The Effect of Daylight on Reliability of Transit Service: Case Study of the Melbourne Tram Network

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ABSTRACT

This paper investigates the effect of seasonal variation of daylight hours on the reliability of public transport service using an extensive data set of AVL records. The hypothesis tested is that travel time varies between days where sunrise is after 7 am on a dark winter day and before 7 am on a light summer day. The datasets used were Automatic Vehicle Location (AVL) of Melbourne trams (streetcar) in 2010 and the sunrise observations for the same period. All trips were made between 5:00 am to 9:00 am by four routes on the peak direction to Melbourne Central Business District (CBD). A linear regression model was developed, where tram travel time was the independent variable. The predictors (independent variables) were schedule travel time, time difference between 5:00 am to sunrise and time difference between 5:00 to trip start time.

Results indicate that daylight start time has a small but statistically significant effect on service travel time. The effect might be explained by travelers leaving home with later departures when it is darker than when it is light. This may result in increased traffic congestion, and as a result, raise travel times for the Melbourne streetcars which operates mainly in mixed traffic. A potential implication of this research is that transit timetables should be adjusted based on seasonal changes of daylight to improve travel time reliability. Environmental as well as congestion effects are demonstrated to impact service reliability.

Total = 238, words Maximum = 250
INTRODUCTION

Transit reliability is a significant attribute of travel time for both passengers and transit authorities. Passengers consider reliability in choosing mode of travel and also in their route choice behaviour. Travel time reliability is weighted equal or even more important than travel time by the passengers [1]. Therefore, there has been a continuous need to understand the key factors influencing service reliability and how to improve it.

There are many factors that can affect the reliability of transit services. Weather, traffic conditions, demand fluctuations, equipment failures, traffic incidents and emergencies can interrupt normal services, resulting in delay and poor customer perception [2, 3]. In this sense, identifying and quantifying factors that affect service’s reliability will provide authorities with useful knowledge when considering investments in transit infrastructure, optimisation, or the creation of robust travel schedule[4].

The effect of daylight on transit service reliability has not yet been considered. The question is if there is any correlation between daylight and reliability. Currie [5] pointed out that passengers are less likely to use public transport in a ‘dark and cold winter morning’ using the number of validated tickets for Melbourne trains. From a different perspective, there is a range of evidence on how Daylight Saving Time (DST) affects traffic safety [see e.g. 6, 7].

This study aims to determine and quantify the impact of daylight start times on tram travel time and reliability of service in Melbourne.

Melbourne has the world’s largest operating tram network with 250 kilometres of double track, 1763 tram stops across the network and 191.6 million patronage in 2011-2012, representing 35.2 per cent [8]. The average speed is 16 km/h dropping to 11 km/h in the central business district [9]. This can be explained by a large proportion of mixed traffic operation as more than 80 per cent of Melbourne’s tram network shares road with other vehicles.

FIGURE 1 Melbourne tram network
RESEARCH BACKGROUND

Maintaining a reliable transit service has always been an important issue for transit stakeholders. Levinson [3] provided a historical perspective of changes in techniques and technologies to control and monitor transit services and to improve their reliability.

Transit reliability has been extensively studied in the literature covering all modes (bus, train, and streetcar (tram)). Mazloumi et al. [10] showed the causes of travel time unreliability for buses in Melbourne and Know et al. (2011) divided the travel time unreliability over a freeway section in San Francisco. Börjesson and Eliasson [11] investigated unexpected delay by train trips. Currie [12] demonstrated the spatial and temporal variation of reliability for trams.

AVL data have facilitated travel time studies around the world by recording and archiving data at a very low cost [13]. El-Geneidy et al. [14] remarked the importance of AVL on enhancing services quality, pointing out the increasing usage of AVL system by transit agencies in US. Moreover, Hounsell et al. [15] state that the future will probably see an increase in AVL transit systems.

Although the effect of daylight and daylight saving time on road safety has been investigated in the literature, this effect on transit service reliability is not known. Considering this gap, this study quantifies the effect of daylight on the travel time of tram services.

DATA PREPARATION

Two datasets are prepared and merged for this analysis, namely the Automatic Vehicle Location (AVL) system and daylight start time data. The Melbourne tram network utilizes an AVL system to record information such actual time of arrival and departure to every stop, schedule time of arrival and departure, time stamp, and vehicle ID. This information is archived for all tram trips into an Automatic Vehicle Monitoring and Management Information System (AVMMIS). The raw AVL data was obtained from the operator (Yarra Trams). One of Melbourne’s AVMMIS advantages is recording the historical schedule times as well as the actual travel times. This provides an opportunity to compare the tram performance with its schedule at the time. The second dataset used was the time of sunrise for the city of Melbourne which is available from various sources including the Australian Department of Meteorology.

Data Extraction

The steps required to extract the tram travel attributes from the AVMMIS data is explained in Mesbah et al. [16]. For the present study, the data for all trips of four radial routes in 2010 were obtained. Routes 1, 8, 64, and 112 travel between Melbourne suburbs and the Central Business District (CBD). The first three routes were used to calibrate the model and the last route was used to validate it. Since all routes run radially to the CBD, the load profile and congestions effects are expected to be similar.

Several formatting options were available to extract data from AVMMIS. The extracted fields for this study are as follows: date, route number, timing point stop, scheduled time of arrival, recorded time of arrival, and recorded time of departure. All times were provided in a seconds after midnight format.

Considering the sunrise time varied from 5:50 am in summer to 7:37 am in winter during a year (2010 Sunrise in Melbourne), data from 5:00 to 8:00 can show the effect of daylight. Moreover, since trips might start before the sunrise and continue after that and the fact that the morning peak is until 9:00 am, the range of data extraction was extended to 9:00 am. Thus, travel time observations between 5am to 9am were analyzed.

Data Cleaning

Based on the above discussion the raw AVL data is cleaned according to the following stops.

- Split the data records by direction of travel (upstream and downstream direction).
- Remove trips that did not start and end between the specified hours.
- Remove non-normal trips which were flagged as short start/end or cancelled. Also, incomplete trips which had one or more timing point missing during their journey were removed.
- Calculate both the schedule and real travel time between each timing point. This was determined as the time between arrival at the previous stop and arrival at the current stop.
The sunrise data did not require any specific cleaning step.

**Travel Time Aggregation**

Using the travel time between each timing point, a representative total travel time was calculated for the route. This was done by adding travel time between the second stop to the second-last stop for each journey.

The actual travel times at the first and the last stop are significantly longer than the scheduled travel time. In the case of the first stop, the reason might be the behavior of the tram drivers who tend to get in to the vehicle before the schedule at the terminus to ensure they would be ready to commence the service on time. In the last stop case, the longer travel time could be due to the fact that arriving early at the tram stop allows drivers to rest slightly longer before starting the next journey. An example of Route 1 can be seen in Figure 2. The four character codes show the name of a timing point stop along the route. Therefore, HOMO is the first stop (starting terminus) and FLSW is the last stop (finishing point). This was consistent with previous studies on this dataset [16, 17].

![FIGURE 2 Difference between Actual and Schedule travel time.](image)

Route travel time was calculated from the second stop to the second last stop. An example of the route travel time can be viewed in Figure 3 where each timing point is represented by a four letter code and the time travel is shown in seconds. Travel time is calculated from COEL stop to COBU stop and is equal to 1314 seconds.

![FIGURE 3 Travel time aggregation.](image)

Finally, the outlier removal process was applied utilizing the three-sigma rule. A route travel time was considered an outlier if it did not fall within three standard deviations for the mean [18].
MODEL DEVELOPMENT

An ordinary least square (OLS) method was adopted to investigate the effect of daylight start time on tram service reliability. The main advantage of this method is the clear interpretation of the model and its coefficients. The total sample size for model calibration was 24,382 trips including data from 3 routes (R1, R8 and R64) during 2010 from 5:00 am to 9:00 am.

Several models were tested with the aim of developing the best set of explanatory variables. The total travel time was selected as the dependent variable to be estimated by the model. The total travel time is strongly correlated with the travel schedule. Therefore, the schedule travel time was considered as a key independent variable to be included in the model.

Relative to earliness of a trip, two independent variables are defined. The first variable is the interval between 5 am and the sunrise. This variable represents the time of sunrise relative to the start of the analysis period (i.e. 5 am). This variable is called Five to Sunrise (FS). The second variable is the interval between 5 am and the trip start time. This variable is called Five to the Trip Starting Time (FTST). The earlier the trip, the shorter is the total trip time. In other words, the earlier trips (smaller FTST) are expected to be further away from the morning peak and thus having a shorter trip time. It should be noted that the trip starting time is calculated from the second stop on a route, following the discussion around Figure 2 and Figure 3. FS and FTST variables are illustrated in Figure 4.

The final model used is shown below.

\[ t_{\text{actual}} = \beta_0 + \beta_1 \times t_{\text{sch}} + \beta_2 \times t_{\text{FTST}} + \beta_3 \times t_{\text{FS}} + \varepsilon \]  

(1)

where:

- \( t_{\text{actual}} \): the actual travel run time (observed).
- \( t_{\text{sch}} \): the schedule travel time.
- \( t_{\text{FTST}} \): the time between 5 am and the trip starting time.
- \( t_{\text{FS}} \): the time between 5 am and the sunrise time.
- \( \beta_i \): the coefficient associated to the variable \( i \).
- \( \varepsilon \): the error term in OLS.

The combined data from the three selected routes was utilized to estimate model coefficients in Equation 1. The result of the regression is summarized in Table 1 below, where coefficients of the variables and p-value are shown.

<table>
<thead>
<tr>
<th>TABLE 1. Coefficients and p-value of the final Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient</td>
</tr>
<tr>
<td>-------------</td>
</tr>
<tr>
<td>Constant</td>
</tr>
<tr>
<td>Travel_schedule</td>
</tr>
<tr>
<td>5toTST</td>
</tr>
<tr>
<td>5toSunrise</td>
</tr>
</tbody>
</table>
The estimated model obtained an adjusted $R^2$ value of 0.94, representing a high explanatory power on the total travel time and all variables are significant at a nominal 95% level of confidence. The value of the coefficient associated to travel schedule ($t_{schedule}$) is nearly 1. This is expected and suggests that an additional second in the schedule time will increase the actual travel time by 1 (ceteris paribus).

The interpretation of the additional variables in the model is described as follows:

**FTST:** The coefficient of FTST is positive which means with an increase in FTST, the total trip time becomes longer. If the trip starts later on a day, the tram journey would occur closer to the peak hour (and would partially or completely run during the peak hour). However, one should note that the tram schedule is already adjusted for a longer travel time when a trip is scheduled closer to the morning peak. Therefore, the effect of FTST is only marginal.

**FS:** As the sun rises later, less daylight is available in the morning period (5:00 to 9:00). Every 1000 seconds that the sun rises later, the actual time travel will increase by approximately 1.6 seconds beyond the schedule time (ceteris paribus). This could be due to two reasons. First is the fact that traffic slows down when dark and this is true for tram drivers as well as car drivers. Second is that tram users or car drivers tend to leave home later when it is darker than when it is light and traffic congestion is higher in winter times. This increases congestion causes a higher travel time of trams which operate in mixed traffic.

It should be noted that the effect of FS and FTST on travel time might initially look negligible; however, the results imply that in the case of higher FS or FTST, trams consistently arrive later than the schedule. This is despite all the opportunities of ‘time points’ along the route to match the schedule. The tram (or generally a transit service) is not expected to be consistently a few seconds late to arrive at the final stop (see definition of Figure 2). Such phenomenon is significant when it occurs consistently over thousands of vehicle trips.

To further test the model, a correlation matrix was calculated. The results are shown in the Table 2.

**TABLE 2. Correlation matrix between each variable**

<table>
<thead>
<tr>
<th></th>
<th>Actual travel time</th>
<th>Schedule travel time</th>
<th>5 to DFSS</th>
<th>5 to Sunrise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual travel time</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule travel time</td>
<td>0.9706</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 to TST</td>
<td>0.3995</td>
<td>0.3779</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>5 to Sunrise</td>
<td>0.0218</td>
<td>0.0169</td>
<td>-0.0063</td>
<td>1</td>
</tr>
</tbody>
</table>

As expected, a strong correlation is noticeable between actual travel time and scheduled travel time. However, slight correlation is found between FTST and schedule travel time. This is because schedule already encapsulates the lateness factor. To check multi-collinearity, Variance Inflation Factors (VIFs) were calculated. The literature suggest that if $1/$VIF is not lower than 0.1, there does not appear to be any multi-collinearity between the variables. The result for the Equation 1 can be observed in the Table 3.

**TABLE 3. VIF value for each variable**

<table>
<thead>
<tr>
<th></th>
<th>VIF</th>
<th>1/VIF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel schedule</td>
<td>1.17</td>
<td>0.856842</td>
</tr>
<tr>
<td>5 to TST</td>
<td>1.17</td>
<td>0.857051</td>
</tr>
<tr>
<td>5 to sunrise</td>
<td>1</td>
<td>0.999528</td>
</tr>
<tr>
<td>Mean VIF</td>
<td>1.11</td>
<td></td>
</tr>
</tbody>
</table>

**MODEL VALIDATION**

The essence of a good model is whether or not it can predict the dependent variable. Although the main objective of this paper was to estimate the effects of daylight, which was obtained by the variable FS, an approach to check the model validation is presented in this section. In this process the estimate travel run time through the model is compared with the actual travel times. If the model is reasonable, then the estimated values would be similar to the observed times.
Observations of Route 112 were used as an independent set of data. The total sample size was 8,567 trips which is equivalent to 33 per cent of the data used for calibration. The Coefficient of Variation of the Root Mean Squared Error (CV RMSE) was calculated to determine how well the model fits the data. In this case, the calculated value was 0.037. The current literature does not suggest an exact value to compare CV RMSE, but it provides a range from less than 10 to less than 5 are acceptable which means the proposed model can be approved.

Figure 5 shows the plot of the estimated travel times by the model vs. the observed values for route 112. As is seen in this figure, a majority of the values lie close to the 45 degree line which suggests a good fit with observation.

Moreover, the distribution of the model error was investigated. This was performed by plotting residuals and analyzing if there was a random pattern. Figure 6 shows that the error terms are scattered and thus the model validation is supported.
CONCLUSIONS

A model was developed to test if the daylight start time variations affect the reliability of tram (streetcar) services. The time difference between 5 am and sunrise was used as a proxy for the effect of daylight. An Ordinary Least Square (OLS) model was calibrated and validated using approximately 33,000 trips of four routes from 5 am to 9 am in 2010. The data was extracted from AVL system in Melbourne, Australia.

The results indicate that the effect of daylight is small but statistically significant. One possible explanation might be that transit passengers and car users tend to depart home later when it is darker than when it is light. As a result of that, less time is available to complete journeys. This suggests higher traffic congestion and an increased travel time during winter days. This increased congestion impacts trams which operate mainly in mixed traffic.

The results can assist the transit planners and operators in understanding the importance and the extent to which daylight can affect transit travel time. This study could warrant investigating a seasonal timetable because of daylight effects.

The model could be extended in the future to other cities or to explore the afternoon peak. A combination of morning and afternoon peaks provides a larger picture on the effect of daylight. A specific and important case is the effect of Daylight Saving Time (DST) on travel time reliability.

Further research could be carried out by the adopting different techniques such as non-linear models or inclusion of a wider range of variables into the analysis.

REFERENCES


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FIGURE 6 Residuals vs FS variable.