The far side story: Measuring the benefits of bus stop location on transit performance

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ABSTRACT

Determining the proper location of bus stops is an important planning decision in the transit planning field. While previous efforts in the literature have suggested several advantages and disadvantages regarding certain bus stop placements, there has been little effort towards understanding the impacts of bus stop location on the transit system performance at the stop level of analysis. This article aims to evaluate the impact of bus stop location on bus stop time and stop time variation. It uses stop-level data collected from the Société de transport de Montréal (STM)'s automatic vehicle location (AVL) and automatic passenger count (APC) systems, in Montréal, Canada. The study findings show that stop times occurring on the near side of intersections are in average 4.2 to 5.0 seconds slower than stop times occurring on the far side of intersections, with no impact on stop time variation. A validation model is utilized to confirm the impacts of bus stop placements on stop time, using data from TriMet's automated bus dispatch system, in Portland, Oregon. This study offers transit planners and policy makers a better understanding of the effects of bus stop location on stop time and its variation in order to improve service quality while minimizing service variation at the stop level.

Keywords: bus service, stop time, stop time variation, AVL/APC, far-side stops, near-side stop

INTRODUCTION

Whether a bus stop should be located at the near side of the intersection or the far side of the intersection has been a source of debate *(1, 2)*. Bus stop placements decisions are made to insure passengers' safety, maintain good quality of service, and avoid conflicts with other vehicles. Transit cooperative research program (TCRP) report 19 presents a detailed discussion of the advantages and disadvantages of bus stop placements options *(3)*.

Many transit agencies tend to locate bus stops at the near side of intersections *(1)*. This is related to the idea that traffic signal design should accommodate buses and bus passengers' activity (e.g. boarding and alighting) *(3)*. However, there has been little effort to investigate bus stop placement impacts on stop time, and on stop time variation. This is an important issue since the effect of bus stop location on service must be considered and integrated by schedulers during various operation stages to add the appropriate amount of recovery time. In addition, as discussed in the literature, passengers are concerned about the day-to-day variability in bus service performance, which affects their decision-making and time-planning processes *(4-6)*. Thus, transit agencies are interested in providing reliable service that is fast and consistent from day to day. Additionally, an increase in service variation can result in the need of adding new buses to maintain the same level of frequency, whereas a reduction in variation can offer the opportunity to obtain additional trips since recovery time added to schedules are reduced.

This paper aims to provide an understanding of the impacts of bus stop location on bus stop time and stop time variation. To achieve this goal, the study uses archived Automatic Vehicle Location (AVL) and Automatic Passenger Counters (APC) system obtained from the Société de transport de Montréal (STM), Canada. Then, a validation model is utilized to confirm the impacts of bus stop placements on bus stop time, using data from TriMet's automated bus dispatch system, in Portland, Oregon. It is important to note that stop time is not the only factor determining where stops should be located, yet understanding the time attributed to stop location is important in evaluating alternative stop locations and design policies. This information can be used to adjust future bus location prior to installation in order to avoid any un-expected delays or earliness among buses or modify some of the existing locations.

LITERATURE REVIEW

Decisions about the location of bus stops are expected to have a major impact on average speeds and reliability of bus transit service *(2, 7)*. In recognition of the importance of bus stop location, TCRP report 19 presents guidelines for placement of bus stops, while discussing the advantages and disadvantages of each location *(3)*. However, it does not provide a quantitative understanding of the stop location impacts on transit system performance. Researchers used simulation models to investigate delays associated with stop locations *(8)*, indicating that far-side stops either causes a very small reduction in delay or has no effect. In contrast, near-side stops often increases delay except when reserved lane can be found. Other researchers investigate the impacts of bus stop location on transit emissions using descriptive statistics *(9)*, or they focus on analyzing the interaction between traffic and bus stops using simulation techniques *(10)*. However, none of the previous efforts have modeled the impacts of stop locations on stop time.

Stop time is the time between bus arrival at a bus stop and bus departure (departure time minus arrival time). Dwell time is a main component of stop time and is defined as door open to door close including passenger activity time *(11, 12)*. As stop time can consume a considerable amount of time due to various reasons *(13)*, improving stop time efficiency is important to reduce the overall service time by passengers, while improving the service reliability and speed *(14)*. Most stop (or dwell) time analyses indicate a strong correlation between stop time and passenger activity time *(14-16)*. Using APC data from New Jersey, Rajbhandari, et al. *(17)* indicate that total number of boardings and alightings has nonlinear impacts on stop time. Later, several researchers confirmed that using passenger activity squared term accounts for this non-linear relationship is sufficient when building stop time models using linear specification *(11, 12, 18)*.

Dueker et al. *(11)* are considered among the first researchers that built a dwell time model based on a large APC/AVL dataset, while isolating the impacts of rare events of lift operation. They found a positive impact of low floor buses and schedule adherence on stop time. Using Automatic Fare Collection (AFC) system and AVL/APC data from Chicago, Milkovits *(19)* modeled stop time based on the number of passengers boarding and alighting, crowding, fare type, and bus design. However, to accurately estimate passenger activity impacts on stop time, the author removed near-side stops from the study dataset, not providing an understanding of the impacts of near-side stops on stop time. El-Geneidy & Vijayakumar *(12)* using AVL/APC data from Montreal, estimated the impacts of articulated buses on service stop time and running time. The operation of articulated buses yield to savings in stop time compared to regular buses due to the existence of bus's third door. The saving further increases with high levels of passenger activity through the third door. While the previous studies provide detailed descriptions of some of the factors impacting stop time, they did not explore the impacts of bus stop location on stop time.

While stop time models are common in the literature, it is rare to find stop time variation models *(20)* because they are more laborious to produce *(21)*. In other words, variation models are not common in the literature *(22-24)*, and when they are provided, they tend to focus only on investigating running time variation by using the coefficient of variation (CV) of running time *(23-25)*. The CV is measured by dividing the standard deviation by the mean value, provides a global measure to understand the bandwidth of the service's variation. Since it is a unit free measure, it is interpreted as percentages *(26)*. Other studies used simple descriptive statistics to understand the impact of various strategies on running time variation *(21, 26)*, without isolating different influential variables' effects on the service. However, none of the aforementioned studies have investigated the impacts of bus stop location on both stop time and stop time variation. Only one recent study has included a variable related to the effects of far-side stops on stop time *(27)*. They indicate that stop times at far-side stops are faster by about 4 seconds. However, the authors failed to account for the difference between the near-side and midblock stops, existence of car turning lanes, and bus reserved lanes. Therefore, to our knowledge, the impacts of bus stop location on stop time and service reliability is rarely discussed in the literature. The availability and accuracy of archived AVL and APC data made it possible to investigate the stop location impacts on stop time and its variation. Using AVL/APC data is common in the transit literature *(24-26, 28)*.

METHODOLOGY

The objective of this analysis is to understand the impacts of bus stop location on bus's stop time and stop time variation at the stop level of analysis. The data used in the analysis come from a sample of STM's AVL and APC archived data system for several heavily used bus routes along the island, namely route 45, 67, 161, 165, 439,467 and 470. These routes are shown in Figure 1. These routes were chosen primary because they experienced no changes on their characteristics in terms of route structure and service planning during the study period, and they do provide a variety in term of route structure and performance. Route 45, 67, 165, 439 and 467 runs north-south serving one metro station at the end of the southern direction, while routes 161 and 470 runs east-west feeding one metro station at the end of the western direction. All routes serve at least one metro station at a midway point except for route 439 and 470. Routes 45, 67, 161 and 165 run for approximately 11.9, 9.5, 11.0 and 7.1 km, offering regular services with an average stop spacing of less than 300 meters, respectively, serving around 40 bus stops per direction. Routes 467, 439 and 470 run for 13.0, 9.4 and 22.4 km offering expresses service with an average stop spacing of over than 600 meters, serving around 20 bus stops per direction. It should be noted that most of bus stop shelter's design is consistent along the route with the existence of side walk area. Table 1 includes a summary of each route characteristics.

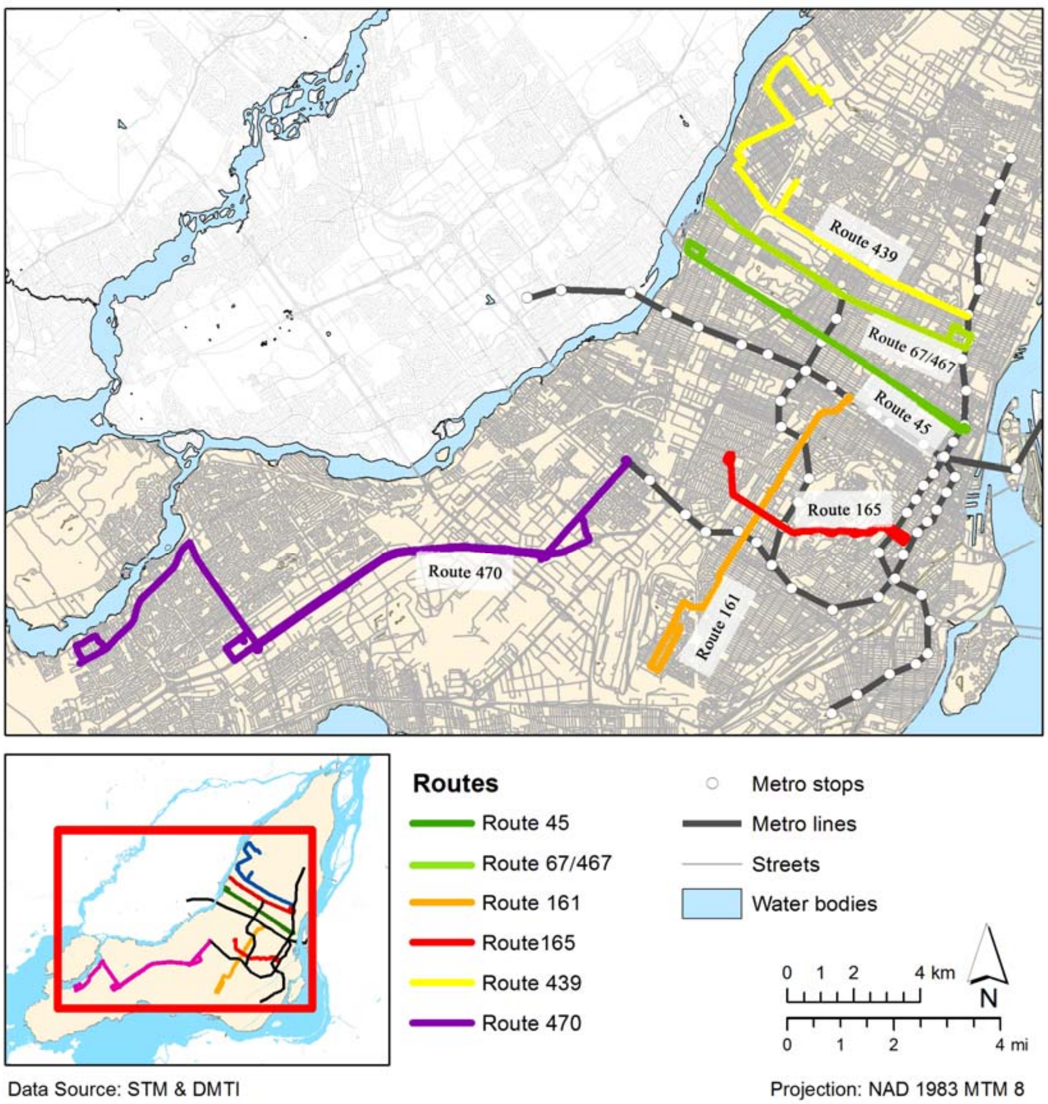

Figure 1: Study bus routes

Table 1: Physical characteristics of studied routes

Route	Dir.	Route length (km)	Running time (min)	Number of stops	Near-side stops	Far-side stops	Mid-block stops	Signalized intersection	Right-turn lane	Stop shelter
45	North	11.2	39.6	43	34	1	8	32	26	18
	South	12.7	41.4	43	37	3	3	37	24	21
67	North	9.2	39.8	38	37	0	1	34	28	19
	South	9.7	40.4	41	37	2	2	36	30	26
161	East	10.3	38.7	44	37	4	3	30	27	12
	West	11.8	42.6	48	44	2	2	32	37	13
165	North	6.6	26.8	31	25	2	4	19	13	8
	South	7.7	35.2	35	26	4	5	23	17	13
439	North	10.8	26.0	19	9	3	7	9	5	3
	South	15.1	41.1	23	15	4	4	15	16	10
467	North	9.1	27.7	16	15	1	0	15	13	9
	South	9.7	33.5	18	17	1	0	17	16	10
470	East	22.3	26.0	24	19	2	1	16	19	17
	West	22.6	24.5	23	17	3	1	14	17	11
Total				446	369	32	41	329	288	190

The data used in this study come from STM's archived AVL/APC systems. Since only about 20% of STM's buses are outfitted with AVL/APC, STM assigns these buses to different routes in order to obtain a sample of the network operational information. AVL/APC data are recorded at the stop level. In addition to trip information, the data include information related to bus arrival time, leave time, schedule, number of passengers on board, and number of passengers boarding and alighting at each stop. Over 800,000 stop observations for all routes were collected from the STM's archival data between January 1st, 2013 and June 1st, 2013. During the data collection period, none of the buses, which data were obtained from, were equipped with an operational transit signal priority (TSP) system. In this paper, two statistical models for stop time and stop time variation are used to measure the effects of bus stop location at the stop level of analysis. After cleaning the source data and removing system recording errors, duplicated records, holiday and weekend trips, layover stops (first and last stops of each trip), stops with no passenger activity (zero boarding and alighting), about 449,170 stop level observations are included in the final database used for the stop time model. Additional information is collected using field observations done in 2013 and shapefiles provided by STM for bus stop location. Using similar cleaning procedures, about 57,000 stop level observations are prepared for a validation model. This data are collected from TriMet's automated bus dispatch system, between February 9th, 2015 and February 13th, 2015. The data come from Route 4 that runs for approximately 39.0 km from the city of Portland to the City of Gresham, serving around 151 bus stops per direction. About 60% of the route's stops are near-side stops, while 10% are mid-block stops, while the rest is far-side (30%).

Since the objective of this analysis is to understand the effect of bus stop location not only on stop time, but also on stop time variation. The previous STM's stop level dataset has been aggregated according to the following criteria: Stop unique id, time of the day (am peak, pm peak, midday, night, and midnight or early morning), type of bus (articulated or regular buses), route number (route 45, 67, 161, 165, 439,467 and 470), and direction (north, south, east or west). For example, all Route 45 northbound stop times done by regular buses at a specific stop (e.g. number 56467) during the afternoon peak, are aggregated into one category in order to understand their stop time range of variation. This is done by calculating the average and standard deviation of stop time for this group of stop times over the study period and then by calculating the coefficient of variation of stop times (CV). The CV of stop time has been calculated by dividing the stop time standard deviation for a group by the group average stop time, and afterwards, multiplying the outcome by one hundred.

It should be noted that to ensure robustness of the generated data, 20 stop times per stop location, time period, bus type, route number, and direction was used as a threshold for a group, which is comparable to previous studies *(24, 29)*. Accordingly, the groups that have 20 stop times or fewer were deleted from the data set. After this process, 1708 groups of stop times are kept for analysis. The included groups in analysis represent more than 98% of all stop observations with an average group size of 260 stop time observations and standard deviation of 192 stop times.

In this research, we will be concentrating on two statistical models to capture and isolate the effects of the stop location on stop time and its variation. The first model is the stop time model. The purpose of the model is to understand the overall quality of data used in this study, to identify its consistency with previous research discussed in literature, and to demonstrate the effects of detailed bus stop location information. The second model is the coefficient of variation (CV) of stop time model, which measures and captures the effect of stop location on stop time variation, while controlling different influential variables.

Table 2 includes a list of variables incorporated in the statistical analysis with a detailed description. Variables squared terms are used to account for non-linear relationship between them and the dependent variable, if such a relationship observed. Other variables have been tested but they were eliminated from the study due to their insignificance such as *route type*, *segment length* and *distance to intersection* and due to correlation to other used variables (with a Pearson coefficient of greater than 0.65) such as *articulated bus* and *bus frequency* variables.

Table 2: Description of variables used in the models

Variable name	Description	Mean	Std. Dev.
Stop time (s)	The time in seconds from when a bus arrives at a bus stop and leaves a bus stop.	26.4	26.9
AM peak	A dummy variable equaling one if the stop time occurred between 6:30 am to 9:30 am and zero otherwise.	0.17	0.37
PM peak	A dummy variable equaling one if the stop time occurred between 3:30 pm and 6:30 pm and zero otherwise.	0.20	0.40
Night	A dummy variable equaling one if the stop time occurred between 6:30 pm to 12:00 am and zero otherwise.	0.22	0.41
Midnight and early morning	A dummy variable equaling one if the stop time occurred between 12:00 am and 6:30 am and zero otherwise.	0.04	0.20
Door 1 boarding	Total number of passengers that boarded at door 1 at a single bus stop during a trip.	2.89	4.78
Door 1 alighting	Total number of passengers that alighted at door 1 at a single bus stop during a trip.	1.28	1.79
Door 2 boarding	Total number of passengers that boarded at door 2 at a single bus stop during a trip.	0.01	0.12

Variable name	Description	Mean	Std. Dev.
Door 2 alighting	Total number of passengers that alighted at door 2 at a single bus stop during a trip.	1.23	2.31
Door 3 boarding	Total number of passengers that boarded at door 3 at a single bus stop during a trip.	0.00	0.09
Door 3 alighting	Total number of passengers that alighted at door 3 at a single bus stop during a trip.	0.69	1.79
Total passenger activity^2	The square of the total number of boardings and alightings at all doors at a stop during a trip.	99.9	386.2
Passenger load	The total number of passengers on a bus at a stop.	25.9	16.9
Friction	The total number of standees plus the sum of the total boarding and alightings at a stop.	8.1	11.3
Delay at the start (s)	The delay at the start of a trip in seconds, which is the difference between the leave time and the scheduled leave time at the first stop of a route.	31.6	120.8
Main stop	A dummy variable equaling one if a bus stop is located at a metro station, main transfer point or at a time point.	0.05	0.21
Main stop boarding	Total number of boardings at a main stop.	0.58	3.62
Main stop alighting	Total number of alighting at a main stop.	0.65	3.82
Wind chill temp (c)	The wind chill temperature in Celsius at the hour of the stop time.	-5.06	8.46
Rainfall (mm)	The amount of rainfall in millimeters on the day of the stop time.	1.05	2.82
Rainfall^2	The square of the amount of rainfall in millimeters on the day of the stop time.	9.02	33.45
Snow on ground (cm)	The amount of snow on the ground in centimeters on the day of the stop time.	5.45	8.99
Snow on ground^2	The square of the amount of snow on the ground in centimeters on the day of the stop time.	110.5	245.6
Near-side stop	A dummy variable equaling one if the bus stop is on the near side of an intersection.	0.89	0.30
Midblock stop	A dummy variable equaling one if the bus stop is within a block.	0.05	0.21
Right-turn lane	A dummy variable equaling one if the bus stop is at an intersection that includes a right-turn lane for cars.	0.68	0.46
Signalized intersection	A dummy variable equaling one if the bus stop is at a traffic light.	0.84	0.36
Reserved lanes in operation	A dummy variable equaling one for stop times occurred during the operation of bus reserved lanes.	0.09	0.28
Car private/public entrance	A dummy variable equaling one if the bus stop is located immediately before or after a car private or public entrance, such as hospital or gas station entrances.	0.23	0.42
Stop Shelter	A dummy variable equaling one if the bus stop includes a bus shelter for passengers and zero otherwise.	0.49	0.50
More than one route	A dummy variable equaling one if more than one bus route are serving the same bus stop.	0.57	0.50
Inbound	A dummy variable for inbound trips.	0.47	0.50
Route 45	A dummy variable equaling one if the stop time occurs on Route 45.	0.15	0.36
Route 67	A dummy variable equaling one if the stop time occurs on Route 67.	0.24	0.43
Route 161	A dummy variable equaling one if the stop time occurs on Route 161.	0.20	0.40
Route 165	A dummy variable equaling one if the stop time occurs on Route 165.	0.22	0.41
Route 439	A dummy variable equaling one if the stop time occurs on Route 467.	0.03	0.15
Route 467	A dummy variable equaling one if the stop time occurs on Route 467.	0.07	0.25

Variable name	Description	Mean	Std. Dev.
Route 470	A dummy variable equaling one if the stop time occurs on Route 470.	0.11	0.31
CV stop time	The coefficient of variation of stop time in percentage at a stop.	72.61	19.06
CV Door 1 boarding	The coefficient of variation of the total boardings at door 1 at a single bus stop over the study period in percentage.	137.3	125.8
CV Door 1 alighting	The coefficient of variation of the total alightings at door 1 at a single bus stop over the study period in percentage.	151.1	121.2
CV Door 2 boarding	The coefficient of variation of the total boardings at door 2 at a single bus stop over the study period in percentage.	568.2	707.4
CV Door 2 alighting	The coefficient of variation of the total alightings at door 2 at a single bus stop over the study period in percentage.	205.9	222.2
CV Door 3 boarding	The coefficient of variation of the total boardings at door 3 at a single bus stop over the study period in percentage.	436.15	635.51
CV Door 3 alighting	The coefficient of variation of the total alightings at door 3 at a single bus stop over the study period in percentage.	160.4	221.4
CV total passenger activity^2	The coefficient of variation of the total number of boardings and alightings squared term at all doors at a stop in percentage.	151.6	97.3
CV passenger load	The coefficient of variation of the total number of passengers on bus at a stop in percentage.	48.8	20.8
CV Friction	The coefficient of variation of passenger friction factor at a stop in percentage.	88.9	32.4
CV Delay at start	The coefficient of variation of the trip delay at start in percentage.	194.9	4333
CV main stop boarding	The coefficient of variation of the total number of boardings at a main stop in percentage.	3.02	20.2
CV main stop alighting	The coefficient of variation of the total number of alightings at a main stop in percentage.	2.16	11.7
CV Wind chill temp	The coefficient of variation of wind chill temperature in percentage.	-165.6	28.6
CV Rainfall	The coefficient of variation of the amount of rainfall in percentage.	272.0	42.3
CV Snow on ground	The coefficient of variation of the amount of snow on the ground in percentage.	166.3	25.23
Validation Model			
Lift	Total number of lift operations at a single bus stop during a trip.	0.02	0.16
Total boarding	Total number of passengers boarding a single bus stop during a trip.	1.56	2.32
Total alighting	Total number of passengers alighting a single bus stop during a trip.	1.52	2.21
Bus bay area	A dummy variable equaling one if the bus stop has bay area to facilitate traffic movement.	0.06	0.23
City of Portland TSP	A dummy variable equaling one if the bus stop is at a traffic light in the city of Portland. All traffic lights at the City of Portland are equipped with transit signal priority system (TSP). When equal 1, the variable compares the traffic lights in the City of Portland to the City of Gersham.	0.41	0.49

ANALYSIS

STOP TIME MODEL

A linear regression model is developed using stop time (departure time minus arrival time) in seconds as the dependent variable. The output of this model is reported in Table 3. The model contains 449,170 stop observations and explains 51% of the variation in stop time. This proportion of explained variance is considered relatively high *(11, 12)*.

Regarding the key policy variables, stop times occurred on the near side of intersections is slower by 5.0 seconds compared to stop times occurred on the far side of intersections. Midblock stop times are slower by 6.5 seconds compared to far-side ones. This may be understood due to a few reasons. Far-side stops minimize conflicts between turning and stopping vehicles and buses, and it results in bus drivers being able to take advantage of the gaps in traffic flow that are created at intersections to move faster from the stops. It also encourages pedestrians to cross behind the bus, thus avoiding blocking the right of way for buses, particularly for passengers upon leaving the bus. Finally, it reduces visibility conflicts for street-crossing pedestrians who may stop in the front of the bus to observe parallel traffic in case of midblock stop *(3)*.

The presence of right-turn lane for cars at near-side stops increases stop times by 3.0 seconds. This can be interpreted to the effects of the cue of cars in front of the buses since cars are allowed to use the bus space on the far right-lane to turn right. Therefore, buses sometime stop before their assigned space to serve passengers, requiring them to walk from the bus stop to the new bus location for boarding. Accordingly, a typical near-side stop with a right-turn lane for cars is expected to increase the stop time by 8.0 seconds compared to far-side stops.

Stop times located at traffic lights are about 9.2 seconds slower compared to other mid-block stops or other non-signalized stops. This can be understood by the fact that buses are required to stop more even with no boardings and alightings until the signal turns to green light, also absence of signal priority in Montreal can be a reason for such high impact. Reserved lanes are found to have a positive effect on stop time, decreasing it by 1.4 seconds. This indicates that buses using reserved lanes are gaining time (in terms of stop time) in comparison to other buses. This last result may be due to the presence of less traffic and the ability to approach and move faster from the stops. *Car private /public entrance* variable, that has been used as a proxy of land use located immediately next to the bus stop, shows statistically significant impact on stop time, decreasing it by 1.6 seconds. This may be caused by the bus drivers' tendency to move faster at these stops so as not to block those entrances.

Stop shelters have a statistically significant impact on stop time, increasing it by 1.2 seconds compared to stops without shelters. This is expected and observed since passengers tend to wait immediately at the bus stop sign (were the bus stops are) when there is no shelter, whereas they wait inside or nearby the shelter when there is one. This adds a few seconds since passengers start moving from the shelter to the bus only when it arrives or show up. Finally, stop times at bus stops served by more than one bus routes are expected to be slightly shorter by 1.1 seconds. This may be related to bus driver's behavior since they may tend to clear the stop for other buses as fast as they can.

For the remaining control variables in model they appear to be consistent with previous studies and following the expected direction and significance *(11, 30)*. Boarding from the bus's first door adds 3.3 seconds to stop time due to the fare collection procedures. Boarding at the second and third doors only adds 3.0 and 2.1 seconds, respectively. Boarding at these doors is a rare event and only take place when the bus is overcrowded.

Passenger alighting at the first door adds 1.9 seconds to stop time, while alighting at the second and third door only add 1.1 and 0.5 seconds to stop time, respectively. Therefore, it is clear that the usage of the second and third doors lead to a decline in the contribution of each alighting passenger to the total stop time. As a result, transit agencies using similar bus layout (all STM's buses include single-channel doors with no possibility for bypassing passengers), should encourage the usage of second and third doors for alighting to decrease stop time.

Passenger activity squared term indicates that each additional passenger adds less time to overall stop time compared to the passenger ahead of him *(11, 12, 18)*. Passenger load decreases stop time by 0.1 seconds for every additional passenger, while the passenger friction factor, which is used to account for passenger activity on overcrowded buses with standees, increases stop time by 0.15 seconds for every additional passenger. Therefore, heavily loaded buses are expected to have greater stop times *(11, 12)*. Buses starting late compared to schedules are generally faster. This is because bus drivers would try to compensate for the delay that they have from the start. Stop time decreases by 0.003 seconds for every second of delay at the beginning of the route.

With regard to meteorological factors, wind chill temperature, rain and snow on the ground showed statistical significance, yet to a small degree. Temperature increases stop time by 0.01 seconds for every additional degree. For every millimeter of rainfall, stop time increases by 0.12 seconds, but each additional millimeter is estimated to decrease it by 0.01 seconds. Every centimeter of snow on the ground decreases stop time by 0.06 seconds, but each additional centimeter increases it by 0.01 seconds. Time-of-day has a statistically significant effect on stop time. Comparing to off peak period, stop times taking place during the morning peak, afternoon peak, night and late night and early morning are generally faster *(11)*.

Route number and direction also affects stop time. This may be because of traffic condition and scheduling, which can be found in pervious stop time models done in the literature *(11, 12, 18)*. Stops that are at main (or metro) stations are about 18 seconds slower than other stops. This because that these stops are most probably used as holding points along the system. Therefore, boarding and alighting at these stops were isolated using two variables. Boarding at these stops tends to be slightly slower by 0.14 seconds per passenger than other non-main stops, while alighting tends to be lightly faster by 0.4 seconds. This is may be due to the extra time provided for boarding (as a result of bus holding) and due to the increased alighting efficiency that comes with the larger volumes of people at these stops *(18, 27)*.

Table 3: Stop time model

Variable	Coefficients		*t*-stat	95% Conf. Interval	
Constant	**-1.03**	***	**-6.15**	**-1.36**	**-0.70**
AM peak	**-1.83**	***	**-20.38**	**-2.01**	**-1.65**
PM peak	**-0.28**	***	**-3.08**	**-0.45**	**-0.10**
Night	**-2.10**	***	**-27.24**	**-2.25**	**-1.95**
Midnight and early morning	**-3.64**	***	**-24.40**	**-3.93**	**-3.34**
Door 1 boarding	**3.31**	***	**272.86**	**3.28**	**3.33**
Door 1 alighting	**1.90**	***	**88.15**	**1.86**	**1.94**
Door 2 boarding	**3.04**	***	**12.37**	**2.55**	**3.52**
Door 2 alighting	**1.12**	***	**53.28**	**1.08**	**1.16**
Door 3 boarding	**2.14**	***	**6.54**	**1.50**	**2.78**
Door 3 alighting	**0.52**	***	**21.81**	**0.47**	**0.57**
Total passenger activity^2	**-0.01**	***	**-47.17**	**-0.01**	**-0.01**
Passenger load	**-0.11**	***	**-39.86**	**-0.12**	**-0.11**
Friction	**0.15**	***	**22.21**	**0.13**	**0.16**
Delay at the start (s)	**-0.01**	***	**-14.03**	**-0.01**	**0.00**
Main stop	**18.99**	***	**59.19**	**18.36**	**19.62**
Main stop boarding	**0.13**	***	**7.16**	**0.10**	**0.17**
Main stop alighting	**-0.44**	***	**-23.58**	**-0.47**	**-0.40**
Wind chill temperature	**0.01**	**	**2.44**	**0.00**	**0.02**
Rainfall (mm)	**0.12**	***	**3.55**	**0.05**	**0.19**
Rainfall^2	**-0.01**	***	**-4.79**	**-0.02**	**-0.01**
Snow on ground (cm)	**-0.06**	***	**-5.15**	**-0.09**	**-0.04**
Snow on ground^2	**0.01**	***	**4.89**	**0.01**	**0.00**
Near-side	**5.01**	***	**36.51**	**4.74**	**5.28**
Right-turn lane	**2.96**	***	**39.28**	**2.82**	**3.11**
Signalized intersection	**9.24**	***	**95.23**	**9.05**	**9.43**
Midblock stop	**6.77**	***	**34.96**	**6.39**	**7.15**
Bus reserved lanes in operation	**-1.38**	***	**-11.68**	**-1.61**	**-1.15**
Car private/public Entrance	**-1.69**	***	**-23.29**	**-1.83**	**-1.54**
Stop Shelter	**1.16**	***	**18.50**	**1.04**	**1.28**
More than one route	**-1.14**	***	**-12.98**	**-1.31**	**-0.97**
Inbound	**-0.41**	***	**-6.75**	**-0.52**	**-0.29**
Route 45	**3.56**	***	**34.17**	**3.36**	**3.77**
Route 67	**4.77**	***	**42.39**	**4.55**	**4.99**
Route 165	**5.87**	***	**46.39**	**5.62**	**6.11**
Route 439	**3.02**	***	**13.83**	**2.59**	**3.45**
Route 467	**6.94**	***	**43.48**	**6.62**	**7.25**
Route 470	**-2.11**	***	**-14.82**	**-2.39**	**-1.83**
N			449,170		
R2			0.51		
F statistics			(37, 449169) 12,563		
F significance (Prob > F)			0.00		

Bold indicates statistical significance
*** Significant at 99% ** Significant at 95% * Significant at 90%

CV STOP TIME MODEL

The second linear regression model is developed for the aggregated grouped stop times. The model uses the coefficient of variation (CV) of stop time in percentage as the dependent variable. Table 4 presents the results of this model. The CV stop time model contains 1708 stop times grouped records and explains 21% of the variation in the stop time variation. Although it is rare to find stop time variation models in the literature, the proportion of explained variance is comparable to other variation models *(25)*. In addition, the F-Test results showed that the F significance is almost equal to zero. Therefore, we rejected the null hypothesis with extremely high confidence above 99.99%, and we conclude that the independent variables as a set have a relationship with the dependent variable.

Regarding the key policy variables, the model indicates that stop times taking place on the near side of intersections or on midblock stops has no significant impacts on stop time variation compared to far-side stop times. This indicates that the expected stop time variation at these three bus stops placements is almost similar. Nevertheless, the existence of right-turn lane at near-side stops has a statistically significant impact on stop time variation, decreasing it by 3.0%. Accordingly, at a typical bus near-side with a right-turn lane for cars, while stop time is expected to increase by 8.0 seconds (as indicated by the first model), stop time variation decreases by 3% compared to far-side stops. In other words, stop times taking on near-side stops with right-turn lane are consistently slower than other stop times.

The existence of traffic light has a statistically significant impact on stop time variation, increasing variability in stop time by 9% compared to other mid-block stops or stops at stop signs, making schedulers' task of minimizing variation along the bus corridor more difficult. This variance can be understood due to the mismatch between signal timing and passenger activity time. For example, passengers may start boarding when the traffic light is green and finish when it is red at one incident, while it can be the other way around at the following incident. Car entrances showed statistical significance impact on stop time variation, increasing it by 3.8%. In other words, while car entrances at bus stops decrease stop time by 1.7 seconds, it increases variability in stop time by 3.8%. Therefore, allocation of bus stops near to car private or public entrances is not recommended due to the increases in stop time variation.

Regarding the remaining control variables, the variance in the number of passenger boarding from the bus's first door has a statistically significant effect, increasing stop time variation by 0.011% for every 1% increase in the variability of boardings. Boarding from the second door and third door is expected to slightly decrease stop time variation by 0.003% and 0.001% for every 1% increase in the variability of the number of boarding passengers, respectively. This is can be understood since boarding from the second and third doors is a rare event and only happens when the bus is overloaded.

Every 1% increase in the variability of the alighting from the first door adds about 0.016% in stop time CV. Meanwhile, alighting from the bus's second and third doors increases stop time variation by only 0.008 % and 0.005 % for every 1% increase in the variability of the number of alighting passengers, respectively. This means that alighting from the first door adds more variance to the stop time than boarding or alighting from any other door. Therefore, transit agencies should discourage using the first door for alighting since it increases the stop time and, significantly, its variation by more than a double and triple the amount compared to the alighting from the second and third doors, respectively.

Every 1% increase in the variability of the total passengers' activity squared term adds 0.016% in stop time CV, while keeping all other variables constant at their mean values. This means that while each additional passenger while it adds less time to overall stop time, it increases stop time variation compared to the passenger ahead of him. Variance in passenger friction factor increases buses stop time variation by 0.08% for every 1% increase in friction variance. This indicates that overcrowded buses with standees are expected to increase variability in stop time, decreasing the attractiveness of the service. This requires schedulers to deal overloaded buses with more attention in order to improve the service reliability.

Variance in rainfall precipitation increases buses stop time variation by 0.026% for every 1% increase in rainfall variance. Afternoon peak, night time, and midnight and early morning stop times experience more variability than midday stop times by 5.3%, 4.1% and 5.1 %, respectively, indicating that while they are faster, they have higher levels of variability over time. Route number and direction also affects stop time variation. This could be explained by traffic conditions and scheduling. Bus stops that are at metro stations decreases variability in stop time by 15.2% compared to other stops. This indicates that theses stop times are consistently slower than other stop times. This is expected since these stops are most probably used as holding points along the routes. Boarding at these stops increases stop time variation by 0.06% for every 1% increase in number of boarding passengers. This indicates that boarding at metro stops tends to be slightly slower and causing more variance than other non-main stops. Finally, while *Bus reserved lanes in operation, Stop Shelter, and More than one route* variables have a significant coefficient affecting the average stop time (first model), they have no significant effect on stop time variation. This indicates that these variables' influences are limited to the mean value of stop time changes, with neutral effects on variation.

Table 4: CV Stop time model

Variable	Coefficients	*t*-stat	95% Conf. Interval	
Constant	**39.29** ***	**5.66**	**25.67**	**52.91**
AM peak	2.620	1.50	-0.81	6.05
PM peak	**5.364** ***	**3.73**	**2.54**	**8.19**
Night	**4.149** ***	**2.85**	**1.29**	**7.01**
Midnight and early morning	**5.179** **	**2.46**	**1.05**	**9.30**
CV Door 1 boarding	**0.011** ***	**2.65**	**0.00**	**0.02**
CV Door 1 alighting	**0.016** ***	**3.20**	**0.01**	**0.03**
CV Door 2 boarding	**-0.001** **	**-2.13**	**0.00**	**0.00**
CV Door 2 alighting	**0.008** ***	**3.31**	**0.00**	**0.01**
CV Door 3 boarding	**-0.003** ***	**-4.01**	**-0.01**	**0.00**
CV Door 3 alighting	**0.005** *	**1.77**	**0.00**	**0.01**
CV total passenger activity^2	**0.016** ***	**3.40**	**0.01**	**0.03**
CV passenger load	0.022	0.95	-0.02	0.07
CV Friction	**0.079** ***	**5.17**	**0.05**	**0.11**
CV Delay at start	0.000	-0.66	0.00	0.00
Main stop	**-15.36** *	**-1.84**	**-31.74**	**1.02**
CV main stop boarding	**0.061** **	**1.96**	**0.00**	**0.13**
CV main stop alighting	0.118	0.97	-0.12	0.36
CV Wind chill temperature	-0.046	-1.52	-0.11	0.01
CV Rainfall	**0.026** **	**1.98**	**0.00**	**0.05**
CV Snow on ground	-0.019	-0.64	-0.08	0.04
Near-side	0.042	0.02	-4.01	4.09

Right-turn lane	**-2.948** ***	**-2.66**	**-5.13**	**-0.77**
Signalized intersection	**9.102** ***	**6.64**	**6.41**	**11.79**
Midblock stop	2.488	0.88	-3.05	8.02
Bus reserved lanes in operation	1.094	0.65	-2.23	4.42
Car private/public Entrance	**3.828** ***	**3.55**	**1.71**	**5.94**
Stop Shelter	-0.621	-0.66	-2.45	1.21
More than one route	-1.069	-0.80	-3.69	1.55
Inbound	**-2.128** **	**-2.26**	**-3.97**	**-0.28**
Route 45	**-2.978** *	**-1.68**	**-6.46**	**0.50**
Route 67	1.584	0.76	-2.52	5.69
Route 165	**-5.053** **	**-2.28**	**-9.40**	**-0.71**
Route 439	-0.610	-0.20	-6.65	5.43
Route 467	**-5.219** **	**-2.01**	**-10.32**	**-0.12**
Route 470	**8.868** ***	**3.60**	**4.04**	**13.69**
N		1708		
R2		0.21		
F statistics		(35, 1707) 12.4		
F significance (Prob > F)		0.00		

Bold indicate statistical significance
*** Significant at 99% ** Significant at 95% * Significant at 90%

VALIDATION MODEL

In order to validate the pervious results that indicate a significant impact of bus stop placement on stopping time (first model), a linear regression model is utilized analyzing data from TriMet's automated bus dispatch system, in Portland, Oregon. Table 5 presents the results of this model. The coefficients generally follow the variables of the first model in terms of sign and magnitude, and they are consistent with previous studies *(11, 12, 18)*. Regarding the key policy variables, stop times occurred on the near side of intersections is slower by 4.2 seconds compared to stop times occurred on the far side of intersections. Midblock stop times are slower by 0.9 seconds compared to far-side ones. This direction of impact is consistent with the previous model's results, with different magnitude, which may be related to drivers' behavior, different congestion levels between the two cities, as well as due to Montreal's no turn on red policy which affects the cue of cars in front of the bus.

The presence of right-turn lane for cars at near-side stops increases stop time by 2.1 seconds. Stop times at traffic lights are about 7.2 seconds slower compared to other mid-block stops or other non-signalized stops in the City of Portland (by adding the results of *Signalized intersection* and *City of Portland TSP* variables), while they are slower by 3.3 seconds at the city of Gresham. This is may be due to the nature of land use and traffic timing at each city. Bus reserved lanes in operation have no significant impacts on stop time, while *Car private/public entrance, and more than one route* have a different impact on stop time compared to the first model. This may be explained by drivers' training and practice. Bus bay areas increase stop times by 2.9 seconds. Finally, stop shelters increase stop time by 2.8 seconds compared to stops without shelters, which is consistent with the first model.

Table 5: Validation model

Variable	Coefficients	*t*-stat	95% Conf. Interval		*Mean*	*Std. Dev.*
Constant	**11.78 *****	**39.22**	**11.19**	**12.37**		
AM peak	**-2.96 *****	**-11.75**	**-3.45**	**-2.47**	0.19	0.40
PM peak	**-1.10 *****	**-4.56**	**-1.57**	**-0.63**	0.23	0.42
Night	**-1.82 *****	**-7.42**	**-2.31**	**-1.34**	0.22	0.41
Midnight and early morning	**-2.59 *****	**-5.43**	**-3.52**	**-1.65**	0.04	0.19
Total boarding	**4.47 *****	**69.13**	**4.35**	**4.60**	1.56	2.32
Total alighting	**2.37 *****	**35.66**	**2.24**	**2.50**	1.52	2.21
Total passenger activity^2	**-0.02 *****	**-8.84**	**-0.03**	**-0.02**	21.17	70.33
Lift	**36.23 *****	**65.29**	**35.14**	**37.31**	0.02	0.16
Passenger load	**-0.08 *****	**-9.03**	**-0.09**	**-0.06**	15.03	12.12
Friction	**0.05 *****	**5.05**	**0.03**	**0.07**	1.75	9.38
Delay at the start (s)	**-0.01 *****	**-5.14**	**0.00**	**0.01**	104.9	194.5
Main stop	**16.00 *****	**20.00**	**14.43**	**17.57**	0.04	0.20
Main stop boarding	**-0.43 *****	**-4.10**	**-0.63**	**-0.22**	0.16	1.25
Main stop alighting	**-0.39 *****	**-3.48**	**-0.61**	**-0.17**	0.18	1.24
Near-side	**4.24 *****	**21.50**	**3.85**	**4.62**	0.57	0.50
Right-turn lane	**2.09 *****	**6.01**	**1.41**	**2.77**	0.08	0.28
Signalized intersection	**3.27 *****	**6.45**	**2.28**	**4.27**	0.44	0.50
Midblock stop	**0.85 *****	**2.62**	**0.21**	**1.49**	0.11	0.31
Bus reserved lanes in operation	0.41	1.36	-0.18	1.01	0.12	0.32
Car private/public Entrance	**1.02 *****	**4.34**	**0.56**	**1.48**	0.17	0.38
Stop Shelter	**2.77 *****	**13.81**	**2.38**	**3.17**	0.42	0.49
More than one route	**0.98 *****	**4.74**	**0.58**	**1.39**	0.31	0.46
Inbound	-0.07	-0.36	-0.43	0.30	0.50	0.50
Bus bay area	**2.87 *****	**6.86**	**2.05**	**3.69**	0.06	0.23
City of Portland TSP	**3.97 *****	**7.70**	**2.96**	**4.98**	0.41	0.49
N			56,995			
R2			0.38			
F statistics			(25, 56995) 1372			
F significance (Prob > F)			0.00			

Bold indicates statistical significance
*** Significant at 99% ** Significant at 95% * Significant at 90%

CONCLUSION

The main objective of this article is to understand the impact of bus stop location on buses' stop time and stop time variation. It analyzes archived data obtained from STM's AVL and APC systems for several routes along the system, using two statistical models. The first model was for disaggregated stop time observations, investigating the impacts of stop location on the stop time. The second model was for the aggregated grouped stop times at the stop level, examining the impacts of bus stop location on stop time variation. Afterwards, the paper uses TriMet's dispatch system data to validate the results.

At the stop level of analysis, stop times located at the near side of an intersection are between 4.2 to 5 seconds slower than far-side stops, with no impact on stop time variation. This is without accounting for the existence of right-turn lane, which consistently adds 2.1 to 3 seconds of delay. Therefore, allocation of bus stops at the near side of intersection that includes a right-turn lane for cars is not recommended in order to avoid time wasted without serving any passengers. In other words, if we considered Route 165, one route with the median number of near-side stops among the STM's studied routes, the total number of near-side stops is 23 stops per direction (without the layovers). Therefore, moving these stops from near-side to far-side of the same intersection would save about 96 to 115 seconds (1.6 to 1.9 minutes) on total route-direction travel time. This means that, hypothetically, we can achieve about 5.2% to 6.1% saving in running time per direction due to the use of far-side stops along this route. This represents about 17% to 20% of Route 165 average total stop time per trip (which is about 30% of total travel time). However, this still does not account for savings that will be gained due to the absence of turning right lanes at the route far-side stops. That would achieve additional 29 to 42 seconds of saving (14 intersections have right-turn lane per route-direction), increasing the total saving to 6.7% to 8.4% in running time per route-direction. Hence, STM operates around 110 trips along Route 165 on a single weekday per direction; this means that shifting from near-side to far-side stops can increase the bus frequency along this route by 7 to 9 trips for every weekday per direction. Furthermore, this does not include the benefits that could be achieved due to the implementation of bus signal priority with extended green, in order to decrease the impact of signalized intersections on the service operational time while improving the service reliability *(3)*. It is important to note that stop time is not the only factor determining where stops should be located. Transit agencies are still required to balance the benefits and drawbacks of each bus stop placements location to ensure passengers' safety and avoid conflicts with other vehicles. Yet, this paper provides an understanding of the time attributed to stop location, which is an important aspect in evaluating alternative stop locations and design policies.

Since it is rare to find stop time variation studies in the literature, the study presents one of the first stop time variation models. One of the key, important finding of the model is related to passenger alighting from the bus first door. The models suggest that alighting from the bus's first door adds more variance to the stop time than boarding from first door (that include fare collection) or alighting from any other door. Therefore, transit agencies should discourage using the first door for alighting since it significantly increases the stop time variation more than other doors. Finally, the models use only AVL and APC data, accordingly information related to fare collection methods impacts on stop time variation is captured by the models *CV Door 1 boarding* variables at the aggregate level. Therefore, a study that combines AVL and APC data with fare box readings is recommended to enable and provide important information about the impact of fare collection methods on bus stop time variation. Finally, the recommendations from this study regarding the impact of bus stop placements on stop time are not limited to STM or TriMet, transit agencies should expect similar impacts of bus stop location on transit system performance in their areas.

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