All aboard at all doors: Route selection and running time savings estimation for multi-scenario all-door bus boarding

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ABSTRACT

The time that buses spend waiting for passengers to board can be a significant portion of a bus route's overall running time. A key determinant of boarding time is the number of doors that passengers are permitted to board through. Transit agencies that allow boarding through all doors, instead of just through the front door, typically enjoy decreased boarding times, and as such, decreased running times. This paper studies the feasibility of an all-door boarding policy for La Société de transport de Montréal (STM), Montréal's public transit agency. The potential benefits of such a policy are assessed through three main steps: first, a selection methodology is developed to determine which of STM's bus routes would benefit most from different all-door boarding strategies; second, a multi-variate regression analysis, using STM's AVL/APC data, is used to estimate the dwell- and running-times savings that would result under different implementation scenarios; and third, a sensitivity analysis is developed to demonstrate the savings associated with implementing such policy. Our findings show that all-door boardings could yield substantial savings in running time, with morning-peak savings of up to 15.8% on the best routes. In many cases, these running time savings are enough to remove a bus from a route while still maintaining existing frequencies. The findings from this research can be beneficial to transit planners and operators, since the presented methodologies show substantial savings from all-door boarding and can be adopted by other transit agencies.

Keywords: all-door boarding, buses, AVL/APC data, regression, off-board payment, running time, dwell time, route selection

INTRODUCTION

Most transit agencies operate their buses with a front-door boarding policy. This means that passengers must board buses via the front door only; the second doors of standard buses, and the third doors of articulated buses, are only to be used for alighting. There are several advantages to such boarding policies. Only one fare-collection machine per bus is needed, since there will only be one stream of boarding passengers. Also, each passenger must pay the bus driver or show proof-of-payment; this has the effect of ensuring a high level of fare-payment compliance without having to hire additional fare inspectors.

However, front-door boarding—coupled with a "pay the driver" system—comes with a high price: slow boarding times (*1*). One alternative to this system is to use all-door boarding, where passengers can board through any of the bus doors. Such systems allow for multiple passenger-boarding streams, which can not only reduce boarding time per passenger, but also reduce the total in-vehicle travel time for all passengers (*2*). Furthermore, reductions in boarding time can result in significant improvements to running times, in the overall efficiency of the bus system (*3*), and in improved customer satisfaction (*4*).

All-door boarding policy can be implemented in three ways. The first is applying the policy to all the routes in a bus network (a system-level implementation), the second is applying it on individual routes (a route-level implementation), and the last is applying it at individual stops (a stop-level implementation). A system-level policy would allow passengers to board any bus in the network through any door. This would allow for a consistent policy across all buses, and as such, it would be easiest for passengers to understand. However, it is unlikely that all routes in a network would see sufficient running-time improvements to offset installing new fare-collection machines on all buses in the system, especially since the benefits are not easily quantified. Accordingly, prior to moving towards a system-level implementation, pilot testing at the route or stop level is needed to capture the most cost-efficient implementation scenario.

The general aim of this study is to determine the feasibility of all-door boarding for La Société de transport de Montréal (STM), the main transit agency serving the island of Montréal. More specifically, the paper uses STM bus data to develop a methodology which evaluates the performance of all-door boarding policies at various scales. The STM has shown interest in testing the potential savings and losses from implementing such policies at both the route and stop levels.

The paper begins with a literature review on the pros and cons of all-door boarding policies and on route-selection criteria for implementing such a policy. This is followed by a section describing a methodology developed for selecting routes and stops which are suitable for all-door boarding. After selecting the routes and stops, statistical running-time and dwell-time models are generated; these models provide the basis for a sensitivity analysis that is used to estimate the time savings from different implementation scenarios. Finally the paper ends with a conclusion and policy recommendations.

LITERATURE REVIEW

Pros and Cons of All-Door Boarding

The main benefit of all-door boarding is a reduction in dwell time—that is, the amount of time spent at bus stops to service passengers. Dwell time typically accounts for 9 to 26% of a bus route's total running time (*5*), so reducing dwell time can result in significant running time savings (*6*). All-door boarding can reduce dwell time in a number of different ways. Firstly, and most obviously, it allows for multiple passenger boarding streams, each of which can board the bus simultaneously. Secondly, it allows passengers waiting at a bus stop to be closer to a door that they can board through (*7*). Thirdly, it allows for a more balanced passenger distribution throughout the bus; this results in less crowding near each door, which in turn can reduce per-passenger boarding time by as much as half a second (*2*). Overall, running time savings are estimated to be between 1.8 and 9.6% when using two-door buses, and between 4.6 and 13.3% with three-door buses while controlling for fare-collection methods (*2*).

Potential savings from all-door boarding will vary depending on the fare payment system in place. There are two main types of payment systems: off-board and on-board. Off-board payment requires that passengers pay for their fares prior to boarding; this can be done via ticket machines at the bus stop (e.g. London, Stockholm), at rapid-transit stations (e.g. Vancouver, Phoenix), or via convenience stores and grocers (e.g. Rome, Los Angeles). On-board payment can be done through electronic ticket-machines (e.g. San Francisco, Paris) or mechanical stampers (e.g. Munich, Freiburg). Off-board payment is the fastest payment method, with per-passenger boarding times of about one second less than typical on-board payment systems that use smartcards (*8*).

A secondary benefit to all-door boarding is improved passenger satisfaction. This occurs for three main reasons: firstly, reduced travel times are greatly appreciated by passengers (*9*). Secondly, the more-evenly balanced passenger distribution in the bus gives passengers more space (*1*). Thirdly, all-door boarding gives passengers the choice to board through whichever door they want, thus creating a more “rapid-transit” experience (*4*).

The most obvious concern to all-door boarding is the fear of increased fare evasion. However, in practice, it has been shown that the *perception* of fare evasion is often much greater than actual rates (*2; 10*). For example, evasion rates are only 2.4% and 4.7% in Ottawa and San Francisco, two cities that have all-door boarding policies. That said, the importance of taking measures to ensure fare payment is crucial; this means either installing turnstile-controlled bus stops or hiring more fare inspectors. Turnstiles are typically only used on heavily used bus-rapid-transit (BRT) routes. Fare inspectors are more appropriate for less heavily used routes. On a side note, it should be mentioned that elimination of fare evasion is virtually impossible, as such, a degree of evasion must be accepted when all-door boarding is implemented (*4*). It is up to each transit agency to determine how much fare evasion is acceptable.

As for implementation costs of all-door boarding, the main expenses are in the purchasing and installing of electronic fare readers (on-board or off-board), and the hiring and training of fare inspectors. The number of fare inspectors in the system must be carefully considered; evasion rates must be kept down to an acceptable level, but so must the budget for fare inspectors (*11*). Since fare inspectors constitute an on-going operating expense, they can be more expensive in the long-term than the cost of fare readers (*12*). However, despite these expenditures, it is largely agreed upon that the costs of providing all-door boarding are outweighed by the savings in operating costs that result from running time improvements (*1; 8*).

Route Selection and Analysis

A considerable literature exists for the analysis of bus running times and dwell times. It is generally agreed upon that a variety of factors exists that affect running times and dwell times, including passenger activity (boarding and alighting), passenger load, distance, delay at the beginning of the trip, period of the day, number of actual stops made, and weather conditions (*5; 6; 13; 14*). The effect of these factors can be evaluated directly by generating statistical running - time and dwell-time models with archived automatic-vehicle-location (AVL) and automatic-passenger-counter (APC) systems data (*15-18*); these models can then be used to measure the effectiveness of different strategies on running time and dwell-time–reduction strategies such as all-door boarding (*19-22*).

To our knowledge, no existing literature could be found on the process of selecting bus routes for all-door boarding, or for other similar bus-efficiency measures. As such, the authors devised their own methodology; see the Route Selection section of this paper.

ROUTE SELECTION

In this section, we explain our methodology to determine which bus routes would benefit the most from all-door boarding. Three quantitative methodologies are presented for selecting the routes that would perform best under system-, route-, and stop-level implementations.

System- and Route-Level Implementations

Two main criteria were chosen to identify which routes would excel under system- and route-level implementations. Firstly, for all-door boarding to result in significant dwell-time savings, high numbers of passengers must board at each stop; as such, the best routes will have a high average number of boardings across all stops. Secondly, in order to achieve significant time savings over the course of a day, a route must have a high number of total boardings. A high total boarding count can be attained either by having many stops on each bus trip, or by having many bus trips in a given time period.

It was determined that the best time periods to focus on were the AM and PM peaks (06:30–09:30 and 15:30–18:30, respectively). Since these periods have the greatest number of passenger boardings, they will also stand to benefit the most from an all-door boarding policy. Additionally, it was decided that both travel directions on a route (north & south, or east & west) should be examined separately, as some routes might perform well in some directions but not in others. The ideal route would perform well in both peaks and directions.

To assess how well each bus route met the boarding criteria described above, a data set with the average boardings per stop in the STM network was obtained. From this data—which contained 1,273,108 records—the average boardings per stop and the total boardings for all routes in each peak and in each direction were calculated. Routes with all of their peak-directions (for example, AM-north, PM-south) in both the top 25% of average boardings per stop and the top 25% of total boardings were considered to be the best performers under a system-level implementation.

To identify which of these routes would be ideal for a route-level implementation, it was necessary to determine how much they overlap with other bus routes. The most suitable routes would be ones that either have minimal overlap with other routes, or ones that have significant overlap with one other route; in this second situation—which might occur on a route served by both an express bus and a local bus—all-door boarding could be implemented on both routes. The idea here is to keep boarding rules at bus stops consistent. It would be confusing to passengers if some of the buses at a stop allow all-door boarding while others do not; this confusion can be reduced by selecting routes that have minimal overlap with front-door-boarding routes. In sum, the ideal routes for a route-level implementation would be those that have either the lowest percentage of overlap or, potentially, the highest.

Table 1 summarizes the boarding and overlap data for the routes that would excel in a system-level implementation; the top five routes in the table (467, 439, 165, 45, and 67) were selected for detailed running-time analysis under a system-level implementation. However, four of these top five routes would not perform well under a route-level implementation, as they generally have significant partial overlaps with several other routes.

The routes that stood out as ideal candidates for route-level implementation are routes 45 and 161. Route 45 has one of the highest numbers of boardings per stop (3.39), has a reasonably good number of overall boardings per peak-direction (1613), and has a low overlap with other routes (9%). Route 161 would also perform well; it has a lower per-stop boarding average (2.85) than the 45, but a higher number of total boardings per peak-direction (1822). These two routes were selected for running-time analysis under a route-level implementation.

Stop-level implementation

Determining the individual bus stops that are best for all-door boarding is simpler than determining the best routes; the only major factor to consider is the number of boardings per stop. With this in mind, the stops in the STM network with the most boardings in the AM and PM peaks were identified.

It was initially assumed that stop-level implementations would not be specific to any bus route, since many routes could share one stop that has all-door boarding. However, it was found that the vast majority of the busiest bus stops were only used by one route, or were shared by parallel routes (that is, local and express). The question, then, became how much would all-door boarding at a specific stop benefit the one route (or occasionally two routes) that serve that stop— and how would this compare with a route-level implementation on the same route? Or, to go one step further, how much would a route benefit if all-door boarding was implemented at each major stop that the route served?

To answer this question, first, the stops with 500 or more boardings during the peaks, combined, were identified as “major stops.” These stops were then classified as first stops on the route, or as mid-route stops—that is, stops that were neither the first nor last stops on the route. The distinction was made here because a significant proportion of boarding at first stops occurs during layovers (scheduled breaks for drivers); as such, improvements in boarding speed could often be swallowed up in the layover time. That said, measuring these layover boarding-speed improvements could be useful to agencies looking to shorten their drivers’ layover times. Table 2 shows the routes with the greatest number of boardings at all the major stops they serve. The routes that rank best here are the 121 and the 435; these routes were selected for dwell-time analysis under a stop-level implementation. The locations of these routes, as well as those of the other routes selected for detailed analysis, are shown in Figure 1.

ROUTE ANALYSIS

Running-time Model

To determine how much time could be saved through different all-door boarding implementations, two multivariate-regression models were generated with AVL/APC data. STM’s AVL/APC data contains information about each bus stop one each trip, including the arrival and departure time, the number of passengers boarding and alighting through each door, and the number of passengers on the bus; the data set obtained had 1,213,691 records. The model for system- and route-level implementations calculated the running time of each route as a function of various factors. For detailed explanation of running-time models and the rationale behind variable selection see Diab and El-Geneidy (*23*) and Tétreault and El-Geneidy (*21*). Table 3 provides a description and summary statistics for each variable, while Table 4 shows the model output.

The running-time model coefficients and R^2 are comparable to previous studies that use running-time models. The coefficients of the model can be explained as follows. Buses are slower in peak periods than in off-peak periods, with the PM peak being the slowest. Passengers take on average 3.5 seconds each to board and 1.2 seconds to alight—although the negative square term (PaxSq) in the model indicates that these values decrease as the number of passengers increases. The negative term Load and the positive square term LoadSq indicates that having more people on the bus will decrease running time up to a point, but will then start to increase running time; it is hypothesized here that the presence of more passengers will increase pressure on other passengers to board and alight more quickly, but when the bus is crowded and full of standees, boarding and alighting time will start to increase. For each second that the bus starts its trip behind schedule, it will run 0.12 seconds faster. Each time the bus stops, about 12 seconds will be added to the trip, regardless of passenger activity. Each bus stop on the far side of an intersection subtracts about 10 seconds from the running time. Rain and snow cause running time to increase slightly. And finally, there are significant differences between the running time of each route-direction, since each one has a different length, different permitted speeds, and so forth.

Dwell-time Model

The model for stop-level implementation was similar to the running-time model; it calculated dwell time as a function of such factors as boardings and alightings through each door, the number of standees on the bus, the presence of a traffic light, and so forth. For detailed specifications of dwell time model and rational behind selection of variables see El-Geneidy and Vijayakumar (*20*). A set of dummy variables was added to the model for each of the major stops on each route. These dummies capture the differences in dwell time between these stops and the rest of the stops in the model. Interaction variables for each major stop were also added; these variables are the product of the total boardings by the dummy variable of the stop. The interaction variables were designed to capture any differences in boarding speeds at the different stops. Table 5 provides a description and summary statistics for each variable, while Table 6 shows the regression output. Note that the amount of boarding through the second and third doors is almost zero, since an all-door boarding policy is not yet in place.

The dwell-time model coefficients and R^2 are comparable to previous studies that used dwell time (*19; 20*). The model coefficients can be explained as follows. Dwell times are about 0.4 seconds shorter in the inbound direction, and are slightly shorter during the peak periods. Boarding through the front door takes about 3.8 seconds per passenger. Alighting is slowest through the front door, at 2.6 seconds per passenger, and drops to 1.6 at the second door and 1.3 at the third door. As in the running-time model, the square terms for passenger activity indicate that boarding and alighting time per passenger decrease as passenger volume increases. Number of standees on the bus and the delay at the start of the trip marginally speed up the dwell time. Stops that are scheduled timing stops are about 16 seconds slower than other stops. Dwell time at stops located near traffic lights is about 5.7 seconds slower compared to mid-block stops or stops at stop signs. Dwell time at stops on the far side of intersections is about 4 seconds faster. Precipitation increases dwell time to a small degree. There are significant differences between dwell-time lengths at different major stops, ranging from 36 seconds slower than average at Fairview-westbound to 13 seconds faster at Emile-Journault-southbound. And lastly, per-passenger boarding is almost always faster at major stops, with Sauvé-eastbound being about 1.5

seconds faster (for a total of 3.871 – 1.457 = 2.414 seconds per passenger); this is due to the increased boarding efficiency that comes with the larger volumes of people at these stops (*24*).

SENSITIVITY ANALYSIS

To estimate the amount of time that would be saved on each route under different implementation strategies, sensitivity analysis was performed using the running time and dwell-time models. The general idea is first to add the products of each variable's mean with the corresponding coefficient in order to calculate the running time or dwell-time; and second, to modify the boarding variables (e.g. divide by two) to simulate different time-saving scenarios under all-door boarding.

For example, with running times, the time taken by all running time factors *except* boarding was calculated—first by finding the mean values of each variable for each route, direction, and time period (e.g. 439, inbound, AM peak), second by multiplying each of these means—except that of the boarding variable—by the running-time model coefficients, and third by summing the products. This resulted in a running time base value that took all running time factors into account except for boarding.

Then, for the boarding variable, four different savings scenarios were simulated: a pessimistic low-saving scenario, an optimistic high-saving scenario, and two similar scenarios with added savings from off-board fare payment. For the low-saving scenario, it was assumed that the current single stream of passengers under front-door boarding would be split into three streams at three-door buses, with the front-door stream being half the length of the current stream. To simulate this, the AllOn variable's mean was multiplied by 0.5 (that is, divided by 2), further multiplied by the AllOn coefficient, and then added to the running time base value; where two-door buses were used, the mean was multiplied by 0.67 instead. In the high-saving scenario, it was assumed that all three boarding streams would be the same length; as such, the AllOn means were multiplied by 0.33 (0.5 for two-door buses) instead of by 0.5 (or by 0.67) as was done in the low-saving scenario. For the off-board fare payment scenarios, the AllOn means were multiplied by the same values, but the AllOn coefficient (3.526 seconds) was reduced by one second; this simulates the expected one-second-per passenger savings achieved by off-board payment (*2*). Finally, the running time savings under each scenario for each route, direction, and time period were calculated to determine the total running time savings in each period. The same overall process was done with the dwell-time model to estimate the savings associated with implementing all-door boarding at each major stop. The obtained savings were then subtracted from the average running times of the route where this stop was present.

As for the layover savings, it was decided that regression would be unsuitable for modeling layover time. This is because the bulk of layover time is scheduled, and is thus largely unaffected by other factors such as weather and passenger activity. Therefore, to estimate layover savings, the average number of passengers who board during layovers was determined. Second, the current layover boarding times were calculated using the boarding average and the dwell-model coefficients, Door1_On and Door1_OnSq. Thirdly, the same four savings scenarios that were simulated for the running-time and dwell-time models were simulated for the layovers. Finally, the differences between the current layover boarding times and the scenario times were subtracted from the average route running times. Table 7 shows the percentage of running-time savings under each implementation strategy.

Generally speaking, a transit agency will only save money if the running time savings are sufficient to remove a bus on a route while providing the same frequencies. To determine whether any of the all-door boarding implementation scenarios could remove a bus, the following process was used: first, the route cycle time—that is, the running time for both directions of a route, plus the layover times at both ends—was calculated for each route in the peaks. Second, the number of buses currently required during the peaks was calculated by dividing the average peak cycle time by the average peak headway and rounding up to the nearest whole number; the rounding up is necessary since a requirement of 10.1 buses actually means that 11 buses are needed. Third, the number of buses required to maintain existing frequencies was calculated under each of the different all-door boarding scenarios. Table 7 indicates whether the time savings from any of the scenarios could lead to removing a bus from a route.

Route-level savings (which are equal to system-level savings for a specific route) range from 4.7 to 13.9%; this is consistent with findings from the literature. Major-stop savings range from 0.8% to 5.0%, while layover savings range from 0.5% to 2.4%. Greater savings can be achieved by combining implementations; for example, combining the route-level and layover implementations on the 467 yields savings of 15.8% in the offboard high scenario.

These savings are generally substantial, but it should be noted that a portion of the savings can be nullified depending on the bus-stop configuration where the all-door boarding takes place. If a bus stop is at a traffic light, then there is the potential for boarding-time savings to be lost if the light turns red; thus, all-door boarding would work best when stops are on the far side of an intersection, past the traffic lights. The running-time model as well as the dwell time models have shown significant savings from moving towards a far-side policy. Also, in order to fully realize these estimated savings, route schedules would have to be revised so as to accommodate shorter running times.

Regarding bus removal from a route: from the figures in Table 7, there appears to be no clear correlation between running time savings and being able to remove a bus. This is due to the fact that the number of required buses on a route must always be rounded up to the nearest integer; therefore, on routes that initially required slightly more than a whole number of buses, very little savings were required to remove a bus. For example, route 165 required 10.1 buses initially (11 after rounding up), but could theoretically remove a bus if the number of required buses dropped to just 10.0 buses. By contrast, the 467 initially needed 10.0 buses, which meant that the running time savings would need to reduce this requirement to at least 9.0 to remove a bus. As such, the ability to remove a bus could be affected by changes to a route's running time or level of service. It should also be noted that routes in the PM peak were more often able to remove a bus, despite similar savings percentages.

As for which implementation strategies are most beneficial, it is clear that overall time savings—and the ability to remove a bus—are highest at the system- and route-level. That said, the extra running time savings that come from combining implementation strategies are sometimes necessary in order to remove a bus. Also, on routes where only a small percentage of savings is needed to remove a bus, a non-route-level implementation would be recommended since fare-inspection costs will be highest at the route/system level.

CONCLUSION

The purpose of this research was to assess the benefits of all-door bus boarding in general, and to develop a methodology for selecting routes for pilot testing or partial implementation of such policy. This was done through using data obtained from STM in Montréal as they have indicated interest in exploring this new policy to identify the greatest running-time savings under a variety of implementation scenarios. The literature review found that all-door boarding, if implemented judiciously, can yield enough operating-cost savings from decreased running times to outweigh any losses from fare evasion. To select the routes in STM's network that would benefit the most from system-level, route-level, and stop-level all-door boarding policies, a new methodology was devised based on route-level and stop-level boarding figures obtained from STM's AVL and APC data. Multi-variate regression was then used to generate running-time and dwell-time models for the selected routes. These models were the first, to our knowledge, to capture the effect of having stops on the far-side of an intersection. Lastly, sensitivity analysis was performed using these models to estimate running-time savings under optimistic and pessimistic scenarios using on-board and off-board payment methods. It was found that, during the morning peak, running-time savings at the route level ranged from 4.7 to 13.9%, and were as high as 15.8% when adding the savings from layovers. Also, in many scenarios, it was possible to save a bus from a route—that is, to operate the route at current frequencies with one fewer bus. This represents substantial operating-cost savings for any transit agency.

It is currently unclear how much of these savings can be realized with current bus-stop configurations in Montréal. Many stops are currently on the near side of intersections with traffic lights; this can have the effect of eliminating savings from faster passenger boarding if the light is red. Future research will need to address this issue and, if necessary, weigh the costs of relocating stops versus the operating-cost savings. More research is needed into several other issues as well: fare evasion rates, which can be determined by comparing farebox data with AVL/APC data; the extent to which operators allow passengers to board during their layovers , and the acceptability to agencies of this practice; the ability of existing bus stop infrastructure to accommodate all-door boarding; and the implications of all-door boarding for disabled passengers. However, despite these uncertainties, this paper concludes that the cost savings and related passenger-satisfaction improvements resulting from all-door bus boarding are significant, and are worth pursuing by any major transit agency.

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LIST OF TABLES

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TABLE 1 Average boardings and percentage of overlap for heavily used routes

Route	Averages across AM & PM peaks		Overlap % with other routes	
	Boardings per stop	*Boardings per peak-direction*	*AM*	*PM*
467	6.81	1968	97	97
439	4.27	1602	42	29
165	3.52	1831	100	100
45*	3.39	1613	9	9
67	3.36	1723	65	65
121	3.06	3477	39	39
105	3.00	1331	46	49
55	2.93	1547	26	26
161*	2.85	1822	9	10
435	2.73	2937	99	99
32	2.56	1311	40	27
427	2.46	1502	90	86
470	2.42	1012	91	91
24	2.41	2135	29	29

** Indicates routes with low overlap*

TABLE 2 Routes with the most peak boardings at the busiest stops

Route	Boardings at stops with 500+ boardings			Stops served
	Total	*First stop*	*Mid-route*	
121	5631	-	5631	Sauvé, Côte-Vertu
435	5065	264	4801	Parc, Place-des-Arts, et al. (14 total)
165	4417	2186	2231	Guy-Concordia, Côte-des-Neiges, et al. (8 total)
467	4068	1191	2876	Joliette, Saint-Michel, et al. (7 total)
141	3209	3209	-	Saint-Michel
51	3101	1114	1988	Laurier, Snowdon
67	2629	867	1762	Joliette, Saint-Michel, et al. (7 total)
69	2456	130	2326	Henri-Bourassa, et al. (5 total)
105	2341	2001	340	Vendôme
161	2268	765	1504	Rosemont, Plamondon
90	2138	618	1520	Atwater, Vendôme
470	2130	1553	577	Côte-Vertu, Fairview
139	2066	-	2066	Pie-IX
18	2051	630	1421	Honoré-Beaugrand, Beaubien
197	2043	2043	-	Langelier

Note: Boardings of under 500 indicate a shared stop

TABLE 3 Summary statistics for variables used in running-time model

Variable	Description	Mean	Std. Dev.
Runtime*	Bus-route trip time (seconds), excluding first/last stops	2126.84	422.20
AM_Peak**	Trip starts between 06:30 and 09:30	.16	.37
PM_Peak**	Trip starts between 15:30 and 18:30	.18	.38
AllOn	Total number of passengers boarding on the route	72.14	39.95
AllOff	Total number of passengers alighting on the route	78.96	39.03
PaxSq	Total passenger boardings & alightings on the route, squared	2596.16	2884.74
Load	Passengers on the bus divided by the bus's capacity * 100	22.99	1.22
LoadSq	The Load variable squared	784.76	695.60
DelayAtStart	Seconds that the bus starts after its schedule	35.18	112.46
RealStops	Actual stops made on the route	23.71	7.83
FarSideStops	Stops on the route that are on the far side of an intersection	1.63	1.73
Rainfall	Millimetres of rain during the day	1.00	2.75
SnowGround	Centimetres of snow on the ground	5.41	8.92
R45south**	Bus route is the 45 southbound (inbound)	.06	.23
R45north**	Bus route is the 45northbound (outbound)	.04	.20
R67 south **	Bus route is the 67 southbound (inbound)	.11	.31
R161east**	Bus route is the 161 eastbound (inbound)	.09	.29
R161west**	Bus route is the 161 westbound (outbound)	.10	.30
R165 south **	Bus route is the 165southnbound (inbound)	.11	.32
R165 north **	Bus route is the 165 northbound (outbound)	.15	.35
R439 south **	Bus route is the 439 southbound (inbound)	.02	.13
R439 north **	Bus route is the 439 northbound (outbound)	.01	.11
R467 south **	Bus route is the 467 southbound (inbound)	.06	.23
R467 north **	Bus route is the 467 northbound (outbound)	.07	.25

*Dependent variable. **Dummy variable

TABLE 4 Running-time model

Variable	Coefficient	t-Stat	Significance
(Constant)	180.20	144.73	.000
AM_Peak	18.26	4.33	.000
PM_Peak	85.53	2.05	.000
AllOn	3.53	31.90	.000
AllOff	1.21	9.81	.000
PaxSq	-0.01	-7.59	.000
Load	-8.29	-12.85	.000
LoadSq	0.05	6.11	.000
DelayAtStart	-0.12	-9.54	.000
RealStops	11.97	23.03	.000
FarSideStops	-10.31	-6.58	.000
Rainfall	1.19	2.37	.018
SnowGround	0.65	4.16	.000
R45south	122.08	16.70	.000
R45north	124.99	13.56	.000
R67south	-67.29	-9.49	.000
R161west	179.42	32.09	.000
R165south	-149.48	-23.83	.000
R165north	-48.61	-71.44	.000
R439south	307.64	23.37	.000
R439north	-411.64	-25.75	.000
R467south	-204.78	-18.24	.000
R467north	-418.81	-4.04	.000
R^2	0.839		
N	15,633		

TABLE 5 Summary of variables used in the dwell-time model

Variable	Description	Mean	Std Dev
DwellTime*	Dwell time, in seconds	25.94	27.009
Inbound**	Bus is headed inbound or not	.484	.500
AM_Peak**	Bus route starts between 06:30 and 09:30	.198	.399
PM_Peak**	Bus route starts between 15:30 and 18:30	.232	.422
Door1_On	Passengers boarding via door 1	3.619	5.692
Door2_On	Passengers boarding via door 2	.009	.120
Door3_On	Passengers boarding via door 3	.006	.103
Door1_Off	Passengers alighting via door 1	1.359	1.874
Door2_Off	Passengers alighting via door 2	1.425	2.436
Door3_Off	Passengers alighting via door 3	.926	2.051
Door1_OnSq	Passengers boarding via door 1, squared	45.500	188.651
Door2_OnSq	Passengers boarding via door 2, squared	.015	.706
Door3_OnSq	Passengers boarding via door 3, squared	.011	.992
Door1_OffSq	Passengers alighting via door 1, squared	5.359	16.956
Door2_OffSq	Passengers alighting via door 2, squared	7.964	34.763
Door3_OffSq	Passengers alighting via door 3, squared	5.065	27.209
Standees	Passengers on bus without a seat	2.462	7.281
DelayAtStart	Seconds that the bus started after its schedule	.799	16.352
TimingStop**	Bus stop is a timing stop in the schedule	.053	.223
TrafficLight**	Bus stop is at a traffic light	.802	.399
FarSide**	Bus stop is on the far side of an intersection	.046	.209
RainFall	Millimetres of rain falling in the day	.352	1.679
SnowFall	Centimetres of snow falling in the day	.136	.961
SnowGround	Centimetres of snow on the ground	1.609	5.319
Plamondon161e**	Bus stop is Plamondon, eastbound	.002	.048
OnPlamondon161e	Boardings at Plamondon, eastbound	.041	.961
Plamondon161w**	Bus stop is Plamondon, westbound	.003	.050
OnPlamondon161w	Boardings at Plamondon, westbound	.051	1.138
CoteDesNeiges165n435w**	Bus stop is Côte-Des-Neiges, outbound	.005	.074
OnCoteDesNeiges165n435w	Boardings at Côte-Des-Neiges, outbound	.077	1.272
CoteDesNeiges165s435e**	Bus stop is Côte-Des-Neiges, inbound	.004	.066
OnCoteDesNeiges165s435e	Boardings at Côte-Des-Neiges, inbound	.038	.710
Barclay165s**	Bus stop is Barclay, southbound	.004	.067
OnBarclay165s	Boardings at Barclay, southbound	.055	.944
Fairview470e**	Bus stop is Fairview, eastbound	.001	.031
OnFairview470e	Boardings at Fairview, eastbound	.016	.574
Fairview470w**	Bus stop is Fairview, westbound	.001	.034
OnFairview470w	Boardings at Fairview, westbound	.013	.477
Peltrie435e**	Bus stop is Peltrie, eastbound	.005	.069
OnPeltrie435e	Boardings at Peltrie, eastbound	.043	.727

Variable	**Description**	**Mean**	**Std Dev**
CoteSteCatherine435e**	Bus stop is Côte-Ste-Catherine, eastbound	.005	.069
OnCoteSteCatherine435e	Boardings at Côte-Ste-Catherine, eastbound	.038	.668
QueenMary435e**	Bus stop is Queen Mary, eastbound	.005	.070
OnQueenMary435e	Boardings at Queen Mary, eastbound	.043	.749
Guy435w**	Bus stop is Guy, westbound	.001	.030
OnGuy435w	Boardings at Guy, westbound	.026	.998
Mansfield435e**	Bus stop is Mansfield, eastbound	.001	.031
OnMansfield435e	Boardings at Mansfield, eastbound	.006	.300
University435e**	Bus stop is University, eastbound	.001	.028
OnUniversity435e	Boardings at University, eastbound	.003	.171
PlaceDesArts435e**	Bus stop is Place-des-Arts, eastbound	.001	.028
OnPlaceDesArts435e	Boardings at Place-des-Arts, eastbound	.018	.754
Parc435e**	Bus stop is Parc, eastbound	.001	.031
OnParc435e	Boardings at Parc, eastbound	.013	.548
OnParc435w	Boardings at Parc, westbound	.011	.391
Durocher435w**	Bus stop is Durocher, westbound	.001	.034
OnDurocher435w	Boardings at Durocher, westbound	.008	.270
Masson67s467s**	Bus stop is Masson, southbound	.005	.072
OnMasson67s467s	Boardings at Masson, southbound	.034	.612
EmileJournault67s467s**	Bus stop is Emile Journault, southbound	.005	.070
OnEmileJournault67s467s	Boardings at Emile Journault, southbound	.036	.660
Louvain67s467s**	Bus stop is Louvain, southbound	.005	.067
OnLouvain67s467s	Boardings at Louvain, southbound	.033	.661
HenriBourassa67s467s**	Bus stop is Henri-Bourassa, southbound	.004	.060
OnHenriBourassa67s467s	Boardings at Henri-Bourassa, southbound	.032	.656
StMichel67n467n**	Bus stop is St-Michel, northbound	.005	.072
OnStMichel67n467n	Boardings at St-Michel, northbound	.096	1.578
StMichel67s467s**	Bus stop is St-Michel, southbound	.004	.064
OnStMichel67s467s	Boardings at St-Michel, southbound	.060	1.187
CoteVertu121e**	Bus stop is Côte-Vertu, eastbound	.004	.065
OnCoteVertu121e	Boardings at Côte-Vertu, eastbound	.124	2.089
CoteVertu121w**	Bus stop is Côte-Vertu, westbound	.004	.062
OnCoteVertu121w	Boardings at Côte-Vertu, westbound	.080	1.535
Sauve121e**	Bus stop is Sauvé, eastbound	.004	.061
OnSauve121e	Boardings at Sauvé, eastbound	.067	1.313
Sauve121w**	Bus stop is Sauvé, westbound	.004	.066
OnSauve121w	Boardings at Sauvé, westbound	.114	1.953

*Dependent variable **Dummy variable

1 **TABLE 6 Dwell-time model**

Variable	Coefficient	t-Stat	Significance
Constant	2.710	44.170	.000
Inbound	-.378	-8.240	.000
AM_Peak	-1.167	-2.060	.000
PM_Peak	-.172	-3.120	.002
Door1_On	3.871	42.290	.000
Door2_On	3.505	14.460	.000
Door3_On	1.918	7.130	.000
Door1_Off	2.570	106.930	.000
Door2_Off	1.607	81.760	.000
Door3_Off	1.287	56.680	.000
Door1_OnSq	-.024	-59.310	.000
Door2_OnSq	-.103	-2.120	.034
Door3_OnSq	-.098	-3.010	.003
Door1_OffSq	-.069	-24.590	.000
Door2_OffSq	-.064	-44.290	.000
Door3_OffSq	-.056	-32.480	.000
Standees	-.035	-1.980	.000
DelayAtStart	-.008	-5.840	.000
TimingStop	15.996	14.580	.000
TrafficLight	5.674	98.200	.000
FarSide	-4.342	-4.250	.000
RainFall	.080	6.110	.000
SnowFall	.067	2.940	.003
SnowGround	.025	5.930	.000
Plamondon161e	3.884	2.610	.009
OnPlamondon161e	-1.029	-19.980	.000
Plamondon161w	.597	.410	.682
OnPlamondon161w	-.716	-15.810	.000
CoteDesNeiges165n435w	-3.586	-2.960	.003
OnCoteDesNeiges165n435w	-.647	-2.400	.000
CoteDesNeiges165s435e	3.896	3.140	.002
OnCoteDesNeiges165s435e	-1.241	-22.920	.000
Barclay165s	1.915	16.580	.000
OnBarclay165s	-.257	-5.460	.000
Fairview470e	22.873	12.380	.000
OnFairview470e	-.700	-8.520	.000
Fairview470w	36.018	24.420	.000
OnFairview470w	-.997	-13.960	.000
Peltrie435e	2.916	4.980	.000
OnPeltrie435e	-.509	-9.050	.000

Variable	**Coefficient**	**t-Stat**	**Significance**
CoteSteCatherine435e	4.100	7.460	.000
OnCoteSteCatherine435e	-.119	-2.070	.038
QueenMary435e	12.413	22.910	.000
OnQueenMary435e	-.738	-14.560	.000
Guy435w	1.362	6.970	.000
OnGuy435w	.186	3.940	.000
Mansfield435e	4.685	5.170	.000
OnMansfield435e	-1.018	-1.670	.000
University435e	3.478	3.180	.001
OnUniversity435e	-.514	-2.870	.004
PlaceDesArts435e	9.695	6.990	.000
OnPlaceDesArts435e	.178	3.280	.001
OnParc435e	-.245	-3.910	.000
OnParc435w	.926	16.550	.000
Durocher435w	1.409	1.200	.230
OnDurocher435w	-.380	-2.570	.010
Masson67s467s	5.023	1.660	.000
OnMasson67s467s	-.599	-1.820	.000
EmileJournault67s467s	-13.014	-1.840	.000
OnEmileJournault67s467s	-.311	-5.890	.000
Louvain67s467s	-1.861	-9.070	.000
OnLouvain67s467s	-.400	-8.030	.000
HenriBourassa67s467s	4.618	7.400	.000
OnHenriBourassa67s467s	.355	6.160	.000
StMichel67n467n	.289	.230	.816
OnStMichel67n467n	-.756	-26.210	.000
StMichel67s467s	7.125	5.810	.000
OnStMichel67s467s	-1.257	-39.210	.000
CoteVertu121e	11.285	8.160	.000
OnCoteVertu121e	-.516	-15.920	.000
CoteVertu121w	21.025	16.320	.000
OnCoteVertu121w	-1.103	-35.260	.000
Sauve121e	34.847	27.430	.000
OnSauve121e	-1.457	-44.090	.000
Sauve121w	18.206	13.810	.000
OnSauve121w	-.879	-28.770	.000
R^2	0.695		
N	473,969		

TABLE 7 Percentage savings of AM-peak running times under each implementation scenario

Savings Scenarios	45	67	121	161	165	435	439	467
Route-level								
Low	6.9	7.6[1]		4.7	6.8[1]		6.2	9.2
High	9.2	10.1[1]		7.1	9.1[1]		8.7	12.2
Offboard low	8.9	9.8[1]		7.4	8.8[1]		7.9	11.8
Offboard high	10.5	11.6[1]		9.1[1]	10.4[1]		9.4	13.9[1]
Major stop								
Low		2.3	2.4	0.8	1.5[1]	1.9		3.2
High		3.2	3.3	1.2	2.0[1]	2.6		4.3
Offboard low		3.1	3.3	1.3	1.9[1]	2.5		4.1
Offboard high		3.7	4.0	1.6	2.3[1]	3.0		5.0
Layover								
Low	1.0	0.9		0.5	1.4		1.5	1.2
High	1.3	1.2		0.7	1.9[1]		2.0	1.6
Offboard low	1.3	1.2		0.8	1.9[1]		2.1	1.6
Offboard high	1.5	1.4		0.9	2.2[1]		2.4	1.8

[1]One bus saved

FIGURES

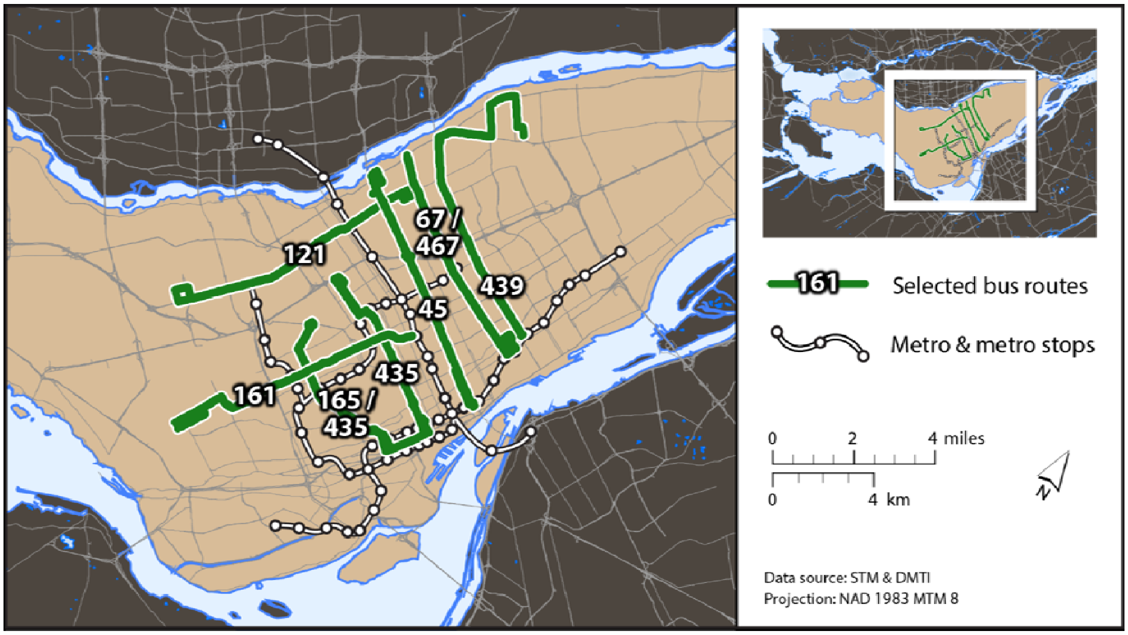

FIGURE 1 Bus routes selected for running time and dwell-time analysis