Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 5, pp. 1433 - 1448, 2005

A REVIEW OF TRAVEL-TIME PREDICTION IN TRANSPORT AND LOGISTICS

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Abstract: Travel-time information could be applied in various fields and purposes. From the travellers' viewpoints, the travel-time information helps to save travel-time and improve reliability through the selection of travel routes pre-trip and en-route. In the application of logistics, travel-time information could reduce the delivery costs, increase the reliability of delivery, and improve the service quality. For traffic managers, travel-time information is an important index for traffic system operation.

A review of the literature has indicated that travel-time can be predicted through a number of alternative methods using various input data. This paper provided a systematic review and comparisons in the field of travel-time prediction. The purpose is to broaden the perspective of research beyond the individual techniques and then provide a detailed overview of travel-time prediction information for future researchers concerning this area. In addition, the paper also provides some finding from field survey data in the later part.

Key Words: Intelligent Transport Systems, Travel time prediction, Micro-simulation model

1. INTRODUCTION

Travel time has been identified by Austroads as an important system performance measure and regular travel-time surveys are now conducted in the capital cities by state road authorities in Australia (Cunningham et al., 1995). Meanwhile, a large number of research studies and literature reviews concerned with the field of travel-time prediction have demonstrated the importance of travel time information in practical applications of transportation and logistics.

Estimated travel-time information has been well applied in various fields and applications. It provides travel-time information for road users to understand the current traffic condition.

Accurate travel time estimation could help to reduce transport costs by avoiding congested sections and increase the service quality of commercial delivery by delivering goods within required time window.

In a view point of time period, current travel-time information might help for a short-term delivery but for long-term scheduling, predicted travel-time information is essential. In the other viewpoint of traffic condition, in an area with relatively stable traffic conditions a fairly simple estimation may be used, but in areas with rapidly changing conditions a prediction model is essential (Van Grol et al., 1999). That is because travel time is a sensitive element and affected by various factors. A single incident might cause huge delay during a trip. The prediction of travel time is the major trend to promote the current application of travel-time information in both transport and logistics fields. the impetus of forecasting traffic information rather than relying on real-time information is to allow the travelling public to be proactive in their travel decisions at both pre-trip planning stage and en-route (Ishak and Al-Deek, 2002).

The purposes of this paper are to review the applications and the prediction methodologies of travel-time from previous literatures and display some finding from filed survey data. The goal of the research is trying to develop and test a potential research methodology to promote the efficiency and accuracy of travel-time prediction for its further applications and development in arterial roads.

2. VARIABLES OF TRAVEL-TIME

Nowadays, travel time information plays a heavy role in transportation and logistics and has been applied in various Intelligent Transport Systems (ITS), such as in-vehicle route guidance (RGS) and advanced traffic management systems (ATMS). However travel time is affected by a range of different traffic factors. Thus accurate prediction of travel time is difficult and needs much traffic data. Understanding those traffic factors affecting travel time is essential for improving prediction accuracy in related travel time studies.

Humans, vehicles and facilities, such as roads and signals, are the main components of traffic environment. Various factors which affect the three elements usually influence the final travel time as well. For instance, different drivers and road conditions could cause large differences in journey times. Even in the same time interval and on the same link, different vehicles can have quite different travel-times (Li and McDonald, 2002).

Free flow travel speed is one of the factors that affect travel time. However, the journey speed along an arterial road depends not only on the arterial road geometry but also on the traffic flow characteristics and traffic signal coordination (Lum et al., 1998). Other main factors related to travel time prediction that have also been cited in previous studies include holiday and special incidents (Karl et al., 1999), signal delay (Wu, 2001), weather conditions (Chien and Kuchipudi, 2003), traffic operation (disturbed level) and congestion level (traffic flow) (Richardson 2004; 1978). The greater the length of the forecasting period, the higher the prediction error (Kisgyorgy and Rilett, 2002). The adoption of specific variables for prediction will determine the efficiency and accuracy of the travel-time prediction model. This paper provides some findings about travel speed, signal impacts, traffic volume and travel time.

3. MEASUREMENT OF TRAVEL-TIME

Travel time data may be recorded through a wide variety of methods. An individual traveller may register his/her time using a stop-watch. More generally applicable methods- that do not involve the individual traveller to determine the travel time- make use of for instance license plate recognition, toll-gates, in car systems (Van Grol et al., 1999) and (Taylor et al., 2000a).

The measurement methods can be simply divided to two types: (1) logging the passage of vehicles from selected points along a road section or route, or (2) using moving observation platforms travelling in the traffic stream itself and recording information about their progress (Taylor et al., 2000a). The site-base methods, group (1), include registration plate matching, remote or indirect tracking, and input-output methods and so on. And the stationary observer techniques that includes loop detectors, transponders, radio beacons, video surveillance, etc (D'Este et al., 1999). Meanwhile, the moving observer methods (vehicle-based methods) include the floating car, volunteer driver and probe vehicle methods. The following sections introduce the main techniques of travel time measurements in there two method groups.

3.1 Site-Based Measurement

Registration plate matching techniques consist of collecting vehicle license plate characters and arrival times at various checkpoints, matching the license plates between consecutive checkpoints, and computing travel times from the difference between arrival times (Turner et al., 1998). The essential survey method is manual transcription of paper or tape records. Nowadays, the license plate can be recorded by speech and video and then transfer to digital data by speech recognition and image recognition techniques (Taylor et al., 2000a) and (Yu, 2002). It has been shown in the previous research, using Automatic Vehicle Identification (AVI) data, that the travel time prediction error decreased by fifty percent when forecasting fifteen minutes into the future. It was shown that the usefulness of the real-time AVI data, as compared to average historical information, was extended from approximately fifteen minutes to thirty minutes (Kisgyorgy and Rilett, 2002).

Remote or indirect tracking use the vantage points to observe vehicles' movements. Travel times of individual vehicles along relatively short stretches of road can be obtained by monitoring them from a vantage point which has a view of the start and end of the route (Taylor et al., 2000a).

Input-output methods can be used to estimate mean travel times for cohorts of vehicles travelling between designed survey sites.

Signpost-based system, typically used by transit agencies for tracking bus locations, relies on transponders attached to roadside signposts. Automatic vehicle identification (AVI) transponders are located inside a vehicle and are used in electronic toll collection applications. A practical case of signpost-based system in Sydney is ANTTS (Automatic Network Travel Time System). On the other hand, the development and application of Radio Frequency Identification (RFID) might extend to the real time goods tracking in freight transport and the travel time measurement in transport research in the near future.

Cellular telephone systems are one of the potential techniques to provide travel time information. In a survey of 2000 in France, 80% drivers carried at least one mobile telephone and 60% carried at least one switched on mobile (Remy, 2001). The information shows the high density of on-trip cellular phone provides an environment to build a 24-hours travel time monitoring system. However the preliminary results show 30% of positioning better than 30 m and 100% better than 500m (Remy, 2001). The accuracy of positing might satisfy the survey of travel time in a long section. For short sections, the accuracy is not enough to estimate the travel time. Travel time measured over short distances are not accurate and are subject to high random variation (Lum et al., 1998).

3.2 Vehicle-Based Measurement

Floating car are the most common travel time collection methods and consist of a vehicle(s) that is specifically dispatched to drive with the traffic stream for the express purpose of data collection (Turner et al., 1998). The simplest method to perform the survey is manually record travel times at designed checkpoints using a clipboard and stopwatch, or computer instrumentation may be used to record vehicle speed, travel times or distances at preset checkpoints or intervals. By fitting a GPS receiver to a vehicle it is possible to obtain time stamped location information which can be used to track location and determine travel times (Zito and Taylor, 1994, Rose, 1996). Furthermore the GPS-GIS combination forms contributes the efficiency in both data collection and results analysis (Zito and Taylor, 1994) and (Taylor et al., 2000c).

Volunteer driver and fleets of probe vehicles can help to collect traffic data more comprehensively, not only travel time but also geographic data and travel behaviour (Hawkins and Stopher, 2004). The cooperation with commercial fleet, such as taxi and delivery companies, can get huge number of data set with a reasonable survey cost.

3.3 Others

Emerging and non-traditional techniques are currently being researched or developed, or may be considered non-traditional when compared to existing methods. These techniques use a variety of methods, such as inductance loops, weigh-in-motion stations, or aerial video to estimate or calculate travel time. Most of the emerging techniques are currently in developmental or testing stages and have not been extensively field-tested or applied (Taylor et al., 2000b).

4. METHODOLOGIES OF TRAVEL-TIME PREDICTION AND ESTIMATION

Previous studies displayed numerous methodologies of travel-time prediction. Most of the conventional short-term forecasting techniques can be categorised under two approaches; regression methods and time series estimation methods. A third approach may be described as combining the first two. This is known as data fusion (Anderson and Bell, 1998). However, most studies show that prediction accuracy is often compromised by the underlying mechanism of prediction methods more than other influencing factors (Ishak and Al-Deek, 2002). The following introduces several prediction methodologies and techniques from previous research studies and projects that include their prediction theories, type of adopted traffic data, criterions of prediction accuracy and so on.

4.1 Historical Data Estimation Method

Travel time can be estimated from historical data through analysing limited traffic information from fields. For instance, the traffic data, such as travel speed and location, from probe vehicle could be linked with historical travel time data. And then various techniques, e.g. Fuzzy theory, AI, statistics and mathematical, could be adopted to develop travel-time estimation model.

In Li and McDonald's study, they used a single GPS equipped probe vehicle to develop a mathematical travel-time estimation model. Meanwhile, speed-time profile, travel-time data from Automatic Number Plate technology and Maximum continue acceleration (MCA) data are the main data sets which are used for travel time estimation. The research results showed that the estimation model cannot perform well in congested traffic and extremely slow vehicles conditions (Li and McDonald, 2002). A similar result happened in Wu's research in Taiwan 2001. The research used real time GPS information to adjust his statistical travel time estimation model based on historical travel time data. The model also perform well in normal traffic condition but lower accuracy during peak hours (Wu, 2001). Those research studies displayed that the combination between historical data and statistics theory could provide well estimation capacity with fluency traffic flow condition. However, for congested and changeful environment, a hybrid method might be needed for improving the accuracy of the estimation method.

4.2 Artificial Intelligence

Artificial Intelligence is the discipline that seeks to understand natural intelligence and to build intelligent systems (Pfeifer and Scheier, 1999). Nowadays, such kinds of techniques have been applied in extensive fields and brings benefits to our societies (Li, 2002). Also, AI has received greater attention in the transportation sector (Billi et al., 1994).

With the development of computer science, a large number of AI applications have appeared in our societies. These include various expert systems, smart vehicles, and AI buildings. One of the most popular techniques in AI is Neural Network. Artificial Neural Networks (ANN) have been applied in engineering, management, science and psychology, and become one of the major AI applications to help improve transport problems (Kirby and Parker, 1994, Dougherty, 1995). Figure 1a shows the structure of natural neurons and Figure 1b shows artificial neurons. The dendrites in the natural neuron correspond to the connections between the cells in the artificial one, the synapses to the weights, the axons to the outputs. Computation is done in the cell body.

Neural networks are statistical models of real world systems which are built by tuning a set of parameters. These parameters are seen as inputs to an associated set of values: the outputs. The process of tuning the weights to the correct values – training – is carried out by passing a set of examples of input-output pairs through the model and adjusting the weights in order to minimize the error between the answer the network gives and the desired output. Once the weights have been set, the model is able to produce answers for input values which were not included in the training data. The models do not refer to the training data after they have been trained; in this sense they are a functional summary of the training data (Swingler, 1996). The major capacity of ANN includes Pattern Recognition, Classification, Detection, Adaptive Filtering, Data Inversion, Target Tracking, Modelling (Proto, 2000), estimation, and prediction.

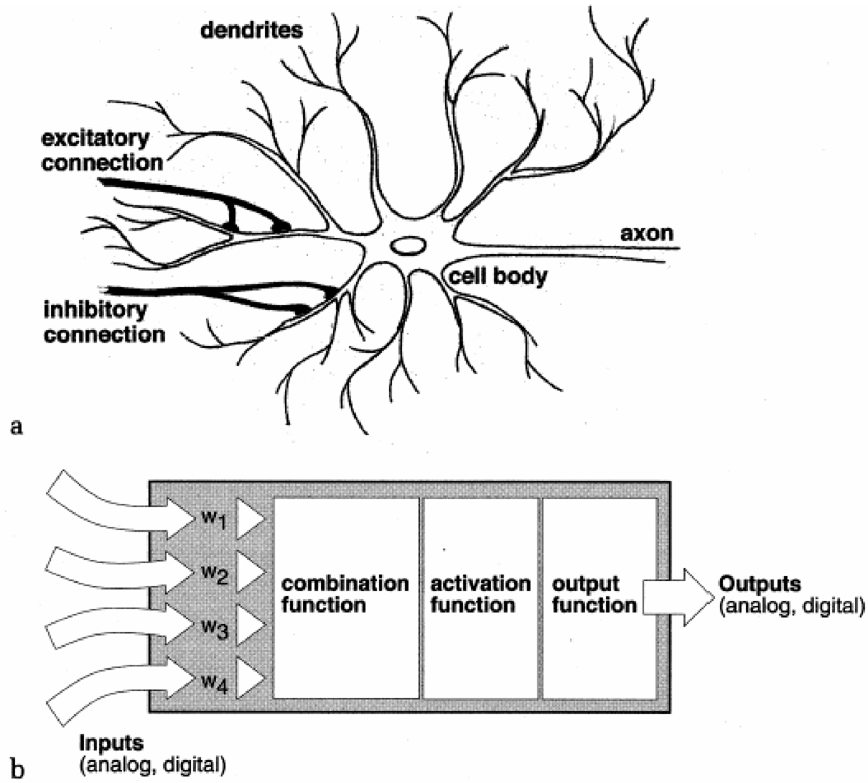

Figure 1. Natural and artificial neurons: (a) a biological neuron, (b) an artificial neuron. Source: (Pfeifer and Scheier, 1999)

> *In model development a key issue is which combination of these data (i.e. the three features respectively, any two of them, or all the three) provides the most information regarding future conditions (Kisgyorgy and Rilett, 2002).*

Many research studies have used ANN techniques to estimate and predict travel-time that includes Advanced Neural Network (Wei et al., 2003) and Mix-structure Neural Network (Jiang and Zhang, 2001). In Anderson and Bell's study, they used traffic data from registration plate survey, traffic detectors and simulation software, VISSIM, to develop Neural Network estimation techniques and a queuing model for travel-time prediction in urban road networks. The research showed that different combination of variables, e.g. speed and volume, have different accuracy in estimation outcomes.

In Wei, Lin and Li's study, ANN has been proved that it has good capacity in travel time prediction. On the other hand, the outcomes from Kisgyorgy and Rilett's research indicated that the expected travel time prediction error with ANN is seven seconds or approximately 4% of practical travel-time. In other word, ANN has the potential for further travel time estimation and prediction.

To deserve to be mentioned, the Mixed-structure NN model has the capacity to predict travel time of non-detector segments base on the data from detector segments (Jiang and Zhang, 2003). Appropriate methodology might help to overcome the shortage of hardware, such as induction detectors and facilities, in road network. Meanwhile, the requirement for large number of detector might be reduced by the improvement of prediction methodology.

4.3 Statistical Techniques

Statistical techniques are applied extensively in estimation, prediction and modelling areas. Rose and Paterson used traffic data, from induction loop detectors, to build a Recursive Cell Processing Model (RCP Model) for dynamic travel-time estimation on instrumented freeways. The concept of travel time estimation is that travel time equal to free travel time plus delay time during the trip. The RCP Model provided a 8% Mean Absolute Percentage Error (MAPE) estimation accuracy level in normal traffic condition (Rose and Paterson, 1999). Again, the model can play well only with normal traffic condition.

DACCORD is a travel time estimation and prediction project in Europe. One of major purposes of DACCORD project is to provide the function of on-line travel-time prediction. DACCORD used traffic data from induction loop detectors, volume and speed, for travel time estimation and then use Statistical Traffic Model and Behavioral Traffic Model (a dynamic assignment model, MIDA) for travel time prediction. In addition, the prediction of network level travel-time is based on the prediction of link level travel-time in the project. The result showed that the prediction of travel-time based on travel speed can achieve better result, Root Mean Square Error Proportional (RMSEP) ≈ 0.18 (Van Grol et al., 1999).

Zhang used the data from both probe vehicle and double loop detectors to develop a linear model for travel time prediction on freeways in 2003. The research showed that in the prediction period from 0~ 30 minutes, the prediction error in a small model is from 5% to 10% and 8% to 13% prediction errors in large model (Zhang and Rice, 2003). However the paper did not mention the outcome in different traffic conditions, i.e. congestion or fluency.

4.4 Limitation From Previous Literatures

The limitations of related travel-time studies from the literatures include data resources, facilities of data collection, prediction techniques, interference traffic environment. The following paragraphs provide some viewpoints and ideas for further improvement.

From the viewpoint of data resources, previous research studies are usually limited by the type of data which available in the research area. Meanwhile, advanced travel time measurement equipment cannot be adapted due to the facilities only being equipped in a few places. On the other hand, to construct new facilities, e.g. Automatic Vehicle Identification (AVI), for satisfying research demands is difficult due to time consumption and high cost. Various combinations of data usage might provide a better path for travel-time research in prediction applications, however the idea still limited by the availability of transport data measurement hardware in the research area.

In terms of research area, previous studies mainly focus on isolated environments, e.g. freeways, bridges and tunnels, due to lower interference under the road sections. To extend the application of travel time information to open environments, such as arterial roads, the overcome of current difficulty is necessary. For instance, signals and intersections are the main factors that affect to prediction accuracy in arterial road sections. Previous travel time research used to extract research sections from road network without intersections and signals. A combination with signal system, such as SCATS, might help to break through the difficulty of arterial road research.

The last limitation of travel time research is based on logistics development. Travel time is one of the important factors in logistics scheduling and the vehicle routing problem, VRP. Nowadays, most travel-time prediction research is developed from transport engineering sectors. And is usually thinking base on engineering concepts and collecting data from transport facilities, such as induction detectors. If the prediction of travel-time can focus on logistics purposes, using logistics and management concepts and collecting travel-time data from logistics sectors, such as the detailed delivery record from delivers. The development of commercial freight scheduling would become more and more flourishing and faster.

5. POTENTIAL PATH- TRANSPORT SIMULATION

This section provides a potential resolution to overcome the difficulty of travel time research development. Given the faster speeds of modern computers, people have more suitable background to develop dynamic modelling and start getting interested in the real-time information so that people develop simulation techniques to address various problems which cannot be solved before. This section provides a brief introduction of simulation techniques and software in transportation area.

Simulation is a valuable decision support tool for evaluating transportation facilities or systems (Paul and Kevin, 1994). The application of simulation in transportation field is wide extending from as small applications such as traffic signal optimisation at an individual intersection to wide scale applications such as evaluating the national transport strategy. Transport simulation provides a path for planner to evaluate their transport designs or strategies without any breakdown test. Many tests that are difficult to be examined before can be analysed easily now (Marcelo, 2002).

(Brunner et al., 1998) indicated that about 84 percent of transport-modelling software users deemed modelling software to be a useful tool for planners. Modelling brings great benefits to us by predicting the unknown future.

Today, both computer power and communication techniques progress rapidly, and that provide strong benefit for developing modelling with computers. Through the assistance of better computer power and modelling techniques, the process of modelling becomes far faster and easier than before. Therefore, transport professionals start trying to predict real-time traffic conditions for gaining more understandings from dynamic modelling. A lot of computer software, for example, PARAMICS, Dynasim, AIMSUN and VISSIM are now being developed and applied well in specific fields. Micro-simulation is a useful tool to be treated with respect, however it is easy to draw the wrong conclusions if not fully familiar with the model (Brunner et al., 1998).

Simulation can capture statistics on the variability of these characteristics (Paul and Kevin 1994). On the other hand, some researchers try to generate traffic data from simulator to do their research (Anderson and Bell, 1998). Also simulation has the ability to trace entities through a system of multiple processes and operations. In the applications of simulation in traffic engineering, transport professionals use both microscopic and macroscopic concepts to produce forecasted data for safety improvement, driver behaviours analysis, traffic-signal optimization and network planning and so on. An important concept of modelling methods is that in dynamic traffic modelling people used Dynamic User-Optimal (DUO) to instead User-Equilibrium (UE) in static modelling.

Simulation of transportation systems is strong and appears to be growing (Brunner et al., 1998). In the near future, the results of dynamic simulation can be applied to Construction Feasibility Studies, Signal Design, Power Consumption, Traffic Study, Railroad Capacity Studies, Train Operation Studies, ITS, ATMS and ATIS etc. On the other hand, simulation techniques will play an important role in the research due to its realisable, convenient, and efficiency. The integration between travel time studies and simulation techniques could promote the research step to the future. Various research ideas could be tested and validated through the help of simulation environment.

6. INITIAL FINDINGS FROM THE RESEARCH

The research selected West Terrace, an arterial road located in Adelaide City, South Australia for the initial travel time research and with the potential to extend to a larger area. West Terrace is the western boundary of the major ring route which surrounds the Adelaide CBD area. The length of the research segment is almost 1.6 km and the speed limit is 60 km/h. On average, it has five lanes for each direction and is a very important arterial road in the Adelaide region.

In the traffic management system, there are eight signalised intersections controlled by SCATS on West Terrace. The number of intersections from the South to the North is nine and the other direction is fourteen. The average daily volume from the South side into West Terrace is around 28000 (vehicles/day). The map of research area is shown as Figure 2, meanwhile a sample of positioning data from GPS instrument vehicle are shown on the picture as well.

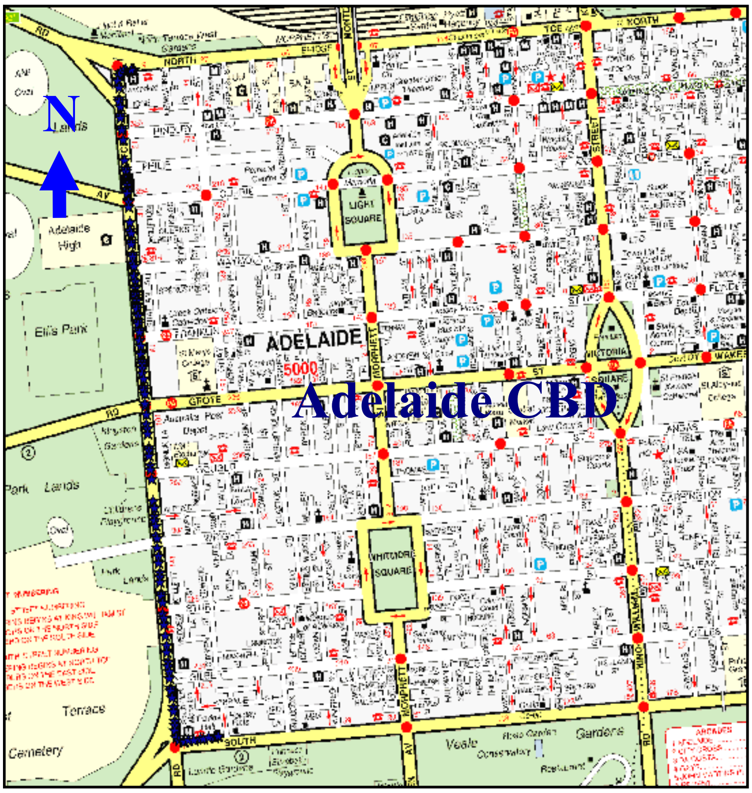

Figure 2. Research Area and The Track of GPS Instrument Vehicle in West Terrace

The research area has large traffic volumes and high capacity and is mainly controlled by the eight signalised intersections. The character of West Terrace is just like to add several signalised intersections into a freeway. The selection of the research area might help to integrate previous research from highway system.

6.1 Signals and Travel-Time

To explore the relationship between signals and travel-time on arterial roads, the research considered two trip movements, with departure at 7:05:01 and 9:44:58 respectively, and represented as red and blue lines in Figure 3. The two trips are conducted under similar traffic volume and travel speed, but have different signal stops during their journeys. Figure 3 shows the relationship between travel-time and signal effects. The earlier trip was not stopped during its trip and spent 109 seconds while the second trip was stopped by signals three times and spent 221 seconds to finish the trip. The result shows clearly that travel-time is affected significantly by signal systems. On the other hand, the trajectory diagram (in Figure 3) also shows the influence of signals on apparent speed reduction. To provide accurate travel-time prediction for arterial roads, signal impacts are the first challenge which has to be overcome. In addition, the small arrows under the x-axis represent the locations of intersections in the route segment.

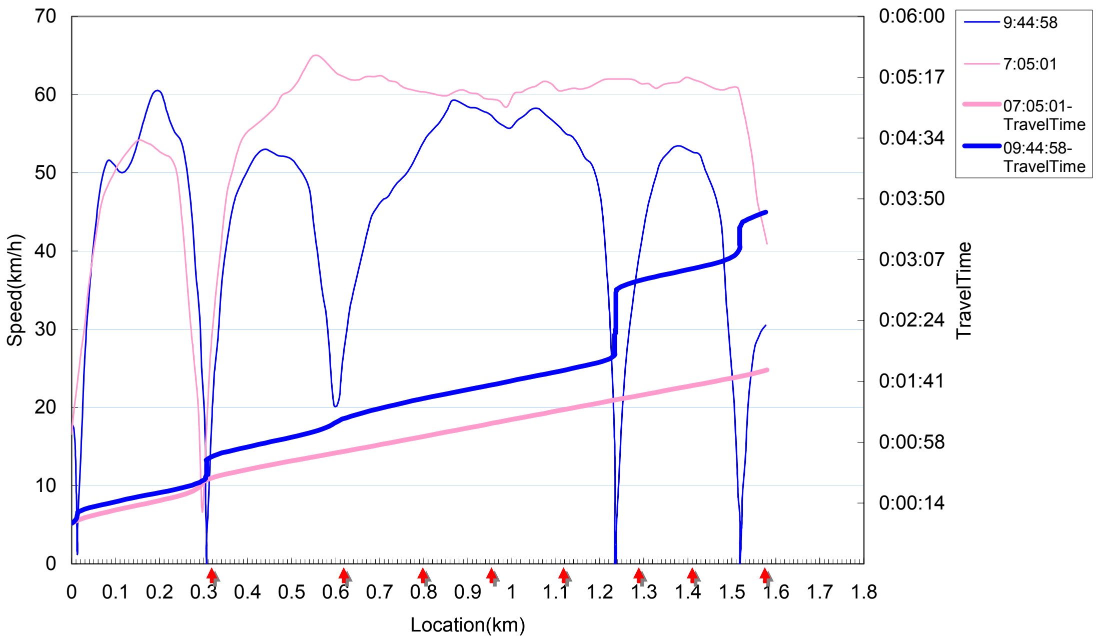

Figure 3. Signals and Travel-Time

6.2 Traffic Volume and Travel-Time

Travel-time is affected by variations in various factors, and traffic volume is one of the most important factors. It reduces travel speed and increases travel-time significantly when traffic volumes approach the capacity of road segment. Meanwhile, the travel speed fluctuates under high volume conditions, as there is more interference in the travel environment. Figure 4 shows the relationship between traffic volume and travel-time and the effects of departure time. The dots represent the traffic volume which been surveyed from the entrance of West

Terrace in south bound in particular time, while the bottom line displays the surveyed travel-time information. The result shows that traffic volume and travel-time has a direct proportion relationship between each other, which means higher volume environment needs more time to travel.

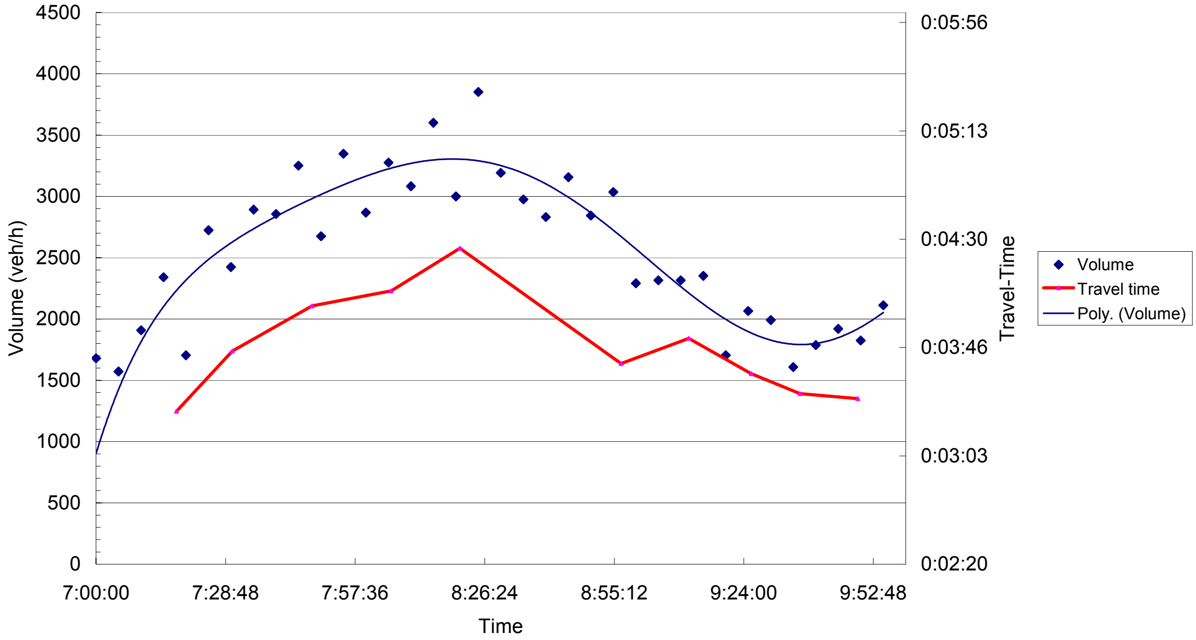

Figure 4. Traffic Volume and Travel-Time

Given the impacts of signals on travel time, there is a need to minimise the influence from signals by dividing the trip data to several groups based on the stop times by signals during the trips. This method cannot resolve all the impacts from signals due to the arrived time of vehicles in each signal intersections could be the start, medium or end of red light phase and the sensitive level of traffic volume data. Figure 5 shows the result of the analysis, the bottom group represents the travel time of trips with non-stop condition. It shows clear trend between travel time and traffic volume. The other groups have a bit confused distribution but their trend lines indicate clear direct proportion between travel time and traffic volume as well.

6.3 Travel Speed and Travel-Time

As discussed in last section, the research divided the travel speed data to four groups to reduce the signal influence on travel speed. Figure 6 shows the relationship between travel speed and traffic volume. The top group represents the relationship between average travel speed and traffic volume under the no signal stop condition. The value of average speed in this group is much higher than the others as because there is no stopped time in the journey. The figure shows that travel speed and traffic volume are inversely proportional. Higher volumes tend to cause lower travel speeds and of course, travel time will increase with lower travel speed.

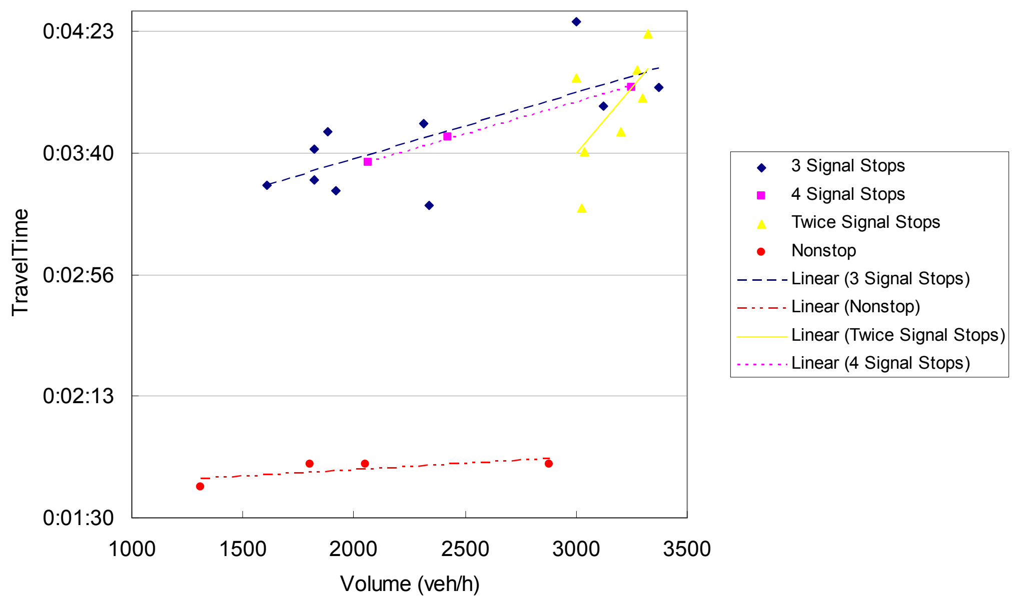

Figure 5. Traffic Volume and Travel-Time

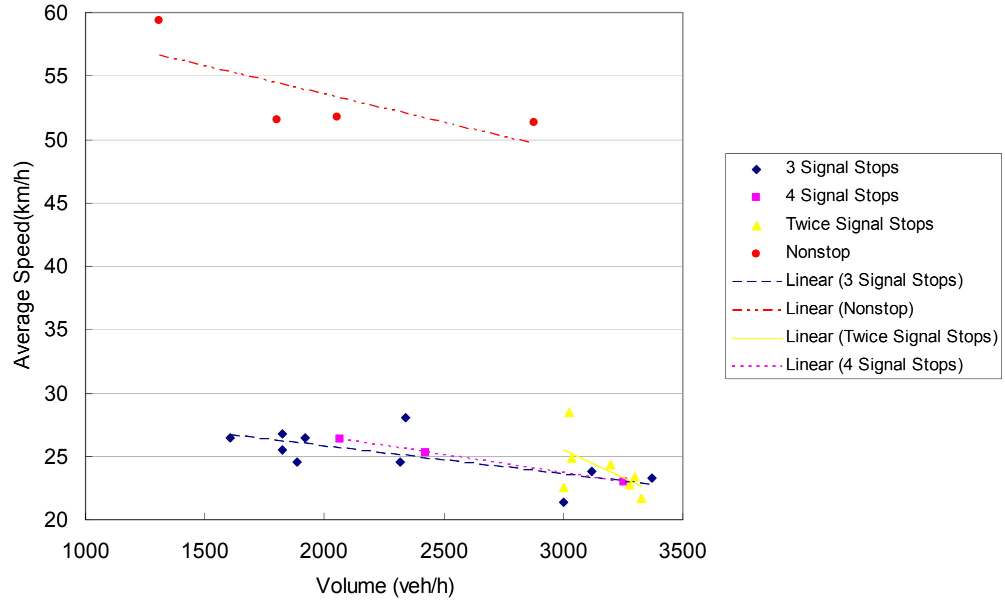

Figure 6. Travel Speed and Travel-Time

More impacts of variables on travel-time still need to be investigated, including road geometry, impacts from turning vehicles, land use, side friction, traffic queues and so on.

7. FURTHER RESEARCH

Previously, research on travel time has usually been limited by data resources. For instance, the lack of traffic detectors in particular location is a problem that cannot be solved easily. On the other hand, GPS equipped probe vehicles might provide poor data in urban areas due to the potential for high obstruction of GPS signals. Even a well-equipped area still provides difficulties in yielding enough traffic data in both quality and quantity, for instance, not every intersection is equipped with detector loops. Nowadays, transport simulation techniques have been improved greatly, due to the commercial competition, and have been validated in various projects. This provides the potential to substitute real data collection in the early period of the research.

Adapting micro-simulation techniques to be a test-bed can solve the problem of data shortage and also perform the various strategies on the test-bed. The method could contribute to the efficiency of related research, as long as a well validated simulation model is available. The final stage of the research will still involve the use of real traffic data from field survey to validate and adjust the developed travel time prediction model. In addition, the integration with traffic management systems, such as SCATS, could help provide data on signal phasings to reduce the uncertainty of travel-time factors for arterial road traffic.

8. CONCLUSIONS

Predicted travel-time information provides the capacity for road users to organize travel schedule pre-trip and en-trip. It helps to save transport operation cost and reduce environmental impacts. Besides, accurate travel time information also helps delivery industries to promote their service quality by delivering on time. However the development of travel time estimation and prediction are suffered from the shortage of traffic data sets and too much interference from transport environment.

This paper provides a review of travel-time studies that includes variables of travel time, measurement of travel time, methodologies of travel-time prediction and estimation, research difficulties, some relationships between traffic variables and travel-time from field data and potential solutions of travel-time prediction studies. The application of micro-simulation techniques could help to overcome the current difficulties of travel-time studies. In addition, the link up with the SCATS traffic control system might extend travel-time prediction from isolated environment to arterial road sections by minimising the uncertainty in factors from signal systems.

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