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Improving Dynamic Travel Time Estimates for Melbourne's Drive Time System

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ABSTRACT: Vic Roads Drive Time is an operational ITS system that dynamically calculates travel times on Melbourne freeways and conveys them to motorists in real time on roadside Changeable Message Signs. While the system has gained acceptance from users, it has a tendency to predict low and high travel times in the lead up to and decline from peak periods respectively. This paper presents a new algorithm for predicting freeway travel times based on work commissioned by Vic Roads. The new algorithm has the ability to be used in any traffic situation between any two points. It also has the ability to account for the relative speeds and densities of vehicles within the traffic stream. Calibration and field testing of the enhanced algorithm has indicated that substantial improvements in travel time prediction can be achieved when compared to the existing system.

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INTRODUCTION

Within the field of Intelligent Transport Systems there is a good deal of interest in Advanced Traveller Information Systems. While much attention has been focused on in-vehicle devices (1, 2, 8) there are still difficulties associated with the market penetration of those devices, particularly in Australia where they are only available in one luxury vehicle. A number of cities around the world have recognised that in between the static information, which has been the mainstay of roadside information, and the elaborate in-vehicle devices, there are opportunities to provide dynamic roadside information.

Drive Time is one such system that dynamically calculates travel times and conveys them to motorists in real time on roadside Changeable Message Signs (CMS). The following section provides a brief overview of the Drive Time System. The Enhanced Drive Time Algorithm is then described before the test results are presented. The final section summarises the conclusions from the study and identifies areas where this work is continuing.

THE DRIVE TIME SYSTEM

Building upon VicRoads Incident Management System, techniques have been developed to gather information from the road system and predict travel times for use by the motoring public (3). In July 1995, VicRoads commissioned Drive Time on Melbourne’s South Eastern Freeway between Punt Road and Warrigal Road. Since that time, VicRoads has extended Drive Time on the South Eastern Freeway to Wellington Road and implemented Drive Time on the West Gate, Eastern and Tullamarine Freeways. The Drive Time System has enabled information to be displayed to motorists through the use of trip information, freeway condition, ramp control and variable message sign displays. An evaluation of the Drive Time system (4) highlighted high user acceptance of the system and considerable benefits in terms of travel time savings.

Data for the operation of the Drive Time system is obtained from on site processors known as incident detection stations. These stations are located at known intervals along the freeway, approximately 500 metres apart. Using inductive loops embedded in the road surface and connected to each incident detection station, the average vehicle speed, volume of traffic and occupancy of the loops is measured and transmitted to VicRoads central processor every 20 seconds. This effectively provides a real time ’snapshot’ of freeway conditions at each incident detection station.

The algorithm currently used in the system calculates travel times between each incident detection station. The estimated travel time between major entry and exit points on the freeway is then determined by the summation of estimated travel times for each of a series of incident detection stations. This information is then broadcast to the various CMS to provide real time information to road users.

Trip Information Signs show current travel times to major freeway exit points together with colour coded traffic conditions (Green: Light, Yellow: Medium, Red: Heavy) for various route segments (Figure 1). In addition, there are freeway condition signs located on key freeway approaches which continuously display current traffic conditions on the freeway using colour coded words (LIGHT, MEDIUM, HEAVY or CLOSED). Ramp control signs are also situated at major freeway entry ramps to advise when the freeway is closed and variable message signs provide a range of messages including travel times and traffic conditions as well as incident, detour or emergency information.

Since its introduction on the South Eastern Freeway in July 1995, various surveys of Drive Time have been undertaken. These surveys are undertaken on a regular basis by VicRoads to gauge the accuracy and reliability of the system. During 1997 and 1998, a series of floating car surveys were conducted on each of the freeways where Drive Time operates. The surveys compared the actual travel time runs of the floating car against the travel time predictions provided by Drive Time. An analysis of the survey results showed that Drive Time estimates of travel time were consistently accurate during most of the day, however, problems of system accuracy were detected in peak traffic periods.

Figure 1: Drive Time Trip Information Sign

During peak periods, there is a tendency for Drive Time to lag the peak. (ie. to under-predict at the start of the peak and over-predict towards the end of the peak). Traffic patterns can change significantly from the start to the end of the system at times when traffic is building or decreasing quickly. This loss of accuracy caused Drive Time to under-estimate travel times when the peak was building and over-estimate travel times at times when traffic volumes were decreasing. To improve the accuracy of Drive Time, some enhancement of the existing Drive Time algorithm was required to detect and compensate for this effect.

THE ENHANCED DRIVE TIME (EDT) ALGORITHM

As noted earlier, one of the features with the existing algorithm is that it uses a 'snapshot' of conditions on the facility. Consequently it does not explicitly consider the build up or decay of queues, which would take place in future time periods, when estimating the travel times. The EDT algorithm has been specifically formulated to overcome these problems without requiring a model which would be overly complex or slow to run in real time.

The Enhanced Drive Time (EDT) algorithm is based on macroscopic traffic flow theory and deterministic queuing theory (6). The model is a software solution that relies on the same data collection system (ie the loops) to calculate travel times. The system can also be used with the existing CMS infrastructure.

The model essentially regards all the vehicles along the roadway as being in an extended queue which can have multiple processing points and varying densities within the queue. Those vehicles must be processed through ramps off the freeway or through the end or termination point of the freeway.

Kurokawa and Ogawa (5) used a deterministic queuing model to estimate travel times on an inter-city freeway in Japan. They compare the performance of that model to an existing model which is essentially the same as the current Drive Time algorithm. They concluded that the deterministic queuing model performs better than the other model which relied on speed data alone. Importantly, they did not have any measured travel time data on which to calibrate their model or to support their conclusion.

There are fundamental differences between the Japanese and Australian work considered here. First there are important differences in the data collection system including different detector spacings and polling intervals. The loop installations in Japan were approximately five kilometres apart whereas in Melbourne they are on average 500 metres apart. Second, the loops in Japan provide five minute average data on volumes and speeds while the Melbourne system provides data every 20 seconds. The second fundamental difference is methodological. The Japanese model makes no account of varying geometric conditions, the relative vehicle densities within the queue or the impact of on/off ramps.

In a similar way to Kurokawa and Ogawa (5) the EDT model divides the freeway into a series of cells (Figure 2). In this model the loops define the cell boundaries. The location $j+1$ is the upstream loop site that bounds cell i, such that cell i is bounded by point j and point $j+1$.

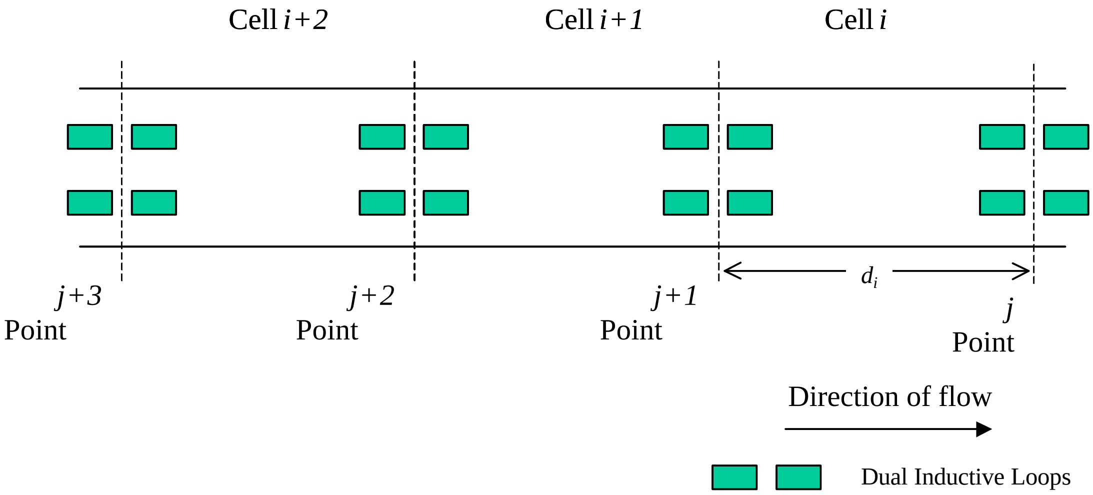

Figure 2: Freeway representation in term of cells

The travel time through the system is composed of a free flow travel time and a delay time. The delay time is analogous to the processing time of vehicles over and above the normal free flow travel times. Therefore the travel time from cell i to the downstream end of the facility is calculated by adding the delay time that vehicles in cell i will be subject to before exiting the system, to the free flow travel time for all the downstream cells that the vehicle must pass thorough before exiting:

$$t_i = t_i^D + \sum_{n=1}^{i} t_n^{FF} \qquad \ldots(1)$$

$$t_{i+1}^D = \begin{cases} t_i^D + t_i^P - t_i^{FF} & \ldots \quad if \ \left(t_i^D + t_i^P\right) > t_i^{FF} \\ 0 & \ldots \quad otherwise \end{cases} \qquad \ldots(2)$$

where:

t_i = Travel time estimate up to and including cell *i*
i = Cell number (numbered downstream to upstream)
t_i^D = delay for cell *i*
t_i^{FF} = Free flow travel time for cell *i*
t_i^P = Processing time for cell i

The free flow travel times are calculated by dividing the cell length by the posted speed limit:

$$t_i^{FF} = \frac{d_i}{v_i^*} \qquad \ldots(3)$$

where:

d_i = length of cell *i*
v_i^* = posted speed limit

Posted speed limits are used to ensure that the minimum time shown is consistent with travel at legal speeds. Alternatively v_i^* could be defined as the measured free flow speed for cell *i*.

In the deterministic queuing model the processing times at a downstream bottleneck are calculated by dividing the number of vehicles in the cell by the maximum outflow rate or cell capacity:

$$t_i^P = \frac{N_i}{C_j^*} \qquad \ldots(4)$$

where:

N_i = Number of vehicles in cell *i*
C_j^* = Maximum vehicle outflow rate for cell *i* (Note: This maximum vehicle flow rate depends on time, location, and geometry).

The number of vehicles in a cell can be estimated by multiplying the cell density by the length of the cell:

$$N_i = k_i \cdot d_i \qquad \ldots(5)$$

where:

k_i = Density of cell *i*

The cell densities can be estimated from the macroscopic traffic flow theory relationship that density is speed divided by flow (6):

$$k_i = \frac{q_j}{v_j} \qquad \ldots(6)$$

where

q_j = Measured flow at point j
v_j = Measured speed at point j

DETERMINATION OF PROCESSING RATES (C_j^*)

With any deterministic queuing model, the processing rate is critical to the determination of the processing time. As a result, it is important to consider the method of determining the processing rate (C_j^*) within this model. The values of C_j^* are based on the maximum number of vehicles that can pass over a cell boundary within a designated time. The value is determined by one of two conditions. The first relates to free flow conditions wherein the value is equivalent to the capacity of the cell. The second relates to constrained conditions where traffic conditions reduce the allowable through put to below the section nominal capacity. This may result from conditions at the end of the freeway such as traffic lights, incidents, or any other capacity reducing event.

The C_j^* value may also be constrained by conditions downstream of the location presently under analysis if there is a downstream bottleneck. The process of determining the value of C_j^* requires two steps. The first calculates individual cell values of C_j. These values are then updated to C_j^* values as follows:

$$C_{j+1}^* = \begin{cases} C_j^* & \ldots \ \text{if } C_j^* < C_{j+1} \\ C_{j+1} & \ldots \ \text{otherwise} \end{cases} \qquad \ldots(7)$$

In this fashion the bottleneck point(s) along the road are incorporated into the calculations by back propagating the constraining values.

Kurokawa and Ogawa (5) imply that they use a single value for the cell capacities in their model. Initial testing of the model described in this paper confirmed that the results are very sensitive to the values of capacity used in the calculations. In the Enhanced Drive Time Model a dynamic method of calculating them has been employed. This approach utilises monitored downstream real time flow values to estimate through puts or processing rates. Those values are then assumed to apply over the forecast time horizon.

FIELD TEST RESULTS

For the purposes of calibrating and testing the EDT model one section of freeway was selected that was considered to offer all of the characteristics necessary to evaluate the model. The location selected is part of Melbourne’s M1 motorway (also referred to as the South Eastern Freeway) which is located to the south east of the CBD. This freeway provides a major link between the city and the growing south eastern suburbs. Over the period from 6:30 am to 10:45 am, on a normal workday in excess of 10,000 vehicles exit the freeway at its termination point at Punt Rd.

The test section was defined between Warrigal Rd and Punt Rd on the inbound carriageway and this represents a travel distance of about 15 kilometres. Field data collection was undertaken from 6:30 am to 10:45 am on September 9th 1998. This time window was selected to ensure that the morning peak period was covered.

The travel times were measured using the timed number plate method (7). Field staff were positioned at five locations; Warrigal Rd, Burke Rd, Toorak Rd, Burnley, and Punt Rd. For a sample of vehicles the last four digits of the number plate and the time the vehicle passed their station was recorded. The sampling procedure employed was to record details for all red cars. These particular sampling features were selected to ensure that data was collected randomly and relatively continuously throughout the survey period. The results from the timed number plate survey highlighted considerable variability reflecting differences in driver lane change behaviour and queuing effects in different lanes at the downstream end of the facility. As a result of this variability, the travel times were merged into 5 minute segments and in this paper we consider average travel times for each 5 minute period.

A graphical indication of the relative performance of the Enhanced Drive Time (EDT) algorithm is shown in Figure 3. Clearly the EDT algorithm tracks the measured travel times more closely than the existing algorithm. It is also clear from Figure 3 that the existing algorithm does not adequately capture the decay in queues after the peak period and so it over predicts travel times in that period.

The performance of each model can be quantified using a range of standard error measures. For each time period there is a travel time measured from the number plate survey (T_t) and a corresponding value estimated from the model ($\hat{T}_t$). The basic measure of error is then determined by subtracting the estimated travel time from the actual travel time:

$$e_t = T_t - \hat{T}_t \qquad \ldots(8)$$

where:

e_t = Error at time t

The simplest error measure is to calculate a mean error across all time periods (from 1 to n):

$$ME = \frac{1}{n}\sum_{t=1}^{n} e_t \qquad \ldots(9)$$

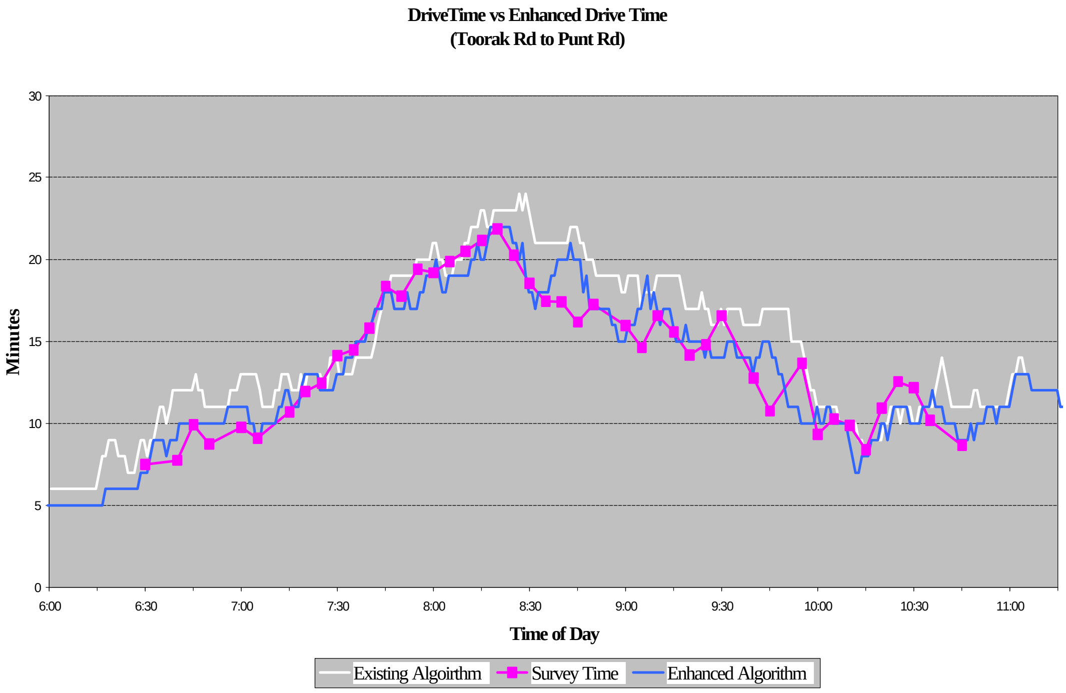

Figure 3: Graphical Comparison of Model Performance

The shortcoming with this measure is that positive and negative errors cancel out and so a mean error close to zero could be obtained even though individual time periods had large positive or negative errors. To overcome this shortcoming, the absolute values of the errors can be used to determine a mean absolute error measure:

$$MAE = \frac{1}{n}\sum_{t=1}^{n} |e_t| \qquad \ldots(10)$$

An alternative method for overcoming the cancelling of positive and negative errors is to square the error term. This results in a mean square error measure which also has the advantage that the squared errors will place more weight on large errors:

$$MSE = \frac{1}{n}\sum_{t=1}^{n} e_t^2 \qquad \ldots(11)$$

Often the relative magnitude of the errors is of interest. Here the percentage error is calculated by dividing the error by the true travel time:

$$pe_t = \left(\frac{T_t - \hat{T}_t}{T_t}\right) \times 100 \qquad \ldots(12)$$

and then this percentage error is averaged to produce a mean percentage error:

$$MPE = \frac{1}{n}\sum_{t=1}^{n} pe_t \qquad \ldots(13)$$

While this summarises the errors in relative terms this measure has the same problem as previously identified that positive and negative errors cancel out. Therefore a mean absolute percentage error measure is also calculated:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n} | pe_t | \qquad \ldots(14)$$

The performance of the Existing and Enhanced Drive Time (EDT) Models is summarised in Table 1 using the error measures defined above. On average (ME) both models over-predict the travel time although in a relative sense (MPE) EDT over-predicts by only one percent versus 12 per cent for the existing model. As noted earlier the problem with using either the ME or MPE measures is that positive and negative errors cancel out. This problem is addressed by considering by error measures formulated in terms of the absolute value of the error (MAE and MAPE) or the squared error (MSE). While the MAE, MAPE and MSE indicate higher error levels than the ME or MPE, it is still clear that EDT produces much lower errors for every error measure. These results highlight that the Enhanced Drive time model is superior to the existing model.

Table 1 : Quantitative comparison of algorithm performance

	Error Measure				
	ME	**MAE**	**MSE**	**MPE**	**MAPE**
Drive Time	-1.55	2.04	6.23	-12.0	16.0
Enhanced Drive Time (EDT)	-0.01	1.12	2.26	-1.0	8.0

CONCLUSIONS AND RESEARCH DIRECTIONS

This paper has described a model developed to improve the accuracy of the travel time estimates obtained in the Drive Time system. Importantly the proposed enhancements amount to a software change in the existing system. The same data collection and display technology are employed. The results from the field test highlight that the EDT model produces less error in the travel time estimates than the existing model.

The EDT algorithm is currently being installed into the VicRoads system. This will facilitate additional testing of the model before a validation field test is conducted. Further model development is being undertaken to enable the next generation Drive Time Algorithm to determine travel times over extended distances. The longer distance capability will be required once the Melbourne CityLink project is operational and motorists will be able to travel from one side of the city to the other on linked freeways. This will make it possible, for example to display travel times from freeway interchanges in the South East of the city to interchanges on the North West side of the city which involves a travel distance of approximately 70 km. As part of this on-going work it will be necessary to explore the limits of the model when used to predict over longer time windows.

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