-of-the-art algorithms usually use a fixed travel time window for data filtering, for example, ±20% from the average travel time associated with observations made in the previous time interval in TranStar algorithm in Houston (http://traffic.houstontranstar.org) and TransGuide algorithm in San Antonio (Southwest Research Institute, 1998). However, such data filtering algorithms may not be capable for tracking the changes in traffic conditions as they depends on the interval of updating window and the threshold parameters. As a result, some valid data are filtered out whereas some invalid data are included for travel time estimation. Recently, a data filtering algorithm has been proposed by Dion and Rakha (2006) to filter AVI travel time data at low levels of market penetration. Their algorithm utilizes a series of filters to identify valid data within a dynamically varying validity window on selected paths between entry and exit points.

Similar to Dion and Rakha (2006)’s algorithm, the proposed data filtering algorithm for RTIS is designed and adapted for real-time travel time estimation using AVI data from entry point to exit point on selected paths, particularly for Hong Kong. The main difference between the proposed RTIS algorithm with the Dion and Rakha’s algorithm is that the proposed RTIS algorithm can provide travel time estimates on all the links either with or without real-time data by using the off-line simulated and real-time updated variance-covariance relationships of the link travel times, while Dion and Rakha’s algorithm only adopts the filtered real-time travel time data for estimation of the current travel times on the selected paths with AVI data. Moreover, in the proposed RTIS data filtering algorithm, some modifications are made to the Dion and Rakha’s algorithm. The objective of such modifications is to filter out the local AVI data reasonably for the Hong Kong road network in order to obtain more accurate travel time estimates. For example, some of the parameters adopted in the proposed algorithm are expressed as sample-size-dependent functions rather than given constants. As Hong Kong traffic condition is more dynamic than that in U.S. throughout a typical day, the use of sample-size-dependent functions would be more flexible to capture both stable and unstable traffic conditions in Hong Kong. It should be also noted that the parameters adopted in the RTIS data filtering algorithm are calibrated using the empirical data collected from observation surveys in Hong Kong.

Figure 4 demonstrates the travel time window for an AVI dataset from Lion Rock Tunnel to Cross Harbour Tunnel in Hong Kong by using the RTIS algorithm with the updating interval of five minutes. It should be noted in the RTIS algorithm that observations fall inside the travel time window may not be considered as valid according to the sequence of vehicle entry and exit times on the path. However, if a fixed threshold of ±20% from the average travel time is adopted, some of the invalid data identified by RTIS algorithm become valid while some valid data in RTIS algorithm are filtered out.
The RTIS data filtering algorithm provides a dynamic travel time window which handles both stable and unstable traffic conditions and functions properly with Hong Kong Autotoll tag data on real-time basis. Applications of the proposed filtering algorithm to three datasets of observed travel times, that were collected at a selected path during AM peak, off-peak and PM peak periods on a typical Friday in May 2006, demonstrate the ability of the proposed algorithm to correctly track the underlying average roadway travel times, while resulting with the lowest mean and maximum estimation errors in comparison with those of the three existing AVI travel time estimation algorithms: TranStar, TransGuide and Transmit systems in U.S. (Chan et al., 2007).

![Figure 4 Travel time window for an AVI dataset from Lion Rock Tunnel to Cross Harbour Tunnel in Hong Kong](image)

**4.2 RTIS On-line Updating Process**

The major contribution of this study is to develop a solution algorithm for estimating the travel times on the road links either with or without real-time traffic data available by integration of real-time valid AVI data, GPS data, off-line travel time estimates and variance-covariance relationships of link travel times together. The on-line updating process for RTIS is outlined in the following Steps 1 to 6 and illustrated in Figure 5.

Step 1: Obtain the average path travel times and the variances of travel times on the predetermined paths from the valid real-time AVI data.

Step 2: Compute the updated path travel time $t_{AB,k}$ from the entry point (tunnel A) to the exit point (tunnel B) at time interval $k$ by the combination of the off-line and the real-time average path travel times with the use of a weighting factor, $W_{AB,k}$.

$$t_{AB,k} = (1 - W_{AB,k}) \cdot t_{AB,k}^{off} + W_{AB,k} \cdot t_{AB,k}^{rt} \tag{1}$$

where $t_{AB,k}^{off}$ is the off-line average path travel time from A to B at time interval $k$ and $t_{AB,k}^{rt}$ is the average travel time between A and B obtained by the valid real-time AVI data at time
interval $k$. The weighting factor $w_{AB}^k$ is depended on the number of valid AVI data at the time interval $k$, which is calculated by Equation (2) below. The more the number of valid AVI data, the larger the weighting factor. It should be noted that if there is no valid real-time AVI data at the current time interval $k$, $w_{AB}^k$ is then set to be the weighted path travel time from A to B at previous time interval $k-1$. In practice, real-time data may not be adequate and/or available for all links within the study area, the use of the off-line travel time data is therefore important for providing area-wide coverage in estimation of link travel times.

$$
w_{AB}^k = \begin{cases} 
1 - (1 - \varphi)^{n_{vk}} & \text{if } n_{vk} > 0 \\
w_{AB}^{k-1} & \text{if } n_{vk} = 0
\end{cases}$$

(2)

Where $n_{vk}$ is the number of valid AVI data at time interval $k$ and $\varphi$ is a predetermined parameter calibrated by the empirical data.

Step 3: Aggregate the GPS speed data into road segment travel time data for updating the off-line link travel times along the predetermined paths between the entry and the exit points.

Step 4: Estimate the real-time mean link travel times on each of the predetermined paths, $\hat{\iota}_d$, based on the updated path travel time $t_{AB}^k$ and the updated link travel times. As the number of AVI data is more than GPS data, it is believed that AVI data provides a more accurate path travel time estimates. Therefore, the sum of the mean link travel time estimates should be equal to the updated path travel time $t_{AB}^k$. However, the travel time estimates on the road segments are based on the distribution of the link travel times updated by GPS data.

Step 5: Update the off-line variance-covariance matrix of link travel times $K = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}$ by the path travel time variances obtained from the valid real-time AVI data. The updated variance-covariance matrix of link travel times is $\hat{K} = \begin{bmatrix} \hat{K}_{11} & \hat{K}_{12} \\ \hat{K}_{21} & \hat{K}_{22} \end{bmatrix}$, where $\hat{K}_{11}$ is the updated variance of the travel times corresponding to the links with real-time data, $\hat{K}_{12}$ is the updated travel time covariance of the links with and without real-time data, $\hat{K}_{21}$ is the updated travel time covariance of the links without and with real-time data, and $\hat{K}_{22}$ is the travel time variances corresponding to the links without real-time data obtained from the off-line system.

Step 6: Estimate the mean travel times on the links without real-time data $\hat{\iota}_e$ using Equation (3) (Bell, 1991; Lam et al., 2002) based on the off-line travel time estimates on the links without real-time data, the updated variance-covariance matrices of link travel times and the travel time estimates on the links with real-time data obtained in Step 4.

$$
\hat{\iota}_e = \bar{\iota}_e + \hat{K}_{21} \hat{K}_{11}^{-1} (\hat{\iota}_d - \bar{\iota}_d)
$$

(3)

Where $\bar{\iota}_e$ and $\bar{\iota}_d$ are the mean link travel times obtained in the off-line system with respect to the road links without and with real-time data. $\hat{\iota}_d$ is the travel time estimates on the links with real-time AVI data computed in Step 4, $\hat{K}_{21}$ and $\hat{K}_{11}$ are the sub-matrices of the updated variance-covariance matrix of link travel time as defined above.
Figure 5 RTIS algorithm for real-time travel time estimation

- **Offline path travel times**
- **Offline link travel times**
- **Updated variance-covariance matrix of link travel times**
- **Offline variance-covariance matrix of link travel times**
- **Variances of real-time path travel time by valid AVI data**
- **Updated link travel times**
- **Link travel time estimates by Eq. (3) (on links without real-time traffic data)**
- **Traffic Flow Simulator (TFS)**
- **AVI data filtering algorithm**
- **Real-time average path travel times by valid AVI data**
- **Real-time average link travel times by GPS data**
- **Path travel times updated by Eq. (1)**
- **Link travel time estimates (on links with real-time traffic data)**
5. SURVEY STUDY FOR RTIS VALIDATION

Kowloon Central road network is used as a test network in this survey study to demonstrate the performance of the developed RTIS in practice. The path from the Lion Rock Tunnel (LRT) to the Cross Harbour Tunnel (CHT) was selected for journey time estimation. This route was chosen as most of the major roads in Kowloon Central urban area take this path, whereas CHT is the most congested of the three road tunnels connecting Kowloon Peninsula with Hong Kong Island. The location of the selected path between LRT and CHT is illustrated in Figure 6. In order to investigate the accuracy of travel time estimates on the road segments along the path, a checkpoint is set at Homantin (HMT) to check whether the RTIS can capture the spillback traffic queue from the toll plaza of CHT in the southbound traffic direction or not. The distance of the road section from LRT to HMT is 5.01 km with average speed limit of 60 km per hour, whereas that from HMT to CHT is 1.22 km with average speed limit of 65 km per hour. Travel times of the road sections from LRT to HMT and from HMT to CHT were estimated at five-minute intervals during the morning peak (08:00-10:00), inter-peak (14:00-16:00) and evening peak (17:00-19:00) periods of a typical weekday on 26 May 2006 (Friday) for the survey study.

In this survey study, the Autotoll tag records collected by tag readers at the toll-gates of LRT and CHT are used for travel time estimation. Moreover, GPS receivers are installed in ten probe vehicles for travel along the selected path to record time, local coordinates and speed of the vehicles every 15 seconds.

Figure 6 Location of the selected path between Lion Rock Tunnel and Cross Harbour Tunnel in Hong Kong
In order to validate the RTIS travel time estimates, observed journey times of all vehicles traveling on the selected path were collected by a manual license plate matching survey carried out in the same time periods on the same day. As aforementioned, there are two types of toll-gates before entering the road tunnels or bridges in Hong Kong. One type of these toll-gates is mainly for vehicles installed with Autotoll tags and hence the observations from Autotoll tag records are obtained. Another type of toll-gates is used for other vehicles without Autotoll tags, at which there is no toll-tag observation and the license plate readings are recorded by video cameras during the survey periods. Therefore, the combination of toll-tag observations and license plate readings are the total observations at all the toll-gates for a particular road tunnel or link. In this survey study, video recording equipments were set at the toll plazas of LRT and CHT to record the license plate readings of vehicles used manual toll-gates. The license plate readings of vehicles recorded at LRT were then matched with those recorded at CHT using a computer program. The journey times of the matched vehicles traveling from LRT to CHT were then computed for RTIS validation together with the journey times obtained from Autotoll tag records.

Travel time estimates on two road sections, from LRT to HMT and from HMT to CHT, are compared with the observed travel times of the total observations traveling along the selected path. The estimation results are evaluated in terms of two measures of performance; namely, the mean absolute error (MAE) and the mean absolute percentage error (MAPE) so as to determine the accuracy of the RTIS estimates. Table 1 shows the MAEs and the MAPEs of the travel time estimates for the three survey periods together with the number of observations and the observed average travel times. It can be seen in Table 1 that the MAEs are about one minute on the two road sections for all the three periods. In terms of percentage, less than 15% of MAPEs are found on average. The validation results show that the RTIS can provide reliable travel time estimates to users.

Table 1 Mean absolute errors and mean absolute percentage errors of the travel time estimates of the selected path during AM, inter and PM peak periods of 26 May 2006 (Friday)

<table>
<thead>
<tr>
<th></th>
<th>AM peak (08:00-10:00)</th>
<th>Inter-peak (14:00-16:00)</th>
<th>PM peak (17:00-19:00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of</td>
<td>885</td>
<td>429</td>
<td>743</td>
</tr>
<tr>
<td>observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>10.4</td>
<td>8.4</td>
<td>9.5</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>travel time (min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAE (min)</td>
<td>1.4</td>
<td>1.2</td>
<td>1.2</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>13</td>
<td>14</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 1 Mean absolute errors and mean absolute percentage errors of the travel time estimates of the selected path during AM, inter and PM peak periods of 26 May 2006 (Friday)

<table>
<thead>
<tr>
<th></th>
<th>AM peak (08:00-10:00)</th>
<th>Inter-peak (14:00-16:00)</th>
<th>PM peak (17:00-19:00)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of</td>
<td>990</td>
<td>835</td>
<td>736</td>
</tr>
<tr>
<td>observations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Observed</td>
<td>12.1</td>
<td>12.4</td>
<td>12.6</td>
</tr>
<tr>
<td>average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>travel time (min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MAE (min)</td>
<td>1.3</td>
<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>MAPE (%)</td>
<td>11</td>
<td>9</td>
<td>10</td>
</tr>
</tbody>
</table>

In order to check the accuracy of the travel time estimates on the road sections without real-time data, two experiments were conducted on the selected path. One is to make use of the real-time AVI data from HMT to CHT to estimate the travel times from LRT to HMT (i.e., assuming that the AVI data from LRT to HMT are not available), whereas another experiment is to use the AVI data from LRT to HMT to deduce the travel times from HMT to CHT (i.e.,
real-time AVI data from HMT to CHT are assumed to be unavailable). However, GPS data are still used to update the offline link travel time estimates in both experiments. An Autotoll tag reader has installed at the checkpoint HMT to collect such additional real-time AVI data for testing. The results of the two experiments are then compared with the observed travel times from LRT to HMT and from HMT to CHT respectively.

The MAEs and the MAPEs for each of the road sections are shown in Table 2. As compared with the results in Table 1, the estimation errors in the two experiments become larger as the real-time AVI data of corresponding road segments are not input to the RTIS for estimation. However, the results are still acceptable with the MAPEs of less than 20% in the three study periods. It is also noted that the MAPEs of experiment 1 (i.e., using the real-time AVI data from HMT to CHT to estimate the travel times from LRT to HMT) is less than those of experiment 2 (i.e., using the real-time data from LRT to HMT to estimate the travel times from HMT to CHT). It is because the spillback traffic queue from CHT significantly affects the traffic condition on the road section from LRT to HMT. Thus, with the available real-time traffic data from HMT to CHT, the estimation of travel time from LRT to HMT is more accurate. However, the traffic queue may not be captured when only the traffic data from LRT to HMT are available. In the other words, estimating the average travel times of upstream traffic by downstream traffic data is more accurate than using upstream traffic data to estimate the average travel times of downstream traffic.

Table 2 Mean absolute errors and mean absolute percentage errors of the travel time estimates on the two road sections of the selected path in experiments 1 and 2

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1</th>
<th>Experiment 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(travel time estimates from LRT to HMT using real-time traffic data from HMT to CHT)</td>
<td>(travel time estimates from HMT to CHT using real-time traffic data from LRT to HMT)</td>
<td></td>
</tr>
<tr>
<td>AM peak (08:00-10:00)</td>
<td>1.7</td>
<td>1.3</td>
<td>2.1</td>
</tr>
<tr>
<td>Inter-peak (14:00-16:00)</td>
<td>1.3</td>
<td>1.3</td>
<td>2.0</td>
</tr>
<tr>
<td>PM peak (17:00-19:00)</td>
<td>1.3</td>
<td>1.5</td>
<td>2.3</td>
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<tr>
<td></td>
<td>MAE (min)</td>
<td>MAE (min)</td>
<td>MAPE (%)</td>
</tr>
<tr>
<td></td>
<td>MAPE (%)</td>
<td>MAPE (%)</td>
<td></td>
</tr>
<tr>
<td>AM peak (08:00-10:00)</td>
<td>16</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>Inter-peak (14:00-16:00)</td>
<td>15</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>PM peak (17:00-19:00)</td>
<td>14</td>
<td>18</td>
<td></td>
</tr>
</tbody>
</table>

6. GIS-BASED RTIS WEBSITE PORTAL

In order to disseminate up-to-date geo-referenced traffic information to road users, a GIS-based website portal is developed for presentation of the RTIS results. In this website portal, the users can access to various traffic information such as average traffic speed on road links, the shortest path for a selected origin-destination pair together with the corresponding path travel time. The link speed information is derived from the link length and the link travel time estimates. Such traffic information is updated at five-minute intervals and the latest results are shown on the website portal. This RTIS has already been subscribed by Hong Kong Transport Department. A real-time speed map for the main routes in Hong Kong North, Kowloon and New Territories South areas, shown in Figure 7, has been launched on Hong Kong Transport Department’s website since January 2007 (http://rtis.td.gov.hk/rtis). In the RTIS speed map, the speeds of the links with real-time AVI data available are considered as directly deduced traffic speeds, whereas the speeds of the links without real-time data are indirectly deduced traffic speeds. Real-time CCTV images are also provided in the speed map.
7. CONCLUSIONS

In this paper, a GIS-based real-time traveler information system (RTIS) for Hong Kong has been presented. This RTIS is a unique system to provide the most up-to-minute territory-wide travel time estimates to road users in Hong Kong. A novel solution algorithm has been developed for estimating the current travel times by integration of both the real-time AVI and GPS data and the off-line travel time estimates by a traffic flow simulator. In the RTIS, an enhanced AVI data filtering algorithm has been adapted for capturing the dynamic traffic conditions in Hong Kong. The on-line travel times, in RTIS, are estimated and updated based on the real-time traffic data, the off-line travel time estimates, and the simulated and real-time updated variance-covariance relationships between road links.

RTIS validation have been carried out by using the empirical data collected from a manual license plate matching survey on the path between Lion Rock Tunnel and Cross Harbour Tunnel during morning peak, inter-peak and evening peak periods of a typical weekday. The validation results are promising with the mean absolute errors of about one minute for travel time estimates on the two road segments of the selected path. Moreover, two experiments were conducted on the selected path to check the accuracy of travel time estimates on the road sections without real-time data available. The results show that the performance of RTIS is still satisfactory and acceptable on the road segments without real-time data.

Further study is being carried out to investigate the effects of weather conditions on travel times. The RTIS will also be enhanced by incorporating short-term travel time prediction and incident detection. Moreover, appropriate number and locations of AVI readers will be determined in order to enhance the accuracy of travel time estimation. In addition, further study will be carried out to disseminate the RTIS results to public via 3-G cellular telephones.
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REFERENCES


