THE SECONDARY EFFECTS OF FARE-COLLECTION STRATEGIES

U. VANDEBONA
Research Scholar

A.J. RICHARDSON
Senior Lecturer in Transport
Department of Civil Engineering
Monash University

ABSTRACT: *It is known that different fare-collection strategies have different passenger boarding and alighting rates for street-based public transport services. This paper reviews various models of stop service times and summarises the available empirical observations of boarding and alighting rates. It then examines the effect of different average boarding rates, and coefficients of variation of boarding rates, on the route performance of a tram service. The analysis is conducted using the TRAMS (Transit Route Animation and Modelling by Simulation) package. This modelling package is briefly described with particular attention being paid to the passenger arrivals subroutine, the alighting passengers subroutine, and the tram stop service times subroutine. As a result of the analysis, it is found that slower boarding rates produce a slower and less reliable service along the route. The variability of boarding rates has no effect on route travel time but does contribute to greater unreliability in level-of-service. It is concluded that these level-of-service effects need to be considered when assessing the effect of changes in fare-collection strategies.*

INTRODUCTION

Public transport operators and managers have found themselves under increasing pressure in recent years because of conflicting expectations from different groups in the community. On the one hand, public transport users demand better levels of service and no increase in fares, whilst on the other hand the general community and the Government Treasury demand that the public transport financial deficit be reduced, or at least curtailed. Given these pressures, public transport managers are continually looking for methods by which the productivity of the public transport system may be enhanced.

In the field of street-based public transport, an area which has received much attention in this respect is that of staffing policies; in particular, the debate about whether to have one-man or two-man-operation of public transport vehicles has been lengthy and vigorous. Investigations of one-man-operation have covered not just staffing policies, but also vehicle design and fare-collection strategies. All three must be well-integrated if an acceptable one-man operating system is to be devised.

In considering this question, it is obvious that the effects of one-man operation go well beyond the immediately apparent staff cost savings. In particular, the choice of fare-collection strategy has a large influence on whether conversion to one-man operation will ultimately prove to be beneficial or not. If boarding the vehicle is slowed down by the one-man operation fare-collection strategy, then it is possible that the degradation in level-of-service provided will outweigh the immediate staff cost savings per vehicle so that, overall, the service is less productive. Obviously, conversion to one-man operation needs careful analysis of the operational, financial and economic consequences.

This paper makes a contribution to this analysis by examining the effects of different boarding rates on the route performance of a tram system. Boarding rates are a critical variable in that they most concisely describe the operational performance of different fare-collection strategies. Route performance is expressed in terms of average passenger travel time, average passenger waiting time, vehicle bunching, route travel time and a number of other level-of-service performance measures. The analysis is performed using the TRAMS (Transit Route Animation and Modelling by Simulation) package, and uses as a case study example loosely based on an actual tram route in Melbourne.

FARE-COLLECTION STRATEGIES

Fare-collection strategies for street-based public transport may be classified under three major headings; two-man-operation where the conductor collects fares, one-man-operation where the driver collects fares, and one-man-operation where the driver does not collect fares. Within each of these classifications, there are a number of different alternatives.

In a two-man-operation, the conductor may function in one of two ways. He may either be a roving conductor who moves through the vehicle collecting fares from passengers whilst the vehicle is in motion, or else he may be seated, with passengers paying their fares as they file past the conductor's position after entering the vehicle. Examples of these two methods of operation, are respectively the W-class (green) tram and the Z-class (orange) tram operating in Melbourne.

One-man-operation with fare collection by the driver gives rise to a wide range of boarding time rates, depending upon the details of the fare-collection procedure and the nature of the fares charged. Two major options for fare collection are to either accept exact fares only or else for the driver to be able to give change to passengers. As will be seen later, the former results in a faster boarding rate, whilst the latter is more conducive to good customer relations. The degree of difference between these two options also depends on the nature of the fares charged. For example, are they flat fares, finely graduated fares according to distance travelled, zone fares, free transfers requiring no extra ticket purchase, or season tickets? Each of these alternatives will have different boarding rates and hence different impacts on the route performance of the service. One-man-operation with fares not collected by the driver means that fares must be collected in some other fashion - unless of course the public transport service is free, at the point of usage, to users. One of the most popular methods of automatic fare collection is the exact-change fare box. This method has been in use in North American services for many years. A minor, though important, aspect of this system is whether the fare is single-coin or multiple-coin; single-coin fares give slightly faster boarding rates but are becoming increasingly difficult in these days of high inflation. Watts and Naysmith (1980) note the need for a coin of value greater than 50p (in the U.K.). Other methods of payment include the use of pay-turnstiles on board the vehicle (although these are often seen as being an unreliable hinderance), and the use of credit card and magnetised ticket-readers.

A complete alternative to the above methods is the "proof-of-payment" system, in which there are no turnstiles or barriers to entry and no need for any fare payment on boarding the vehicle. All that is required is that the user have a valid ticket which must be produced if required. Ticket inspectors perform random checks for fare evasion, and the penalty imposed must be such that the expected cost of purchasing a ticket be no more than the expected cost (including penalties) of not purchasing a ticket. Given this general approach to fare collection, the range of ticket-selling procedures is quite wide. Tickets may be purchased from ticket-sellers at major stops, season tickets may be used, books of tickets could be bought from newsagents or other stores, tickets may be purchased from ticket-selling machines (either at stops or on-board the vehicle), tickets may be purchased from drivers (at a premium price), or users could simply elect to pay the penalty when caught without a ticket. In a proof-of-payment system, with appropriate penalty charges and a systematic ticket inspection roster, this last method of payment would be quite legitimate and need no longer be thought of as a crime of fare evasion.

A major advantage of the proof-of-payment system is that it results in a very quick boarding rate and hence a higher level-of-service to users. It also allows considerable freedom in vehicle design because there is now no need for all boarding passengers to file past the driver. Wide central doors and articulated vehicles become distinct possibilities. A disadvantage of proof-of-payment systems is that operators can no longer obtain ridership statistics from ticket sales, and may therefore have to conduct special sample surveys to obtain ridership details.

BOARDING AND ALIGHTING RATE MODELS

Given the wide variety of fare-collection strategies and associated vehicle designs, it is not surprising that a number of different models have been proposed to predict service time at a stop as a function of the numbers of passengers boarding and alighting from the vehicle at that stop. In summary, there are four basic models which have been proposed for the prediction of service times.

(i) The Sequential Model

$$T_i = \gamma + \alpha A_i + \beta B_i \qquad (1)$$

where:
T_i = service time at stop i
A_i = no. of alighting passengers at stop i
B_i = no. of boarding passengers at stop i
γ = dead time
α = alighting time per passenger
β = boarding time per passenger

This model is likely to be appropriate where boarding and alighting takes place through the same door, and hence proceed sequentially (alighting usually preceding boarding). The dead time γ accounts for the time lost at the beginning and end of the stopping manoeuvre and is a function of the presence or absence of doors on the vehicle, the nature of any door interlocking device fitted to the vehicle (e.g. a transmission interlock which prevents doors being opened until the vehicle is stopped; an acceleration interlock which prevents the vehicle moving off until the doors are closed), and the layout of the stop (e.g. safety zone boarding Vs loading from the kerb). The coefficients α and β depend primarily on the fare collection system employed, but may also vary with the time of day (peak Vs off-peak), and with the type of passenger being served (e.g. elderly or infirm), the current occupancy of the vehicle, and the amount of baggage carried by passengers.

(ii) The Interaction Model

$$T_i = \gamma + \alpha A_i + \beta B_i + \delta (A_i \cdot B_i) \qquad (2)$$

This model is again applicable to a single door vehicle but instead of assuming complete independence between board and alighting events, it allows for the possibility of interaction between the two streams of passengers. The coefficient δ may be either positive or negative, accounting either for conflicting and congestive effects or for overlapping boarding and alighting flows.

(iii) The Simultaneous Model

$$T_i = \max \begin{bmatrix} \gamma_A + \alpha A_i \\ \gamma_B + \beta B_i \end{bmatrix} \qquad (3)$$

This model is appropriate when the vehicle has separate doors for boarding and alighting. In this case, both processes may occur simultaneously and the service time will be determined by whichever process takes the longer time. In this model, different dead times are allowed for boarding and alighting processes to account for the effect of different types of door interlocking devices.

(iv) The Multi-rate Boarding Model

$$T_{Bi} = \begin{cases} \gamma + \beta_1 B_i & 0 < B_i < x \\ \gamma + \beta_1 x + \beta_2 (B_i - x) & x \leq B_i \end{cases} \qquad (4)$$

Under some circumstances, in any of the first three models, the boarding time (T_{Bi}) may best be explained by means of a multi-rate boarding process. Thus for the first x boarding passengers, boarding takes places at a rate of β_1 seconds per passenger. Above this number, extra passengers board at a slower rate of β_2 seconds per passenger. This situation may occur, for example, when boarding passengers must pay fares at a turnstile, or to a seated conductor situated inside the vehicle, and where there is only enough queuing space for x passengers within the vehicle.

Some Empirical Observations

In all the above models, the parameters α, β, γ and δ must be determined by empirical observation. Surprisingly, for such a basic measure of public transport vehicle performance, there is little evidence of reported studies in the transport literature. One major U.K. study (Cundill and Watts, 1973), one major U.S. study (Kraft and Bergen, 1974) and a number of smaller studies comprise the literature on the subject. Some limited information on the Melbourne tram system is also available (Fouvy, 1972; Fraser, 1980; Hawke and Yem, 1981). Whilst the analysis reported later in this paper is not dependent on particular values of boarding and alighting rates, it is informative at this stage to review the empirical values reported in the literature, for different vehicle design and fare-collection strategy configurations, to obtain an idea of the range of values likely to be met in practice.

Cundill and Watts (1973) report on a major study of bus boarding and alighting times carried out in various cities in the U.K. Their study covered a wide range of bus designs and fare-collection strategies. They found that a linear sequential model was satisfactory for one-door buses whilst a simultaneous model described two-door operation. They found little justification for using a non-linear or multi-rate model, although they did show that a multi-rate model could be constructed for some automatic-ticketing-machine vehicles. They found that the alighting rate was similar for all vehicles studied with values ranging from 1 to 1.6 seconds. Boarding rates ranged from 1 to 2 seconds for two-man-operation, and from 2.3 to 5 seconds for one-man-operation. Exact fare systems were at the lower end of this range whilst procedures requiring drivers to give change and provide information were at the upper end. The dead times ranged from 1 to 7 seconds with the presence and type of interlocking device being the main contributing factor to long dead times.

Kraft and Bergen (1974) report on studies of U.S. bus loading and unloading rates. Their report supersedes some earlier studies by Kraft and Boardman (1969) and Boardman and Kraft (1970). They studied both one-door and two-door operation and used stepwise regression analysis to fit either sequential, interaction or simultaneous models to the data. Their results should be interpreted with caution, however, because of two features of their study. Firstly, the data were collected such that "passenger service times were recorded from the moment the doors opened until the last passenger alighted from or boarded the vehicle". This is in contrast to other studies which start timing from the moment the vehicle stops and continues until the vehicle moves off (or is ready to move off). The data collection method therefore means that dead times will be underestimated, especially in view of Cundill and Watts (1973) comments about door interlocking devices. In fact, many of Kraft and Bergen's (1974) regression equations imply dead times of less than zero. The second problem is that for several options, data were collected only over a limited range of boardings and alightings. This therefore limits the usefulness of the equations in other studies and gives a false impression of the meaning of each of the model parameters.

Irrespective of the above limitations, some of the overall conclusions of Kraft and Bergen (1974) are worth noting:

(i) Morning and evening peak period results are similar, but off-peak boarding and alighting rates are greater than peak period rates.

(ii) Exact fare systems save between 1.4 and 2.6 seconds per passenger in boarding operations (this compares with a saving of 3 seconds given by Cundill and Watts (1973)).

(iii) Alighting rates were fairly constant within the range of 1.0 to 1.4 seconds.

Jordan and Turnquist (1979) quote a dead time of 2.25 seconds and a boarding rate of 2.71 seconds per passenger from a sample of 92 stopping manoeuvres in Chicago. Unfortunately, they do not describe the type of bus in service and hence not much can be made of these mean values. It is of interest however that they state that the variance of the stopping times was constant (and equal to 8 sec.^{2}) for all boarding numbers greater than one (and up to twelve). This constrasts with the statement by Cundill and Watts (1973) that "the variance of stop time was found to increase with the number of persons handled". From a single distribution of stop times for one passenger boarding a two-doorway one-man-operation bus (Cundill and Watts, 1973) it is possible to calculate that the coefficient of variation for a single boarding is approximately unity. The value of these meagre results on boarding time variability will be apparent later in this paper.

The only study in which alighting rates were found to be very different from 1.0 to 1.5 seconds was by Nelson (1976), in which he described the operation of a credit card fare collection system. In this system, fares were fixed according to distance travelled. This required that a credit card be inserted into a validation machine at the beginning and end of the trip. In this study, both boarding and alighting rates were found to be approximately 4 seconds per passenger. This study clearly demonstrates that it is the ticketing procedure which determines the boarding and alighting rate.

The dependence on ticketing procedure is also clearly shown in boarding rates quoted by Grigg (1982). He gives boarding rates of 1.5 to 2.5 seconds for roving conductors and proof-of-payment systems, 3.0 to 5.0 seconds for flat-fare one-man-operation systems, and 3.5 to 8.0 seconds for graduated and zone fares with one-man-operation.

Whilst the above studies serve to set some general guidelines for street-based public transport boarding and alighting rates, data relating specifically to the vehicles under consideration in this study would be useful. In discussing Melbourne public transport services, Fouvy (1972) quotes a free-flow boarding or alighting rate of 1.5 to 2.0 seconds per passenger and a one-man-operation ticket selling rate of 3.75 seconds per passenger. More specific published data on boarding and alighting rates for Melbourne trams is, however, not available.

In an unpublished thesis project, Fraser (1980) provides information on boarding rates for Melbourne's Z-class tram and W-class tram. The Z-class boarding rate is a multi-rate model (as first described by Cundill and Watts (1973)) of the form:

$$T_i = \begin{cases} 5 + 1.4\,B_i & (0 \leq B_i \leq 10) \\ 19 + 2.4\,(B_i - 10) & (10 \leq B_i \leq 20) \\ 43 + 4.0\,(B_i - 20) & (20 \leq B_i \leq 40) \end{cases} \qquad (5)$$

The W-class curve is non-linear but can be approximated by:

$$T_i = 2.5 + 0.85\,A_i + 0.85\,B_i \qquad (A + B \leq 10) \qquad (6)$$

Whilst these two relationships provide starting points, they can not be accepted completely because no details were provided as to how they were derived and no indication was given of the variability of service time at each point on the curve. Also, for the Z-class, no information was provided on alighting rates. Therefore, a more comprehensive study was undertaken to measure boarding and alighting rates on Z-class trams. This study (Hawke and Yem, 1981) examined boarding and alighting rates for Z-class trams on the East Burwood tram route in the morning peak period. Data was obtained for 125 boarding events within the range of 1 to 9 boarders, and 124 alighting events within the range of 1 to 26 alighters. A simultaneous model was fitted to the data to yield:

$$T_i = \text{Max} \begin{bmatrix} 4.3 + 1.0\,A_i \\ 4.5 + 1.4\,B_i \end{bmatrix} \qquad \begin{matrix} (0 \leq A_i \leq 26) \\ (0 \leq B_i \leq 9) \end{matrix} \qquad (7)$$

The boarding rate model agrees almost perfectly with that given by Fraser (1981), whilst the alighting rate of 1.0 seconds per passenger falls within the range given by most other studies (i.e. $1.0 < \alpha < 1.5$).

In addition to the mean values of the rates given in equation (7), this study also allowed investigation of the variance in boarding and alighting rates. The variances in boarding and alighting rates for boarding numbers up to 5 and alighting numbers up to 6 (beyond which sample sizes were too small to allow meaningful calculation of the variance) are shown in Figure 1. It appears that the data collected in this study would tend to reinforce the finding of Cundell and Watts (1973) rather than that of Jordan and Turnquist (1979) i.e. variance increases with increasing numbers of boarders or alighters rather than remaining constant. To infer any more from Figure 1 about the form of a definite relationship would, however, be difficult without a specific behavioural hypothesis.

Consider, then, the proposition that successive boarding or alighting events are independent of each other. In this case, the variance of the boarding time for n boarders is equal to n times the variance in the boarding time for one boarder. If the variance in dead time is assumed to be zero, then the relationships shown in Figure 1 should be represented by straight lines passing through the origin. Least-squares estimates of these lines are overlaid in Figure 1 on the actual data points. Whilst being far from a perfect fit, the assumption of independence between successive boardings or alightings does provide a useful working relationship in an attempt to describe the variability of boarding and alighting times. All that is needed to quantify this relationship is the coefficient of variation for single boarding and alighting events. From the lines of best fit shown in Figure 1, the coefficient of variation for a single boarding, given that the average boarding rate is 1.4 seconds per passenger, 0.8, whilst the coefficient of variation for a single alighting is 0.75. These values are in general agreement with the value of 1.0 derived from Cundill and Watts (1973).

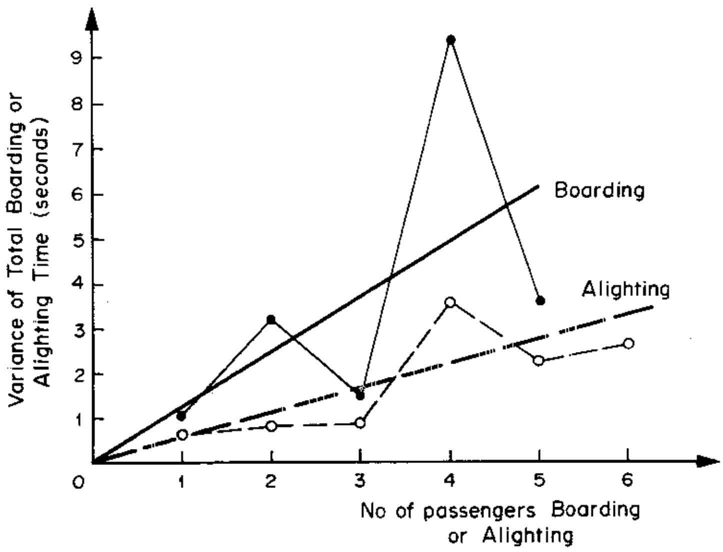

Figure 1. The Variance of Boarding and Alighting Times

This review of boarding and alighting rate models, supplemented by some empirical observations, has served to provide some background to the analysis carried out in the remainder of this paper. In particular, it has given a feeling for the range of boarding and alighting rates likely to be encountered in practice, together with some possible values of the coefficients of variation. Obviously, more empirical observations are needed to fully quantify the boarding and alighting rate models for Australian conditions. In particular, the variation in boarding and alighting rates is a topic where very little is known.

THE TRAMS PACKAGE

The TRAMS (Transit Route Animation and Modelling by Simulation) package is a vehicle-by-vehicle simulation model which simulates the movement of individual trams as they traverse a user-specified route. The model structure and characteristics have been described previosuly (Vandebona and Richardson, 1981; 1982a; 1982b) and will not be described in detail in this paper. Briefly, though, the model accepts inputs describing the route, the vehicles, the external environment, and the passenger demand pattern over time and space. The model then simulates tram movements on the route for a specified time period, and then outputs a wide array of route performance measures.

The simulation model operates by reference to a series of submodels which generate stochastic outputs for further use in the model. The major submodels handle the generation of:

- (i) Departure time from terminus
- (ii) Vehicle characteristics
- (iii) Link travel time
- (iv) Passenger arrivals at tram stops
- (v) Alighting passengers from trams
- (vi) Tram stop service times
- (vii) Traffic signal phasing and timing
- (viii) Right turning traffic arrivals and departures.

The details of many of these submodels have been described previously. In this paper, reference will only be made to three of these submodels: passenger arrivals, alighting passengers, and tram stop service times.

Passenger Arrivals Submodel

The generation of passenger arrivals at tram stops is based on two user-specified inputs; the distribution of passenger boardings along the route and the distribution of total passenger boardings over the period of the simulation. This two-dimensional passenger boardings matrix may be either a reflection of long-term average passenger boarding values or else it may be an estimate of anticipated passenger boardings.

Determination of the number of passengers at the stop when the tram arrives is performed as follows. The expected arrival time of the tram is firstly calculated as the time when it would actually stop at the tram stop, if it in fact does stop. Note that the tram stop is not a point, but is actually a zone with a default length equal to that of two trams. This is to allow for the fact that at tram stops immediately upstream of traffic signals, the tram may be prevented from reaching its designated stopping point by a queue of motor vehicles waiting at the signals. In such a case, it is assumed that loading and unloading will take place immediately if the tram stops within two tram lengths of the designated stop, i.e. passengers will walk to the tram rather than wait for it to come to them.

Given the arrival time at the stop, the expected number of passenger arrivals in the period between the depature of the previous tram and the arrival of the current tram is calculated by multiplying the average passenger arrival rate at this stop and time of day (as given by the passenger boardings matrix) by the inter-tram period. A lognormal generator with the expected number of arrivals as the mean and a prespecified coefficient of variation then generates a stochastic number of passenger arrivals, which is then checked for reasonable bounds and rounded off stochastically. This number of passenger arrivals is then added to the number of passengers (if any) who were left waiting when the previous tram departed to obtain the number waiting when the current tram arrives.

Alighting Passengers Submodel

The generation of passengers who wish to alight from a tram at a particular stop takes account of the overall distributions of boarding and alighting passengers along the route and the number of passengers currently in the tram as it approaches a stop. As a tram approaches a stop, the probability of passengers alighting at the next stop is known from a consideration of the total numbers alighting at this and subsequent stops and the numbers yet to board at this and subsequent stops. Given the current occupancy of the tram, the expected number of alighting passengers can be calculated. This number is then fed through a lognormal generator with prespecified coefficient of variation, checked for reasonable bounds and rounded off stochastically to produce the number of alighting passengers at the next stop.

Tram Stop Service Time Submodel

The first task which this submodel performs is to check whether the tram actually does stop at the tram stop. If there is an alighting passenger then the tram will always stop. If there are no alighting passengers but there are passengers wanting to board, then the tram will stop provided that the tram is not full. Otherwise the tram will proceed through the stop without stopping, unless it is blocked by a previous tram which is waiting at the stop.

Assuming that the tram will stop, the submodel then calculates the time needed to service boarding and alighting passengers. Although the number of alighters can be determined before the tram stops, it is not possible to exactly determine the total number of boarders until the tram leaves the stop because some passengers (the so-called "runners") will not arrive at the stop until after the tram has stopped and is engaged in loading passengers who are already waiting. In this study reported in this paper, a simultaneous service time model is used to reflect the use of two-door trams on the route.

The final determinant of tram stop service times is the capacity of the tram itself. Obviously when the tram is full, no further passengers can board. The definition of "full", however, is somewhat subjective. Rather than apply a rigid definition of vehicle capacity, the boarding submodel compares the number of passengers waiting to board with the number of spaces left on the tram. If the number of boarders does not exceed the number of spaces by more than five, then all boarders will be allowed to board. This avoids the situation where only one or two people are left standing at the stop and is a reasonable approximation to the discretion shown by drivers and conductors. If, however, the difference is greater than five, then the tram will only accept boarders up to its official capacity before leaving the stop. This situation is more characteristic of heavy peak-hour loading situations. The capacity restraint affects the tram stop service time, however, only when boardings are the critical element in the service time process.

THE SIMULATION STUDY

The objective of the study was to examine the effect of different fare collection strategies on the tram performance along a route. Different fare collection strategies are reflected quantitatively in terms of different boarding rate parameters. It is assumed that no other factors (such as alighting rates and dead times) are affected by the changes in fare collection strategies. The changes are tested with reference to a specific route structure as described below.

Simulation Inputs

Rather than test the effect of fare collection strategies on a completely hypothetical route, the study reported herein was based on Melbourne and Metropolitan Tramways Board Route No.75 which runs between East Burwood and the City. The route is approximately 18km in length, contains 73 regular stops and passes through 32 signalised intersections. Whilst the route used in this study is not identical in all respects to the East Burwood route, the use of the route as a basis ensures that there are realistic assumptions about stop spacing and the placement of tram stops relative to signalised intersections. In addition passenger boarding and alighting distributions were based, fairly generally, on limited observations of patronage during the morning peak period.

In addition to the general route description, a number of specific input parameters must be specified to enable the model to run. Some of the more important parameters, and the values used in this analysis are:

- (i) Tram cruise speed = 50 kph
- (ii) Acceleration rate = 1.25 m/s^2
- (iii) Deceleration rate = 1.50 m/s^2
- (iv) Passenger alighting rate = 1.0 seconds
- (v) Alighting rate coefficient of variation (C.O.V) = 0.1
- (vi) Boarding dead time = 4.5 seconds
- (vii) Alighting dead time = 4.5 seconds
- (viii) Boarding dead time C.O.V. = 0.1
- (ix) Alighting dead time C.O.V. = 0.1
- (x) Tram Capacity = 75
- (xi) Tram Seating Capacity = 52
- (xii) Simulation Period = 7am to 9am
- (xiii) Average headway = 5 minutes
- (xiv) Number of simulation repetitions = 10

In testing the effect of variations in boarding rate, the simulation was run for a range of average boarding rates and for a range of single-passenger-boarding coefficients of variation. Given the results of previous empirical observations described earlier in this paper, it was decided to test average boarding rates in the range of 1.0 to 8.0 seconds per passenger. The selection of a range for the coefficient of variation was more difficult because of the limited amount of information on this parameter. Given that the limited information available indicated a value in the vicinity of 1.0, it was decided to test for values on either side of this coefficient of variation. At one extreme the coefficient of variation was set to zero (i.e. perfectly regular boarding) whilst at the other extreme a very high value of 4.0 was selected. Pending further empirical observation it was felt that this range would cover the values likely to be encountered in practice. Within the range of average boarding rates and coefficients of variation, any fare-collection strategy for a two-door tram can be identified, ranging from proof-of-payment or two-man-operation up to one-man-operation with the driver collecting graduated fares and giving change to passengers.

Simulation Results

The results of the simulation can be presented in terms of the effect on route productivity, and the effect on the level-of-service offered to passengers.

Route Productivity

To the operator, the productivity of the service will be reflected primarily in terms of the tram travel time along the route and the variability of this travel time. These measures will determine the number of trams required to maintain a specific frequency along the route. To the operator, costs or savings obtained by changes in fare-collection strategy must be offset against costs or savings experienced as a result of changes in the fleet numbers required to maintain a specified route frequency.

The route travel times obtained for different values of average boarding rate, and boarding rate coefficients of variation, are shown in Figure 2. As expected, route travel times increase as the average boarding time per passenger increases. Route travel times increase from 46 minutes to 57 minutes as the boarding time per passenger changes from the lowest value tested (applicable to a two-man roving conductor operation, or a one-man proof-of-payment operation) up to the highest value tested (applicable to a one-man-operation with the driver collecting graduated fares and giving change). Assuming that the return trip is similarly affected, the change in route travel time is equivalent to a 20% reduction in productivity of the vehicles on that route. Thus extra costs would be incurred in maintaining the service frequency on this route. Note that apart from one extreme case, the boarding rate coefficient of variation appears to have no effect on the average route travel time.

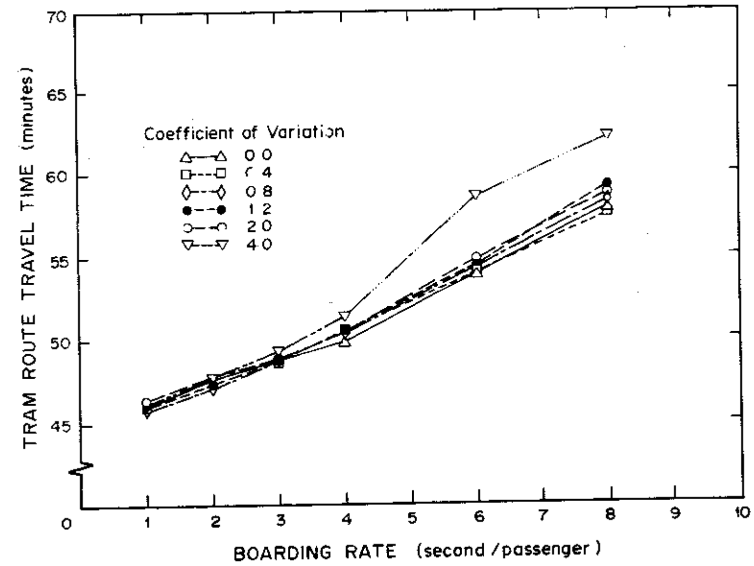

Figure 2. Average Tram Route Travel Time

The extent to which route travel time variability is affected by changes in the boarding rate is shown in Figure 3. It should be noted that the variability referred to herein is the variability across individual vehicles in a morning peak period. It can be seen that the variability of travel time rises as the boarding rate slows down. Slower boarding times therefore produce a slower and more variable service in terms of route travel time. Both these effects would need to be taken account of when assessing vehicle productivity on this route. In addition to the effect of average boarding rate on the variability of route travel time, there is also a small, but statistically significant, effect of the coefficient of variation of boarding rate on the variability of travel time.

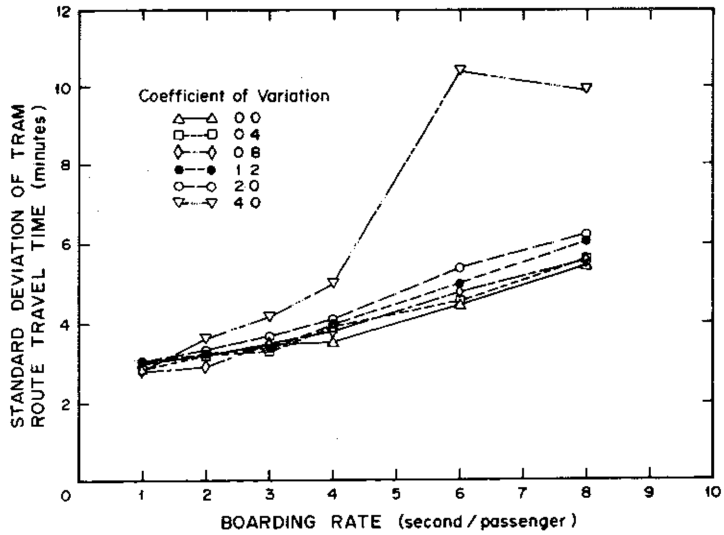

Figure 3. Standard Deviation of Tram Route Travel Time

Level of Service

In addition to the changes in productivity described above, the use of different fare-collection strategies will result in changes in the level of service offered to passengers. Figure 4 shows the changes in average passenger travel time as a function of the average and coefficient of variation of the boarding rate. It can be seen that the average travel time increases substantially from 14 minutes to 18 minutes as the boarding rate changes from 1 to 8 seconds per passenger. The rate of change is near linear and is dependent on the total passenger boardings along the route. Routes with higher patronage would obviously be more affected by changes in the boarding rate. Once again,the average passenger travel time appears to be independent of the coefficient of variation of boarding rate, except for combinations of high average boarding rates and high coefficients of variation. These combinations may however be unrealistic in practice, and so one may conclude that generally passenger travel times are independent of the boarding rate coefficient of variation.

One feature of public transport services which is often seen as being a measure of the reliability of the service is the tendency of vehicles to form bunches. Ideally, operators and passengers would prefer vehicles to maintain their initial separation over the entire length of the route. Breakdowns in service regularity are highlighted by the appearance of bunches. Figure 5 shows the change in average bunch size with changes in boarding rate. At the fastest boarding rate (1 second/passenger), approximately 4% of the trams are in bunches. At the slowest boarding rate, approximately 20% of trams are in bunches. This increase in bunching is due to the very slow boarding rates causing excessive service times which trigger off the formation of bunches. (For a full description of the bunching process, see Vandebona and Richardson

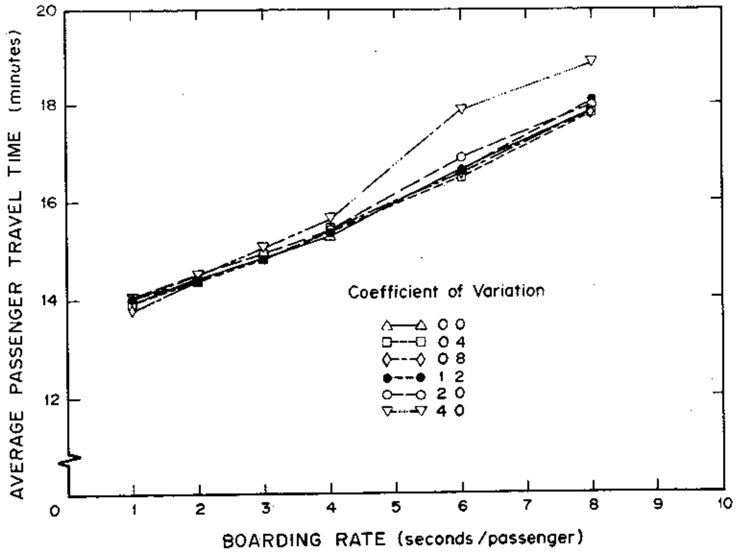

Figure 4. Average Passenger Travel Time

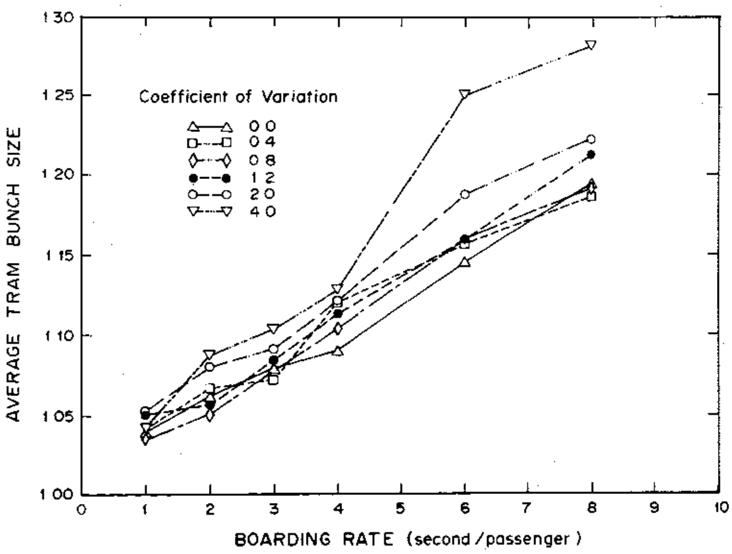

Figure 5. Average Tram Bunch Size

(1982b)). Once again increases in the coefficient of variation have no significant effect, except for combinations of high boarding rate and high coefficient of variation. In these cases, higher coefficients of variation result in an increased tendency for trams to form bunches.

The combination of slower and more irregular service results in an increase in the average passenger waiting time as shown in Figure 6. In changing from the fastest to the slowest boarding rate, average waiting time changes from 3 minutes to 4 minutes. Given that passengers are generally thought to value waiting time more highly than they value on-board travel time (by a factor of perhaps 2.5), this change represents an effective increase of 2.5 minutes compared to the change in average travel time of 4 minutes. With respect to waiting time, the coefficient of variation of boarding rate has a small, though statistically significant, effect for all average boarding rates except the quickest.

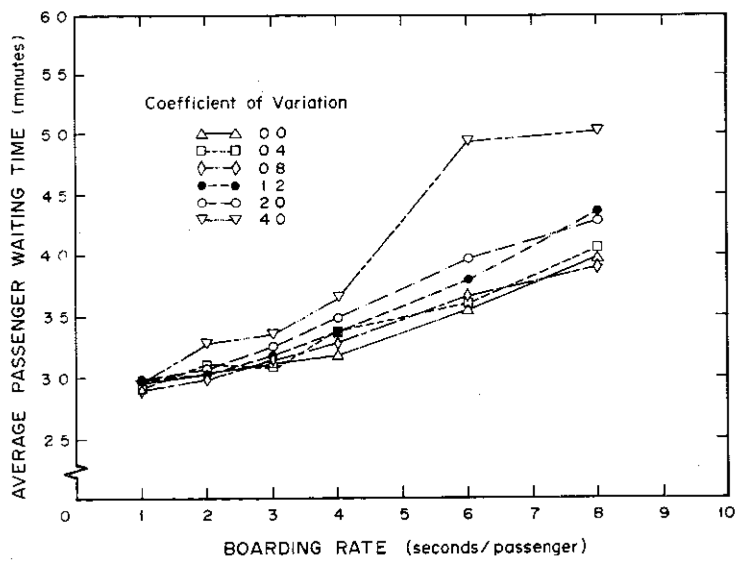

Figure 6. Average Passenger Waiting Time

Another level-of-service measure, which is perhaps even more acutely perceived by passengers as a measure of waiting, is the probability of being left at a stop as a tram either departs the stop with a full load or else does not even stop because it is already full. Whilst waiting time is measured on a continuous scale, being left at a stop is measured on a discontinuous scale; experiencing increased waiting time may not be perceived, but being left at a stop is unlikely not to be perceived (and complained about). The variation in this measure is shown in Figure 7. It can be seen that in going from the fastest to the slowest boarding rate, the probability of being left at a stop increases from 1% to about 7%. Put another way, for the regular commuter it increases once from every five months (a rare event) to once every three weeks (a regular event?). Once again, the coefficient of variation has a small, but statistically significant, effect except at the quickest boarding rate.

The final level-of-service measure attempts to account for some aspects of passenger comfort. In particular, it measures passenger crowding in the vehicle in terms of the probability that passengers will be required to stand. As can be seen in Figure 8, the probability of standing increases as the boarding rate slows down. In fact, the probability of standing approximately doubles as the boarding rate changes from fastest to slowest. Again, the coefficient of variation has a relatively small, though statistically significant, effect.

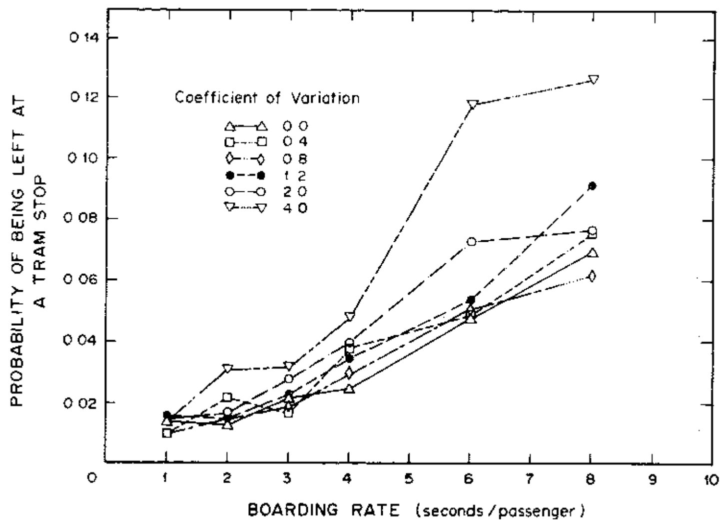

Figure 7. Probability of Being Left at a Tram Stop

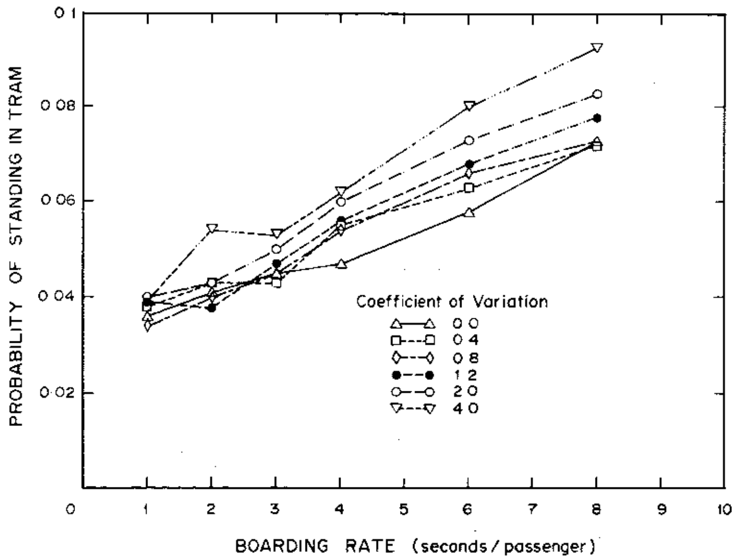

Figure 8. Probability of Standing in the Tram

From the foregoing results it can be seen that the changes in boarding rate have both primary and secondary effects. The primary effect, which is chiefly evident in the travel time results, is simply the result of spending longer times at stops loading and unloading passengers. As a result the tram service slows down, as expected. The secondary effect, which is evident in the results for travel time variability, bunching, waiting time and passenger crowding, is the result of trams departing from schedule because of the occasional very long service time. This departure from schedule triggers the formation of bunches which causes several manifestations of irregular service. It is interesting to note that the coefficient of variation of the boarding rate has no effect on level-of-service measures exhibiting the primary effect, but is a contributing factor to variations in level-of-service measures exhibiting the secondary effect.

CONCLUSION

This paper has demonstrated the effect of different boarding rates on the productivity and level-of-service of a tram route. It is shown that slower boarding rates produce a slower and less reliable service along the route. The variability of boarding rates has no effect on route travel time but does contribute to greater unreliability in the level-of-service offered to passengers. The analysis reported in this paper is, however, only the first step in a complete investigation of the changes induced by a change in fare-collection strategy. As noted in Vandebona and Richardson (1982a), the complete public transport evaluation process consists of three distinct modelling phases; supply modelling, demand modelling and cost modelling. This paper has described only one of these phases, that being the supply model. Knowing that different fare-collection strategies have different boarding rates and that these, in turn, result in different route performance does not give the public transport manager enough information on which to base a decision about whether to change fare-collection strategies. In particular, he needs to know about three other factors.

Firstly, he needs to know whether the changes in the level-of-service offered to passengers will be sufficiently large to affect usage along the route. If so, what will the effect be on revenue collected on that route? This question can be addressed by a demand model. Secondly, he needs to know the initial cost of implementing the changes in fare-collection strategy, in terms of direct costs (staff and other costs), variable overheads, and fixed overheads. Thirdly, he needs to be able to cost the changes in productivity brought about by introduction of the new fare-collection strategy. Both these tasks can be addressed by means of a costing model (e.g. Benham and Kneebone, 1982). If the public transport manager wishes to go further and conduct an economic analysis, rather than the financial analysis outlined above, then he needs further information about the value of level-of-service changes and the resource costs involved in providing the service.

At the present stage of development, the TRAMS model does not include the demand and costing models. It is however being developed with that ultimate objective in mind. Even in its present form, however, it is a useful tool to assist public transport managers in the evaluation of various options for public transport route design.

REFERENCES

BENHAM, G.R. and KNEEBONE, D.C. (1982). "Comparative Operating Costs of Public Transport". Proc. 11th ARRB Conf., 11(6), pp.126-139.

BOARDMAN, T.J. and KRAFT, W.H. (1970). "Predicting Bus Passenger Service Times: Part II". Traffic Engineering, 40(5), pp.36-40.

CUNDILL, M.A. and WATTS, P.F. (1973). "Bus Boarding and Alighting Times". Transport and Road Research Laboratory, Laboratory Report LR521, Crowthorne, U.K.

FOUVY, C.L. (1972). "Metropolitan Public Transport Services". Proc. 6th ARRB Conf. 6(2), pp.176-213.

FRASER, M. (1980). "Tram Priority in Melbourne". M.Eng.Sc. Thesis, Department of Civil Engineering, Monash University (unpublished).

GRIGG, J.L. (1982). "The Impact of Fare Systems on Vehicle Design and Operations". Seminar on Light Rail Transit, The Ministry of Transport, Victoria.

HAWKE, G. and YEM, K.C. (1981). "Boarding and Alighting Rates of the Melbourne Z-class Tram". 4th Year Project Report, Department of Civil Engineering, Monash University (unpublished).

JORDAN, W.C. and TURNQUIST, M.A. (1979). "Zone Scheduling of Bus Routes to Improve Service Reliability". Transportation Science, 13(3), pp.242-256.

KRAFT, W.H. and BERGEN, T.F. (1974). "Evaluation of Passenger Service Times for Street Transit Systems". Transportation Research Record 505, pp.13-20.

KRAFT, W.H. and BOARDMAN, T.J. (1969). "Predicting Bus Passenger Service Times". Traffic Engineering, 40(1), pp.16-20.

NELSON, G. (1976). "FAIRTRAN : Operation of a Credit-Card Transit Fare System". Transportation Research Record 590, pp.26-30.

VANDEBONA, U. and RICHARDSON, A.J. (1981). "The Effects of Priority Signals on Tram Route Performance". Transportation Conference 1981, The Institution of Engineers, Australia, Nat. Conf. Publ. 81/10, pp.56-62.

VANDEBONA, U. and RICHARDSON, A.J. (1982a). "The Simulation of Tram Route Service Improvements", Forum Papers, 7th ATRF, pp.71-92.

VANDEBONA, U. and RICHARDSON, A.J. (1982b). "The Effects of Right-Turning Traffic at Signalised Intersections on Tram Route Performance", Proc. 11th ARRB Conf. 11(4), pp.125-134.

WATTS, P.F. and NAYSMITH, A. (1980). "Urban Bus Revenue Collection : Current Methods and Directions of Development" Transport and Road Research Laboratory, Supplementary Report SR629, Crowthorne, U.K.