

Causes of travel time unreliability – a Melbourne case study

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1 Introduction

Reliability has been identified as one of the 10 most important determinants of service quality in public transport (Morpace, 1999). Transit reliability studies have mainly focussed on passengers waiting at stops through studies of schedule adherence and headway regularity (e.g. Abkowitz and Engelstein, 1984; Strathman and Hopper, 1993; Strathman *et al.*, 2000). These studies have explored how uneven headways and inconsistent arrivals increase passenger waiting time (e.g. Newell, 1971; Mohring, 1972; Furth and Muller, 2006; Csikos and Currie, 2007). However, reliability problems can also impact passengers who are on board the vehicles.

Day-to-day Travel Time (TT) variability can deteriorate transit system reliability by increasing in-vehicle travel time and passenger waiting time. Previous studies have suggested that a reduction in TT variability is valued by users (Bates *et al.*, 2001; Lam and Small, 2001; Sun *et al.*, 2003), since it reduces the anxiety and stress and decreases uncertainty in departure time and route choice decision making (Sun *et al.*, 2003). Knowledge of TT variability is also important for transit operators, who are interested in developing timetables that guarantee on-time performance and hence minimize operating costs.

The extent of research on public transport day-to-day TT variability is relatively small compared to efforts directed to that of passenger cars. This is mainly due to the difficulties in data collection. In addition, public transport TT observations are not as frequent as those of passenger cars since transit vehicles have substantially longer headways between vehicles. However, with the emergence of advanced vehicle monitoring systems, the collection of a relatively large sample of required data is now feasible.

This paper explores the causes of day-to-day TT variability of on-road public transport, and proposes a model to estimate travel time reliability as a function of causal factors. The paper first describes the dataset developed for this research. Section 3 describes the methodology adopted, followed by section 4 which details the results of the modelling undertaken. This includes the development of two theoretical models to estimate TT variability based on these findings. The paper concludes with a summary of key findings and suggestions for future research in this area.

2 Research data

Two main types of data were sought in the research:

- Measures of bus TT reliability, and
- Explanatory variables, which might be related to reliability performance.

Bus route 700 in Melbourne, Australia, was selected for analysis. The 27 kilometre-long bus route starts from Box Hill shopping centre, about 15 km east of Melbourne. Passing from residential areas in eastern and industrial areas in southern suburbs, the bus route ends at Mordialloc shopping centre. The route is segmented into 13 links ranging from 1.5 to

5.7 kilometres in length, demarcated by timepoint stops, where arrival times and departure times of buses are recorded by the GPS system. The weekday TT dataset from year 2007 was provided for this research with the kind assistance of the operator Ventura National Bus Company. This included the TTs for 3351 complete vehicle trips, which were further divided into TTs of different route sections.

The TT observations of each section were aggregated into 15-minute intervals. Where intervals had zero observations, these were removed from the analysis. This produced a total of 547 categories of time-space observations which were used to explore bus TT reliability. The resulting sample size within any given category ranged from 15-180 observations.

Analysis focuses on computing day-to-day TT variability and defining transit system characteristics that might influence TT reliability for each time-space category. This includes physical route characteristics (link length, traffic signals, bus stops, and land-use) as well as departure delay, and a number of temporal variables, including 'AM peak': 7:00 - 9:00, 'Inter-peak': 9:00 - 16:30, 'PM peak': 16:30 - 18:30, and 'Off-peak': 6:00 - 7:00 and 18:30 - 24:00.

An appropriate measure of TT variability needs to be defined for research purposes. A range of different measures is reported in the literature (Mazloumi *et al.*, 2008). One approach is to use the difference between different TT percentiles in TT distribution. In this research, the difference between 90th and 10th TT percentiles (Tu *et al.*, 2007a, b) of each time-space category is used. The higher this difference, the more variable and less reliable the TTs are.

Only a limited range of explanatory variables is available at this stage in the research program. This includes the variables presented in Table 1.

Table 1 – Definition of analysis variables

Dependant Variable		
TT variability	=	day-to day travel time variability: difference between 90 th and 10 th percentiles of TT (minutes)
Explanatory Variable		
LENGTH	=	section length (km)
STOPS	=	number of bus stops in each kilometre
SIGNALS	=	number of signalized intersections in each kilometre
DELAY	=	average of (scheduled departure time minus observed departure time) divided by section length (minute/km)
AM	=	1 if AM peak and 0 otherwise
INTER-PEAK	=	1 if Inter-peak and 0 otherwise
PM	=	1 if PM peak and 0 otherwise
OFF-PEAK	=	1 if Off peak and 0 otherwise
LAND-USE	=	1 if surrounding land-use is 'Industrial' and 0 otherwise

Section length, number of stops, signals and time periods were calculated from an analysis of route maps and a field survey. Delay concerns timing point delays and is defined as the difference between scheduled and observed departure times. A land-use variable is also considered for each route section. Here, a route section is classified as either residential or industrial based on a field survey of each section.

3 Methodology

The Linear Regression technique is used to develop the model, which uses the method of minimum least squares. The Backward Stepwise selection method is used to select the significant variables, where the analysis begins with a model including all the variables. In this method, insignificant variables are eliminated from the model in an iterative process. When no more variable can be eliminated from the model, the analysis is completed. Only the variables with the expected sign and statistical significance are selected for the final model. The overall statistical fit of the model (adjusted R^2) is considered along with the overall model significance value to examine the performance of the model.

To structure the model, *a priori* knowledge is needed about how different factors affect day-to-day TT variability. To assist development of the model, the relationship between TT variability and average TT in all time-space categories is explored. Figure 1 (top) shows the relationship between the TT variability ($T_{90}-T_{10}$) and the average TT in all sections. Accordingly, TT variability increases with increasing average TT. However, if a measure of variability is adopted which is neutral to trip length, $(T_{90}-T_{10})/T_{50}$, variability is seen to show an inverse to constant relationship with average TT (Figure 1, Bottom). This suggests a higher variation in relation to the median in shorter route sections. However, in long sections, there is less variation relative to the median value.

The variables considered for inclusion in the TT variability model are included in Table 1. The reasons for considering these variables and the expected results are presented in the following discussion.

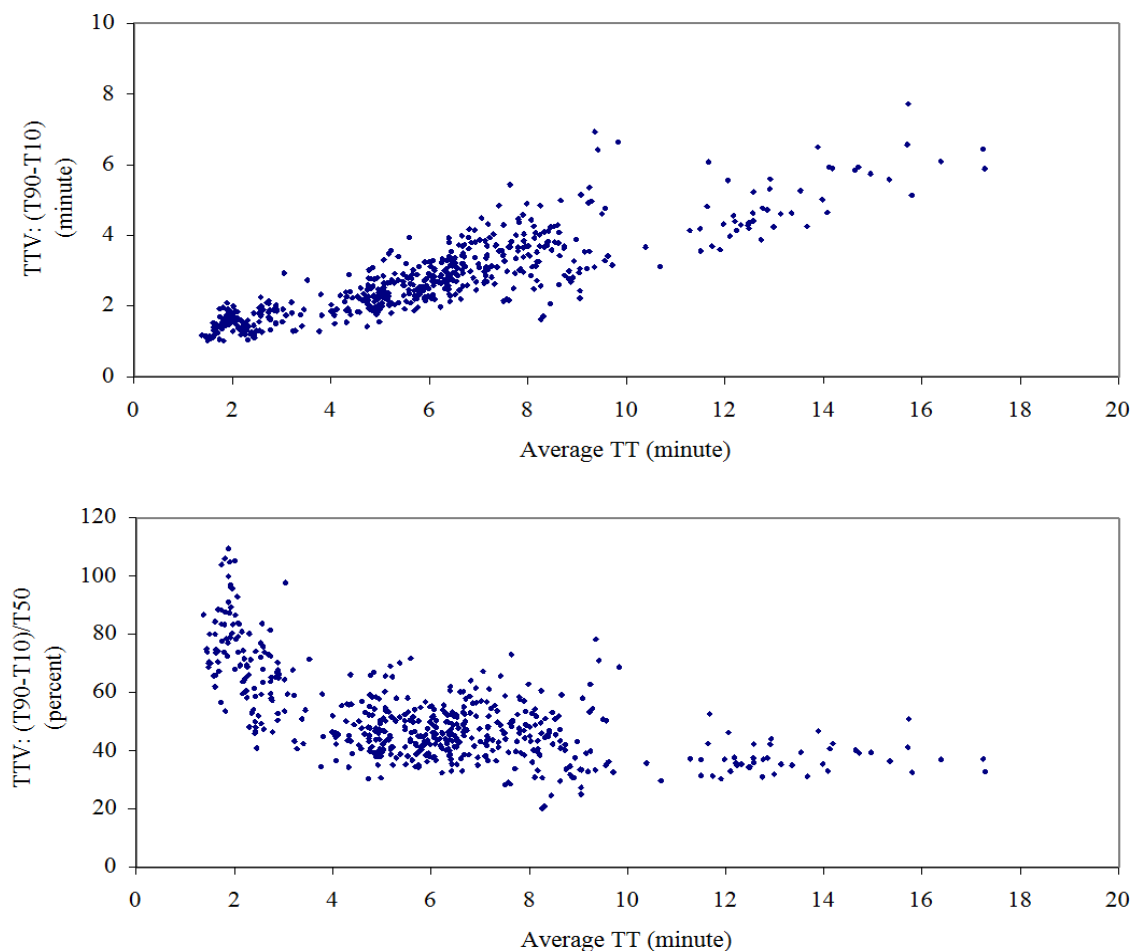


Figure 1 – The relationship between TT variability and average TT for all sections

Research suggests a longer route section length can have an adverse effect on transit reliability (Sterman and Schofer, 1976; Abkowitz and Engelstein, 1983; Strathman and Hopper, 1993). This variable has been shown to have a direct relationship with average TT (e.g. Abdelfattah and Khan, 1998; Strathman *et al.*, 2000). The higher the length is, a higher difference between the 90th and 10th TT percentiles is expected. Length is defined in kilometres and a positive coefficient sign is expected.

A large number of bus stops is also thought to adversely affect transit reliability (Sterman and Schofer, 1976) as well as increase average TT. When the number of bus stops increases, the total number of occasions, where some buses stop and others don't, increases. This increases the variability of TT and hence the difference between 90th and 10th TT percentiles. The number of stops per unit section length is defined for modelling and a positive coefficient sign is expected for this variable.

Research also suggests that a higher number of signalized intersections has a negative effect on reliability (Sterman and Schofer, 1976; Abkowitz and Engelstein, 1983). Traffic signals act to delay buses and the variation in these delays increases with the number of traffic signals encountered. The number of signalized intersections per unit section length is the variable considered, and a positive coefficient sign is anticipated for this variable¹.

Analysis also considered the possible impacts that timing point delays have on TT reliability. To manage variability in running times, bus operators require that bus drivers must wait at timing points to leave at the scheduled time if they arrive early. Difference in the scheduled and actual departure times is analysed as a part of the analysis. Figure 2 shows the effect of lateness and earliness on the TT of a route section. TTs are longer when buses are operating earlier than scheduled. This is where bus drivers are 'dragging the road' i.e. going slower to make sure depart times at time points don't involve excessive waiting. Where buses are running late, in general TTs prove to be lower as drivers attempt to make up time. To consider this effect, the average value of difference between scheduled departure time and observed departure time divided by length in each time-space category is considered for analysis and a positive sign is expected for the coefficient.

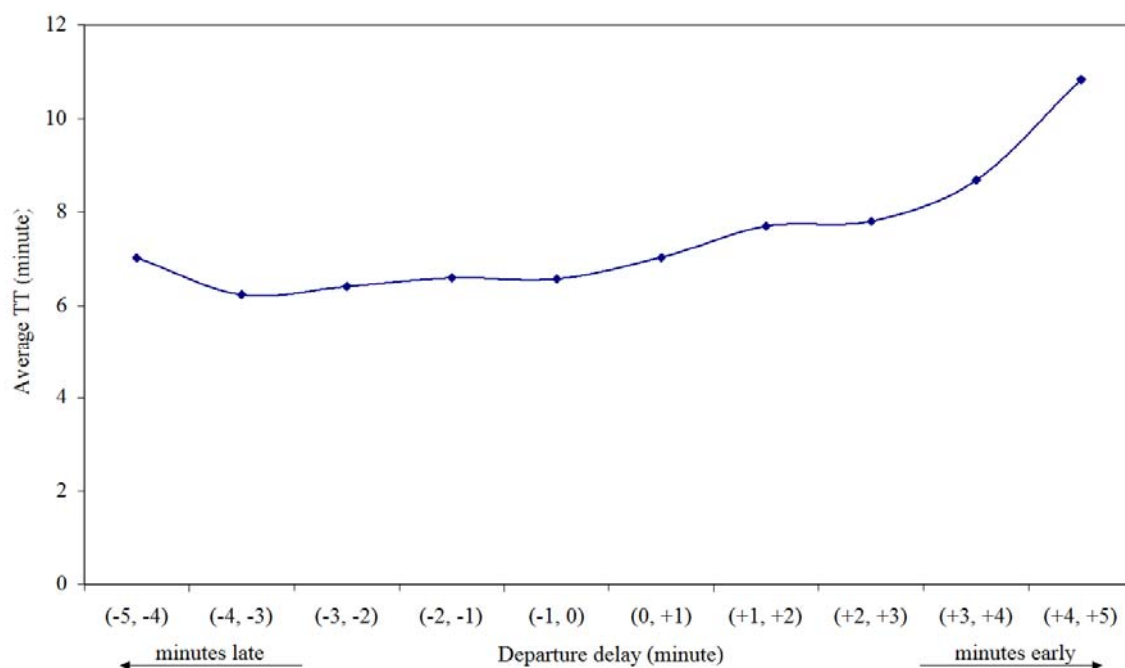


Figure 2 – The effect of departure time delay on average travel time

¹ Active traffic signal priority was not provided on this bus route during the data collection period.

Time periods reflect general traffic conditions notably peak periods where congestion is known to be high. The effect of time period is represented by defining four Boolean variables: 1 if morning peak, 0 otherwise; 1 if inter-peak, 0 otherwise; 1 if afternoon peak, 0 otherwise; and 1 if off-peak period, 0 otherwise. A positive coefficient sign is expected for peak-hour variables, while a negative coefficient sign is anticipated for inter-peak and off-peak variables.

Research suggests that land use type is associated with varying passenger demands at stops and traffic congestion levels at intersections (Levinson, 1983). Kimpel (2001) showed that the socioeconomic and land-use characteristics influence the reliability of a transit service. Route 700 operates in areas of two main land-use types; 'industrial' and 'residential'. Passenger demand is relatively lower in industrial areas compared to residential areas. In addition, the signalized intersections are not as congested as those in industrial areas. It may therefore be hypothesised that industrial sections of route should show a lower TT variability compared to that in other parts of the route. A negative coefficient sign is expected for this variable.

A constant is also considered in the model to take into account omitted effects. Possible factors omitted include driver characteristics, passenger demand and traffic flow variation. Data for these variables is not available for the research at this stage.

4 Estimation results

An underlying assumption of a linear regression analysis is that the standard deviations of the error terms are constant and do not depend on the independent variables. In order to satisfy this assumption, the logarithmic value of TT variability is used in the estimation procedure.

The estimated TT variability model results are shown in Table 2. The variable coefficients all have the expected signs, and are statistically significant at the 1% level except the PM, which is significant at the 5% level. The variable 'Inter-peak' is not included in the model final variables due to its statistical insignificance. The model as a whole explains 66% of the variation in TT variability values. The last column in Table 2 shows the percent of change in TT variability if the explanatory variable increases by 1 unit.

The results presented in Table 2 suggest the following about the causes of TT variability on bus route 700 (in order of significance):

- LAND-USE is found to be the most sensitive variable examined in relation to its impact on TT reliability. The results for 'LAND USE' suggest that TT variability in an 'industrial' area is 33 percent less than that in a residential area.
- Section LENGTH has the largest single positive relationship with TT variability. For each kilometre added to the section length, TT variability will increase by 17 % assuming all other variables are kept constant. This implies that shorter routes are likely to be more reliable.
- OFF-PEAK variable has a coefficient of -0.135 suggesting it has one of the more sensitive and negative relationship with TT variability. As expected, the peak time periods are positively associated with TT variability, although their coefficients proved to be not as sensitive as a range of other factors.
- The number of SIGNALS is the next in terms of sensitivity of the relationship with TT variability. Each additional signal added to the unit length of a route section increases TT variability by 8%. This highlights the need for the provision of active signal priority for buses. Active signal priority reduces signal delay experience by buses hence it acts to improve TT reliability (Sterman and Schofer, 1976).

- The number of bus STOPS is the next most sensitive explanatory variable in relation to TT variability. The addition of one stop in one kilometre of a route section will increase TT variability by almost 5%. This suggests that wider stop spacing will act to improve TT reliability. Strategies like consolidating bus stops, back-door only for alighting, front-door only for boarding and low floor buses that shorten the boarding and alighting time can be of value to improve TT reliability by reducing dwell time delays associated with bus stops.
- DELAY is found significantly associated with TT variability. One additional minute of early running per unit section length increases TT variability by 4%. Clearly, a stricter management of on-time performance can act to improve scheduling adherence, and also improve TT reliability.

Table 2 – TT variability estimation model

$$\text{Log(TT variability)} = \beta_1 + \beta_2 \times \text{LENGTH} + \beta_3 \times \text{STOPS} + \beta_4 \times \text{SIGNALS} + \beta_5 \times \text{DELAY} + \beta_6 \times \text{AM} + \beta_7 \times \text{PM} + \beta_8 \times \text{OFF-PEAK} + \beta_9 \times \text{LAND-USE}$$

Variable	Coefficient	t-statistic	significance	change in TT variability for 1 unit increase in variable value
(Constant)	-0.120			
LENGTH	0.159	12.348	0.000	+17.0%
STOPS	0.047	9.328	0.000	+4.8%
SIGNALS	0.077	9.333	0.000	+8.0%
DELAY	0.038	7.312	0.000	+3.9%
AM	0.042	2.950	0.003	+4.3%
PM	0.030	2.174	0.030	+3.0%
OFF-PEAK	-0.135	-12.448	0.000	-12.6%
LAND-USE	-0.402	-8.570	0.000	-33.1%
No. of Observations = 547		Adjusted R ² = 0.66		

Although only a limited number of explanatory variables were available for analysis, a surprisingly large degree of the variation in the TT variability values has been explained (66%) by this model. This model could be used in route planning purposes where different route alternatives are assessed. Clearly, there is much scope to improve the quality of this modelling by expanding the range of explanatory variables included. This is the agenda for future research.

In an effort to develop a better TT variability estimation model, the average TT is considered as an independent variable along with all the previously considered variables. The results of this analysis are included in Table 3. The model can explain 83% of the variation in the TT variability. All the model variables are significant at the 1% level. In this model, since the effect of some variables have been already embedded in the variation of 'AVG TT', their individual effects are not significant. However, still 'LENGTH', 'OFF-PEAK' and 'LAND-USE' are significant. This model estimates the variability with a higher precision level compared to the model presented in Table 2. This predictive model could be used to assist in schedule development once the average TT is known.

Table 3 – TT variability prediction model including average TT

$$\text{Log}(\text{TT variability}) = \beta_1 + \beta_2 \times \text{AVG TT} + \beta_3 \times \text{LENGTH} + \beta_4 \times \text{OFF-PEAK} + \beta_5 \times \text{LAND-USE}$$

Variable	Coefficient	t-statistic	significance	change in TT variability for 1 unit increase in variable value
(Constant)	0.027			
AVG TT	0.059	31.072	0.000	+6.1%
LENGTH	0.025	2.732	0.006	+2.5%
OFF-PEAK	-0.043	-5.495	0.000	-4.2%
LAND-USE	-0.255	-9.069	0.000	-22.5%
No. of Observations = 547		Adjusted R ² = 0.83		

5 Summary and Conclusion

Public transport reliability has been mainly researched from the viewpoint of passengers waiting at bus stops with little attention being paid to 'in-vehicle' TT reliability. This is due to difficulties in collecting public transport TT observations; a problem solved by the emergence of modern AVL monitoring systems, which have been used in this paper.

This paper has identified the causes of TT unreliability for bus route 700 by modelling the relationship between day-to-day TT variability and a range of explanatory variables. The first TT variability estimation model is a function of (in order of significance) land use, section length, temporal variables, number of signals, number of stops and timing point delay. This model could be used for assessing the TT reliability of different alternatives in route planning. When the average TT is considered for modelling, a model with a better performance is derived. The second model, which would be of value to route scheduling, explained 88% of the variation in TT variability values.

The results of this research are preliminary and based on a limited range of explanatory variables available to the researchers at this stage. Inclusion of a wider range of variables into the analysis including passenger demand, traffic condition, weather condition, traffic accident data, and the impact of divided/undivided road and bus lane on TT reliability is a promising direction for future research.

References

- Abkowitz M. D. and Engelstein I. (1983). 'Factors affecting running time on transit routes', *Transportation Research Part A*, 17(2), pp. 107-113.
- Abkowitz M. and Engelstein I. (1984). 'Methods of maintaining transit service regularity', *Transportation Research Record*, 961, pp. 1-8.
- Abdelfattah A. M. and Khan A. M. (1998). 'Models for predicting bus delays', *Transportation Research Record*, 1623, pp. 8-15.
- Bates J., Polak J., Jones P. and Cook A. (2001). 'The valuation of reliability for personal travel', *Transportation Research Part E*, 37(2-3), pp. 191-229.

- Csikos D. and Currie G. (2007). *The impact of transit reliability on wait time-insights from AFC data*, TRB annual meeting. Transportation Research Board, Washington DC, USA.
- Furth G. P. and Muller T. H. J. (2006). 'Service reliability and hidden waiting time: Insights from automatic vehicle location data', *Transportation Research Record*, 1955, pp. 79-87.
- Kimpel T. J. (2001). *Time point analysis of transit service reliability and passenger demand*, PhD thesis, Portland State University, OR, USA.
- Kittelton and Associates (2003). *Transit Capacity and Quality of Service Manual (TCQSM)*. 2nd Edition, Report 100, Transit Cooperative Research Program, Washington DC, USA.
- Levinson H. S. (1983). Analysing transit travel time performance, *Transportation Research Record*, 912, pp. 1-6.
- Lam T. C. and Small K. A. (2001). The value of time and reliability: measurement from a value pricing experiment, *Transportation Research Part E*, 37(2-3), pp. 231-251.
- Mohring H. (1972). Optimization and scale economies in urban bus transportation, *American Economic Review*, 62(40), pp. 591-604.
- Morpace International Inc. (1999). *A handbook for measuring customer satisfaction and service quality*, Report 47, Transit Cooperative Research Program, Washington, DC, USA.
- Mazloumi E., Currie G. and Sarvi M. (2008). *Assessing Measures of Transit Travel Time Variability and Reliability Using AVL Data*, TRB annual meeting, Transportation Research Board, Washington DC, USA.
- Newell G. F. (1971). 'Dispatching policies for a transportation route', *Transportation Science*, 5, pp. 91-105.
- Sterman B. P. and Schofer J. L. (1976). 'Factors affecting reliability of urban bus services', *Transportation Engineering*, 102, pp. 147-152.
- Strathman J. G. and Hopper J. R. (1993), 'Empirical analysis of bus transit on-time performance', *Transportation Research Part A*, 27(2), pp. 93-100.
- Strathman J. G., Dueker K. J., Kimpel T., Gerhart R.L., Turner K., Taylor P., Callas S. and Griffen D. (2000). 'Service reliability impacts of computer-aided dispatching and automatic location technology: A Tri-Met case study', *Transportation Quarterly*, 54(3), pp. 85-102.
- Sun C., Arr G. and Ramachandran R. P. (2003). 'Vehicle re-identification as method for deriving travel time and travel time distribution', *Transportation Research Record*, 1826, pp. 25-31.
- Tu, H., Van Lint, J. W. C. and Van Zuylen, H. J. (2007a). *The impact of adverse weather on travel time variability of freeway corridors*, TRB annual meeting. Transportation Research Board, Washington DC, USA.
- Tu, H., Van Lint, J.W.C. and Van Zuylen, H.J. (2007b), *The impact of traffic flow on travel time variability of freeway corridors*, TRB annual meeting. Transportation Research Board, Washington DC, USA.