Using Automatic Vehicle Identification Data for Estimating Current Travel Times in Hong Kong

K.S. CHAN
Postdoctoral Fellow
Department of Civil and Structural Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Tel.: +852-2766-6056
Fax: +852-2334-6389
E-mail: cekschan@polyu.edu.hk

Mei Lam TAM
Research Fellow
Department of Civil and Structural Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Tel.: +852-2766-4485
Fax: +852-2334-6389
E-mail: cemltam@polyu.edu.hk

Mei Ling TAM
Research Associate
Department of Civil and Structural Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Tel.: +852-2766-4485
Fax: +852-2334-6389
E-mail: susanna.tam@polyu.edu.hk

William H.K. LAM
Chair Professor
Department of Civil and Structural Engineering,
The Hong Kong Polytechnic University, Hong Kong, China
Tel.: +852-2766-6045
Fax: +852-2334-6389
E-mail: cehklam@polyu.edu.hk

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ABSTRACT

This paper presents a Real-Time Travel Information System (RTIS) for Hong Kong, in which a solution algorithm is proposed for estimating current travel times using automatic vehicle identification (AVI) data. The RTIS solution algorithm estimates the current travel time by integrating both the filtered on-line travel time data and off-line travel time estimates. The on-line travel time data are filtered based upon the following four factors: expected average journey time and journey time variability in previous and current time intervals; number of consecutive intervals without any readings since the last recorded trip time; number of consecutive data points either above or below the validity range and validity of observed travel times on a given path based on the sequence of vehicle entry and exit times from the path. The proposed RTIS solution algorithm can update the current travel time database once every 5 minutes on the basis of both the filtered on-line travel times and the off-line travel time forecasts. The RTIS solution algorithm can integrate off-line and on-line data together for provision of area-wide traffic information in the whole network of Hong Kong. In addition, it can be extended to facilitate the incorporation of other real-time data such as the GPS data so as to improve accuracy of the travel time estimation. A case study is carried out in Hong Kong to collect observed data for validation of the results of the proposed RTIS solution algorithm and comparison with the results of the other three existing AVI travel time estimation algorithms: TransGuide, TranStar and Transmit algorithms.

INTRODUCTION

The rapid development of Intelligent Transportation Systems (ITS) and electronic information and communication technologies has alerted researchers to the potential of the application of advanced technologies to alleviate traffic congestion, particularly in large Asian cities like Hong Kong. The Advanced Traveler Information System (ATIS) is one of the options adopted in many Western countries. ATIS detectors are located at some sections of road networks to collect historical and real-time data such as traffic flow and speed data. Link flows and travel times within networks can be estimated based on these partially detected data and delivered to drivers by various means, such as variable message signs, mobile phones and the internet. Drivers are then able to make route choice decisions based on a combination of the received estimated travel times and their own driving experience.

An ATIS prototype, Journey Time Indication System (JTIS), was introduced in Hong Kong, mid-2003. This system provides current traffic conditions in terms of travel times via displays on gantry signs near major roads along the Hong Kong harbour side (http://jtis.td.gov.hk/X_RTIS/JTIS_Seg_Webpage/RoadTrafficV2.asp?T=1&C=2). 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. This JTIS is being planned for extension to other urban areas in Hong Kong. It was estimated that, with the introduction of the JTIS, the traveling time of 5% of the daily 260,000 passenger trips crossing the harbour during the peak hours could be reduced by three 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/SwitchCenter.do). There are a total of 119 CCTV images captured by the CCTV cameras have been broadcast to the public via the internet and these 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.

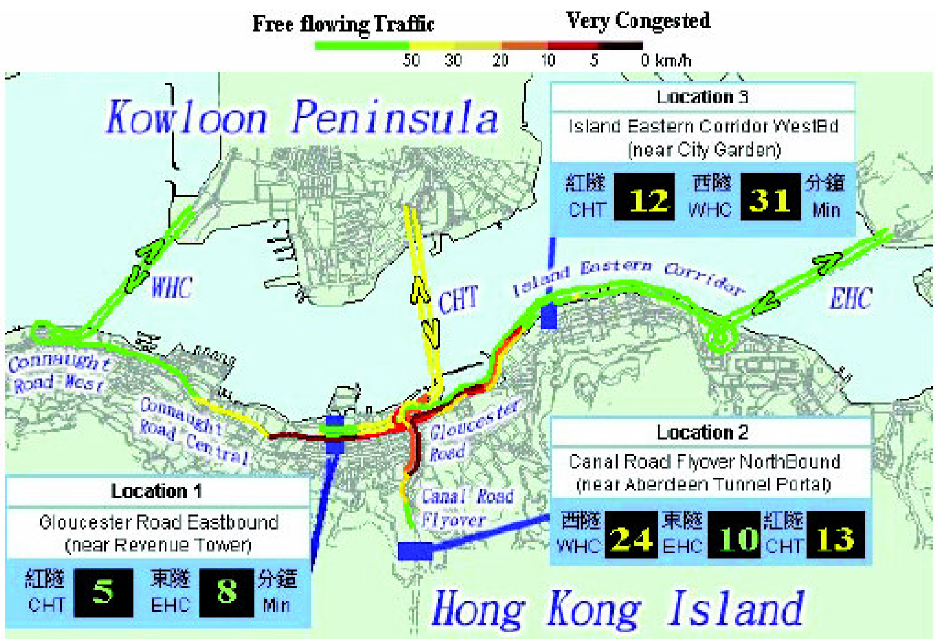

FIGURE 1 Journey Time Indication System (JTIS)

In view of this, Lam *et al.* (*1*) have developed an off-line short-term traffic forecasting platform with Geographic Information System (GIS) functions for Hong Kong. In this system, a Traffic Flow Simulator (TFS) (*2*) has been calibrated for short-term forecasting of travel times by making use of the Hong Kong Annual Traffic Census (ATC) data. The models for short-term prediction of the hourly traffic flows at ATC detector locations have also been investigated by Lam *et al.* (*3*). 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. Using these off-line travel time estimates, a website called SpeedOnRoad has been developed by The Hong Kong Polytechnic University to provide Hong Kong traffic information via the internet. However, the real-time traffic conditions have not yet been incorporated in the off-line system and hence travelers are unable to access road condition information whilst on route and on a real-time basis. In order for information to be given to drivers on route, a Real-Time Travel Information System (RTIS), with such a capacity, is required for Hong Kong. The on-line travel time forecasting system (*4, 5*) is based on the off-line results obtained by TFS and real-time traffic data. One of the major products of this study is a website portal which delivers real-time traffic information to users via the internet.

There are three existing automatic vehicle identification (AVI) travel time algorithms include the TranStar system in Houston (*6*), the TransGuide system in San Antonio (*7*) and the Transmit system in the New York/New Jersey metropolitan area (*8*) that are widely used for real-time estimation of roadway travel times using AVI data. Moreover, Eisele *et al.* (*9*) adopted the nonparametric loess statistical procedure to estimate the travel time distribution using the AVI data. A comparative assessment has also been carried out to investigate the use of AVI tag technologies to obtain the individual travel times (*10*). Recently, a new AVI travel time algorithm has been developed by Dion and Rakha (*11*) which utilizes a robust data-filtering procedure that identifies valid data within a dynamically varying validity window.

In this paper, a novel solution algorithm is proposed for the Hong Kong RTIS to estimate the current travel time using AVI data in Hong Kong. The main contribution of the RTIS solution algorithm is to integrate both off-line and on-line travel time data for provision of area-wide traffic information in the whole network of Hong Kong. In addition, it can be extended to facilitate the incorporation of other real-time data such as the GPS data so as to improve accuracy of the travel time estimation. The current travel time is estimated on the basis of the journey time of those vehicles equipped with AVI traveling from an origin to a destination. For example, vehicles depart from an origin A at 8:32 and arrive at a destination B at 8:57. The current travel time from A to B is then 25 minutes for the time interval 8:55-9:00.

The RTIS for Hong Kong is developed by The Hong Kong Polytechnic University in collaboration with Autotoll Limited. Real-time travel times 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. In this paper, real-time Autotoll tag data are the on-line AVI data of the proposed RTIS. In Hong Kong, there are about 390,000 registered private cars and 170,000 registered commercial vehicles. Over 110,000 of the private cars and over 90,000 of the commercial vehicles have been installed with Autotoll tags to enable toll charge payments automatically at ten road tunnels or bridges in Hong Kong. Therefore, tolltag penetration of private cars and commercial vehicles are around 28% and 53% in Hong Kong, respectively. The locations of the tolled tunnels/links are shown in Figure 2. Autotoll tag data are collected at the toll gates of all ten tunnels/links in Hong Kong. The times of vehicles passing through the tunnels/links toll gates 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 ten tunnels/links can be extracted at 5-

minute intervals.

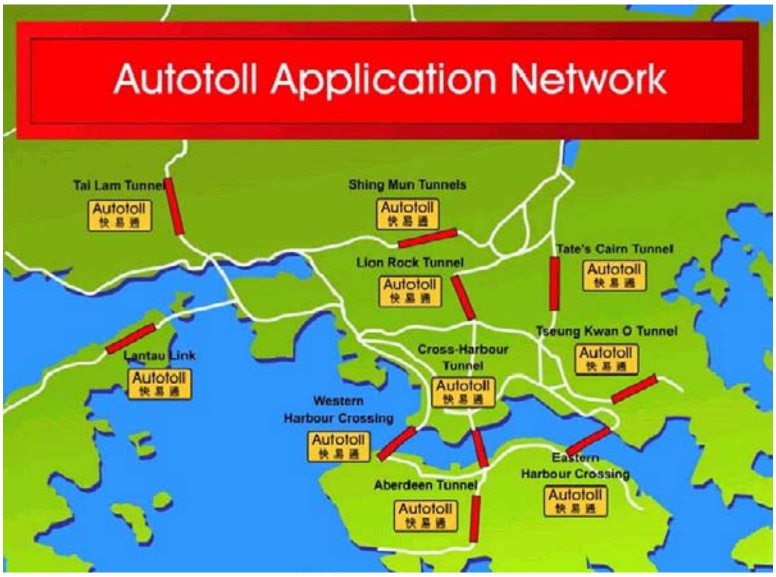

FIGURE 2 Locations of tunnels/links with Autotoll system in Hong Kong

The remainder of this paper is structured as follows. The RTIS solution algorithm and the other existing AVI algorithms are described and compared in the next section. A case study set in the Kowloon Central urban area is presented together with validation results. Survey is conducted to obtain the observed travel times on the selected path of the study area for validation. Finally, conclusions are given and recommendations for further study suggested.

SOLUTION ALGORITHM

Proposed filtering algorithm

The purpose of the AVI travel time algorithms is to filter the data in order to remove outlier observations. The outlier observations may be due to the stop or detour taking by those vehicles. The AVI travel time algorithms are a data-filtering procedure that identifies valid data within a validity range. The sizes of the validity window and the observation intervals are different for various AVI travel time algorithms. For example, the TransGuide algorithm (*7*) filters out all recorded travel times that differs by more than 20% from the average travel time associated with observations made in the previous 2 min. A shorter rolling average window of 30 sec is adopted in the TranStar algorithm (*6*). However, the 15-min observation interval is used in Transmit algorithm (*8*). The RTIS and these three existing AVI travel time algorithms are compared in Table 1. The main difference between RTIS solution algorithm and the other AVI algorithms is that RTIS solution algorithm makes use of both the on-line AVI data and the off-line travel time forecasts. The threshold in the RTIS solution algorithm depends on the smoothed travel time standard deviation at current time interval and the number of preceding time intervals without observations. However, the thresholds in TransGuide and TransStar algorithms are fixed to ±20% from the average travel times whereas the threshold in Transmit algorithm is defined by users. It is also noted that the current travel times are estimated and updated at 5-minute, 2-minute, 30-second, and 15-minute intervals by the solution algorithms adopted for RTIS, TransGuide, TranStar and Transmit, respectively.

TABLE 1 Comparison of the AVI Travel Time Algorithms

Algorithm	RTIS	TransGuide	TranStar	Transmit
Data	On-line AVI data and off-line travel time estimates	On-line AVI data	On-line AVI data	On-line AVI data
Interval of updating window	5-min	2-min	30-sec	15-min
Threshold	Depends on the smoothed travel time standard deviation at current time interval and the number of preceding time intervals without observations	Fixed (±20% from the average travel time)	Fixed (±20% from the average travel time)	User-defined
Application in	Hong Kong	San Antonio	Houston	New York/ New Jersey
Remarks	Integrate the on-line AVI data and the off-line travel time data together	Less accurate under non-recurrent traffic congestion	High level of market penetration of AVI-equipped vehicles	Long observation interval of 15-min

Similar to the algorithm proposed by Dion and Rakha (*11*), the proposed RTIS algorithm provides a dynamic travel time window. The main difference between the proposed RTIS algorithm with the Dion and Rakha algorithm is that the proposed RTIS algorithm makes use of both the filtered on-line travel time data and the off-line travel time forecasts for estimation of the current travel times in the whole Hong Kong road network while their algorithm only uses the filtered on-line travel time data. The approach of the algorithm obtains the average travel times between successive AVI readers where duplicate records are ignored and a series of filters are applied to remove invalid observations. The RTIS algorithm considers the travel times as invalid for any observed travel time that falls outside a validity range that is determined based upon the following four factors (a) Expected average journey time and journey time variability in previous and current time intervals; (b) Number of consecutive intervals without any readings since the last recorded journey time; (c) Number of consecutive data points either above or below the validity range and (d) Sequence of vehicle entry and exit times from the path. Figure 3 shows the framework of the proposed RTIS solution algorithm. For each time interval, the smoothed average travel time and variance are calculated to determine the lower and upper bounds of the validity window. The observations that fall within or outside the validity window are then identified. However, the algorithm considers the $\mu_{skips}{}^{th}$ of the μ_{skips} consecutive points outside the validity window may be valid, provided that all these observations are either above or below the validity window. The sequence of the vehicle entry and exit times of the observations that fall within the validity window and the $\mu_{skips}{}^{th}$ of the μ_{skips} consecutive points that are outside the validity window are checked. These observations are finally considered as valid if the travel times of these vehicles are not significantly different from another similar (valid) vehicle's within the same time frame. By using these valid observations, the average travel time and the variance at a particular time interval are calculated. The current travel times are then estimated by integrating the average travel time of the filtered on-line travel time data and the off-line travel time estimates. The process continues to iterate until the current travel times at all time intervals are estimated.

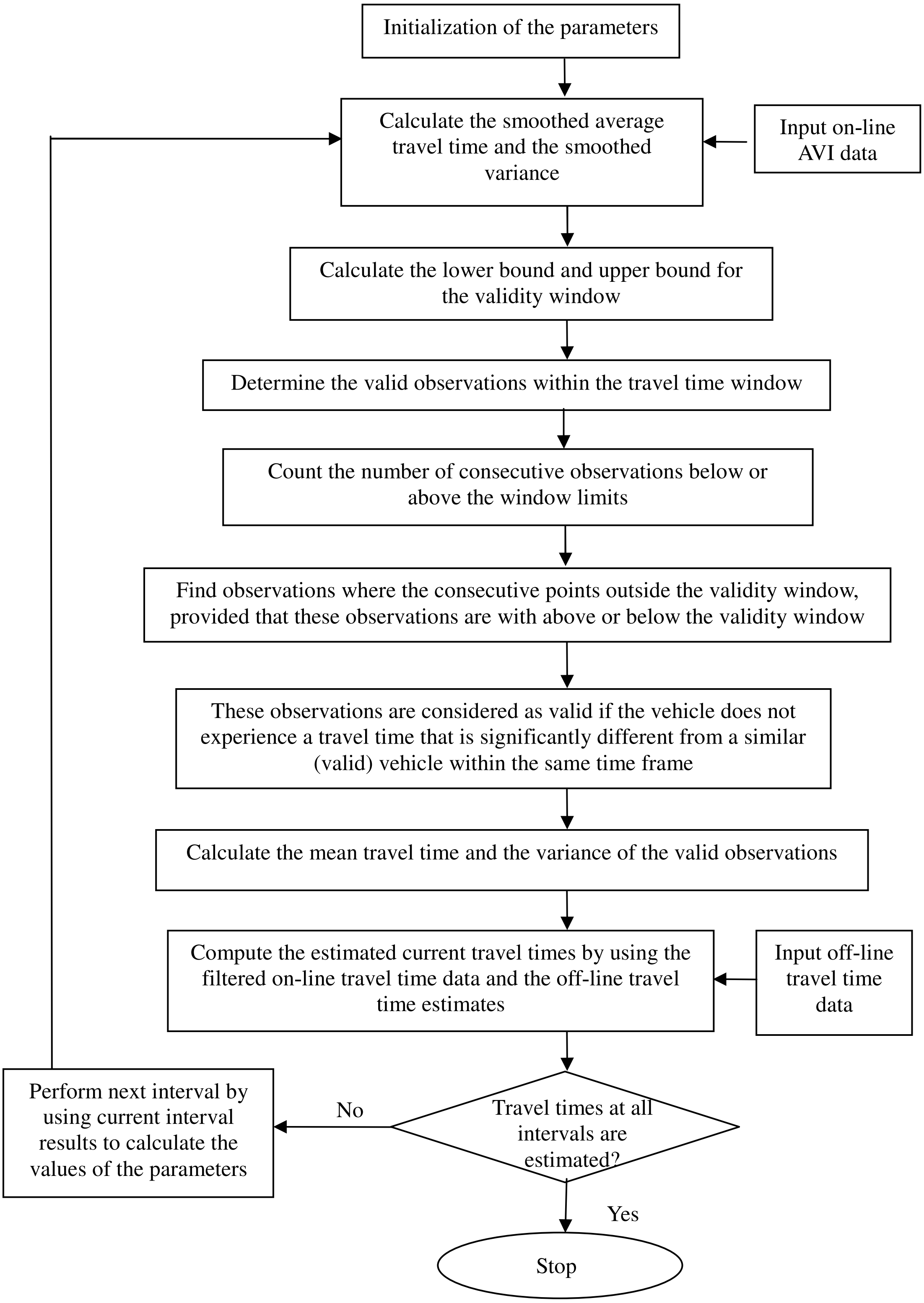

FIGURE 3 Framework of the RTIS solution algorithm

Within each time interval, the basic data validity window is computed based on a confidence interval that is estimated using a number of standard deviations, $\mu_{\sigma k}$, above and below the expected interval average travel time of a tunnel pair AB as defined in Equations (1)-(3).

$$Stt_{\mathrm{AB}\,k} = \{t_{\mathrm{B}i} - t_{\mathrm{A}i} \,|\, t_k - t_{k-1} < t_{\mathrm{B}i} \le t_k \;\; and \;\; tt_{\mathrm{AB}\min k} \le t_{\mathrm{B}i} - t_{\mathrm{A}i} \le tt_{\mathrm{AB}\max k}\} \tag{1}$$

$$tt_{\mathrm{AB}\min k} = e^{[\ln(tts_{\mathrm{AB}k}) - \mu_{\sigma k}(\sigma_{stt_{\mathrm{AB}k}})]} \tag{2}$$

$$tt_{\mathrm{AB}\max k} = e^{[\ln(tts_{\mathrm{AB}k}) + \mu_{\sigma k}(\sigma_{stt_{\mathrm{AB}k}})]} \tag{3}$$

where $tt_{\mathrm{AB}\min k}$ and $tt_{\mathrm{AB}\max k}$ represent the lower and upper limits for the valid travel time observations; t_k represents the time at the end of each interval k at which the calculation takes place; t_{Ai} and t_{Bi} are the detection times of a vehicle i at tunnels A and B respectively. The travel time of the valid observations should also be greater than or equal to the free-flow travel time from A to B. In computing the confidence limits for the next time interval, the smoothed average travel time, $tts_{\mathrm{AB}k}$, and travel time variance $\sigma^2_{stt_{\mathrm{AB}\,k}}$ of all valid observations within the current sampling interval must be known. These two elements are calculated by Equations (4) and (5).

$$tts_{\mathrm{AB}\,k} = \begin{cases} e^{[\phi_{k-1}\ln(tt_{\mathrm{AB}k-1}) + (1-\phi_{k-1})\ln(tts_{\mathrm{AB}k-1})]} & \text{if } \mu_{vk-1} > 0 \\ tts_{\mathrm{AB}k-1} & \text{if } \mu_{vk-1} = 0 \end{cases} \tag{4}$$

$$\sigma^2_{stt_{\mathrm{AB}\,k}} = \begin{cases} \phi_{k-1}\sigma^2_{tt_{\mathrm{AB}k-1}} + (1-\phi_{k-1})\sigma^2_{stt_{\mathrm{AB}k-1}} & \text{if } \mu_{vk-1} > 1 \\ \sigma^2_{stt_{\mathrm{AB}k-1}} & \text{if } \mu_{vk-1} = \{0,1\} \end{cases} \tag{5}$$

where μ_{vk-1} is the number of valid observations in the previous time interval (k-1).

The number of standard deviations $\mu_{\sigma k}$ within each time interval k is based on the number of intervals with zero observations.

$$\mu_{\sigma k} = \gamma_k + \gamma_k[1 - (1-\rho_\sigma)^{\mu_{0k}}] \tag{6}$$

where μ_{0k} is the number of preceding time intervals without observations, γ_k is a parameter representing a minimum number of standard deviations to consider, and ρ_σ is a sensitivity parameter.

The estimated average travel time for the current time interval between AB, $tt_{\mathrm{AB}\,k}$, the estimated travel time variance for the current time interval, $\sigma^2_{tt_{\mathrm{AB}\,k}}$, and the parameter ϕ_k are calculated by Equations (7)-(9).

$$tt_{\mathrm{AB}\,k} = \begin{cases} \dfrac{\sum_{i=1}^{\mu_{vk}}(t_{\mathrm{B}i} - t_{\mathrm{A}i})}{\mu_{vk}} & \text{if } \mu_{vk} > 0 \\ 0 & \text{if } \mu_{vk} = 0 \end{cases} \tag{7}$$

$$\sigma^2_{tt_{\mathrm{AB}\,k}} = \begin{cases} 0 & \mu_{vk} = 0 \text{ and } \mu_a < \mu_{skips} \text{ and } \mu_b < \mu_{skips} \\ \dfrac{[\ln(t_{\mathrm{B}i} - t_{\mathrm{A}i})_k - \ln(tts_{\mathrm{AB}\,k})]^2}{\mu_{vk}} & \mu_{vk} = 1 \text{ and } \mu_a < \mu_{skips} \text{ and } \mu_b < \mu_{skips} \\ \dfrac{\sum_{i=1}^{\mu_{vk}} [\ln(t_{\mathrm{B}i} - t_{\mathrm{A}i})_k - \ln(tts_{\mathrm{AB}\,k})]^2}{\mu_{vk} - 1} & \mu_{vk} \geq 2 \text{ and } \mu_a < \mu_{skips} \text{ and } \mu_b < \mu_{skips} \\ \xi(tt_{\mathrm{AB}\,k}) & \mu_a \geq \mu_{skips} \text{ or } \mu_b \geq \mu_{skips} \end{cases} \tag{8}$$

$$\phi_k = \begin{cases} 1 - (1-\rho)^{\mu_{vk}} & \mu_a < \mu_{skips} \text{ and } \mu_b < \mu_{skips} \\ \max(0.5, 1 - (1-\rho)^{\mu_{vk}}) & \mu_a \geq \mu_{skips} \text{ or } \mu_b \geq \mu_{skips} \end{cases} \tag{9}$$

where ξ and ρ are sensitivity parameters.

In Equations (8) and (9), the parameters μ_a and μ_b are counters for the number of consecutive observations above or below the validity window limits. The values for both parameters are determined by processing the travel time data in the order they are received. For instance, the reception of an observation above the validity window results in μ_a being incremented by 1. The value of μ_a is: (a) increased to 2 if the following observation is again above the validity range; (b) reset to zero 0 if the following observation is valid; and (c) reset to 0 and μ_b is incremented by 1 if the following observation is below the validity range.

Equation (10) is used to verify the validity of observed travel times on a given link based on the sequence of vehicle entry and exit times from the path. The equation indicates that any observed travel time from a vehicle *i* that is exiting a link will be considered part of the set of valid observations $Stt_{\mathrm{AB}\,k}$ provided that this vehicle does not experience a travel time that is significantly different from a similar vehicle within the same time frame. Similar to the determination of the basic data validity range, the allowed variation in link entry time is set to correspond to the estimated shorter travel time plus the confidence interval of a number of standard deviations τ.

$$Stt_{\mathrm{AB}\,k} = \{t_{\mathrm{B}i} - t_{\mathrm{A}i} \,\big|\, (t_k - t_{k-1}) \leq (t_{\mathrm{B}i-1} - t_{\mathrm{A}i-1}) + e^{\tau(\sigma_{stt_{\mathrm{AB}\,k}})} \text{ for } t_{\mathrm{B}i} \geq t_{\mathrm{B}i-1} \text{ and } t_{\mathrm{A}i} \leq t_{\mathrm{A}i-1}\} \tag{10}$$

From the above procedure, the filtered on-line AVI data can be obtained. For the proposed RTIS solution algorithm, the weighted resultant travel time t^k_{AB} from tunnels A to B at time interval *k* is estimated on a combination of the off-line and the on-line travel time data with the use of a weighting factor w^k_{AB}, which is shown as follows:

$$t^k_{\mathrm{AB}} = (1 - w^k_{\mathrm{AB}}) \times t^{off}_{\mathrm{AB}} + w^k_{\mathrm{AB}} \times p^k_{\mathrm{AB}} \tag{11}$$

where t^k_{AB} is the weighted path travel time from tunnel A to tunnel B at 5-minute time interval *k*, t^{off}_{AB} is the off-line path travel time from A to B and p^k_{AB} is the average path travel time from A to B obtained by the filtered on-line AVI data. The weighting factor w^k_{AB} at the time interval *k* is calculated by Equation (12). It should be noted that if there is no valid real-time data at the current time interval *k*, p^k_{AB} is then set to be the weighted path travel time for tunnel pair AB at previous time interval (*k*-1). As real-time data may not be adequate for all locations, the use of the off-line travel time data is important for providing reasonable travel time estimates.

$$w^k_{\mathrm{AB}} = \begin{cases} 1 - (1-\psi)^{\mu_{vk}} & \text{if } \mu_{vk} > 0 \\ w^{k-1}_{\mathrm{AB}} & \text{if } \mu_{vk} = 0 \end{cases} \tag{12}$$

where ψ is a pre-determined parameter.

A CASE STUDY

Kowloon Central road network is used as a test network in this case study to demonstrate the performance of the proposed RTIS in reality. In this case study, the path from the Lion Rock Tunnel (LRT) to the Cross Harbour Tunnel (CHT) was selected for journey time estimation. Figure 4 displays the location for the selected path in this case study. It is one of the major arterial roads in urban area of Hong Kong. This route was chosen as most of the major roads in Kowloon Central join this path, whereas CHT is the most congested of the three road tunnels connecting Kowloon with Hong Kong Island. The total travel distance of the selected path is 6.78 km, with free-flow travel time equals 7.4 minutes.

Travel times are estimated at 5-minute intervals during the morning peak period (08:00-10:00), off-peak period (14:00-16:00) and evening peak period (17:30-19:30) of a typical weekday on 26 May 2006 (Friday), for the case study. Real-time data is collected from RFID readers which are installed at the toll plazas of LRT and CHT. Figure 4 shows the locations for equipment setup.

Manual License Plate Survey

To validate the estimation results, a manual license plate survey was conducted in the same time periods on the same day. With the use of video recording equipments, license plate numbers of vehicles passing through the toll plazas of LRT and CHT during the study period were recorded in videotapes. With the aid of a computer program, the passing times of observed vehicles were extracted from videotapes on the basis of the synchronized time clock in a personal computer, whereas their corresponding license plate numbers were input manually. Figure 5 shows the images captured from the video tapes.

The license plate numbers recorded at the two survey locations were matched with the use of a computer program. The license plate number has a maximum of six characters, including two alphabetic and four numeric characters. In this case study, for each pair of license plate numbers, at least one alphabetic and three numeric characters had to be matched. The time required for a vehicle to travel between any pair of the survey locations was then computed.

The proposed data filtering algorithm was applied to the observations collected from the manual license plate survey. The appropriate travel time windows for travel between the survey locations at 5-minute interval are then determined. Table 2 shows the number of valid observations obtained at the survey locations. In Hong Kong, there are two types of toll-gates before entering the road tunnels or bridges. One type of these toll-gates is mainly for vehicles installed with Autotoll tags and hence the observations from Autotoll tag are obtained. Another type of toll-gates is used for other vehicles without Autotoll tags, at which there is no tolltag observation and the license plate readings are recorded by video cameras during the survey periods. Therefore, the combination of tolltag observations and license plate readings are the total observations at all these toll-gates for a particular road tunnel or bridge. The number of vehicles in the data set is the number of vehicles traveling between these two road tunnels during the survey period. It should be noted that there were only 1,922 vehicles traveling from LRT to CHT, however, the total traffic flow at each of these two tunnels was greater than 15,000 vehicles during the 6-hour survey period. In order to make it clear, the data size for each time period are given in Table 2 with the number of vehicles passing through each of these two tunnels and that traveling from LRT to CHT. It was found that less than 40% of the valid observations are installed with tags. Figure 6 shows the travel time window for traveling between LRT and CHT. Based on the valid observations, the mean travel time and standard deviation of travel time for traveling from LRT to CHT can be computed at 5-minute interval. It can be seen in Figure 6 that there are a few valid observations below the validity window as the proposed solution algorithm allows the $\mu_{skips}{}^{th}$

of the μ_{skips} consecutive data points that outside the validity window are also considered as valid, provided that all these observations are either above or below the validity window. However, with consideration of the sequence of vehicle entry and exit times (i.e., Equation (10)), most of the consecutive observations above the validity window are filtered out.

FIGURE 4 Location of the selected path for the case study

FIGURE 5 Images captured from videotapes

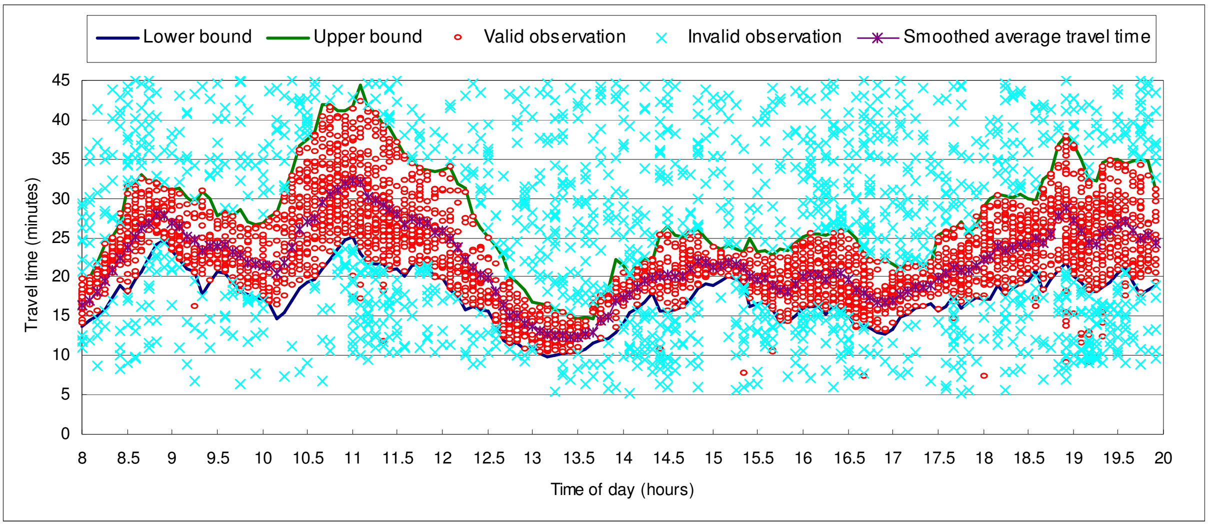

FIGURE 6 Travel time window of the selected path from LRT to CHT

TABLE 2 Number of Valid Observations Obtained during the Survey Periods*

			LRT to CHT		
	CHT	LRT	Valid observations from Autotoll Tag (U)	Valid observations from manual license plate survey (V)	Total (U + V)
AM	6,613	5,362	285	303	588
OP	6,531	4,735	217	250	467
PM	7,029	5,643	259	608	867
Total	20,173	15,740	761 (39.59%)	1,161 (60.41%)	1,922 (100%)

* Survey periods are 08:00-10:00, 14:00-16:00 and 17:30-19:30 on 26-May-2006 (Friday).

Evaluation Results

In order to evaluate which AVI algorithm is most applicable for Hong Kong under various traffic conditions during peak and off-peak periods, the same set of observation data is used to validate the results of various algorithms. The four AVI algorithms (RTIS, TransGuide, TranStar and Transmit) are used to filter the tag data from LRT to CHT which is the southbound traffic of the selected path. The validation of the AVI algorithms are conducted by comparison between the estimated travel times of each algorithm with the observed travel times obtained from the manual license plate survey. In this case study, the following assumptions are made to define the values of the parameters. In Equation (6), the parameters are set to be γ_k =2, ρ_σ =0.2. In Equation (8), the parameters ξ = 0.001 and ρ =0.2. In

Equation (9), μ_{skips} = 3. In Equation (10), τ = 2. In Equation (12), ψ = 0.2. Most of these values have been recommended by Dion and Rakha (*8*) and all of them are re-examined with the observation data collected in Hong Kong.

The AM peak, Off-peak and PM peak periods are chosen in the case study. The three periods are 08:00-10:00 (AM), 14:00-16:00 (OP) and 17:30-19:30 (PM) respectively. The results are summarized in Tables 3, 4, and 5. The absolute error and absolute percentage errors are the measures for validating the accuracy of each algorithm in this paper.

As indicated by the evaluation results, the RTIS is superior to the TransGuide, TranStar and Transmit algorithms. For example, the mean absolute errors are 0.85, 1.36, 1.34 and 2.20, respectively, for the RTIS, TransGuide, TranStar and Transmit algorithms during AM period. The mean absolute percentage errors of the RTIS solution algorithm is only 3.67% and the other three algorithms are 5.86%, 5.66% and 9.47% during AM period. Therefore, both the mean absolute error and the mean absolute percentage error of the RTIS are much lower than those of the other three algorithms. The mean absolute error and the mean absolute percentage error of the Transmit algorithm are highest among the four algorithms. However, there is no significant difference between the mean absolute errors and the mean absolute percentage errors for the TransGuide and TranStar algorithms.

For both the peak and non-peak periods, the lowest absolute and absolute percentage errors are obtained by the proposed RTIS solution algorithm. From the results, it is clear that the performance of the Transmit algorithm is worse than other algorithms. The maximum absolute percentage errors are 11.55%, 16.69%, 15.23% and 23.95% for the RTIS, TransGuide, TranStar and Transmit algorithms during AM period, respectively. The Transmit algorithm has the highest errors as it used the15-minute interval for the validity window. The maximum absolute percentage errors of the Transmit algorithm are around double of the RTIS solution algorithm. For the TransGuide and TranStar algorithms, the mean absolute percentage errors and the maximum absolute percentage errors are very close and the differences are less than 2%.

In addition, the errors are higher in the peak periods than in the non-peak period. For example, the mean absolute errors are 0.85, 0.88, 0.41 and the mean absolute percentage errors are 3.67%, 3.63%, 2.1% for RTIS solution algorithm during AM, PM and OP periods respectively. For the AM and PM periods, there is no significant difference between the mean absolute error and the mean absolute percentage error for RTIS solution algorithm. However, the mean absolute error and the mean absolute percentage error during OP period are only half of the values obtained during peak periods. This indicates that the travel time estimation of the RTIS performs better under the uncongested condition than the congested condition.

TABLE 3 Absolute Errors and Absolute Percentage Errors for AM Peak Period

	Southbound Traffic (08:00-10:00)			
Absolute Error (minutes)	RTIS Solution Algorithm	TransGuide algorithm (San Antonio)	TranStar algorithm (Houston)	Transmit algorithm (New York/New Jersey)
Minimum	0.02 (0.08)*	0.11 (0.44)	0.06 (0.28)	0.22 (0.90)
Mean	**0.85** **(3.67)**	**1.36** (5.86)	**1.34** (5.66)	**2.20** **(9.47)**
Maximum	2.62 (**11.55**)	3.79 (**16.69**)	3.28 (**15.23**)	5.73 (**23.95**)

* Absolute Percentage Error (%)

TABLE 4 Absolute Errors and Absolute Percentage Errors for Off-Peak Period

	Southbound Traffic (14:00-16:00)			
Absolute Error (minutes)	RTIS Solution Algorithm	TransGuide algorithm (San Antonio)	TranStar algorithm (Houston)	Transmit algorithm (New York/New Jersey)
Minimum	0.00 (0.01) *	0.02 (0.10)	0.02 (0.09)	0.05 (0.24)
Mean	**0.41 (2.10)**	0.59 (2.99)	0.55 (2.73)	1.18 (6.06)
Maximum	1.22 (6.30)	2.86 (14.59)	1.26 (6.46)	2.91 (14.95)

* Absolute Percentage Error (%)

TABLE 5 Absolute Errors and Absolute Percentage Errors for PM Peak Period

	Southbound Traffic (17:30-19:30)			
Absolute Error (minutes)	RTIS Solution Algorithm	TransGuide algorithm (San Antonio)	TranStar algorithm (Houston)	Transmit algorithm (New York/New Jersey)
Minimum	0.03 (0.14)*	0.08 (0.36)	0.04 (0.14)	0.10 (0.39)
Mean	**0.88 (3.63)**	1.13 (4.66)	1.09 (4.43)	1.54 (6.28)
Maximum	2.46 (10.12)	3.46 (14.22)	3.25 (13.33)	3.68 (15.09)

* Absolute Percentage Error (%)

CONCLUSIONS

A real-time travel information system (RTIS) for Hong Kong has been presented in this paper. A novel solution algorithm has been proposed for estimating the current travel times in Hong Kong, with making use of both the on-line automatic vehicle identification (AVI) data such as Autotoll tag data and the off-line travel time forecasts from the Traffic Flow Simulator (TFS). A case study of validating RTIS results in the Kowloon Central area has been carried out. The observed journey times were measured from manual license plate survey. The estimated current travel times on a selected path within Kowloon area have been evaluated by the observed journey times. Validation was based on the observed surveys conducted in the morning peak, off-peak and evening peak periods of a typical Friday on 26 May 2006.

The validation results imply that the RTIS solution algorithm is superior to the other three existing AVI algorithms: TransGuide, TranStar and Transmit algorithms in application of Hong Kong empirical data. Both the absolute errors and the absolute percentage errors of the proposed RTIS solution algorithm are the least for the study periods. Further study can be carried out to adapt the proposed solution algorithm to estimate the instantaneous travel times on the selected path. In addition, sensitivity tests will be conducted to investigate the effects of other factors such as location, level of service, and weather on the proposed RTIS solution algorithm. Surveys should be continuously carried out to measure journey times on various major paths in different urban areas of Hong Kong during various time periods. Hence, the travel time estimates will be validated by road types for the whole strategic road network of Hong Kong. With satisfactory validation results, the travel times estimated by 5-minute intervals for the whole territory can then be fed into an on-line platform with Geographic

Information System (GIS) functions for Advanced Traveler Information System (ATIS) applications in Hong Kong.

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