The Effects of Fare-Collection Strategies on Transit Level of Service

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ABSTRACT

It is known that different fare-collection strategies have different passenger boarding and alighting rates for street-based public transport services. In this paper, various models of stop service times are reviewed, the available empirical observations of boarding and alighting rates are summarized, and the effects of different average boarding rates and coefficients of variation of boarding rates on the route performance of a tram (light rail transit) service are examined. The analysis is conducted using the TRAMS (Transit Route Animation and Modeling by Simulation) package. This modeling package is briefly described with particular attention to the passenger demand subroutine as well as the tram stop service times subroutine. As a result of the analysis, it was 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.

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, while 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, a subject that has received much attention in this respect is staffing policy; in particular, the debate over whether to have a one- or two-man operation of public transport vehicles has been both lengthy and vigorous in Australia and elsewhere. Investigations of one-man operations 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 operation system is to be devised.

In considering this question, it is obvious that the effects of a 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 a one-man operation will ultimately prove to be beneficial or not. If boarding the vehicle is slowed by the one-man operation, fare-collection strategy, then it is possible that the degradation in the level of service provided will outweigh the immediate staff cost savings per vehicle so that the service is less productive overall. Obviously, conversion to a one-man operation needs careful analysis of the operational, financial, and economic consequences. Even in situations such as in North America, where all transit services are already one-man operations, it is important to consider the effects that different fare collection strategies will have on the level of service provided. The conversion of pay-the-driver systems to proof-of-payment systems will generally bring about significant level-of-service improvements that should be considered in any analysis of such fare collection strategies.

This paper makes a contribution to this analysis by examining the effects of different boarding rates on the route performance of a light rail transit (tram) system. Boarding rates are a critical variable in that they most concisely describe the operational performance of different fare-collection strategies, as well as different vehicle designs. 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 Modeling by Simulation) package (see paper by Vandebona and Richardson elsewhere in this record), and uses a case study example loosely based on an actual tram route in Melbourne, Australia.

FARE-COLLECTION STRATEGIES

Fare-collection strategies for street-based public transport may be classified under three major headings: (a) two-man operation where the conductor collects fares, (b) one-man operation where the driver collects fares, and (c) one-man operation where the driver does not collect fares. Within each of these classifications, there are a number of different alternatives. In the two-man operation, the conductor may function in one of two ways--either as a roving conductor who moves through the vehicle collecting fares from passengers while the vehicle is in motion, or seated with passengers paying their fares as they file past the conductor's position after entering the vehicle.

A one-man operation with fare collection by the driver gives rise to a wide range of boarding time rates, depending on the details of the fare-collection procedure and the nature of the fares charged. Two major options for fare collection are to accept exact fares only or to enable the driver to give change to passengers. As will as seen later, the former results in a faster boarding rate, while 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 the distance traveled, 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. A 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 at the point of usage is free 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 these days. Watts and Naysmith (1) note the need for a coin of value greater than 50p (in the United Kingdom). Other methods of payment include the use of pay-turnstiles on board the vehicle (although these are often seen as being an unreliable hindrance), and the use of credit card and magnetized ticket-reading machines.

A complete alternative to the previous 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 that 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. Season tickets could be used, books of tickets could be bought from news agents or other stores; tickets may be purchased from ticket-sellers at major stops, ticket-selling machines (either at stops or aboard the vehicle), or drivers (at a premimum 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 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 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 that have been proposed for the prediction of service times.

The Sequential Model

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

where

T_i = service time at stop i,
A_i = number of alighting passengers at stop i,
B_i = number of boarding passengers at stop i,
γ = dead time,
α = alighting time per passenger, and
β = boarding time per passenger (sec).

This model is likely to be appropriate where boarding and alighting take 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 maneuver 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 that prevents doors from being opened until the vehicle is stopped and an acceleration interlock that prevents the vehicle from moving until the doors are closed), and the layout of the stop (e.g., safety-zone boarding versus curb-loading). The coefficients α and β depend primarily on the fare collection system employed, but may also vary with the time of day (peak versus 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.

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 boarding 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.

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.

The Multi-rate Boarding Model

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

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 place at a rate of β_1 sec per passenger. Above this number, extra passengers board at a slower rate of β_2 sec 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 of the previous 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 United Kingdom study (2) and one major United States study (3) as well as a number of smaller studies comprise the major literature on the subject. Some limited information on the Melbourne tram system, which is the subject of the case study in this paper, is also available (4). While although 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, so that an idea of the range of values likely to be met in practice can be obtained.

Cundill and Watts reported on a major study of bus boarding and alighting times carried out in various cities in the United Kingdom (2). 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 while a simultaneous model described a two-door operation. They found that the alighting rate was similar for all vehicles studied with values ranging from 1 to 1.6 sec. Boarding rates ranged from 1 to 2 sec for a two-man operation, and from 2.3 to 5 sec for a one-man operation. Exact fare systems were at the lower end of this range while procedures requiring drivers to give change and provide information were at the upper end. The dead times ranged from 1 to 7 sec with the presence and type of interlocking device being the main contributing factor to long dead times.

Kraft and Bergen reported on studies of U.S. bus loading and unloading rates (3). They studied both one- and two-door operations 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 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 that start timing from the moment the vehicle stops and continues until the vehicle moves (or is ready to move). The data collection method employed by Kraft and Bergen (3) therefore means that dead times will be underestimated, especially in view of Cundill and Watts' (2) comments concerning door interlocking devices. In fact, many of Kraft and Bergen's (3) regression equations imply dead times of less than zero.

Bearing this limitation in mined, some of the overall conclusions of Kraft and Bergen (3) are worth noting:

1. Morning and evening peak period results are similar, but off-peak boarding and alighting rates are slower than peak period rates.
2. Exact fare systems save between 1.4 and 2.6 sec per passenger in boarding operations [this compares with a saving of 3 sec given by Cundill and Watts (2)].
3. Alighting rates were fairly constant within the range of 1.0 to 1.4 sec.

The only study in which alighting rates were found to be very different from 1.0 to 1.5 sec was by Nelson (5), in which he described the operation of a credit card fare collection system. In this system, fares were fixed according to the distance traveled, and 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 sec per passenger. This study clearly demonstrates that it is the ticketing procedure that determines the boarding and alighting rate. The dependence on ticketing procedure is also clearly shown in boarding rates quoted by Grigg (6). He gives boarding rates of 1.5 to 2.5 sec for roving conductors and proof-of-payment systems, 3.0 to 5.0 sec for flat-fare one-man operation systems, and 3.5 to 8.0 sec for graduated and zone fares with one-man operation.

Few studies have examined the variability of boarding times. Jordan and Turnquist (7) stated that in their study of Chicago buses, the variance of the stopping times was constant (and equal to 8 sec²) for all boarding numbers greater than 1 and up to 12. This contrasts with the statement by Cundill and Watts (2) 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 (2), it is possible to calculate that the coefficient of variation (COV) for a single boarding is approximately unity.

The meager published data on boarding time variability was supplemented by a study carried out on Melbourne trams (4). In addition to calculating the mean values of the boarding rates, 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 Cundill and Watts (2) rather than that of Jordan and Turnquist (7) (i.e., variance increases with increasing numbers of boarders or alighters rather than remaining constant). To infer

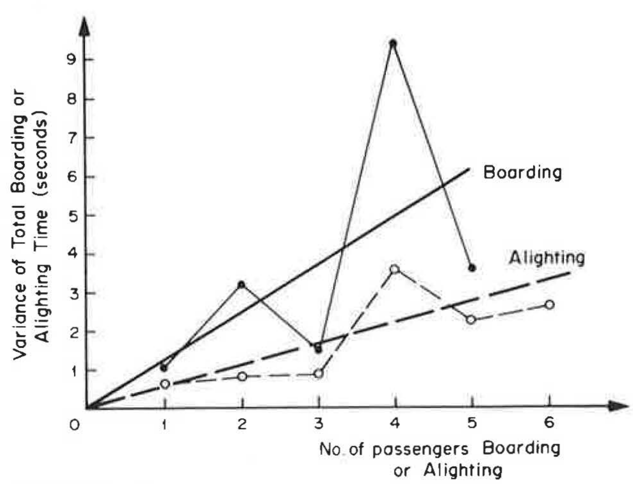

FIGURE 1 The variance of boarding and alighting times.

any more from Figure 1 concerning the form of a definite relationship would, however, be difficult without a specific behavioral 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. While 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 sec per passenger, is 0.8, while 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 (2).

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 COVs. Obviously, more empirical observations are needed to fully quantify the boarding and alighting rate models for local conditions. In particular, the variation in boarding and alighting rates is a topic about which little is known (or, at least, has been published).

THE TRAMS PACKAGE

The TRAMS package is an event-update simulation model that simulates the movement of individual trams as they traverse a user-specified route. The model structure and characteristics have been described previously (see 8-10 and paper by Vandebona and Richardson elsewhere in this record) and will not be described in detail in this paper. Briefly, though, the model accepts inputs describing the route, vehicles, external environment, and passenger demand pattern over time and space. The model then simulates tram movements on the route for a specified time period, and outputs a wide array of route performance measures.

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

- Departure time from terminus,
- Vehicle characteristics,
- Link travel time,
- Passenger demand patterns,
- Tram stop service times,
- Traffic signal phasing and timing, and
- Other turning traffic arrivals and departures.

The details of many of these submodels have been described elsewhere. In this paper, reference will only be made to two of these submodels (passenger demand patterns and tram stop service times), which are of greatest relevance to the current study.

Passenger Demand Patterns

The TRAMS program allows for variations in passenger demand along the route as well as time of day. The program requires the passenger origin-destination linkages to be identified in the form of an origin-destination matrix for a specified time period. Different origin-destination matrices can be input for different time periods of the simulation session. However, in the absence of origin-destination data, the program has the facility to synthesize such data from boarding and alighting information. Again, provision is allowed to incorporate variations with the time of the day.

The TRAMS package incorporates a pregeneration section that processes the previous data and produces a passenger list based on stochastic generations. This list contains the time of arrival and the desired destination for each passenger at each stop along the route. In some simulation experiments, it could be desirable to use a passenger list produced previously for the same network. Such a method would be especially useful for comparative studies of different system characteristics.

Therefore, there are three different ways in which the passenger demand can be introduced to the program. The passenger demand could be described by an origin-destination matrix, by passenger boarding and alighting vectors (in which case the program synthesizes the origin-destination matrix) or by an existing passenger list (in which case the pregeneration is no longer required). Once passengers have boarded a tram, their movements are recorded by means of a vehicle matrix that keeps track of the desired destinations and the seating status of all passengers currently on board. The program refers to this vehicle matrix to determine which passengers wish to alight at the next stop.

Tram Stop Service Time Submodel

The first task that 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 unless it is blocked by a previous tram that is waiting at the stop, or if the stop is at a traffic signal that is red.

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 the study reported on 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 of 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 in the following paragraph.

Simulation Inputs

Rather than test the effect of fare collection strategies on a completely hypothetical route, the study reported herein was based on Melbourne Metropolitan Transit Authority tram route 75, which runs between East Burwood and the central business district. The route is on-street, approximately 18 km in length, contains 73 regular stops, and passes through 32 signalized intersections. While although 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 concerning stop spacing and the placement of tram stops relative to signalized intersections. In addition, passenger boarding and alighting distributions were based generally on 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

1. Tram cruise speed = 50 kph
2. Acceleration rate = 1.25 m/sec ^{2}
3. Deceleration rate = 1.50 m/sec ^{2}
4. Passenger alighting rate = 1.0 sec/passenger
5. Alighting rate COV = 0.1
6. Boarding dead time = 4.5 sec
7. Alighting dead time = 4.5 sec
8. Boarding dead time COV = 0.1
9. Alighting dead time COV = 0.1
10. Tram capacity = 75
11. Tram seating capacity = 52
12. Simulation period = 7 a.m. to 9 a.m.
13. Average headway = 5 min
14. 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 COVs. 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 sec per passenger. The selection of a range for the COV 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 COV. At one extreme, the COV was set to zero (i.e., perfectly regular boarding) while at the other extreme, a 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 COVs, any fare-collection strategy for a two-door tram can be identified, ranging from proof-of-payment or two-man operation 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 COVs, 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 to 57 min 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 percent 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.

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 individdual 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, statistically significant effect of the COV of boarding rate on the variability of travel time.

Passenger Level of Service

In addition to the changes in vehicle productivity described previously, 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

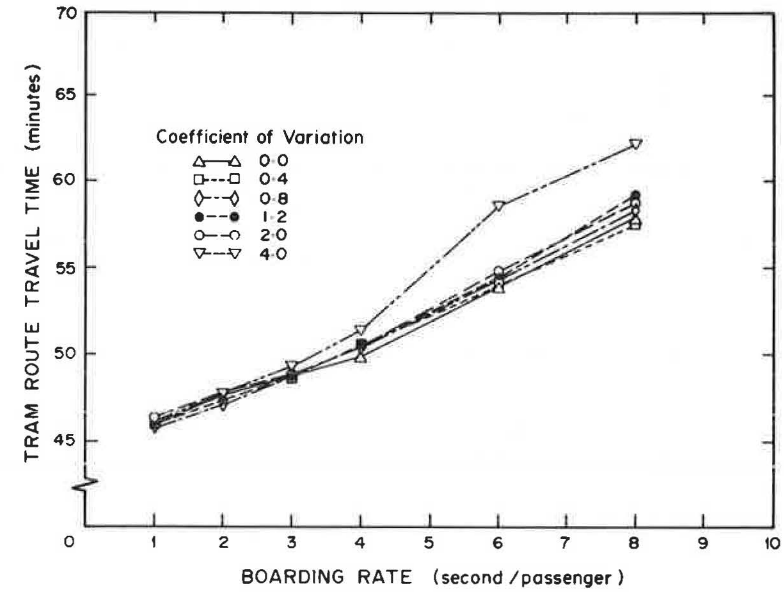

FIGURE 2 Average tram route travel time.

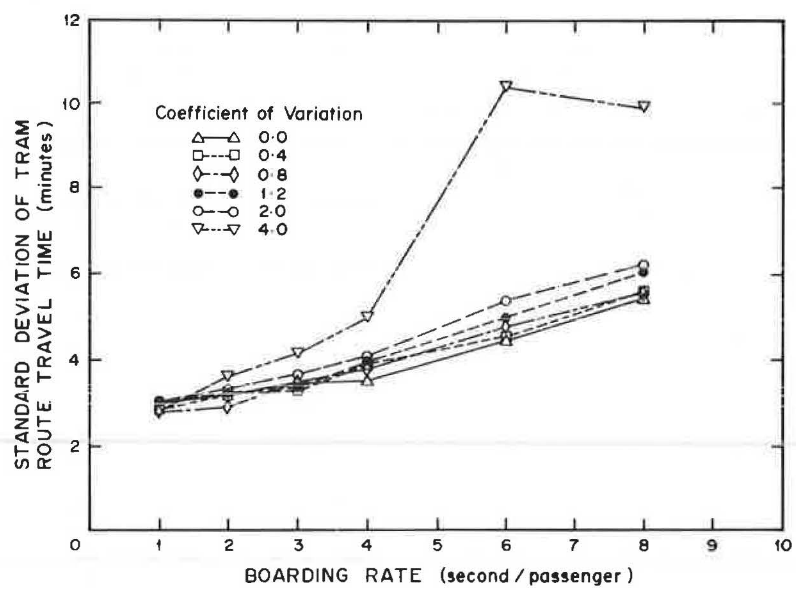

FIGURE 3 Standard deviation of tram route travel time.

as a function of the average and COV of the boarding rate. It can be seen that the average travel time increases substantially from 14 to 18 min as the boarding rate changes from 1 to 8 sec 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 COV of boarding rate, except for combinations of high average boarding rates and high COVs. These combinations may, however, be unrealistic in practice, and so it may be concluded that passenger travel times are generally independent of the boarding rate COV.

One feature of public transport services that 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 sec/passenger), approximately 4 percent of the trams are in bunches. At the slowest boarding rate, approximately 20 percent of trams are in bunches. This increase in bunching is due to the slow boarding rates causing excessive service times that trigger off the formation of bunches. [For a full description of the bunching process, see Vandebona and Richardson (10).] Once again, increases in the COV have a small, significant effect, especially for combinations of high boarding rate and high COV where 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 chang-

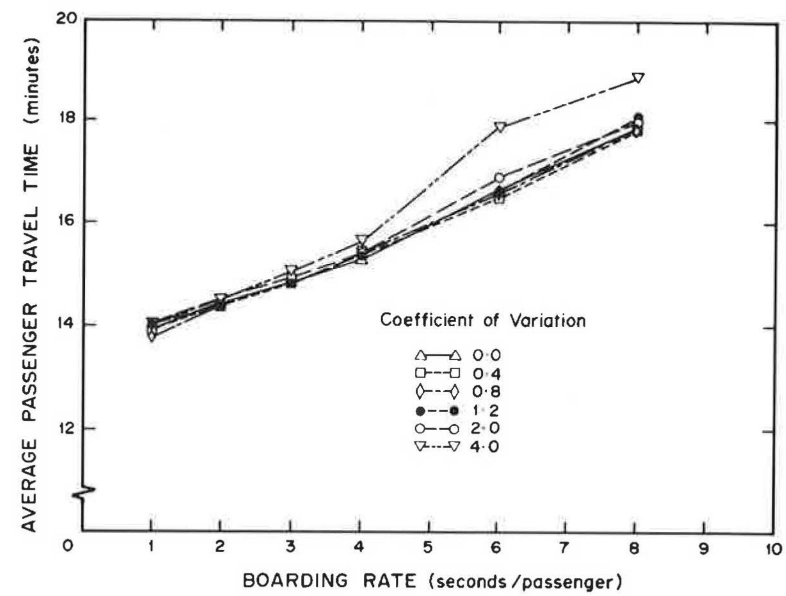

FIGURE 4 Average passenger travel time.

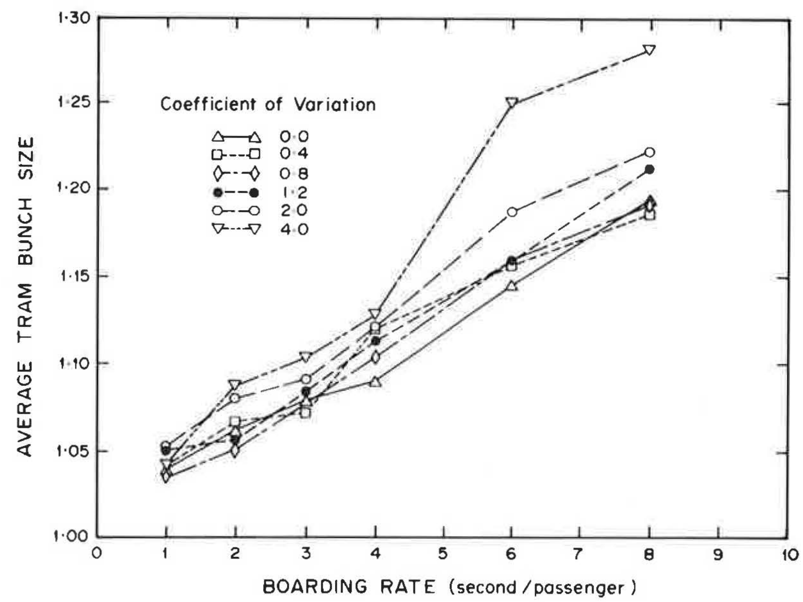

FIGURE 5 Average tram bunch size.

ing from the fastest to the slowest boarding rate, average waiting time changes from 3 to 4 min. 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 min compared to the change in average travel time of 4 min. With respect to waiting time, the COV of boarding rate has a small, significant effect for all average boarding rates except the quickest.

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. While 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 percent to approximately 7 percent. Put another way, for the regular commuter, it increases from once every 5 months (a rare event) to once every 3 weeks (a regular event). Once again, the COV has a small, 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

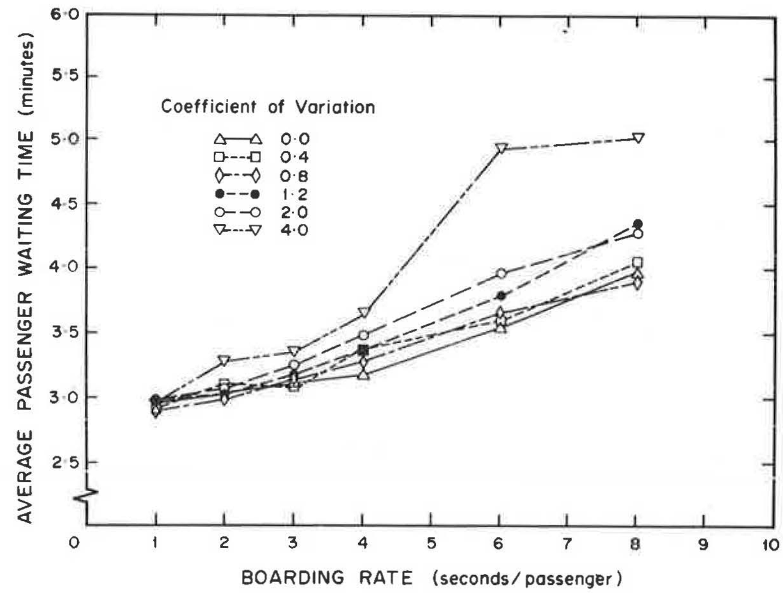

FIGURE 6 Average passenger waiting time.

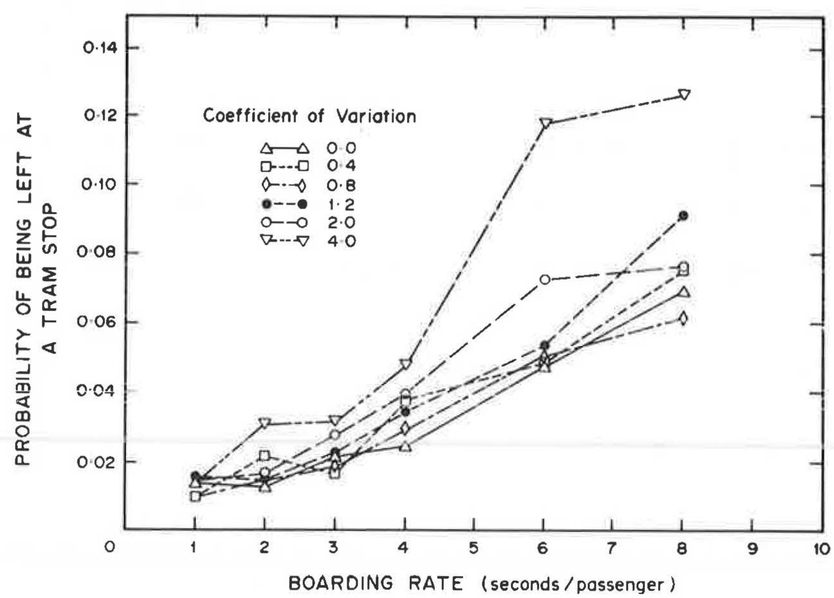

FIGURE 7 Probability of being left at a tram stop.

rate changes from fastest to slowest. Again, the COV has a relatively small, significant effect.

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 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 long service time. This departure from schedule triggers the formation of bunches that cause several manifestations of irregular service. While although the coefficient of variation of the boarding rate has no effect on level-of-service measures exhibiting the primary effect, it is a contributing factor to variations in level-of-service measures exhibiting the secondary effect.

CONCLUSION

In this paper, the effect of different boarding rates on the productivity and level of service of a tram route has been demonstrated and the fact that slower boarding rates produce a slower and less reliable service along the route has been shown. 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 (10), the complete public transport evaluation process

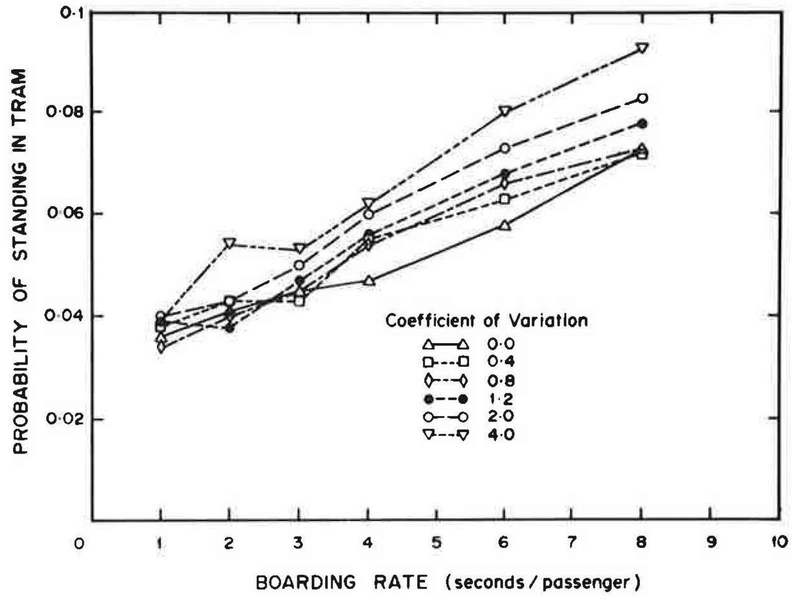

FIGURE 8 Probability of standing in the tram.

consists of three distinct modeling phases: (a) supply, (b) demand, and (c) cost. In this paper, only one of these phases--the supply model--has been described. 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 on whether to change fare-collection strategies. In particular, he needs to know about three other factors.

First, the manager 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. Second, the manager needs to know the initial cost of implementing the changes in fare-collection strategy in terms of direct costs (staff and other costs) and variable and fixed overheads. Third, the manager 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 (11). If the public transport manager wishes to go further and conduct an economic analysis, rather than the financial analysis outlined previously, then he needs further information concerning the value of level-of-service changes and the resource costs involved in providing the service.

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