REDUCING BUS DWELL TIME BY SHIFTING THE LOCATION OF PAYMENT

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Introduction

In most transit systems buses serve two general purposes. The first is to transport passengers directly from Point A to Point B while the second is to transport passengers to an intermediary Point C where they can board a rapid transit system such as a subway, light rapid transit, elevated rail, or other system which can transport large numbers of people relatively quickly. In the latter case, the bus's role is to move people from outlying areas to a central point and then the subway system moves the passengers to their final destination or potentially to a second bus and then to their final destination. In the majority of transit systems, passengers purchase a fare at the first stage of their journey and then present this proof of payment at each subsequent stage.

As passengers queue to get on a bus they must wait as each person in front presents proof of payment to the driver or makes a cash payment if they have not already paid. The time taken to present a proof of payment is greater than the time it would simply take to board, and the time taken to purchase a fare is far greater than the time taken to present proof of payment. Obviously there is inefficiency created within this process but the inefficiency is justifiable as passengers must pay their fare so that the system can operate. However, this begs the obvious question: can this system be improved while still capturing the necessary revenue to operate the system? This paper investigates the hypothesis that charging only for subways in a large commuter transit system will increase efficiency sufficiently that it will outweigh the lost revenues.

As previously noted, many public transit trips have two or more segments with at least one occurring on a subway or other mass transit system (referred to collectively as a subway hereafter). The mass transit system has the ability to let dozens of passengers pass through its turnstiles at the same time whereas buses only allow one individual at a time to make payment. If an individual pays his fare on the bus then he does not have to pay on the subway as the fare covers the entire journey, and conversely if one pays on the subway then that fare also covers the bus portion of their trip. If all bus passengers also take the subway at some point in their trip then one can conclude the system could only charge passengers at the subway station without losing revenue. The precondition to this assertion is all bus passengers are also subway passengers, which is not a reasonable assumption, however within some systems the portion of bus-subway passengers may be sufficiently high as a portion of bus passengers that the minimal lost revenue could be recuperated by increases in efficiency and decreases in costs.

This hypothesis is not without comparisons around the world as there are dozens of no-fare transit systems. Many small systems have decided to have no fares at all across their systems because the costs of fare collection are too high and the efficiencies outweigh the lost revenue (Perone, 2002). Within the large metropolitan transit center of Vancouver, a no-fare system is effectively done on one small route. The 99 B-Line is an express bus route between the University of British Columbia, an extremely popular transit destination, and two different mass transit lines. On this route, the system allows multi-door boarding without fare-checking because it is assumed that most riders already have bus passes and that those who have not paid their fare to board can do so via the front door as normal; however, as fares are never checked, not even with random screening, it can be effectively seen as a no-fare vehicle whose main purpose is to transport people to other portions of the mass transit system. At that point, the fares will be checked to ensure that people have paid. In the decision to allow such a system on this specific bus line, the transit authority clearly saw the benefits to efficiency as outweighing the minimal loss of revenue from free-riders. This illustrates that within a system that is predominately used as a feeder to other mass transit lines, that the efficiency gains are worthwhile.

This paper will discuss the costs and benefits of implementing a no-fare bus policy on a hypothetical system. It will draw heavily on data available from the New York City public transit system, but the system described is hypothetical. The conditions necessary for these cost benefit calculations will be noted throughout, but two conditions are central. Firstly, the bus system primarily operates as a feeder system to a subway system. Secondly, the transit system charges one fare for all portions of the journey regardless of the mode of travel.

The Models

The increased efficiency within the system comes from quicker boarding. The quicker boarding is attributed to two factors: not presenting proof of payment allows speedier boarding at each door and multi-door boarding is allowed (Fernandez, Zegers, Weber, & Tyler, 2010). There are several models available to examine the passenger boarding process. The issue of dwell time and how it affects overall system capacity is well documented with studies finding up to 26% of total travel time is consumed by dwell and that this is higher in high-density areas (Rajbhandari, Chien, & Daniel, 2003). The authors also disagree over whether dwell time should be defined broadly including the time taken for a vehicle to slow to the stop, the passenger boarding, and then the time taken to regain full speed or more narrowly as the time taken from the moment the doors begin to open until they are closed after the last passenger has boarded. Luckily, these differences are not relevant to the discussion on fare boarding procedures as engineering changes on the bus that would alter either its deceleration or acceleration process are not being considered.

One of the first models for dwell time was created by Turvey and Mohring (1975). It specifically examined a two-person bus operation with one person checking fares and a second focusing solely on driving the vehicle versus a bus where the driver acted as a fare collector in addition to his driving duties. Removing fares allows the driver to focus on driving the vehicle and is very similar theoretically to the issues that they were modelling, so it will be used as a basis for analysis. Turvey and Mohring established the equation for modelling the amount of time boarding takes as:

$$T + aA + bB$$

Where T is the fixed time for the bus to decelerate to and accelerate from the stop, a is the time per passenger for alighting, and b is the time per passenger for boarding, and A and B are the number of passengers alighting and boarding, respectively. Using their model, one could express the model for no-fare buses as:

$$T + a`\mathrm{A} + b`B$$

with $a`$ and $b`$ being the time taken for boarding and alighting under no-fare conditions. As nothing else is changing within stopping process T will stay constant. Therefore, the difference between the two is:

$$T - T + (a - a`)A + (b - b`)B$$
$$= (a - a`)A + (b - b`)B$$

This indicates that as long as it takes less time to board without fare payment than with, that there is an efficiency gain created. The idea that not making payment is quicker than making payment is obvious, so it is established that this system is more efficient. The calculations that are key throughout this entire paper is how much of an increase would be achieved. This is dependent on the number of people boarding and alighting as well as the time decrease per person.

As noted earlier, the efficiency gains come from two sources: not having to present proof of payment to the driver and allowing multi-door boarding. The model's functional form however only captures the efficiency gains from faster boarding through the front-door; furthermore, it assumes there is only one door which passengers can board and alight from the vehicle. This explains why the form is additive rather than having the dwell time defined by a maximum of either the boarding or alighting time. This assumption is no longer true across most transit systems with most buses having at least two doors, with three to four common on larger buses.

The second concept of multi-door boarding is likely the dominating effect for efficiency gains. Under a traditional system the driver must see proof of payment meaning that customers can only board via the front door while customers generally alight by the rear door or doors. Under a no-fare system customers can board and alight by all doors.

This effectively doubles the rate of boarding, as long as there is no conflict between boarding and alighting customers. If the hypothetical system used articulated buses with three doors then the boarding rate could be tripled. The *Highway Capacity Manual* (HCM) proposes a dwell model that encapsulates multiple doors by examining the busiest doors then using a Turvey and Mohring-type model (Transportation Research Board, 2000):

$$\max\ (a_i A_i, b_i B_i)$$

Given the above discussions on models, the author believes that the no-fare bus situation is best represented by:

$$T + \max\left(\sum a_i A_i\,, \sum b_i B_i\right), \text{where } i \text{ is the number of doors}$$

It can be reasonably assumed that the time spent alighting is not going to be affected by such a policy and that alighting is a smaller portion of time than boarding, therefore:

$$T + \sum b_i B_i$$

Under the current and proposed systems we see:
Current:

$T + bY$, because i must only be 1 because of front-door boarding

Proposed:

$T + b`(Y/n)$, where n is the number of doors on the bus

This assumes that people will spread so that the boarding time is uniform across all doors. Therefore, the efficiency gained is:

$$Y(b - b`/n)$$

This functional form implies that the efficiency gains are greatest when Y and n are higher. This is empirically true based upon the author's experience. More complicated models exist that look specifically at the interplay amongst passengers boarding and alighting from the same door and across all different doors of a bus, but for the purpose of this analysis these models are overly complicated. One can assume the passengers would tend to find the optimal mix of boarding and alighting at each door so that one need not model the interplay of the bi-directional passenger flow.

Establishing Values of Parameters

Establishing the values of the different parameters is challenging and is highly dependent on the individual system. For example, the time difference for boarding in a system such as Hong Kong is likely negligible whereas other systems such as in Victoria, BC could be quite significant. In the public transit system within Victoria, BC passengers holding passes must manually swipe them through a fare payment machine which is time consuming whereas in Hong Kong a contactless RFID system is near instantaneous. Furthermore, the average time taken is likely to differ across routes within the same system as some will have a higher proportion of transit pass holders, who likely board more quickly as they do not have to pay and are more familiar with the system. One study found: “The average service time per passenger ranged from 1.5 to 6.0s per alighting passenger and 1.5 to 8.0s per boarding passenger, depending on different fare collection systems, presence of transfers, and baggage” (Transportation Research Board, 2000). Another study of the New Jersey transit system, using a Turvey and Mohring model, found:

$$\textit{Dwell Time} = 5.07 + 2.92A + 5.66B$$

with an R^2 of over .7, which was the highest of the four models tested, except for one that used additional data on the number of passengers standing (Rajbhandari, Chien, & Daniel, 2003). The validity of these values when applying them to another metropolitan centre may be questionable as it is complicated by the fact this New Jersey transit system involves a line that was connected to the airport, in addition to many other stops. This implies it was likely used by more infrequent riders than most routes, and the riders may be slower than regular commuters. The HCM has summarized the available research and has established parameters that it uses for its calculations. The table is partially reproduced below:

Table 1: Parameters of Dwell Time (Transportation Research Board, 2000)

Bus Type	# Doors	Dead Time (s)	Boarding (s/pax)		Alighting (s/pax)
			Prepayment	Single Coin	
Conventional	1	2.0-5.0	2.0	2.6-3.0	1.7-2.0
	2		1.2	1.8-2.0	1.0
	4		0.7	--	0.6
Articulated	2	2.0-5.0	1.2	--	0.8
	3		0.9	--	--

Note: -- means no data

Data available on New York City provides a full analysis of a no-fare scenario and finds even lower values than the HCM states. Komanoff calculates that a passenger boarding takes 1.06s, and one alighting from the rear doors 0.82s or from the front 1.54s with prepayment of fares. Furthermore, his model accounts for the interplay amongst passengers boarding and alighting. He examines a specific commuter route in New York City and found that dwell time would be reduced by 82% with three-door buses and 76.6% with two-door buses. He notes that originally dwell time was 16:16min or 28.9% of the total trip time. Eliminating the need for fares, dwell time was reduced to 3:48min or by 22.1% of the total trip time (Komanoff, 2011). He continues on to examine the additional gains that come from reduced road congestion, which will be discussed later.

Operator Perspective

From a system operator’s perspective, it needs either for operating costs to decrease or for revenues to increase for a change in system design to be beneficial. Each question will be addressed in turn. Each individual bus run has marginal costs related to things such as fuel and driver time, but also joint costs that are shared over dozens of runs such as maintenance staff and the capital costs of the buses themselves (Turvey & Mohring, 1975, p. 285). By varying the numbers of routes and the number of buses on each route, it is clear that all other expenses will be varied in a roughly proportional rate. Moving from one bus to two buses effectively doubles the cost (Parry & Small, 2009, p. 8). This constant returns to scale for costs is notably only true within larger systems. In a smaller system the indivisibilities of different resources affect the returns to scale but for the sake of simplicity need not be considered. Any system that is sufficiently large to have a subway system is likely to be sufficiently large to overcome the issue of indivisibilities of resources. The other important feature of the public transit cost structure is the negligible marginal cost for an additional passenger to travel on a bus. On a per-vehicle basis, the costs of a route are fixed regardless of the number of passengers riding until the bus reaches capacity and the addition of another bus shifts the cost curve outward. This feature brings about two goals: firstly, that the operator should seek to reduce as much as possible its fixed cost per-vehicle and secondly, that the operator should seek to fill all vehicles to their maximum capacity to maximize revenue.

In regard to implementing a no-fare system, the important question to answer is how many fewer buses would be needed to maintain the same level of service, holding the amount of passengers constant. After establishing how capacity could be altered while still maintaining the same level of service, an investigation would have to occur into what costs could be reduced. Drawing on the above assertions that a reduction in buses roughly corresponds to a proportional reduction in all costs then the cost reduction should be large. Taking the data from Komanoff (2011) for illustration, if the overall reduction in dwell time is 12mins on a 60min route, then the number of buses could be reduced by 20% to still achieve the same capacity to move people per hour. If this example could be extended across an entire system then a 20% reduction in direct costs could be achieved.

Reducing Operating Costs

The largest reduction that would occur is that fewer buses would be needed to maintain the same level of service to customers. Fewer buses translate into significant costs savings from personnel, capital, and maintenance costs. It has been estimated that a driver costs approximately $72,000 with benefits (Komanoff, 2011) and assuming that they work 2000hrs per year that translates to $36/hr. Furthermore, there are significant additional support staff such as mechanics, supervisors, etc. which are needed to assist bus drivers. If we assume these are proportional at roughly one support staff per driver, as Komanoff's data states, then that adds $36/hr of cost to the drivers' wages meaning that personnel cost of a bus is $72/hr. This excludes the fringe costs of benefits and the like which are high given the unionized environment of transit and effectively doubles the wage cost. The entire compensation package for staff accounts for 85% of operating costs. In addition to personnel costs, fuel and maintenance are significant costs. Using data from New York City, Komanoff estimates the cost of one bus at $171.80/hr or $22.21 per vehicle-mile (Komanoff, 2011). As well, these operating costs fail to account for the depreciation and capital expense of actually purchasing the bus itself. The high costs of service indicate that a relatively large loss in revenue can be offset by even minor efficiency gains.

Another large cost that would be reduced is the fare collection system. This is significant cost as demonstrated by the systems that have completely eliminated fare collection because of the cost. Two major costs are readily apparent. The first cost is the elimination of fare collection machinery on each bus across the fleet. This machinery is a high capital cost at $15,000 per unit (Metropolitan Council, 2011) as well as continuing maintenance costs. This cost reduction will be partially offset by the increased cost of adding more fare collection machinery at stations as the volume of users at that point will increase. The second cost is the actual cost of processing the fares collected. At the end of each night, the fare machines must be emptied and the coins counted, rolled, and readied for deposit at the bank. Again by moving payment to stations versus buses, the cost of managing coins will be significantly reduced because more customers would pay by credit card, buy pre-paid tickets or tokens in groups meaning that the money would only have to be processed once for a dozen or more trips. Furthermore, the costs of collection in a few machines in likely considerably lower than collecting from hundreds of buses spread across a transit yard. Overall, the costs of fare collection were calculated to average 6% of revenues across a variety of US transportation systems but ranged as high as 20% (Transit Cooperative Research Program, 1998).

The above costs are two of the most significant savings; however, there are also numerous other costs that would be reduced and would require significant investigation based on the specific system. One particular cost will be used to demonstrate the less visible cost reductions. For example, bus drivers will no longer have to engage in disputes with customers over fare collection. A majority of disputes are caused by issues around fare collection and these incidents could result in lost-time for staff or at minimum physical and emotional stress (Perone, 2002). Elimination of this part of their duties may result in an overall happier workforce that could offer productivity and other gains. Furthermore, drivers may accept lower wages because there is implicit premium within the wage rate for this unpleasant and potentially dangerous component of work.

Revenues

Revenues are likely to decrease though it is possible that they would increase depending on whether the effect of free-riders on the system or an increase in ridership dominates. As riders of buses would not have to pay for their trips under assumption that they would later pay for their trip at the subway station, riders who never have to take the subway as part of their trip would never pay for their trip. The impact on revenue is a function of the degree to which the bus systems serves as a feeder network for the subway system. Additionally, this will not simply result in the loss in revenue from the one-time payment riders but also those who hold transit passes. The decision to purchase a transit pass is based on the calculation that the average cost per trip is lower with the pass then without. The majority of an individual’s trips are commuting to school or work. If these journeys could be achieved via bus without the need for the subway, then the customers are unlikely to purchase a pass and instead purchase individual fares for the few journeys that they do make that involve the subway.

Contrastingly, revenues are likely to increase from new ridership. A person decides which mode and route to take based on the generalized cost of the travel. If the public transit system becomes quicker this will result in the generalized cost of transit being lower and it may induce people to switch from other modes. The literature on increasing subsidies to operators effectively mirrors the benefits that would occur by increasing the operational efficiency because in both cases the generalized cost is reduced. The literature shows a lower fare induces mode shift from alternatives. The extent of the shift must be examined through an econometric study to establish the generalized costs of different modes of transit based on an individual's value of time.

The mode shift that is most beneficial is from cars to public transit as these journey are typically longer and are most likely to use the subway during a portion of the trip. Studies have shown that 60-85% of switchers shift from automobile to public transit (Parry & Small, 2009). As the marginal cost in no-fare bus transit is 0, consumers who would have previously not used transit for short journeys may now begin. This may have deleterious effects on the system as the buses will become overly crowded by non-paying customers who are taking advantage of the no-fare on journeys completed only on buses which could either push away paying customers or force the transit operator to increase the number of buses to maintain the same level of service. This concern has not proven to be an issue with highly subsidized systems so is again only of minimal concern in a no-fare bus system (Parry & Small, 2009).

An issue that prevents potential customers from using public transit is that they cannot be certain of their arrival time due to factors outside of their control. An important benefit of allowing multi-door boarding is decreasing the variance of dwell time. When boarding is limited to one door, any passenger that takes an overly long time boarding because of disability or asking questions of the driver delays the entire queue by that amount. In a multi-door situation the customers respond to the slow boarding individual by shifting to other doors meaning that overall the bus is delayed less than under a single door condition. This lower variability will also help to eliminate the issue of headway with buses where they tend to bunch together because one bus gets ahead of or behind schedule. As the variation in dwell time is decreased schedules can be improved. Given the extremely high value of time that customers place on delay as well as the possibility of missing connections, lower dwell time variance can translate into a significant cost to users (Dorbritz, Luthi, Weidmann, & Nash, 2009). This will also help decrease costs to the operator which may currently oversupply capacity to provide slack for potential headway issues.

Social Benefits

The benefits of implementing such a system extend outside of the operator. This paper does not focus on these numerous benefits so will choose to highlight briefly two while noting their relevance to the cost-benefit calculations to the operator itself. Current users of public transit are the largest beneficiaries of such a system. As proposed, fares would stay constant while service would necessarily improve. All passengers must suffer dwell time on their trip but would prefer that it not exist. This dwell time can be seen as "average dwell time per passenger from boarding and alighting divided by trip length" (Parry & Small, 2009, p. 7) which can be used to produce an equation for average trip time as bus speed multiplied by a congestion multiple plus dwell time costs. The generalized cost of travel will be decreased by each individual's value of travel time multiplied by the total time saved. If we extend the earlier example, the time cost would be reduced by 20%. Furthermore, as discussed above, decreasing variance in the schedule will allow users to better predict travel time which is of benefit to the users.

Also a benefit to society at large is lower traffic congestion. Komanoff concluded that bus travel time would decrease by 3.4% because of reduced road congestion because of eliminating bus fares (2011). His research concluded this would come from users shifting from automobiles as well as the buses impeding traffic for a shorter period of time at each stop. This obviously has large benefits for all road users as lower traffic congestion will decrease travel time for all users regardless of mode. Using the comparison of subsidies, it is clear that increasing the efficiency of the system will result in "substantial incremental welfare gains from the combination of net scale economies and externality benefits, the former being especially important for off-peak service and the latter for peak service" (Parry & Small, 2009).

Conclusion

Inefficiencies result from the fare collection process. Collecting the fare on each bus takes considerable time, making the journey slower for all users and dissuading potential riders, and has a high monetary cost, in capital and staff costs. This paper proposes a system where the place of payment is shifted from the bus to the subway station where fares can be collected in a more efficient way and eliminates the single-file queue where one customer paying prevents all other customers from boarding. From the operator's perspective, whether such a system is advantageous is complicated and highly dependent on the features of individual system. As noted, two features are fundamental for the successful implementation of such a scheme. The first is that the buses serve a feeder role to the subway and second that one fare is charged for the entire trip regardless of mode. The key factor is the proportion of bus riders that also use the subway.

The efficiencies gains are obvious through the use of such a system but the operator must ensure that it continues to extract fare revenue from its riders. Alternatives to a completely no-fare bus system could include a partial implementation of a no-fare system or a proof-of-payment system. In the first, an operator may wish to implement such a system on only a portion of its routes such as those which mainly serve a feeder role. From this, an issue that arises is the additional transaction costs of the public being unsure which buses are fare and which are no-fare. In the second, a proof-of-payment model could be implemented where individuals can board at all doors if they have already paid and board using the front door only if they have not. Random audits are used to control fare evasion. Lastly, one could imagine a system where the last effect discussed, the increase in new ridership, was strong enough that it may be possible that ridership would increase to a point where more buses are added so that service is again improved which induces more people to mode shift to public transit allowing further improvements in services and inducing more people to mode shift. This virtuous circle would provide benefits to all. The multiple contrasting forces demand that stringent cost-benefit analysis be done on this strategy.

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