The Effects of Fare Payment and Crowding on Dwell Time:

A fine Grained Analysis

Supervised Research Project

Prepared by: Grant Fletcher
Supervisor: Ahmed El-Geneidy
In partial fulfillment of the requirements for the degree:
Master's of Urban Planning
McGill School of Urban Planning
July 7, 2012

ACKNOWLEDGEMENTS

Prof. Ahmed El-Geneidy was a great resource, a source of inspiration and a guide through this project. As my supervisor, these traits were appreciated. However, it was the late night phone calls to the lab, his never ending patience, kindness and his enduring sense of humor that made this project and the past two years at McGill especially enjoyable.

Thank you Ahmed.

I would like to express my gratitude to Marianne Hatzopoulou for providing her comments as the second reader. Special thanks go to Geoff Cross, Lorie Srivastava, and Nithya Vijayakumar, all of TransLink, for providing the opportunity, advice and guidance needed to bring this project to fruition. William Hui of TransLink also deserves special recognition for helping to define the research and for providing detailed comments during the writing of this paper. I would like to also show my appreciation to Ehab Diab, Kevin Manaugh, and the Urban Planning students at McGill for their support and feedback throughout this project. Thank you to my dedicated data collection volunteers, motivated by their interested in transit and research, for their tireless hours of bus riding.

Thank you to Mitacs and TransLink for providing the funding that allowed me to carry out this research.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Appendices

ABSTRACT

Dwell time, the time a transit vehicle spends stopped to serve passengers, contributes to the total reliability of transit service in several aspects. Dwell time is affected be many factors such as passenger activity, bus crowding, fare collection method, drivers experience, time of day, and others. The type of impacts crowding can have on dwell time is debatable, due to its interaction with passenger activity and the accuracy in calculating it. Also different types of payments have another debatable impact in terms of the power of its impact on dwell time. These debates can be linked to the absence of appropriate data that can actually capture the real impacts of these variables. This research attempts to determine the influence of crowding and fare payment on dwell time, through manual data collection and compares it to findings from automatic data collection methods. The study is conducted along three heavily used bus routes in the TransLink system from Vancouver, BC. Multiple regression models are performed using a traditional model and a new expanded model with the additional details that manually collected data provides. The traditional model overestimated dwell times due to lack of detail in fare payment and crowding. While the expanded model shows that crowding affect dwell time after approximately 60% of bus capacity increasing dwell time. The different fare payments had various positive impacts on dwell time. This research can help public transit planners and operators in developing better guidelines for fare payments methods as well as policies associated with crowding.

RÉSUMÉ

Le temps d'arrêt, est le temps qu’un véhicule de transport passe en arrêt complet pour servir les passagers. Cela contribue à la fiabilité totale du service de transport dans plusieurs aspects. Le temps d'arrêt est affecté par plusieurs facteurs qui sont l'activité des passagers, le surpeuplement de l’autobus, la méthode de collection de tarifs, l'expérience du conducteur, le temps de la journée, et d'autres. Les types d’impacts que l'encombrement peuvent avoir sur le temps d'arrêt sont discutable, en raison de leurs interaction avec l'activité des passagers et la précision dans leurs calcul. Aussi, les differentes types de paiements ont un autre impact discutable en termes de leur puissance d’impact sur le temps d’arrêt. Ces débats peuvent être liés à l'absence de données appropriées qui peuvent réellement saisir les impacts réels de ces variables. Cette recherche tente de déterminer l'influence de l'encombrement et le paiement des tarifs sur le temps d'arrêt, grâce à la collecte des données manuelle et les comparent aux résultats des méthodes de collecte automatique. L'étude est menée selon trois lignes de bus qui sont utilisés fréquemment dans le système de TransLink à Vancouver, en Colombie-Britannique. Plusieurs modèles de régression sont effectuées à l'aide d'un modèle traditionnel et un nouveau modèle élargi avec les détails supplémentaires que les données qui ont été collectées manuellement ont fournit. Le modèle traditionnel a surestimé le temps d'arrêt, en raison d'un manque de détail dans l'encaissement du tarif et le surpeuplement. Alors que le modèle élargi démontre que le surpeuplement affecte le temps d'arrêt après environ 60% de la capacité croissante de l’autobus. Les différents paiements de tarifs ont eu de divers effets positifs sur la durée de séjour. Cette recherche peut aider les urbanistes qui spécialisent en transport en commun et les opérateurs dans l'élaboration de meilleures directions pour les méthodes de paiements de tarifs ainsi que les politiques liées à l'encombrement.

INTRODUCTION

The doors on an already crowded bus open and as passengers disembark, even more are waiting to board. The last passenger finally steps off of the curb, throws their arms out and literally falls back into the already uncomfortably close passengers to clear the doors for closing. When the doors close, the passengers sigh an uncomfortable relief, not particularly happy to be on such a crowded bus, but happy to be on one nonetheless[1]. With ridership increasing and budgets shrinking at public transit agencies across North America, situations like this on public transit vehicles are likely to increase. Vancouver, BC is no exception and is experiencing these constraints. Dwell time consumes around 26% percent of the total trip time and as such, longer and shorter dwell can have significant effects on run time variation (Rajbhandari, Chien, & Daniel, 2003). Understanding the relationship between fare payment, in-vehicle crowding and dwell times will assist agencies in delivering quality public transit by improving service planning and scheduling. While a full bus may appear to be the epitome of efficiency, the additional load may cause dwell and run times to increase significantly (Lin & Wilson, 1992). This research paper attempts to explain the paradoxical situation of how the presence of extra passengers on a crowded vehicle can both increase and decrease the efficiency of the vehicle. It also tries to understand the different impacts of a variety of fare payments on dwell times.

Crowding on buses is a challenge that many transit agencies are facing. TransLink, the local transit provider Vancouver, BC is not an exception. On some routes, vehicles fill to capacity at their origin, leading to pass-ups[2] and extreme crowding; this is a daily occurrence on many routes. Several of these crowded bus routes suffer from delays due to the high demand experienced throughout the route. In order to research this phenomenon, three urban, high frequency and heavily used bus routes

[1] This series of events actually occurred during the data collection period of this project.
[2] Pass-ups occur when the bus is at 100% occupancy and unable to board more passengers. Passengers waiting at stops are unable to be picked up and are passed by.

are studied to determine the effects of crowding and fare payment on dwell time. Manual counts were performed detailing passenger movements, fare type used, dwell times, and levels of crowding.

This paper begins with a review of current literature on dwell times and the different factors that can affect them. The following sections explain the methods used to gather, clean and interpret the data. The final sections analyse the dwell time model, compare a sensitivity analysis, and provide recommendations and conclusions.

LITERATURE REVIEW

Dwell time is defined as "the amount of time a bus spends while stopped to serve passengers" (Transportation Research Board, 2000). As dwell time can consume up to 26% of the total travel time of buses, it is vitally important to understand the factors affecting them. By better understanding these factors, transit agencies can introduce changes that can help in reducing dwell times (Rajbhandari et al., 2003). Many researchers have developed dwell time models that help to better predict vehicle travel times and thereby improve reliability of service (Lin & Wilson, 1992; Rajbhandari et al., 2003). In creating these models, researchers hope to better understand the complex interactions between the factors that influence dwell times and recommend strategies to reduce them.

DWELL TIME

To truly understand the factors influencing dwell time, a more refined formulaic definition is needed. The following formula has been adapted from the Highway Capacity Manual and literature in the field (Dueker, Kimpel, Strathman, & Callas, 2004; Transportation Research Board, 2000).

$$t_d = P_a t_a + P_b t_b + t_{oc} + t_{unexp} + f_{rl}$$

where

t_d = Average dwell time in seconds
P_a = Number of alighting passengers at a stop
t_a = Average passenger alighting time
P_b = Number of boarding passengers at a stop
t_b = Average passenger boarding time

t_{oc} = Door opening and closing time
f_{rl}= Friction factor accounting for the additional delay caused by interaction between the number of passengers on board and the number of passengers boarding and alighting (captures the effect of crowding)
t_{unexp}= Time of unexpected activities e.g. wheelchair lift use

The first five variables in the equation are defined in the Highway Capacity Manual. They quantify how many passengers board and alight, the time it takes for this exchange per passenger and the time it takes to open and close the door. The final two variables, f_{rl} and t_{unexp}, have been added, based on the literature, to create a more realistic model (Dueker et al., 2004). The variable f_{rl} captures the effect that the load of the bus has on boarding and alighting passengers. Unexpected delays caused by wheelchair ramp use, waiting for passengers to board or other delays are captured in the variable t_{unexp}. All are influenced by, and to an extent determined by, policy, bus design, method fare collection, passenger behaviour, route and stop design, and many other factors.

Levinson (1983) was one of the first researchers to examine dwell times in detail. Through field surveys, he estimated that every dwell included 5.0 seconds for the opening and closing of doors and an additional 2.75 seconds per passenger movement. In comparing delays associated with dwell time and traffic congestion, Levinson (1983) concluded that reducing dwell time delays on a city wide basis would have a greater impact on run time than by reducing traffic congestion . Levinson's seminal research has inspired others to develop comprehensive and more detailed dwell time models.

In examining the effects of passenger activity on dwell time, Dueker et al. (2004) found that each boarding and alighting passenger had diminishing marginal effects on dwell time. The first passenger to board adds 3.5 seconds to dwell time and the first passenger to alight adds 1.7 seconds. Each additional boarding and alighting passenger was estimated to take between 0.03 - 0.04 seconds less than the first passenger. Wheelchair ramp events, while rare, add significantly to dwell time and can affect run time performance. Although wheelchair lift events occurred in less than 1% of dwells in their dataset, they were able to collect dwell time information on over 2,300 lift events. The researchers were then able to develop a dwell time model for lift events and found that dwells with lift events were approximately one minute longer than a typical dwell.

Other studies have looked at a multitude of vehicle characteristics that affect dwell time. Analysing the effect of low vs. high floor (with stairs) buses, Tirachini (2011) found that the presence of stairs added 2.2 seconds to boarding times for adults and seniors. However, high floor buses had no effect on dwell times when students were boarding and alighting. Fernández, Zegers, Weber, and Tyler (2010) found that wider doors expedite passenger movements and can significantly reduce dwell time. Articulated buses, with three doors, are also attributed with a reduction in dwell times (El-Geneidy & Vijayakumar, 2011). However, due to the additional time these buses need to accelerate, decelerate and merge into traffic, the reduction in dwell time was not reflected in the total running time. Articulated buses, although saving time during dwells, actually took 1.5% longer to complete their routes.

Other off vehicle factors influence dwell times as well. Similar to the presence of steps on the bus, the difference between curb height and floor of the bus affects dwell times. When compared to a 0mm and 300mm vertical gap from the platform to the floor of the bus, the presence of a 150mm gap had the smallest associated dwell times (Fernández et al., 2010).

Research shows that one of the more efficient ways to reduce the total dwell time on a route is to reduce the total number of stops that create dwells in the first place. TriMet, the local transit agency in Portland Oregon, USA initiated the Streamline project; an initiative to gain travel time efficiencies throughout the transit system. Bus stop consolidation was a key part of this initiative. This project provided an opportunity to study the pre- and post- implementation effects of this program on both passenger activity and bus operating performance. Bus run times improved while total passenger activity (total boardings + total alightings) was unaffected (El-Geneidy, Strathman, Kimpel, & Crout, 2006). Although passenger access time was increased due to the reduction in the number of stops, it is hypothesized that these increases were offset by reductions in in-vehicle travel time as passenger volumes remained steady through pre and post implementation. It is argued, however cautiously, that more aggressive consolidation activities could result in more efficient operations with minimal impacts on ridership (El-Geneidy et al., 2006).

Rajbhandari et al. (2003) examined dwell times on the New Jersey Department of Transportation bus system and tested four different models. Similar to Lin and Wilson, they found that a multivariate, non-linear model that treated the number of passengers and standees as independent variables was the best predictor of dwell times. However, it is noted that including the presence of standees in the model did not improve the predictive value of the dwell time model. There was also no significant effect caused by time of day or service type. These results are not unexpected as the route under study was a high frequency intercity service that did not normally experience crowding. Statistical analysis on crowding was not performed because they did not have a crowded condition sample size large enough to properly perform this analysis.

Electronic Data Collection

Automatic Passenger Counters (APC) have been used to gather data remotely and inexpensively since their introduction in the mid-70s (Moore II, Giuliano, & March, 2002). APC use sensors mounted near the doors on a bus to count boarding and alighting passengers and door open time at all doors. Automatic Vehicle Locators (AVL) are part of a larger integrated communications system. The Transit Management and Communication System (TMAC) used by TransLink, provides GPS based location information, voice and data capabilities for every bus operated by Coast Mountain Bus Company. The system is in constant contact with central control and provides real time feedback about schedule adherence, delays and reroutes. The combined use of these systems provides a breadth of data that is unattainable using standard manual counting techniques. Most research on dwell time uses data collected by these systems. Building on existing literature, researchers began to analyse dwell time by using large data sets collected automatically by AVL and APC. While the aggregate of this data is useful for dwell time analysis, there are concerns of data validity, reliability and loss of detail.

The first iteration of APCs were found to have several major technical problems. As of 2002, Moore II et al. (2002) concluded that “there is no fully objective evidence that APCs can provide adequate data for section 15 reports” (p.145)[3]. Additionally, Dueker et al. (2004) mention that wheelchairs, walkers and strollers can confound APCs. Although many of these technical problems have been resolved, there are continuing questions of how data processing can affect the accuracy of the data (Kimpel, Strathman, Bertini, Bender, & Callas, 2005; Moore II et al., 2002).

In their study of two different bus routes containing different APC equipment, Kimpel, Strathman, Griffin, Callas, and Gerhart (2003) found that estimates of boardings were accurate at the system level. However, one type of equipment over estimated boardings by a statistically significant margin, while APCs of both types overestimated passenger loads by a statistically significant margin (Kimpel et al., 2003). These deficiencies are attributed to the load balancing algorithm that prevents a load value of less than one (Kimpel et al., 2003). This propensity to overestimate passenger loads could affect the results of previous research that relied upon APC data. Using data where loads were overestimated would serve to underestimate the effects of crowding on dwell time.

More recently, the Champaign-Urbana Mass Transit District posted an entry to their blog describing inaccuracies in their APC data due to a sensor being installed improperly (Snyder, 2011). They also attribute inaccuracies to passengers at busy stops boarding or alighting in ‘chunks’ where the sensors of the APCs are unable to differentiate between people. While there can be problems with APC data, all of the authors caution that manual counts often contain errors and Kimpel et al. (2003) claims that manual counts often contain more randomized error than those obtained with APCs making these errors harder to discover and account for(Moore II et al., 2002; Snyder, 2011). Other issues arise concerning the integration of multiple data collection systems. The potential for errors exist not only in

[3] Section 15 in the United States requires transit operators to report passenger counts and other data to receive funding.

collection, but also in bringing data from multiple sources and combining entries. There is no perfect method for data collection and a combined approach that reduces errors is ideal.

CROWDING

Passenger crowding in public transit vehicles is difficult to define. Simply, a vehicle is in a crowded state when people on the vehicle impede the flow of individuals boarding and alighting. Dueker et al. (2004) define a crowded vehicle as such when its load is greater than 85% of total capacity. A typical 12 metre bus has a total capacity of 77 passengers (31 seated, 46 standees), meaning that there would be 35 passengers standing in the aisle and doorway before it was defined as crowded. This definition appears problematic as the threshold is quite high.

Alternatively, some researchers use a lower threshold for crowding. Milkovits (2008) asserts that crowding occurs when passengers on the bus begin to interfere with the boarding and alighting process. He claims that this occurs when the number of passengers on board is greater than the number of seats and justifies this claim by arguing that people will stand, even though there are seats available. According to Lin and Wilson (1992), the effects of crowding are the most pronounced at the highest levels of occupancy. It is therefore doubtful that this threshold of crowding will significantly affect dwell times.

Regardless of how it is defined, crowding on transit vehicles has affected the quality of service and passenger comfort for the past century ("Crowding in Street Cars," 1900). Research on crowding and dwell time has evolved through the years. Preliminary studies on this relationship showed that vehicles with passenger loads greater than the number of seats experienced an increase in passenger service time (Zografos & Levinson, 1986). This increase was directly attributed to the occupancy of the vehicle as the study was performed on a no fare bus system.

Dwell times for the Metro Boston Transportation Authority's green line light rail system were examined and it was found that dwell time is affected by the number of passengers boarding and alighting, and the number of people on board the vehicle (Lin & Wilson, 1992). However, the number of passengers on the vehicle only affected dwell times when there were passengers standing in the aisles or door wells (standees). When examining the effects of crowding on dwell time, they tested linear and non-linear models and found that non-linear models performed better. They concluded that dwell times increased exponentially as crowding worsened, especially on single car trains. These crowded, single car trains would run slower than other, less crowded trains. The longer headways associated with these slower trains cause platforms to become more crowded thereby increasing passenger movements at each stop. This effect creates a positive feedback cycle that slows crowded trains significantly. With headways of 1-2 minutes, service along the entire line can degrade quickly due to bunching. They concluded that headways must be closely monitored to ensure crowded trains do not affect other less crowded trains along the line. These system wide delays occur because of extended dwells caused by crowding.

Corroborating past research, Milkovits (2008) found that a non-linear model was the best predictor of dwell times. Unlike the research performed by Rajbhandari, he was able to measure the effects of crowding on dwell time. Crowding was found to affect dwell time; however, the effect was only realized on heavily loaded buses. When the effects of crowding were apparent, only a few extra seconds were added to the dwell time.

Another component of crowding is friction. Friction is a compound variable that attempts to incorporate the effects of crowding and the number of passengers boarding and alighting. Friction was included by Dueker et al. (2004) in their dwell time model. They hypothesised that passengers moving to exit the vehicle are slowed down by the presence of other passengers on board, thereby creating the friction. To measure friction, they developed a proxy variable for crowding that added total passengers boarding, alighting and standing. Although included in their regression model, this variable is not mentioned in the analysis. With a coefficient of 0.069, it appears that friction had a marginally positive effect on dwell time. Other studies have also looked at fiction with more reliable results. In Sidney, Tirachini (2011) found that when people formed two queues at the front door, friction was experienced. Dwell time per passenger increased by 1.25 seconds for individuals waiting in the left queue when the right queue was present. Additionally, passengers alighting at the rear doors were affected by standees in close proximity to the doors which increased dwell time per passenger by over half of a second. These results express a relationship between crowding, passenger movements and dwell time.

Fare Payment

The method and location of fare payment can have a significant effect on dwell time. Different fare media types also have different effects. Passengers that pay with cash where change is given have the largest effect on dwell time, while fare that is merely shown to operators (not swiped or tapped) had the smallest effect (Milkovits, 2008). A passenger that pays with a magnetic strip ticket adds 4.6 seconds to dwell time and passengers using cash where no change is given add 5.7 seconds (Tirachini, 2011). The newest innovation in fare payment technology is the introduction of electronic smart media cards. These passes need only be tapped or swiped against a sensor to register payment. These cards were reported to be 1.5 - 2 seconds faster than magnetic stripe tickets. However, this difference was negligible with the presence of crowding. This suggests that crowding slows down the boarding process regardless of the fare type used.

Where the payment takes place also affects dwell time. The placement of the fare collection box was attributed to the difference in speed at which passengers could board two different types of buses in Chicago (Milkovits, 2008). The most expedient way to collect fares is to have the process occur prior to boarding the bus. Off-board fare collection is common on rapid transit systems and has proven to reduce dwell times (Fernández et al., 2010). This is especially true when buses have wide doors. When off-board fare collection was introduced, dwell times for buses with 800mm doors were reduced by 1-8% and buses with wider, 1600mm doors saw reductions of 10-22%.

TransLink

On June 25th, 2007, TransLink and CMBC implemented a policy change that would allow customers to board buses on certain routes from all doors. This change was enacted as a response to heavy demand and crowding on the 99 B-Line. The City of Vancouver used APC data to study three stops along this line before and after the policy change (Dobrovolny, 2009). After the implementation of all-door boarding, the City of Vancouver discovered that the average dwell time per person was reduced by 17%, a one second reduction. They also found that total trip time in both directions decreased by 3%, a one minute reduction. Public response to the change was also measured through an onboard survey. Over all, most service attributes had higher scores after implementation, however, only boarding speed, ease of existing and personal security at stops were statistically significant. While other routes have been considered for all-door boarding, the 99 B-Line is currently the only bus route in the TransLink system that permits boarding from the rear doors.

CONTEXT

The South Coast British Columbia Transit Authority (TransLink) was a partner in this research project. They provided institutional knowledge and experience to guide the research. The research question was further defined based on their experiences during times of extreme crowding, notably during system delays and the 2010 Winter Olympics. This research will aid TransLink in reviewing and refining the Transit Service Guidelines, which were prepared in 2004. The guidelines state that “severe overcrowding that impedes circulation of passengers can also increase passenger loading and unloading times” (Greater Vancouver Transportation Authority, 2004, p. 35). This paper is looking to quantify this statement and develop an optimal level of crowding that can be used to balance the efficiency of the transportation system with customer comfort and satisfaction. It also looks at the different impacts of fare payment types on dwell time.

TRANSIT SERVICE GUIDELINES

TransLink's Transit Service Guidelines provide objectives on the maximum desired occupancy of transit vehicles. These objectives informed the development of three different thresholds for acceptable levels of crowding at different times. The first two thresholds relate to the highest occupancy during the peak 30 and 15 minute[4] periods during the AM and PM peaks[5]. The busiest 30 and 15 minute thresholds are approximately 60% and 70% of bus capacity, respectively. The third threshold uses a 60 minute period during midday, evenings and weekends and is approximately 50% of bus capacity. These thresholds are referenced while analysing the data throughout this project.

TransLink is currently in the planning stages of implementing a new electronic fare collection system. The Compass Card is a contactless electronic fare payment system that requires passengers to tap on to the system when they board and tap off the system when they alight. When active in 2013, the system will fundamentally change how passenger boarding and alighting will affect dwell time. This study will provide a baseline from which the effects of this implementation can be measured.

ROUTE DESCRIPTION

#5 Robson/Downtown

The #5 Robson/Downtown bus circulates through Vancouver's downtown peninsula. It serves the residential, commercial and tourist area along Denman and Robson Streets before continuing through the employment sector of downtown Vancouver. It then loops back through the employment sector and continues in the opposite direction along Robson to Denman terminating where the route began (see Figure 1). This route is flanked by residences and commercial establishments through the entire length leading to many boardings and alightings throughout. It also connects with the SkyTrain

[4] "The maximum number of passengers is calculated as the **average** of the maximum numbers of passengers on-board all bus trips starting within the 15, 30 or 60 minutes period (as applicable) that has the highest average maximum number of passengers. The busiest time period is identified by calculating the 15, 30 or 60 minutes (as applicable) moving average maximum numbers of passengers and finding the highest value."(South Coast British Columbia Transit Authority, 2008)
[5] AM Peak Period is 6-9 A.M. and PM Peak Period is 3-6 P.M." (South Coast British Columbia Transit Authority, 2008)

rapid transit system. Twelve metre, low-floor electric trolley buses are operated at headways of 5-10 minutes throughout the day. A complete loop, from terminus to terminus, takes 35-40 minutes traversing 6km and passing 31 stops (Table 1). Due to construction, two stops were temporarily closed near Robson and Richards Streets. When stopping to service passengers, the driver manually controls the opening and closing of the front door. The rear doors are unlocked by the driver but require a passenger to press on the handle to trigger them to be opened. They close automatically after a predetermined time, unless retriggered by a passenger.

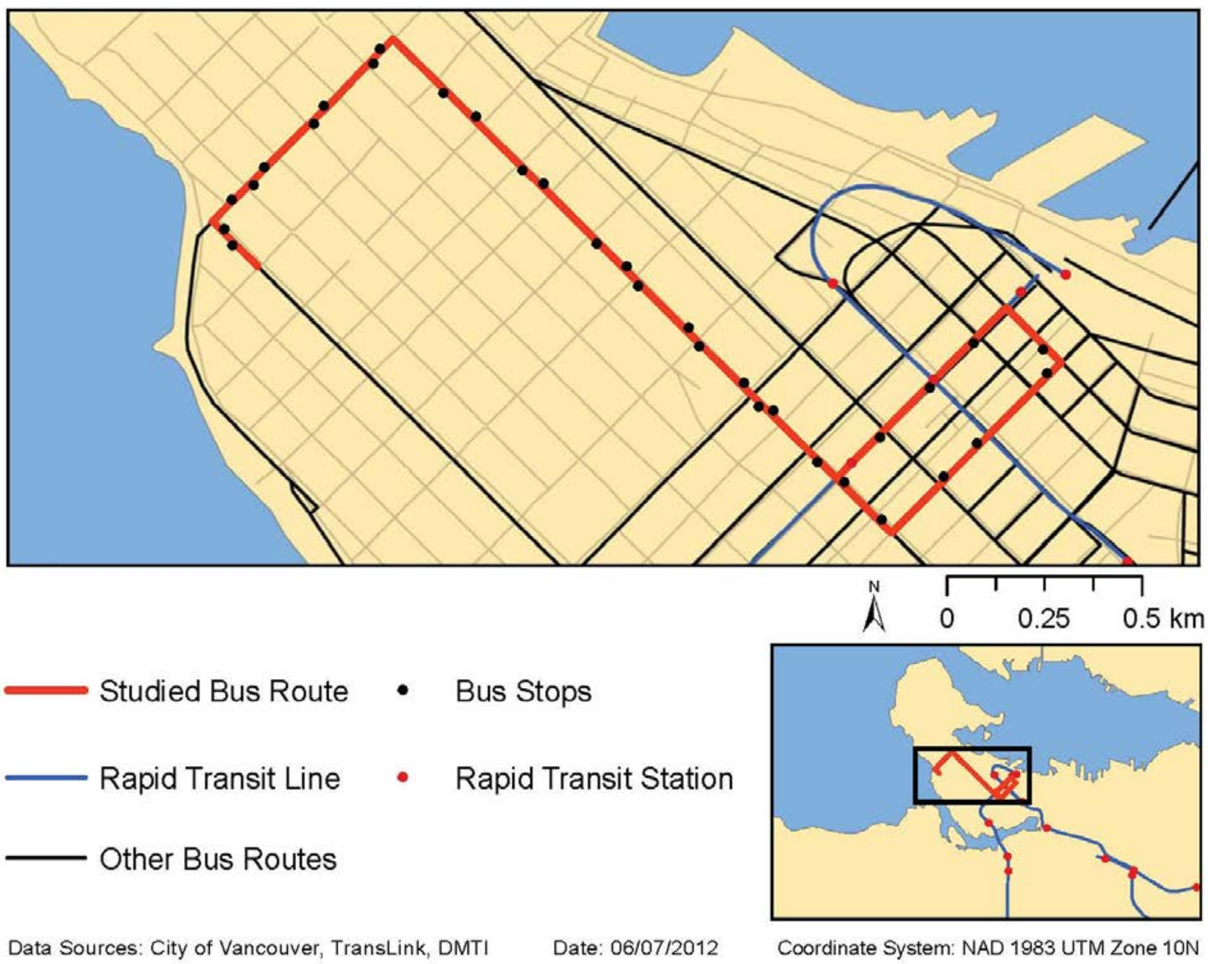


FIGURE 1: DOWNTOWN PENINSULA, VANCOUVER, BC, SHOWING THE ROUTE OF THE #5 ROBSON

Broadway Corridor

The Broadway corridor extends from the Burnaby-Vancouver boundary to the University of British Columbia (UBC). Central Broadway, loosely defined as the area between Main Street and Arbutus

Street, is the commercial and employment center of the street (Figure 2). Central Broadway and UBC are the two largest transit trip destinations outside of the downtown core which creates one of the busiest bus-only transit corridors in North America (Dobrovolny & Howard, 2010). With over 80,000 boardings per day, current bus service is overwhelmed and unable to satisfy demand. Future plans include rapid transit through the Central Broadway corridor to meet current and future demand. Curbside dedicated bus lanes are used during the rush hour periods (7-9:30am 3-6pm); however, right turns by general traffic are still permitted which reduce the efficacy of these lanes. Broadway contains many major destinations including City Hall, Vancouver General Hospital, Vancouver Community College and the Great Northern Way campuses of Simon Fraser University, UBC, British Columbia Institute of Technology and Emily Carr. It is also intersected by the Millennium/Expo SkyTrain line and Canada Line.

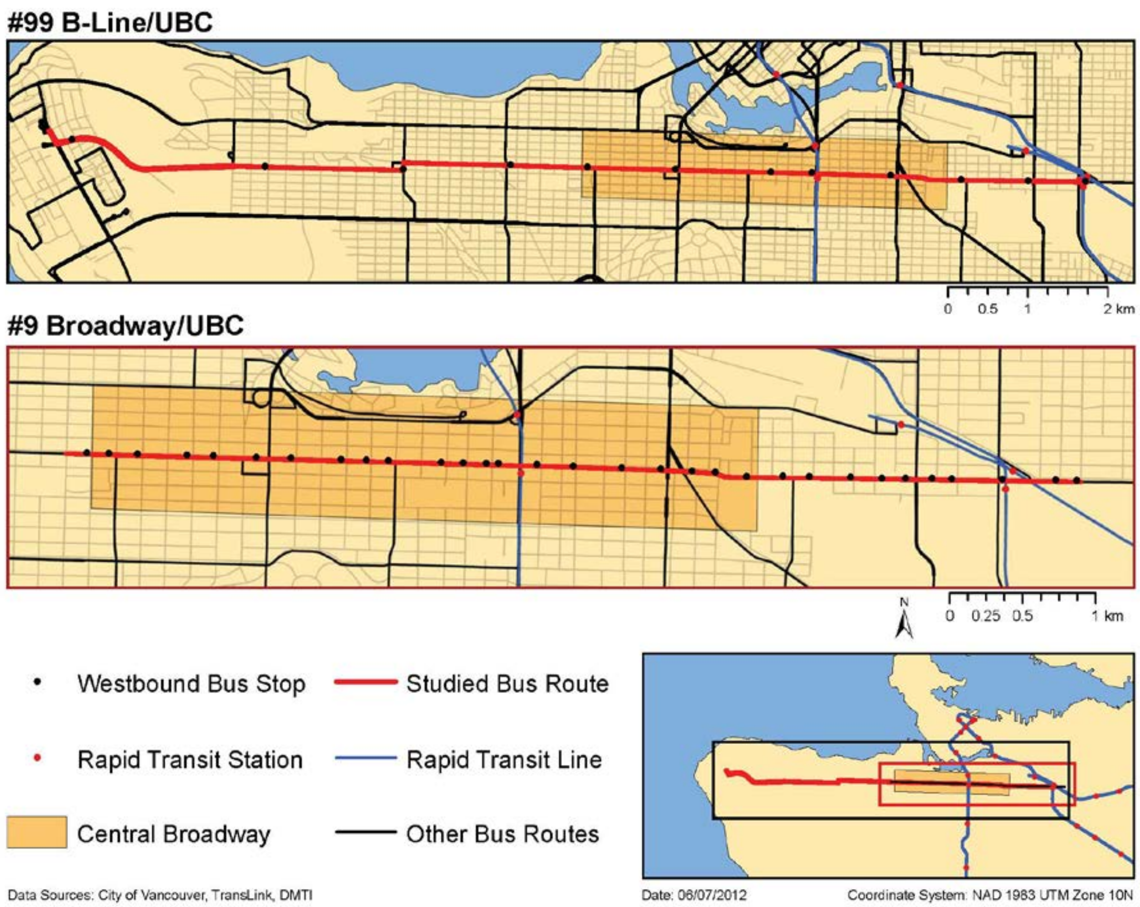


FIGURE 2: BROADWAY CORRIDOR, VANCOUVER, BC STUDIED SECTIONS OF THE #9 BROADWAY & #99 B-LINE

#9 Broadway/UBC

The #9 travels the entire length of the Broadway corridor, from Boundary Road, through central Broadway and on to UBC. The frequency on this line averages between 5-15 minutes throughout the day. The surveyed section took approximately 30 minutes to complete a 7 km run and passed 31 stops in the westbound direction, 30 eastbound. As with the #5, twelve metre, low-floor electric trolley buses are operated on this route. Door operations are also the same as the #5. The #9 bus route is the complementary local service to the 99 B-Line express bus.

#99 Commercial-Broadway/UBC (B-Line)

The #99 B-Line is a limited stop, express route that begins at Commercial/Broadway Skytrain station and travels the same corridor as the #9, through central Broadway to its terminus at UBC. With over 54,000 boardings per day, the 99 B-Line is cited as the busiest bus line in North America (Dobrovolny, 2010). This line is serviced by three door, articulated diesel buses running at 2-3 minute headways during rush hour periods and 5-10 minute headways at other times. This 16 km route is served by thirteen dedicated stops in each direction and was surveyed in its entirety. The #99 is unique in the TransLink system in that it allows passengers with valid fare to board through any of the three doors. All-door boarding requires a different procedure regarding opening, closing and triggering the rear doors. The drivers open all doors at all stops without needing passengers to trigger them. The driver also closes the doors; however, the handles remain active allowing passengers to keep them open until the boarding and alighting procedure is complete.

TABLE 1: PHYSICAL CHARACTERISTICS OF ROUTES 5, 9 & 99

	Route (Westbound)		
	#5 Robson	#9 Broadway	#99 B-Line
Length (km)	3.4	6.9*	16.2
Number of stops	15	31*	13
Daily boardings (Mon-Fri)	9,400	25,300	54,350
Annual boardings	3,167,000	8,298,000	16,642,000
Service type	Local	Local	Express
Population (400m Buffer)	42,000	79,000	68,000
Employment (400m Buffer)	105,000	68,000	58,000

Based on 2011 data
(Klitz, Nunez, & Hyslop, 2012)
*Section of route under study

ROLLING STOCK

As mentioned, the #5 & #9 use the same New Flyer E40LFR low-floor trolleybuses. These 12 metre non-articulated electric coaches were delivered between 2006 and 2007. The seating layout, door width, and the method for opening the rear doors were the same through all of these vehicles. The coaches used on the #99 B-Line were varied; however, they had many important characteristics in common. All vehicles used on this route were New Flyer 18 metre articulated low-floor diesel or diesel hybrid buses. The oldest of these vehicles were first used in service in 1998 and have minor differences compared with the newer vehicles built in 2009. Interior layout is similar amongst vehicles with subtle changes in seating layout, wheelchair storage, hand-hold locations and the method for triggering the rear doors to open. Door size was not noticeably different amongst all vehicles. The fare box, fare collection methods and fare structure were the same on every vehicle. While differences in bus type can affect dwell times, it is anticipated that the subtle differences between model years will not have an effect on the dwell times recorded in this study (Fernández et al., 2010; Tirachini, 2011). Although APCs are installed on 15% of TransLink's fleet, 20% of surveying occurred on vehicles with APCs installed[6].

[6] Roughly 30% of runs on the #5 & #9 had APC's installed. APC's only occurred on 6% of #99 runs.

METHODOLOGIES

Vancouver, BC's public transportation system, with instances of severe crowding, provided an idea opportunity to study the effects of crowding and fare payment. Data was collected from April 12th – May 12th, 2012. To best capture the effects of crowding, data was collected on weekdays, predominantly during the morning (7-10am) and afternoon (3-6pm) rush hour periods. After consulting with TransLink, three routes were chosen to survey, one express and two with local service. Routes were chosen that experienced regular crowding and had both origins and destinations throughout the route. Choosing routes with these characteristics ensured large flows of people on and off the bus at many different stops. Data was collected with permission from TransLink and its subsidiary bus operations company, Coast Mountain Bus Company (CMBC). Additional APC and GIS data was provided by TransLink for the routes that were studied.

DATA COLLECTION PROCEDURE

Data was collected with a team of student volunteers onboard CMBC vehicles. Prior to boarding the bus, the weather, temperature, date and recorder's name were documented. Terminus stops are defined as the first and last stops that data collection occurred. As such, dwell times are not accurate because operators are required to wait for scheduled departure times or, if mid route, passenger counts will not correspond to the dwell time. On the #5 and #9 the researchers would enter at the front door and if the bus was occupied with passengers, both researchers would perform a head count. This number would then be recorded as passengers boarded at the front door (D1_Prepay). As this stop is considered a terminus, the data entered will not affect the dwell time model as all termini are removed before analysis. The 99 B-Line, with all-door boarding and lines that form at each door, required each research assistant to approach the front of the line at their respective door to ensure they boarded the vehicle first to get an accurate count of the number of passengers alighting. Clipboards with the TransLink logo on them and official permission letters were used to identify volunteers as researchers working with TransLink. Once on the bus, the time at the beginning of the run, the bus number and gender and the number of years of experience of the driver were recorded. The researcher at the front of the bus spoke with the driver and introduced themselves as a researcher. The permission letter was presented if requested and the driver, advised that there was no requirement to answer, was asked how many years of experience they have. The researcher only interacted with the driver before the run began or after the run competed.

At each subsequent stop, research assistants, equipped with stopwatches, clipboards and data collection sheets (Appendix A), recorded the number of boarding and alighting passengers, dwell time, level of crowding, the accuracy of the entry and any relevant notes. Dwell time at the front door was defined as the time from door opening to door closing. An additional variable, PassServiceTime, was recorded to capture the difference between the time taken to serve passengers and the non-passenger related delays during dwell time (changing operators, waiting at time points, or waiting for red lights, all with their doors open). To capture the true length of the dwell, including the time needed to reach the door from elsewhere in the bus, the method of capturing the middle and rear door dwell times was different. Above each door, a green light signals that the driver has released the door and that they are available to be triggered for opening. Dwell time at these doors was defined as the time from the illumination of the green light to door close.

Crowding at the front door was measured as a qualitative feeling of the level of crowding (proximity of passengers to each other and the ease of movement through vehicle). The crowding variable for the second and third door was defined as the number of people standing in the area near the door (Appendix B). This variable was created in response to previous research that claimed passengers standing near the door inhibited boarding and alighting (Tirachini, 2011). At the end of the run, if at a terminus, final alightings were recorded. If the vehicle was still in transit, total occupancy was determined through a head count and recorded as total alightings. Run end time was also recorded after exiting the transit vehicle. The researchers were always included in the boarding and alighting totals. Data from the collection sheets were then entered into a spreadsheet for analysis.

The #5 and #99 were surveyed in their entirety in both the eastbound and westbound directions. Surveying of the #9 was focused on the Central Broadway section of the route as crowding at the extremities of the line, near Boundary Road and UBC, was not as pronounced as the central section (Figure 2). The surveyed section began at Lakewood Dr. and concluded at Vine St. and included stops at both rapid transit lines and all of the aforementioned major destinations.

Variable Definition

PassServiceTime captured the portion of the dwell that is used by passengers to board or alight. This variable was only recorded when dwells that were longer than a typical dwell occurred. Extra seconds taken at the end of a dwell were not recorded as non-passenger related dwell time. Dwell_Longest is the longest dwell time recorded at any door during a dwell. The difference between Dwell_Longest and PassServiceTime is Dwell_Difference. Dwell_Difference represents the extra dwell time spent at stops that is not due to passenger movements. Total_PAX2[7] is the is the squared terms of passenger movements, the sum of total boardings and alightings at all doors, which, when used in the regression analysis, represents the marginal effects of one additional passenger movement on dwell time. As buses in this study have different maximum capacities, load (occupied capacity) was translated to into percent of occupied capacity as represented by the variable Load_%ofbusCapacity. The squared term of Load_%ofbusCapacity was also used to determine the marginal effects of one additional percent of occupied capacity on dwell time, represented by Load_%ofbusCapacity2. StandPAXInteract was created based on prior research and measures the interaction between boarding and alighting passengers and the number of standees ((Standees^2)*Total_PAX) (Milkovits, 2008). The number of standees was determined by subtracting the total number of people on board from the number of seats on the bus. The remaining variables are described in Table 2.

[7] PAX = Passenger movements, both boardings and alightings at one stop.

TABLE 2: VARIABLE DEFINITION

Variable Name	Description
Route5	A dummy equal to 1 if the trip was on the #5 Robson
Route99	A dummy equal to 1 if the trip was on the #99 B-Line
Westbound	A dummy equal to 1 if the trip was in the westbound direction
Driver_Experience	The number of years of experience the diver has been operating the bus for TransLink
Driver_Gender	A dummy equal to 1 if the drivers gender is female
AM_Peak	A dummy equal to 1 if the trip began during the am peak (6-9am)
PM_Peak	A dummy equal to 1 if the trip began during the pm peak (3-6pm)
Dwell_Difference	Difference between Dwell_Longest and Dwell_Service
Wheelchair_Dummy	A dummy equal to 1 if there was a wheelchair ramp event
Bike_Dummy	A dummy equal to 1 if the bike rack was used
Stroller_Dummy	A dummy equal to 1 if during the dwell, a passenger boarded with a stroller, luggage, or other large bags that prolonged the boarding process
D1_Prepay	Front door, Number of passengers that use a pass that is shown directly to driver
D1_MagneticSwipe	Front door, Number of passengers that use a magnetic pass, verified by fare box
D1_Cash	Front door, Number of passengers that pay cash at fare box, receive Magnetic pass
D1_NoFarePresented	Front door, Number of passengers that enter without presenting fare
D1_ Boarding	Front door, Number of people entering at stop
D1_Alighting	Front door, Number of people exiting at stop
D2_Boarding	Middle door, Number of people entering at stop
D2_Alighting	Middle door, Number of people exiting at stop
D3_Boarding	Rear door, Number of people entering at stop
D3_Alighting	Rear door, Number of people exiting at stop
Total_PAX2	Total boardings and alightings at all doors, squared
Load_%ofbusCapacity	Load expressed as a Percentage of bus capacity
Load_%ofbusCapacity2	Load expressed as a Percentage of bus capacity, squared
Standee_PAX_Interaction	Interaction variable, Standees squared multiplied by total PAX
PassServiceTime	Dwell variable, Only recordsthe proton of the dwell that is used to serve passengers
Dependent Variable	
Dwell_Longest	Longest dwell at any door

DATA CLEANING

Data from the collection sheets was entered in its entirety, regardless of whether dwells or passenger movements had occurred. Data for the dwell time model required extensive cleaning. Stop level data entries were removed where Total_PAX=0 or Dwell_Longest=0. This removed data that did not contain passenger movements or dwell time information. Terminus stops were also removed in this step. Entries were also removed where the recorder labelled the entry as inaccurate. Entire runs were removed where Total_OFFS + Total_ONS > ±10. Finally, to remove the presence of outliers, service time per passenger was calculated by dividing PassServiceTime by Total_PAX. The top 5% of dwells with the largest passenger service time were removed. Through data cleaning, 762 data points were removed leaving a working dataset of 1,764 dwells for the development of the dwell time model. APC data was not used in the cleaning procedure as complete data was not available at the time of this research.

ANALYSIS

Assessing dwell times based on the average time required for a passenger to board or alight shows that there is a distinct difference between crowded and non-crowded conditions and between the different routes analyzed. Dwell time per passenger movement (Dwell_Time/PAX) was determined by dividing PassServiceTime time by the maximum passenger movements, boardings and alightings, at any door. As can be seen in Table 3, crowded conditions, as defined as loads exceeding 70% of bus capacity, show a marked increase in passenger service time of 1.7 second on the #5 and 0.48 seconds on the #9. This result is indicative of a reduction in the efficiency of dwell times during crowded conditions. Conversely, the #99 actually shows a decrease in passenger service time of 0.41 when buses are crowded. This gain in efficiency is likely attributed to all-door boarding where the driver is in control of the doors and may prolong dwells to ensure all boardings and alightings have occurred. During non-crowded times this would leave a few extra second of non-passenger service time that would not have been captured in PassServiceTime. As well, passenger movements through the rear doors are faster and volumes are higher than those at the front. This is likely because boarding and alighting are impeded by a smaller door, narrower access and passengers making fare payment. The large standard deviations are reflective of a wide range of values, particularly where passenger volumes are low and boarding and alighting times are long.

TABLE 3: SUMMARY STATISTICS AT THE STOP LEVEL

	#5 Robson				#9 Broadway				#99 B-Line			
	Non-Crowded		Crowded		Non-Crowded		Crowded		Non-Crowded		Crowded	
Variable	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
D1_Prepay	**1.82**	2.84	**5.38**	9.70	**2.43**	3.92	**5.57**	9.53	**0.85**	1.26	**1.53**	1.93
D1_MagneticSwipe	**0.57**	1.25	**1.23**	2.13	**0.58**	1.22	**0.90**	1.69	**0.36**	0.80	**0.38**	0.74
D1_Cash	**0.22**	0.56	**0.38**	0.96	**0.15**	0.46	**0.07**	0.25	**0.17**	0.48	**0.23**	0.52
D1_NoFarePresented	**0.02**	0.16	**0.00**	0.00	**0.02**	0.15	**0.00**	0.00	**0.01**	0.13	**0.02**	0.15
D1_Alighting	**0.57**	1.07	**0.31**	0.63	**0.66**	1.28	**0.90**	1.32	**0.75**	1.33	**1.26**	1.79
D2_Boarding	**0.00**	0.04	**0.00**	0.00	**0.03**	0.50	**0.10**	0.40	**2.00**	2.30	**5.11**	3.21
D2_Alighting	**2.54**	3.25	**1.62**	2.06	**2.86**	3.83	**2.40**	3.64	**2.93**	3.14	**4.79**	4.76
D3_Boarding	**-**	-	**-**	-	**-**	-	**-**	-	**2.90**	3.08	**7.45**	4.67
D3_Alighting	**-**	-	**-**	-	**-**	-	**-**	-	**3.72**	3.76	**5.98**	5.60
Load_%ofbusCapacity	**24.72**	16.25	**77.31**	4.79	**37.81**	15.20	**74.53**	2.70	**35.71**	16.74	**79.17**	5.81
Dwell_Time/PAX	**3.69**	2.31	**5.35**	2.65	**3.58**	2.25	**4.06**	2.21	**2.18**	1.78	**1.77**	1.95
Number of Dwells	562		13		689		30		423		47	
	Crowded Condition = Load > 70% of Capacity											

DWELL TIME MODEL

Using the longest dwell at any door (Dwell_Longest) in seconds as the dependent variable, two linear regression models were developed (traditional and expanded Model). The variables and associated coefficient, t-statistic and statistical significance are shown in Table 4.

The traditional model uses the non-detailed variables to simulate APC collected information. While the expanded model uses all the collected variables. Comparing these two models will enable us to show the value of obtaining such detailed information about every dwell and the impact of these variables on dwell time. The expanded model explains 86% of the variation in Dwell_Longest using a sample size of 1764 dwells, compared to the traditional model which explains only 58% of the variation. The coefficients in the traditional model follow the expected signs and direction. In general the model is comparable to previous research (Dueker et al., 2004; El-Geneidy & Vijayakumar, 2011). This illustrates the reliability of the collected data in term of its accuracy in predicting dwell time.

The traditional model shows that dwell times begin to increase at 40% of occupied capacity, or, at a passenger load of approximately 31 people for a trolley bus. With a seated passenger capacity of 31 people, it is possible, although unlikely, that there would be no standees. Under the expanded model, the trough occurs sooner at 31%, or 24 people. Both of these models are probable, however, the expanded model is likely more accurate when considering the entire curve. Through to about 60% of occupied capacity, dwell times derived with the expanded model are relatively static. From this point they begin to increase, which is corroborated by previous research (Lin & Wilson, 1992; Milkovits, 2008). The traditional model is less realistic with dwell times that are exaggerated at both the low and high end of bus occupancy.

Moving to the expanded model, dwell times on #5 Robson and #99 B-Line are 0.8 and 3.3 seconds longer, respectively, than those of #9. The doors on the #99 B-line are controlled by the driver to facilitate all-door boarding; operators waiting for passengers to clear the rear doors before closing them could contribute to the longer dwells on the 99. The direction of travel, years of driver experience and driver gender all did not show a statistically significant effect on dwell time in our sample. Dwell times are only marginally faster during the AM and PM peak than during non-peak times. This effect has been attributed to more regular riders using prepaid fare and more directional passenger traffic reducing the mix of boardings and alightings at the same stop (Dueker et al., 2004; El-Geneidy & Vijayakumar, 2011). Delay related variables, wheelchair ramp events, bike rack events and passengers with strollers or other bulky items, show statistically significant increases in dwell time. A wheelchair event adds 38.4 seconds to dwell time which is 24.0 seconds faster than has been previously found (Dueker et al., 2004). This reduction in dwell time is likely attributable to the age of CMBC's fleet of buses. The majority of the buses in the fleet are less than 10 years old and all have low floors, fast ramp actuations and efficient tie down systems, which reduce the time needed to service passengers in wheelchairs.

TABLE 4: DWELL TIME MODEL

	Traditional Model			Expanded Model		
Variable Name	**Coefficient**	**t-stat**	**Stat. Sig.**	**Coefficient**	**t-stat**	**Stat. Sig.**
(Constant)	9.42	7.61	0.00	6.87	9.10	0.00
Route5	-0.10	-0.15	0.88	0.77	1.89	0.06
Route99	0.68	0.69	0.49	3.30	5.60	0.00
Westbound	-0.52	-1.00	0.32	0.08	0.24	0.81
Driver_Experience				0.00	-0.19	0.85
Driver_Gender				-0.34	-0.65	0.52
AM_Peak	-0.40	-0.53	0.60	-0.20	-0.45	0.65
PM_Peak	0.87	1.52	0.13	-0.12	-0.34	0.73
Dwell_Difference				0.91	55.17	0.00
Wheelchair_Dummy				38.48	18.12	0.00
Bike_Dummy				3.85	2.82	0.01
Stroller_Dummy				5.51	4.92	0.00
D1_Prepay				2.23	29.25	0.00
D1_MagneticSwipe				3.03	19.33	0.00
D1_Cash				4.21	13.50	0.00
D1_NoFarePresented				1.57	1.53	0.13
D1_Boarding	3.11	32.81	0.00			
D1_Alighting	1.86	7.78	0.00	1.31	9.18	0.00
D2_Boarding	0.60	2.19	0.03	0.24	1.49	0.14
D2_Alighting	0.97	9.00	0.00	0.64	9.98	0.00
D3_Boarding	1.46	6.72	0.00	0.84	6.51	0.00
D3_Alighting	0.97	5.60	0.00	0.52	5.09	0.00
Total_PAX2	-0.01	-6.93	0.00	-0.01	-4.66	0.00
Load_%ofbusCapacity	-0.18	-3.00	0.00	-0.06	-1.76	0.08
Load_%ofbusCapacity2	0.00	2.35	0.02	0.00	2.34	0.02
Standee_PAX_Interaction	0.00	2.05	0.04	0.00	3.69	0.00
R Squared	0.58			0.86		
N	1764			1764		

a Dependent Variable: Dwell_Longest

As would be expected, boardings, alightings and fare type used at all doors are associated with an increase in dwell time. All passenger movement variables are significant except boardings with no fare at door 1 and boardings at door 2. Passengers boarding with prepaid fare are the fastest to board as they have no interaction with the fare box and only need to show their pass to the driver (2.2s/per passenger). Each passenger using a magnetic swipe ticket adds 3.0 seconds to dwell time, while those using cash add 4.2 seconds while keeping all other variables constant at their mean value. Finally, each passenger who does not pay the fare, even though they do not interact with the fare box or show a pass to the driver, adds 1.6 seconds. This is attributed to these passengers offering an explanation to the operator as to why they cannot pay. It is important to note that throughout this study, less than 0.5% of passengers boarded with no fare.

Passengers alighting at the front door take longer than those alighting through rear doors. A passenger alighting at the front door will extend the dwell by 0.7 seconds more than one alighting through rear door. Crowding and friction around the front door likely create this difference as passengers tend to resist moving to the back of the bus. Additionally, this could also be attributed to the time needed to access the front door. Unlike the rear where passenger can wait directly adjacent to the doors, passengers alighting at the front door are required to wait behind the driver's seat to ensure the driver's sightlines are not obstructed and till other passengers board the bus. A passenger boarding at door 2 adds 0.24 and 0.84 seconds at door 3. Boarding events at the second door occurred in less than ½ percent of all dwells on the #5 and #9 as alighting through the rear door is normally not allowed on either of these routes[8]. Therefore, the effects of this variable can be attributed almost entirely to the 99 B-Line. The effects of boarding and alighting through door 3 are entirely attributed the B-line as it is the only route that uses articulated buses.

As buses in this study have different maximum capacities, the effect of passenger load was determined by using the percent of occupied capacity. The squared term of this variable was also used to determine the marginal effects of one percent greater occupied capacity. A one percent increase in the passenger load of the bus generated a 0.06 second reduction in the dwell time. Meanwhile square term of the bus capacity has a statistically significant positive effect. This indicates that the amount of dwell time will decrease with the increase in passenger load till a certain threshold.

[8] Occasionally a CMBC attendant would check fares at door 2 on the #9 Broadway at Commercial-Broadway Station during the am and pm peak. This only occurred on two runs during the data collection period.

DISCUSSION

TRADITIONAL & EXPANDED DWELL TIME MODELS

Using coefficients derived from Table 4 a sensitivity analysis is conducted for both the extended and traditional model. The coefficients are multiplied by the mean values of each independent variable in the model. Figure 3 shows the output from the first sensitivity analysis for both for both traditional and expanded models while varying the occupancy of the bus and fixing PAX at 5 and 11 passengers per dwell. These passenger movement were chosen based on the average PAX during non-crowded dwells (5) and crowded dwells (11) on the #5 and #9.

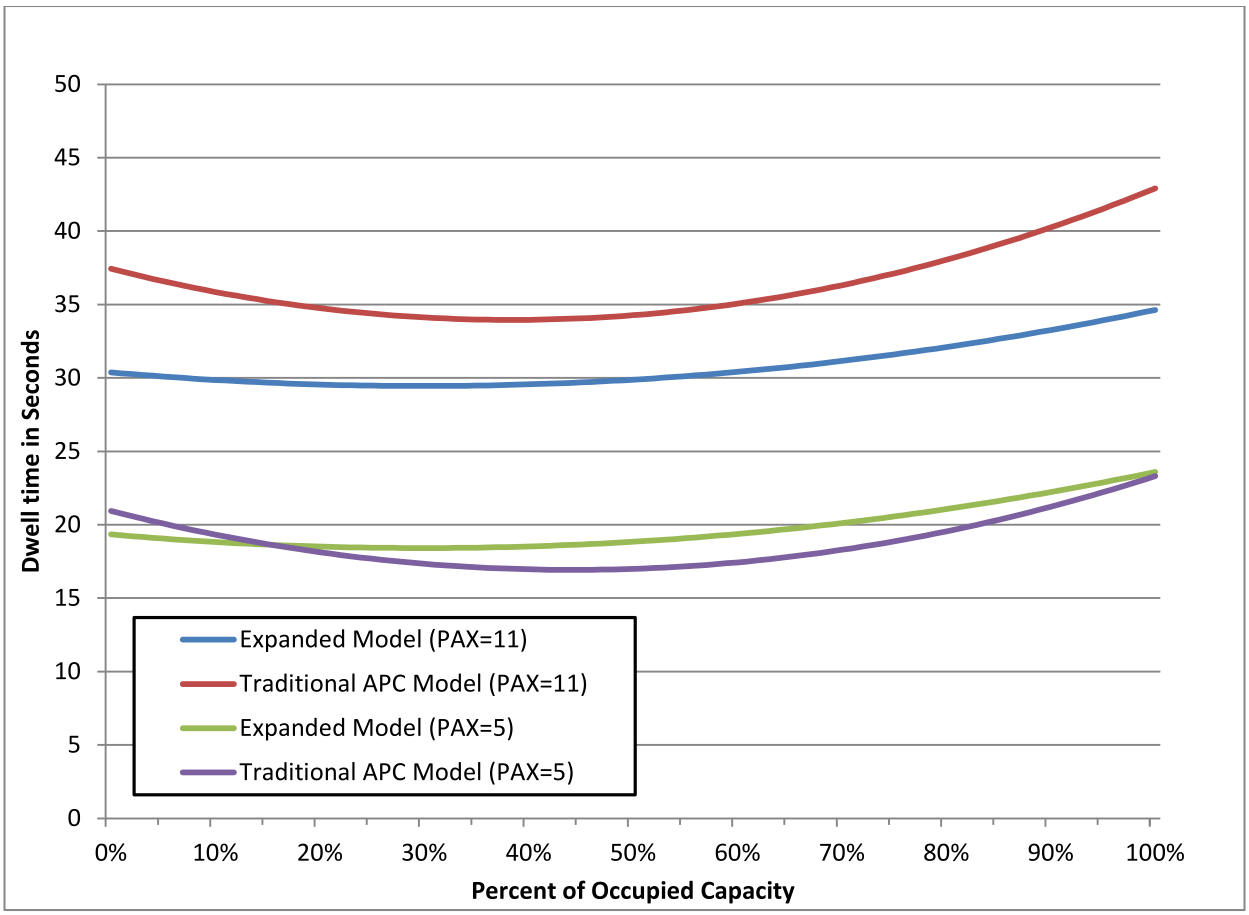


FIGURE 3: COMPARISON OF TWO DWELL TIME MODELS: TRADITIONAL AND EXPANDED AT PAX=11 & PAX=5

As shown in Figure 3, the effect of PAX and payment method is apparent in the relationship between the two sets of curves. At both levels of PAX, the traditional model tends to overestimate dwell times at the lowest levels of bus occupancy. With low PAX, the dwell times predicted by both models are similar. However, as passenger movements and the diversity of payment methods increase, the traditional model begins to overestimate dwell times. This effect is due to the additional passenger boarding detail in the expanded model. The traditional model uses the average boarding time for all fare types and, regardless of payment method, added 3.1 second to the dwell for a passenger boarding at the front door while keeping all other variables constant at their mean value. A passenger boarding with a pass that only needed to be shown to the driver adds only 2.2 seconds to the dwell as seen in the e model. With the majority of passengers using this type of fare media, as PAX increases, the error in the traditional model increases as well.

Dwell times produced using the traditional model are similar at both ends of the curve. The expanded model is different in that the curve is much flatter through to about 50% of capacity. This difference is expected as the variable Dwell_Difference is not included in the traditional model. This variable measures the difference between the time required to service passengers and total dwell time inclusive of non-passenger related delays. Including this variable changes how the variables Load_%ofbusCapacity, Load_%ofbusCapacity2, and StandPAXInteract affect the curve. The majority of these non-passenger related delays occurred where occupied capacity was less than 30%. This helps to explain the difference between the two curves at lower bus occupancy. Non-passenger related service delays are clearly an important component of dwell time that is very difficult to capture with only APC data.

As bus occupancy increases above 50%, both models show an increase in dwell time. Prior research has attempted to define a bus occupancy threshold above which, crowding begins to affect dwell time (Dueker et al., 2004; Lin & Wilson, 1992; Milkovits, 2008). The results of this research suggest that crowding, as it relates to dwell time, occurs at approximately 60% of bus capacity. As can be seen in

Figure 3, dwell time begins to increase dramatically after this point. On a typical Vancouver trolley bus with all seats occupied, this would leave approximately 15 standees. This corroborates observations made during data collection.

The thresholds outlined by TransLink in the Transit Service Guidelines are reasonable based on the data presented here. While all of the thresholds are associated with increases in dwell times, the most pronounced increases occur above 60% of capacity. While not explored in this paper, other factors must also be considered in developing crowding thresholds. For instance, the fiscal efficiency of the route needs to be maintained by ensuring certain metrics are satisfied (total boardings, capacity utilization, etc.). The personal safety and comfort of customers must also be considered when defining these guidelines. The context of the route must also be understood. The #5 and #9 are traverse dense urban areas where crowding may be more tolerable as trips are likely shorter than a suburban route. Whereas passengers on the 99 B-line express, with longer stop spacing, are likely spending more time onboard and are less likely to tolerate crowding.

Passenger Movements, Fare Payment and their Effects on Dwell Time

Passengers boarding and alighting the bus, particularly those paying fare at the front door, have the largest impact on dwell times. Passengers with bikes, strollers, other large items and those in wheelchairs also affect the length of dwells. However, the one regulating force in the efficacy of these movements is the level of occupancy of the vehicle; as the occupied capacity of the vehicle increases, the movement of all passengers on, off and through the vehicle slows down.

To assess the effects of different numbers of passenger movements on dwell time, three passenger movement scenarios based on high, medium, and low PAX averages have been analysed (Figure 4). The high scenario has PAX=36 and is based on the average of dwells where the percent of occupied capacity is greater than 85%. The medium scenario has PAX=13 and is based on the average boarding and alighting activities of dwells that occurred when the bus was at less than 55% of occupied capacity. For comparison, an additional low PAX scenario where only one passenger is boarding with prepaid fare has been added. These Passenger movements are analysed over all ranges of vehicle occupancy. The dwell times are presented as the percent change in dwell time over a baseline dwell of 31% of occupied capacity.

Figure 4 clearly illustrates that the effect of crowding on dwell time is most evident when PAX is low. The dwell time associated with each passenger movement is very high when stopping for few passengers. This is because the constant (door open and close time) and crowding penalty are distributed among very few passengers. Bus stops that serve few passengers are the least efficient and most affected by crowded conditions. With large numbers of passenger movements, people can more easily move through to the exit. Conversely, with a static passenger load, one individual will have much more difficulty moving through the crowd towards the exit.

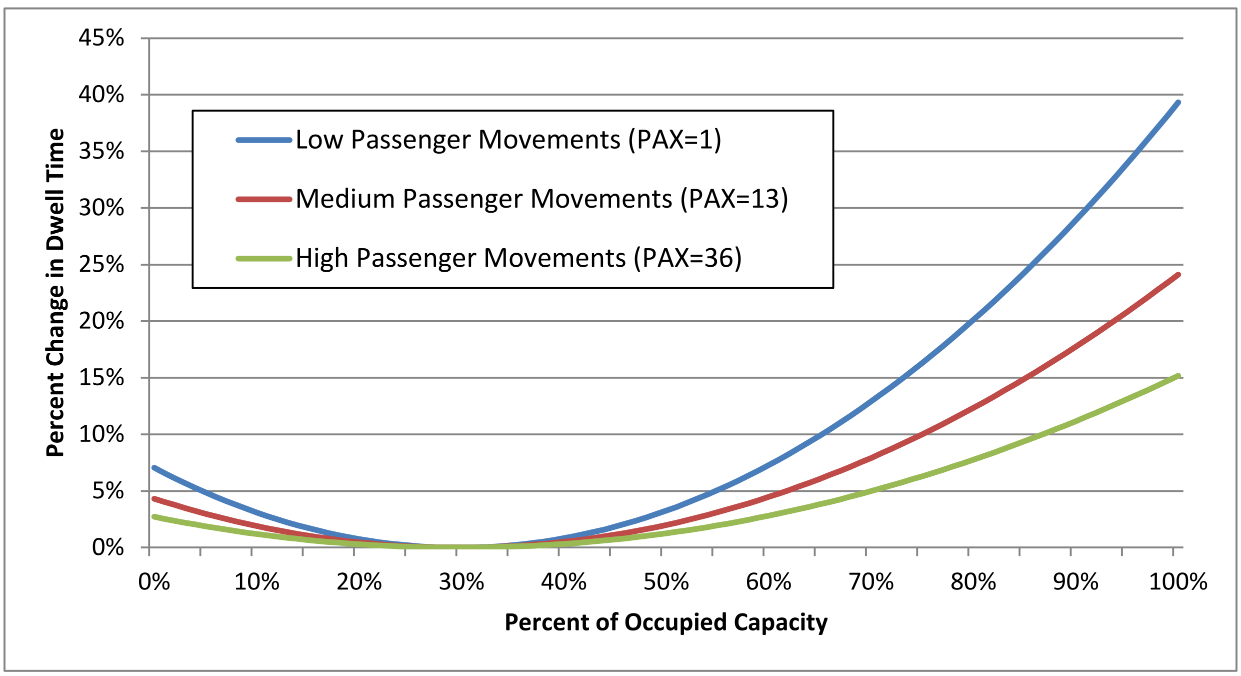


Figure 4: Percent Change in Dwell Times using 31% of Occupied Capacity as a Baseline (#99 B-Line)

Sections of routes that consistently experience crowding (% of occupied capacity>70%) should be examined closely to determine if there are unproductive stops that could be consolidated. Bus stop consolidation usually results in more boardings and alightings, and therefore longer dwells, at the remaining stops (El-Geneidy et al., 2006). As explained, this will result in a much more efficient service over the course of a run. Although stops with high PAX will be most efficient, there is potential to reduce dwell times even further.

Routes that experience regular crowding in excess of 70% of occupied capacity would be well served by allowing all-door boarding at the busiest stops. Boarding and alighting at door 2 and 3 are much faster than through the front doors and will likely save greater than 1 second per passenger that shifts from the front door and boards or alights through one of the rear doors (Dobrovolny, 2009). As experienced during the data collection, this already happens on occasion at Commercial-Broadway SkyTrain station. For safety, a TransLink employee is required to monitor passengers alighting at the rear doors. As such, allowing all-door boarding would be most feasible only at major transit stations where multiple lines converge.

Previous research on the influence of fare type on dwell time have used APC, AVL and automatic fare counting systems to analyse this relationship. Comparing the research presented here to the literature, the most directly comparable variables are the use of a magnetic ticket and cash by a boarding passenger. Researchers have found that using magnetic strip tickets are associated with a 4.9 or 4.6 second increase in dwell time per passenger (Milkovits, 2008; Tirachini, 2011). Cash payment are also comparable and were found to add 5.7 seconds per boarding passenger (Tirachini, 2011). These findings are 1.5 and 1.9 seconds longer than what was discovered in the research presented here. This is likely attributable to the inability of remote sensors to capture the difference between passenger service time and extra dwell time not associated with passenger movements. To deal with this shortcoming, Milkovits (2008) was forced to group non-paying passengers, passengers paying with cash and passengers who's transactions were completed after the dwell had occurred as one group. This was because the data collections systems did not record these details. Atypical passengers were defined as any passenger that took longer than 8 second to board or alight the bus. In the current model, all atypical passengers, including those in wheelchairs, with bikes, or with strollers are included in the model without needing to delineate.

TransLink is currently installing and will be implementing the Compass card, a new fare collection system that includes turnstiles at SkyTrain and SeaBus and new sensors on all buses. The introduction of this electronic fare collection system, set to launch in 2013, will dramatically change dwell times throughout TransLink's system. This contactless system will require passengers to tap onto the system when boarding and tap off again when alighting. From previous research, dwell time will increase by 2.6 seconds for every passenger that uses an electronic fare card while keeping all other variables constant at their mean value (Milkovits, 2008). As with the other coefficients compared to the literature, this one is likely reduced by a similar margin. However, it is very likely that the transaction time will still be higher than simply showing a pass to the driver. Alighting will be greatly affected as the majority of passengers will be required to tap off, adding a transaction time where there formally was none. As the system will require card readers at all doors, one potential strategy to mitigate these longer transaction times would be to allow all-door boarding throughout the system. Future research should use the methodologies outlined in this paper to examine how the implementation of this new fare collection system will affect dwell times.

Interaction Between Passenger Movements and Bus Occupancy

TransLink's Transit service guidelines were used to develop load thresholds to better understand how dwell times are affected by different levels of crowding. These thresholds are approximately 50, 60 and 70% of occupied capacity and are compared to a baseline of 31%, the fastest dwell time predicted by the model. Looking at Figure 3, the #5 Robson, with a passenger load of 50% and PAX=11 will see a dwell time increase of approximately 0.43 seconds. An additional 10% increase in occupied capacity, to 60%, increases dwell time by 1.02 seconds from the base. At the maximum acceptable level of crowding, 70% according to the TSG, dwell time increases by 1.70 seconds. Although loads greater than 70% of capacity are not desirable, a number of runs in this study experienced loads much greater than the 70% threshold. The impact of these loads on dwell time is significant. At 80, 90 and 100% of capacity, dwell times increase by 2.65, 3.81 and 5.18 seconds, respectively. The relationship between dwell time and load shown here corroborates past research that demonstrated that the relationship is non-linear and most evident at the highest levels of crowding (Lin & Wilson, 1992; Milkovits, 2008).

Using the coefficients derived from Table 4, a sensitivity analysis is conducted to predict dwell times for the 99 B-Line traveling westbound with a male driver during the am peak (Table 5). The coefficients are multiplied by the mean values of each independent variable in the model. These estimates are based on two different passenger boarding and alighting scenarios, 13 and 36. Using these two different boarding and alighting scenarios while keeping all other variables constant at their mean, the effect on dwell time is examined at 30, 60 and 90 % of occupied capacity.

TABLE 5: #99 B-LINE, SENSITIVITY ANALYSIS

Variable Name		**PAX=13**			**PAX=36**	
D1_Prepay		1			1	
D1_MagneticSwipe		1			2	
D1_Cash		0			1	
D1_NoFarePresented		0			0	
D1_Alighting		0			0	
D2_Boarding		3			8	
D2_Alighting		2			7	
D3_Boarding		3			6	
D3_Alighting		3			11	
Occupied Capacity of Bus	**30%**	**60%**	**90%**	**30%**	**60%**	**90%**
Dwell time in Seconds	21.5	22.6	27.0	34.1	35.6	42.6
Increase in dwell time attributed to Crowding		1.1	4.4		1.5	7.0
% increase		5%	19%		4%	20%

The first increase in occupied capacity, from 30% to 60%, sees an increase in dwell time of 1.1 seconds for the Medium PAX scenario and 1.5 for high PAX. This represents a 5% change in dwell times. This increase is minor considering the dwell penalty is associated with a doubling of occupancy. However, adding the next 30% in occupied capacity increases dwell time by 4.4 and 7 seconds. This represents a 20% increase in dwell times regardless of the number of passengers boarding and alighting.

According to the results presented here, buses running above the 70% capacity threshold outlined in the Transit Service Guidelines will run much slower than those below this threshold. This is due to two interrelated factors. Buses with heavier loads experience larger flows of people on and off than those with smaller loads. On the #5, dwells with passenger loads greater than 70% saw 40% more passenger movements than dwells below 70%. This is compounded by the increase in dwell time associated with crowding. These two factors serve to prolong dwells and slow the bus along its route. As Lin and Wilson (1992) found, overcrowding turns into a vicious cycle that only exacerbates the crowding problem. This can quickly lead to bunching and severely degraded service throughout the route. This is especially true on routes serviced by trolley buses where it is difficult to pass slow vehicles. On busy, high frequency routes, focus should be in maintaining headways as opposed to adhering to schedules.

While pass-ups are not desirable, they occur throughout the system and may even be advisable when vehicles are heavily loaded and a stop request has not been made. This would serve to reduce bunching, maintain headways and improve reliability. With technological advances and integrated systems, the route number and destination signage on the front and side of the bus could be used to advise passengers of when the next bus will be coming and its approximate load. Other forms of social media could be implemented to alert passengers of crowding and possible pass-ups. Having certainty around the length of the delay and the likelihood of boarding the next bus would help reduce passenger frustration when pass-ups do occur.

CONCLUSION

The purpose of this research was to examine the effects of crowding and fare payment on dwell time. Remotely collected data allows for broad analysis, however, much of the detail during the dwell is lost. The manual data collection methods used in this study allowed for the delineation of dwell times that were passenger related and those that were caused by other events. The type of fare used was also recorded allowing for a more detailed and accurate model regarding front door alightings.

A traditional dwell time model and an expanded model were analysed and compared. While both models showed that as the occupancy of the bus increases, dwell time also increases, the traditional model overestimated dwells especially at high and low levels of bus occupancy. This difference is attributed to the detailed fare payment and dwell time data garnered through manual data collection.

When examining the sensitivity of dwell times to different levels of passenger movements, a clear distinction between different levels of crowding is apparent. Dwell times clearly increase with the number of passenger movements occurring. However, under crowded conditions, the time taken to service passengers at stops with low Passenger movements is far greater than to service those stops with at high passenger movements, on a time per passenger basis. Consolidation of bus stops with low passenger movements on frequently crowded routes is recommended to reduce runtime. Allowing passengers to alight through the rear doors at the busiest stops would also vastly improve dwell times.

Crowding begins to affect dwell time at approximately 60% of occupied capacity. Based on this information, TransLink's Transit Service Guidelines, with their maximum desired occupancy of 70% averaged over the route, appear to strike a good balance between the efficiency of the service and passenger comfort especially on urban routes. It is recommended that the type of route (Regular or express sevice), the context of the route (Urban or Suburban), and the boarding and alighting activities be considered when addressing crowding. As the level of crowding on the bus increases, so do the associated passenger movements during dwells. This serves to dramatically increase dwell times on heavily loaded buses. These crowded buses can affect the headways of vehicles following, especially on high frequency routes serviced by trolley buses that are unable to easily pass a slow vehicle. During periods of crowding, focus should be on maintaining headways instead of adhering to a schedule.

With patronage on public transportation systems increasing across North America, continued investment is needed to accommodate this demand. Planners can find more efficiency through the system which will reduce costs and encourage more ridership. However, without investment, our transit systems will continue to be bogged down with crowding, reducing reliability and customer satisfaction.

REFERENCES

Crowding in Street Cars. (1900, Aug 22). *The Lewiston Daily Sun,* p. 1.

Dobrovolny, J. (2009). All Door Boarding on the 99 B-Line Progress Report. Vancouver, BC: City of Vancouver.

Dobrovolny, J. (2010). TransLink's UBC Line Rapid Transit Study Shortlist of Alternatives. Vancouver, BC: City of Vancouver.

Dobrovolny, J., & Howard, R. (2010). Rapid Transit Principles for the Broadway Corridor and the UBC Line Rapid Transit Study. Vancouver, BC: City of Vancouver.

Dueker, K., Kimpel, T., Strathman, J., & Callas, S. (2004). Determinants of bus dwell time. *Journal of Public Transportation, 7*(1), 21-40.

El-Geneidy, A., Strathman, J., Kimpel, T., & Crout, D. (2006). The effects of bus stop consolidation on passenger activity and transit operations. *Transportation Research Record*(1971), 32-41.

El-Geneidy, A., & Vijayakumar, N. (2011). The effects of articulated buses on dwell and running times. *Journal of Public Transportation, 14*(3), 63.

Fernández, R., Zegers, P., Weber, G., & Tyler, N. (2010). Influence of Platform Height, Door Width, and Fare Collection on Bus Dwell Time. *Transportation Research Record*(2143), 59-66.

Greater Vancouver Transportation Authority. (2004). *Transit Service Guidelines: Technical Report*. Vancouver, BC: TransLink.

Kimpel, T., Strathman, J., Bertini, R., Bender, P., & Callas, S. (2005). Analysis of transit signal priority using archived TriMet bus dispatch system data. *Transportation Research Record*(1925), 156-166.

Kimpel, T., Strathman, J., Griffin, D., Callas, S., & Gerhart, R. (2003). Automatic passenger counter evaluation: Implications for transit database reporting. *Transportation Research Record*(1835), 93-100.

Klitz, P., Nunez, A., & Hyslop, A. (2012). 2011 BSPR Route Summaries 1 to 99. Retrieved from http://www.translink.ca/~/media/Documents/bpotp/managing_the_transit_network/2011%20BSPR%20Route%20Summaries%201%20to%2099.ashx

Levinson, H. (1983). Analyzing transit travel time performance. *Transportation Research Record*(915), 1-6.

Lin, T., & Wilson, N. (1992). Dwell time relationships for light rail systems. *Transportation research record*(1361), 287-295.

Milkovits, M. (2008). Modeling the factors affecting bus stop dwell time: Use of automatic passenger counting, automatic fare counting, and automatic vehicle location data. [10.3141/2072-13]. *Transportation Research Record*(2072), 125-130.

Moore II, J., Giuliano, G., & March, J. (2002). Performance of Automatic Passenger Counters in the Ventura/Lompoc Smart Card Demonstration Project. *Journal of Intelligent Transportation Systems, 7*(2), 131-150.

Rajbhandari, R., Chien, S., & Daniel, J. (2003). Estimation of bus dwell times with automatic passenger counter information. *Transportation research record*(1841), 120-127.

Snyder. (2011). Sampling Tests Automatic Passenger Counters. *The INSIDElane Blog*, from http://www.cumtd.com/the-inside-lane/2011/09/26/sampling-tests-automatic-passenger-counters/

South Coast British Columbia Transit Authority. (2008). *Maximum Number of Passengers Guidelines*. Standards. Policy and Planning. TransLink.

Tirachini, A. (2011). Bus dwell time: the effect of different fare collection systems, bus floor level and age of passengers. *Transportmetrica, DOI:10.1080/18128602.2010.520277*, 1-22.

Transportation Research Board. (2000). Highway Capacity Manual. Washington, DC: National Research Council.

Zografos, K., & Levinson, H. (1986). Passenger service time for a no-fare bus system. *Transportation Research Record*(1051), 42-48.

APPENDIX 1: EXAMPLE DATA COLLECTION SHEET

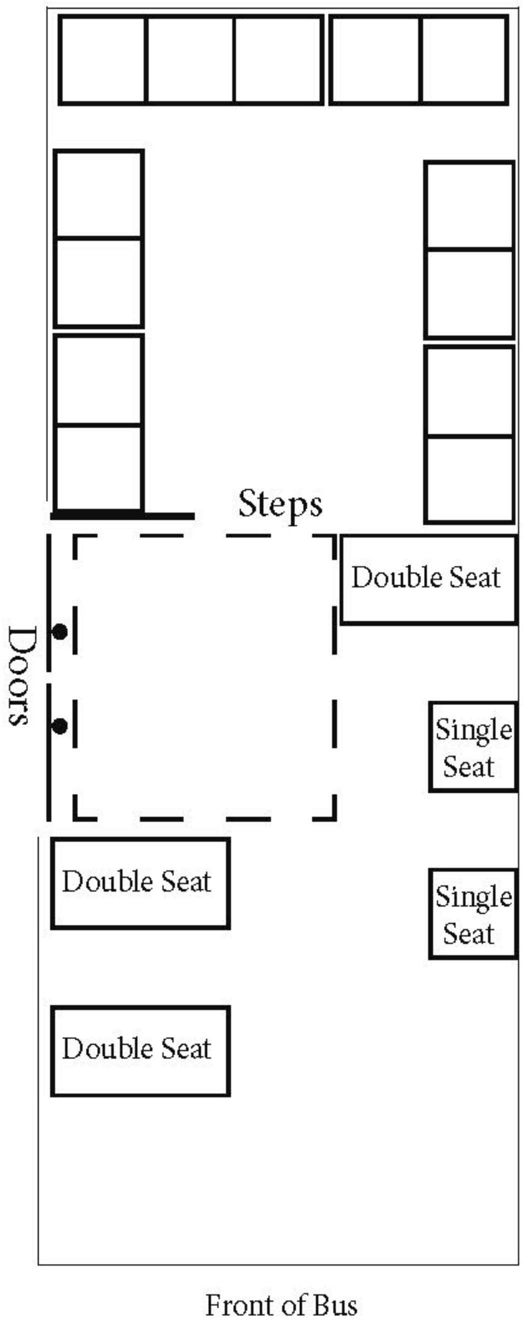
Bus Dwell Time Study DCS# 99EW - F - ____ Name ____________

APC? ______ Driver experience ____ Years Date ____________

Start/End *Scheduled* ______/______ *Actual* ______/______

Stop #	Stop Location	OFFS	ONS	Length of dwell (s)	Crowding? (after stop)	Exceptional Dwell	Accu-rate?	*Monthly/ Pass*	*Magnetic swipe*	*Cash*	*No fare presented*	*Accu-rate?*
50913	WB E BROADWAY AT COMMERCIAL											
50916	WB E BROADWAY AT CLARK DR											
58613	WB E BROADWAY AT FRASER ST											
58500	WB E BROADWAY AT MAIN ST--											
58501	WB W BROADWAY AT CAMBIE ST											
58502	WB W BROADWAY AT WILLOW ST--											
58239	WB W BROADWAY AT GRANVILLE ST-											
61453	WB W BROADWAY AT ARBUTUS ST--											
52095	WB W BROADWAY AT MACDONALD ST											
50357	SB ALMA ST AT W 10 AV											
58023	WB W 10 AV AT SASAMAT ST											
50605	WB UNIVERSITY BLVD AT ALLISON RD											
59265	UBC LOOP BAY 1											
Eastbound Start/End *Scheduled* ______/______ *Actual* ______/______ **Driver experience** ____ **Years** **APC?**______												
59266	UBC LOOP BAY 2											
50268	EB UNIVERSITY BLVD AT ALLISON RD											
50276	EB W 10 AV AT SASAMAT ST											
58037	EB W BROADWAY AT ALMA ST--											
50319	EB W BROADWAY AT MACDONALD ST											
61660	EB W BROADWAY AT ARBUTUS ST-											
58503	EB W BROADWAY AT GRANVILLE ST--											
52099	EB W BROADWAY AT HEATHER ST											
50875	EB W BROADWAY AT CAMBIE ST											
52101	EB E BROADWAY AT MAIN ST											
58614	EB E BROADWAY AT FRASER ST											
58499	EB E BROADWAY AT CLARK DR--											
58491	NB COMMERCIAL DR AT N GRANDVIEW											

<u>APPENDIX 2: CROWDING AREA DEFINED AROUND REAR DOORS</u>



Count people standing in the dashed area but not those that are alighting at the stop. Count the people that could be or are 'in the way'.