DESIGNING A PARALLEL LIMITED STOP SERVICE BUS ROUTE IN MONTRÉAL USING AUTOMATIC VEHICULE LOCATION AND PASSENGER COUNTING DATA

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ABSTRACT

In recent years, several transit agencies have been trying to be more competitive with the personal automobile in order to attract more choice riders. Transit agencies can only be competitive if they can provide services that are reliable (short wait time and less variation), have a short access time at both ends of the trip, and offer run times comparable to the personal automobile. This report uses AVL and APC data, in addition to a disaggregate data obtained from a travel behaviour survey, to select stops and estimate run times for a limited-stop (or express) service along a heavily used bus transit corridor, route 67 Saint-Michel. A run-time model is established at the trip level and incorporates variables on rainfall, snowfall and accumulated snow as well as separating passenger activity by door, among other operating variables. The climatic variables had a significant impact on increasing runtimes. Passenger activity through the back door decreased bus travel times. Three different scenarios are developed based on theory and practice to select stops to be incorporated in the new limited service. The savings from each scenario is then evaluated as a range and a fourth scenario is developed. A limited-stop service is recommended based on selecting stops serving both route directions, major activity points and an average spacing of between 800 to 1,600 meters. Running times ranges for this scenario are estimated by varying the run time model through isolating activity and actual number stops served by the new service. Implementing an express service would yield substantial time savings for both the limited route and a parallel regular route in the order of 10 to 20 percent for the limited service. The STM will be implementing a limited-stop service, route 467, starting on March 30, 2009 using the analysis presented in this paper.

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INTRODUCTION

In recent years, several transit agencies have been trying to be more competitive with the personal automobile in order to attract more choice riders. Transit agencies can only be competitive if they can provide services that are reliable (short wait time and less variation), have a short access time at both ends of the trip, and offer faster or comparable run times compared to passenger automobiles. Improving the reliability and frequency of service is important because "a main deterrent to bus travel is the uncertainty of bus arrival times at stops" [1]. Transit agencies should also work towards increasing the satisfaction of their clients [2]. Revising the current distribution of service coverage based on knowledge on travel needs can increase the competitiveness of transit agencies. Improving running times is also an important measure, yet it has to be significant enough for users to be able to perceive changes in service [3].

In order to improve decision making and manage transit fleets, many transit agencies in North America and around the world have implemented automatic vehicle location (AVL) and automatic passenger counting (APC). These technologies can be used, among others, to improve route design and scheduling [1]. They can also provide a comprehensive information set about the state of existing services.

The *Société de transport de Montréal* (STM), provides transit service on the island of Montréal and is considering various measures to improve bus service. One such improvement is the introduction of limited-stop or express bus service in parallel to the existing route in order to improve run times. Of course, express service is one of many techniques that can be implemented to improve travel times, such as stop-consolidation, reserved lanes and adjusting the placement of stops.

This report focuses on using archived AVL and APC data from the SCAD system for route 67 Saint Michel, a high frequency route in the eastern part of the City of Montréal, to select stops for implementing limited-stop bus service and to estimate run time savings along the modified route. This report is divided into a literature review of bus run time and limited-stop service followed by a description of the studied route. The next section pertains to the methodology used to prepare and analyze the data for run time, select stops for limited service and estimate the bus run time for the new service. Run time estimates for a weekday express service that will be implemented starting March 30, 2009 are given afterwards. It is then followed by a discussion of those results, a discussion on the applicability of this technique to other routes and cities, and a conclusion.

LITERATURE REVIEW

When passengers choose to use transit as a transportation mode, they take a number of factors into account. Passengers want a reliable service that arrives on-time, and minimizes both in-vehicle time [4] and access time [5]. In order for transit agencies to be able to meet these demands, it is necessary for them to understand and measure their performance. Therefore, AVL and APC systems have been implemented by a number of transit agencies [6, 7] and analyzed by a number of researchers with these goals in mind [6, 8, 9].

Run-time

A number of factors have an influence on the running time of buses. They can be divided into those that do not fall under the control of the transit agency, such as congestion or weather, and those that can be controlled by the agency such as route design and the behaviour of drivers [10]. Nevertheless, operators can still account for uncontrollable factors through scheduling and "real-time corrective actions" [10]. Reducing mean travel times is beneficial for the transit operator since it reduces operating costs and the number of vehicles required [11]. Transit users also seek to minimize their total travel time because it is a cost [11]. Minimization of transit travel times can thus attract new users to the system [12] and will greatly increase their overall satisfaction [5]. In order to reduce travel times, various strategies have been advanced. Vuchic [12] proposes various measures to increase the average speed of bus operations. These can be grouped into vehicle design, intersection design, stop placement and operational improvements. Levinson [13] found that many factors influence the running time, but that reducing the number of stops from 8 to 6 per mile leads to more time savings than eliminating the effects of congestion. Route length, passenger activity, and the number of intersections all have an effect on bus run times [14]. The number of actual stops [9, 15-17] also has an influence on run time. Strathman et al. [9] also found that passenger demand increases running time but that the time consumed per passenger decreases as the passenger activity increases at the stop. Low-floor buses are also expected to have an effect on bus running times [18]. The implementation of an AVL system on the whole fleet and relaying real-time information to operators through computer-aided dispatching (CAD) increases the reliability and reduces the running time. After implementation of these systems in Portland, OR, running times were reduced by an average of 1.45 minutes per trip [19]. Reducing the number of stops has been discussed as an effective measure for reducing run time. This reduction can be achieved either by stop consolidation [8] or by offering limited or express bus service. A limited-stop service is expected to reduce run time for the new limited service as well as for the regular service running in parallel. The use of archived AVL and APC data can help in estimating the time savings from implementing limited-stop service, which I have not noticed in the transit literature before.

Limited-stop service

Limited stop or express bus service has been recommended as a measure to decrease travel times and the number of vehicles needed for service [3, 12, 20]. Express or limited buses stop at only a few stops along a route while, in most cases, a parallel "local" or regular route serves all of the limited and intermediate stops. This can be contrasted with zonal service which makes all the stops in one zone and few or none in another [12]. One of the drawbacks of express service is that wait times tend to increase after implementation [20], therefore they should be parallel to routes with high ridership to allow passengers to minimize disruptions. There are no established criteria in the transit industry in order to select stops that should be served by express service. The selected stops should be located at major generators or stops with high activity [12, 21]. Stops on the limited route should be spaced several times greater than local stops [12]. In general, standards call for a spacing of 800 to 1,600 meters [20, 22, 23] or 450 meters [21] between express stops. This spacing contrasts with “local” bus stop spacing in urban areas which generally ranges from 200 to 600 meters [24]. It is also recommended that stops be located near transfer points and that they be paired with another stop in the opposite direction to avoid confusion for passengers [21]. The dilemma when designing a new limited-stop service is that the objective should be to minimize travel times – Ercolano [3] contends that user time savings need to be at least 5 minutes in order for users to perceive improvements – while trying to maximize the use of the service.

CASE STUDY

The STM operates bus and subway services on the island of Montréal which is home to about half of the inhabitants of the region. Four subway lines served by 759 cars and 192 bus routes served by 1600 vehicles comprise the STM network which carries over a million trips per weekday. Route 67 is located to the east of downtown Montréal and runs North-South along a boulevard crossing the neighbourhoods of Hochelaga-Maisonneuve, Rosemont-la-Petite-Patrie, Villeray-Saint-Michel-Parc-Extension, Ahuntsic-Cartierville and Montréal-Nord in the city of Montréal. The route is 9.16 km long in the northbound direction and 9.96 km southbound. Line 67 connects to two métro (subway) stations at its southern terminus and another at its midway point. As such, it is one of the busiest surface routes in the city with an average ridership of 40,400 on weekdays. The built form around the route consists mostly of 2 to 4 storey residential buildings mixed with some commercial and institutional buildings near major intersections. Table 1 includes a summary of route characteristics, while Figure 1 is a map of the studied route. Table 2 provides a list of stops for route 67 and gives the numbering used for the report and the STM stop numbers. Time points are highlighted in bold characters in this table.

Table 1: Physical Characteristics of Route 67 Saint-Michel

		Direction	
		Northbound	Southbound
Total	Length (kilometres)	9.16	9.96
	Intersections	45	62
	Traffic signals	40	43
	Number of stops	39	40
	Average stop spacing (meters)	241	255
Analysis	Length (kilometres)	8.43	9.34
	Intersections	50	56
	Traffic signals	36	40
	Number of stops	36	38

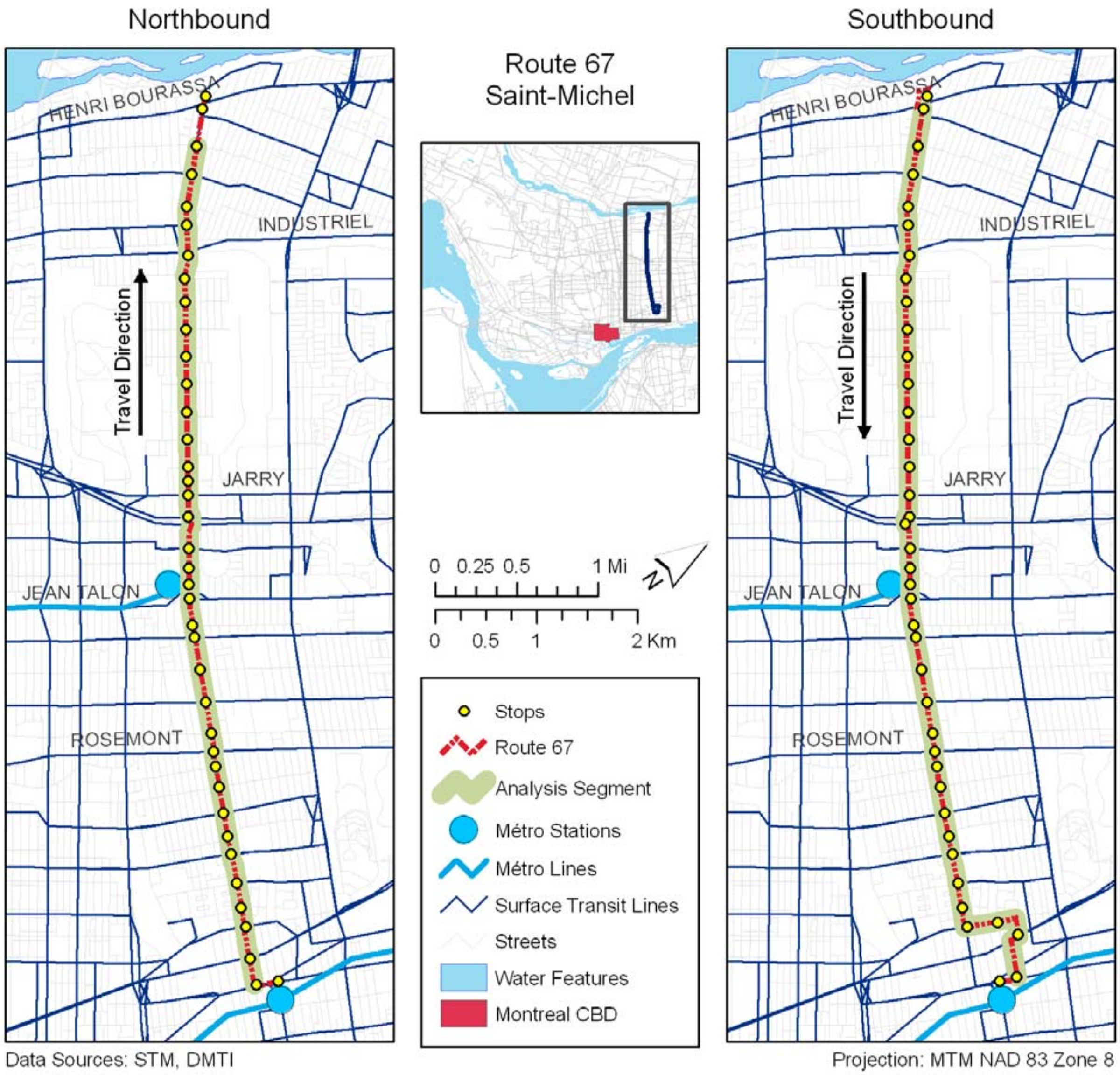

Figure 1: Route 67 Saint-Michel

The experience with APC and AVL technology at the STM dates back to 1999. The current system is the third generation and is equipped on 220 buses out of a fleet of 1,600. Buses equipped with APC and AVL are assigned to different routes to obtain a sample of bus operational information. Information is recorded at both the stop and trip levels by this system. This system is mostly used by the STM for revising schedules and generating performance measures such as schedule adherence.

Table 2: Route 67 Stops

Stop Number	Location	STM Stop Num.		Stop sequence	
		North	South	North	South
1	**Hochelaga at Joliette (Métro Joliette)**	**120142**	**120142**	**1**	**40**
2	Hochelaga at Davidson	119942	--	2	--
3	Davidson at Sherbrooke	119261	--	3	--
4	Saint-Michel/Davidson at Rachel	118491	118495	4	36
5	Saint-Michel at William-Tremblay	127391	127393	5	35
6	Saint-Michel at du Mont-Royal	117461	117293	6	34
7	**Saint-Michel at Saint-Joseph**	**116671**	**116673**	**7**	**33**
8	Saint-Michel at Laurier	116171	116173	8	32
9	Saint-Michel at Masson	115581	115583	9	31
10	Saint-Michel at Dandurand	114881	114883	10	30
11	Saint-Michel at Holt	114361	114363	11	29
12	Saint-Michel at Rosemont	114101	114103	12	28
13	Saint-Michel at de Bellechasse	113661	113663	13	27
14	Saint-Michel at Beaubien	112971	112973	14	26
15	Saint-Michel at St-Zotique	112381	112383	15	25
16	Saint-Michel at Bélanger	111761	111763	16	24
17	Saint-Michel at Bélair	141051	138423	17	23
18	Saint-Michel at Jean-Talon	111071	111073	18	22
19	**Saint-Michel at Everett (Métro Saint-Michel)**	**110916**	**110913**	**19**	**21**
20	Saint-Michel at Puccini	110631	110548	20	20
21	Saint-Michel at Villeray	110321	110323	21	19
22	Saint-Michel at Crémazie (Sud)	--	110068	--	18
23	Saint-Michel at Crémazie (Nord)	110061	110063	22	17
24	Saint-Michel at Jarry	109591	109593	23	16
25	Saint-Michel at d'Hérelle (Sud)	109321	--	24	0
26	**Saint-Michel at d'Hérelle (Nord)**	**129871**	**109323**	**25**	**15**
27	Saint-Michel at Deville	108791	108793	26	14
28	Saint-Michel at Robert	135291	108413	27	13
29	Saint-Michel at Denis Papin	107971	107973	28	12
30	Saint-Michel at Émile Journault	107616	107613	29	11
31	Saint-Michel at Legendre	107181	107183	30	10
32	**Saint-Michel at de Louvain**	**106781**	**106783**	**31**	**9**
33	Saint-Michel at Champdoré	106481	106488	32	8
34	Saint-Michel at Charland	106161	106168	33	7
35	Saint-Michel at Sauvé	105681	105683	34	6
36	Saint-Michel at de Mont-Joli	1800321	1800323	35	5

Stop Number	Location	STM Stop Num.		Stop sequence	
		North	South	North	South
37	Saint-Michel at Fleury	1800221	1800223	36	4
38	Saint-Michel at Prieur	1800171	1800173	37	3
39	Saint-Michel at Henri-Bourassa (Sud)	1802171	1802198	38	2
40	**Saint-Michel at Henri-Bourassa (Nord)**	**1802186**	**1802186**	**39**	**1**
41	Rachel at de Chambly	--	118844	--	37
42	Valois at Sherbrooke	--	119473	--	38
43	Nicolet at Hochelaga	--	120303	--	39

*Note: Time points are indicated using **bold** characters.

METHODOLOGY

The objective of this report is to select stops for a parallel limited-stop bus service and to estimate the run time of the new service by using archived AVL and APC data.

AVL and APC data was obtained from a sample of trips serving route 67. Over 273,000 individual stop records were obtained from the STM data archival system representing bus arrival and departure times at each stop along the route including information on passenger activity. The data was collected between August 27, 2007 and January 6, 2008.

The records were cleaned in order to remove errors in the raw data at the stop level. Errors included incomplete trips in which there were only 1 to 3 stops recorded per trip (976 stop level records). A number of trips, 135, were also removed from the analysis because they were bogus trips created to compensate for under-sampling; in addition, all of these trips had no time entries. One trip was also removed because the dwell time at a stop was negative (departure time was less than the arrival time). Another 122 trips were also excluded from the analysis because boardings and alightings were not equal. A total of 6,620 trips were kept for use in the analysis after data cleaning.

Table 3: Variables

Variable Name	Description
Run Time	The run time per trip in seconds from the departure of the second stop to the departure from the before last stop (southbound) and the 3rd last stop (northbound)
Average Load	The average load per trip
Boardings + Alightings Front Door	The number of boardings and alightings per trip through the front door
(Boardings + Alightings Front Door)^2	The square of the sum of boardings and alightings through the front door
Boardings + Alightings Back Door	The number of boardings and alightings per trip through the back door
(Boardings + Alightings Back Door)^2	The square of the sum of boardings and alightings through the back door
Southbound	Dummy variable for southbound trips
Weekday	Dummy variable for weekday trips (i.e. excluding weekends, holidays and weekdays over the Christmas holidays)
Low Floor	Dummy variable for trips served by low-floor buses
TD Early AM	Dummy variable for trips that departed between 3 AM and 6:30 AM
TD Peak AM	Dummy variable for trips that departed between 6:30 AM and 9:30 AM
TD Midday	Dummy variable for trips that departed between 9:30 AM and 3:30 PM
TD Peak PM	Dummy variable for trips that departed between 3:30 PM and 6:30 PM
TD Evening and Night	Dummy variable for trips that departed between 6:30 PM and 3 AM
Scheduled Stops	The number of scheduled stops for the trip
Actual Stops	The number of actual stops made during the trip
Rain (mm)	The amount of rain in millimetres for the day of the trip at Trudeau International Airport (obtained from Environment Canada)
Snow (cm)	The amount of snow falling on the day of the trip in centimetres at Trudeau International Airport (obtained from Environment Canada)
Snow Ground (cm)	The amount of snow on the ground on the day of the trip in centimetres at Trudeau International Airport (obtained from Environment Canada)
Delay Start	The delay at the start of the route
Actual Stops Scenario X	The number of actual stops made if the trip had been run as a scenario X limited service
Actual Stops Skipped Scenario X	The number of actual stops skipped if the trip had been run as a scenario X limited service
Passenger Activity Front Limited Scenario X	The number of passengers (boardings + alightings) using the front door at stops served by scenario X limited service for the trip
Passenger Activity Front Skipped Scenario X	The number of passengers (boardings + alightings) using the front door at stops skipped by scenario X limited service for the trip
Passenger Activity Back Limited Scenario X	The number of passengers (boardings + alightings) using the back door at stops served by scenario X limited service for the trip
Passenger Activity Back Skipped Scenario X	The number of passengers (boardings + alightings) using the back door at stops skipped by scenario X limited service for the trip

Analysis of this data was conducted at both the stop and trip levels. The first step was to prepare summary tables and a run time model to verify the quality of the data and identify if problems in the schedule do exist or not. After data cleaning and the elimination of short-turn runs, 6620 trips were left for trip level run time analysis. The trip level analysis excluded data from the first and last stops in both directions. The second last stop in the northbound direction also had to be removed from the analysis because layovers were often taken at this stop rather than the last scheduled stop. As such, the run time for this analysis was calculated from the departure at the second stop until the departure time at the last analysis stop (second last for southbound trips; third last for northbound trips). Table 3 contains a list of variables prepared for conducting the analysis.

In order to assess the robustness of the obtained AVL and APC data, a running time model was established at the trip level. The model incorporates a number of variables relating to the time of day, bus type, delay and passenger activity as well as variables that to our knowledge have not yet been used accounting for the weather [25] and separating the passenger activity by door. The following model was generated:

(1) Run Time = f(average load, passenger activity (boardings and alightings) at the front door, passenger activity at the front door squared, passenger activity at the back door, passenger activity at the back door squared, weekday trip, southbound trip, low-floor bus, early morning trip, AM peak trip, Midday trip, PM peak trip, number of actual stops, rain (mm), snow fallen (cm), snow on the ground (cm), delay beginning of trip)

In this model, the run time is expected to increase with passenger activity, for trips made on weekdays, for southbound trips, peak hour trips, with the delay at the beginning at the trip and with adverse weather conditions or the amount of snow on the ground. Trips served by low-floor buses and early morning trips are expected to decrease the run time.

Limited-stop route design

In order to design a limited-stop service, 3 scenarios based on a single criterion were created. To derive scenarios based on generators, we selected 1 out of 4 stops. This is based on the average spacing of stops on this route (250 meters) and the recommended spacing of 800 to 1,600 meters [20, 22, 23].

The first scenario kept only transfer stops (see figure 1). The second scenario selected the stops in the first quartile of passenger activity as measured by the APC counts. The third scenario used the Montréal origin-destination data for users of this route and selected the top quartile of stops with the most activity. The Montréal origin-destination survey dates from 2003 and contains disaggregate information on travel behaviour. For transit users, it contains the sequence of transit routes that were used in a trip. The walking distance to the nearest limited-service stop in each scenario was calculated and compared to the current situation by using the street network. For trips that were transferring from other bus routes, it is assumed that users whose transfer stop is not served by a limited service scenario would use another bus route before connecting to route 67.

Estimation of limited-stop service run times

To estimate the mean run time of the modified routes a model which divides passenger activity and actual stops between the stops served by the limited service and those that are skipped by this service was generated. A separate model is created for every scenario. It is expected that coefficients in these models will change slightly with each scenario. The general model is given below:

(2) Run time = f(average load, weekday trip, southbound trip, low-floor bus, early morning trip, AM peak trip, Midday trip, PM peak trip, number of actual stops, rain (mm), snow fallen (cm), snow on the ground (cm), delay beginning of trip, actual stops at stops served by limited stops, actual stops at skipped stops, front door boardings and alightings at stops served by limited service, front door boardings and alightings at stops skipped, back door boardings and alightings at stops served by limited service, front door boardings and alightings at skipped stops)

The model mentioned above was then used to estimate run times for the various scenarios. In fact, the effects of passenger activity and the actual stops made by the current service at skipped stops are isolated in order to estimate run times. Since estimating the actual number of passengers switching between regular and limited bus services is not possible without generating a demand function, a range of run time savings will be estimated. Three run times were estimated for each of the limited stop service scenarios and the regular service. The estimated mean travel times were calculated by multiplying the coefficients from the models with the mean values of these variables (hereby referred to as time component).

For the "realistic" (or best estimate) limited-stop estimated mean travel time, the time associated with front and back door passenger activity and the actual stops skipped is subtracted from the mean running time derived from the models. For the realistic regular route, the time associated with passenger activity at the stops served by the limited service is subtracted from the mean running time derived from the models. This assumes that all passengers at skipped stops would use the regular service and all passengers at actual stops served by the limited service would use this new service. This method assumes a zero sum game among the number of passengers switching between stops when limited service is offered. For the optimistic run time estimate for limited service, the passenger demand and actual stops skipped is removed. The optimistic regular route would have the same average running time as the current route. For the pessimistic run time estimate, it is assumed that all passenger demand would use the limited service by removing the actual stops skipped. The pessimistic regular route subtracts the passenger demand from the mean run time.

The assumptions mentioned in the previous paragraph are given in the table below:

Table 4: Assumptions used to estimate limited-stop service run times

Time Estimate	**Variable(s) Removed**		**Assumption**
	Express	**Regular**	
Realistic	-Actual stops skipped -Boardings and alightings at front door skipped -Boardings and alightings at back door skipped	-Boardings and alightings at front door -Boardings and alightings at back door	Passengers at stops served by the limited use this service; passengers boarding or alighting at stops not served by the limited use the regular service.

Time Estimate	Variable(s) Removed		Assumption
	Express	Regular	
Optimistic	-Actual stops skipped -Boardings and alightings at front door -Boardings and alightings at front door skipped -Boardings and alightings at back door -Boardings and alightings at back door skipped	(none)	Passengers only use the regular service.
Pessimistic	-Actual stops skipped	-Boardings and alightings at front door -Boardings and alightings at front door skipped -Boardings and alightings at back door -Boardings and alightings at back door skipped	All passengers only use the limited-stop service (i.e. every passenger walks to the closest stop served by the express).

ANALYSIS

The average run time along route 67 is just over 40 minutes which contrasts with the mean scheduled time of just under 39 minutes. For the analysis section, the pattern is similar: vehicles take longer to complete the route than is scheduled. This might be a problem in terms of schedule adherence when the fact that the average bus leaves 48 seconds later than the scheduled departure is considered. Summary statistics are reported in Table 5.

In terms of passenger activity, there is an average of 116 passengers using the front door while an average 48 passengers use the back door per trip. Because passenger activity outside the analysis segment for the trip was excluded, as would be expected, the number of passengers boarding and alighting does not add up in any trip. In average around 92 passengers will board a bus on an average trip, although the average load over the length of the trip is of less than 24 passengers. The mean number of actual stops in the analysis segment (30 out of 35 or 37 scheduled stops depending on route direction) suggests that limited service might yield some significant time savings. The high stopping frequency is also reflective of high passenger activity.

The average daily rainfall, snow and snow on the ground per trip during the study period were 1.46 mm, 0.84 cm and 6.9 cm respectively. The problem with these weather variables is that they vary considerably from their mean values. The extreme values suggest that certain weather events might have important impacts on travel time.

Table 5: Summary Statistics

Variable	Minimum	Maximum	Mean	Std.
Run Time (Analysis)	1096	3548	2088.30	237.39
Scheduled Run Time (Analysis)	1680	2460	2181.33	207.86
Actual Run Time	1208	7896	2408.88	276.35
Scheduled Run Time	1800	2640	2334.70	194.66
Delay Start	-783	1758	47.89	120.22
Boardings front door	0	247	91.98	37.72
Alightings front door	0	130	43.73	15.45
Boardings and alightings front door	0	323	115.97	47.23
$(\text{Boardings and alightings front door})^2$	0	104329	15680.37	12233.40
Boardings back door	0	40	0.54	1.84
Alightings back door	0	170	48.79	25.12
Boardings and alightings back door	0	201	48.11	25.24
$(\text{Boardings and alightings front door})^2$	0	40401	2951.19	3197.50
Average Load	0	59	23.87	9.32
Boardings (Analysis)	0	229	73.68	34.28
Alightings (Analysis)	0	249	90.40	37.57
Southbound	0	1	0.48	0.50
Actual Stops	0	37	30.06	3.69
Low floor bus	0	1	0.89	0.31
Weekday	0	1	0.671	0.470
TD Early AM	0	1	0.049	0.216
TD Peak AM	0	1	0.17	0.37
TD Midday	0	1	0.38	0.48
TD Peak PM	0	1	0.18	0.39
TD Late PM	0	1	0.22	0.42
Rain (mm)	0	39	1.46	4.07
Snow (cm)	0	32	0.84	2.89
Snow ground (cm)	0	40	6.90	11.82

Run-time and delays

The running times and delays were then analyzed by direction. The objective is to confirm whether or not there are any problems with the schedule or with schedule adherence. The following variables were analyzed: actual run time (departure at the first stop to the arrival at the last stop), the scheduled run time (from the first to last stop), the delay at the start of the route (departure time minus the scheduled departure time), the delay at the end of the route and the delay at the last time point (Saint-Michel and Saint-Joseph southbound; Saint-Michel and de Louvain northbound).

Southbound buses take on average an additional 2.5 minutes more per trip (40.49 minutes northbound vs. 39.78 minutes southbound) which is expected given the additional stop, the extra turns, traffic signals and route length (run times per direction are given in table 6). When looking at the mean scheduled time per direction and the standard deviation of the actual run time, we notice that there is a problem with the schedule in the northbound direction because this delay (3.24 minutes) is greater than the standard deviation. For southbound buses, the difference between the mean scheduled and run times, 40.69 and 39.78 minutes respectively, is less than a minute and also less than the standard deviation of the actual run time (2.59 minutes). This suggests that there are no major problems with the schedule in the southbound direction.

Table 6: Run times by direction

		Mean	Std.	Minimum	Maximum
Northbound	Actual run time (minutes)[1]	40.49	4.59	20.13	61.70
	Analysis segment actual run time (minutes)	33.43	3.56	18.26	49.98
	Scheduled Route Run Time (minutes)	37.25	2.90	30.00	42.00
	Delay at start of route (minutes)	0.91	2.10	-12.84	28.51
	Delay at end of route (minutes)	4.15	4.40	-13.03	33.05
	Delay at before last timepoint (minutes)	1.07	2.88	-14.50	29.13
Southbound	Actual run time (minutes)	39.78	4.60	21.67	131.60
	Analysis segment actual run time (minutes)	36.26	3.84	19.80	59.13
	Scheduled route run time (minutes)	40.69	2.59	31.00	44.00
	Delay at start of route (minutes)	0.68	1.89	-13.05	29.30
	Delay at end of route (minutes)	-0.22	4.24	-13.25	92.79
	Delay at before last timepoint (minutes)	1.46	2.99	-10.80	32.31

Histograms of the actual run time and schedule run time per direction were then generated and are given in figures 2 to 5. For both directions, the actual running times are distributed normally around the mean. The distribution for scheduled run times is not normal since schedules are adjusted based on the time of day. Southbound scheduled run times are mostly clustered in the upper ranges while northbound scheduled times vary more.

[1] It is important to distinguish between the run time for the entire route and the analysis segment. The analysis segment is shorter than the entire route. The extreme values of the run time were due to problems that were outside of the analyzed segment for the purposes of this analysis.

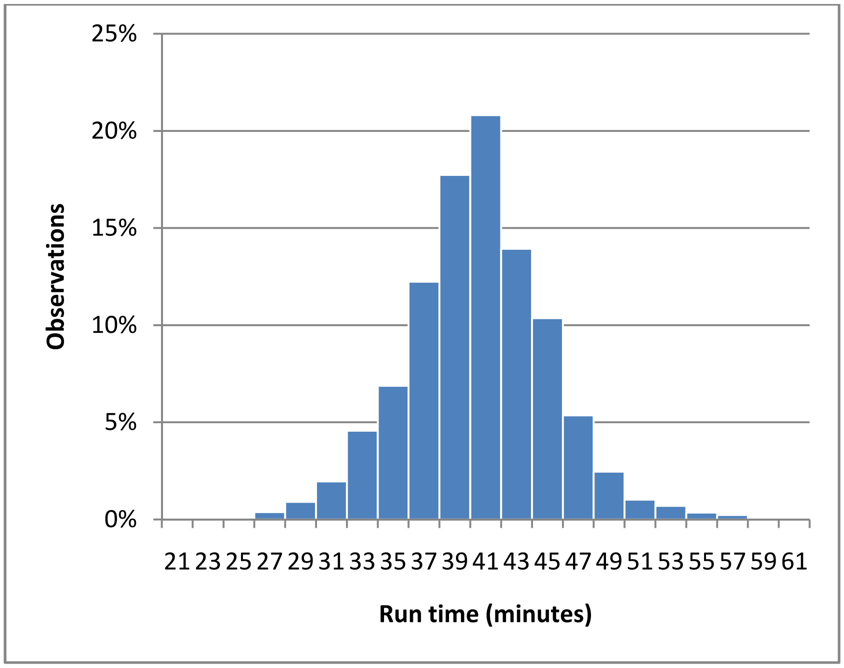

Figure 2: Actual run time – northbound

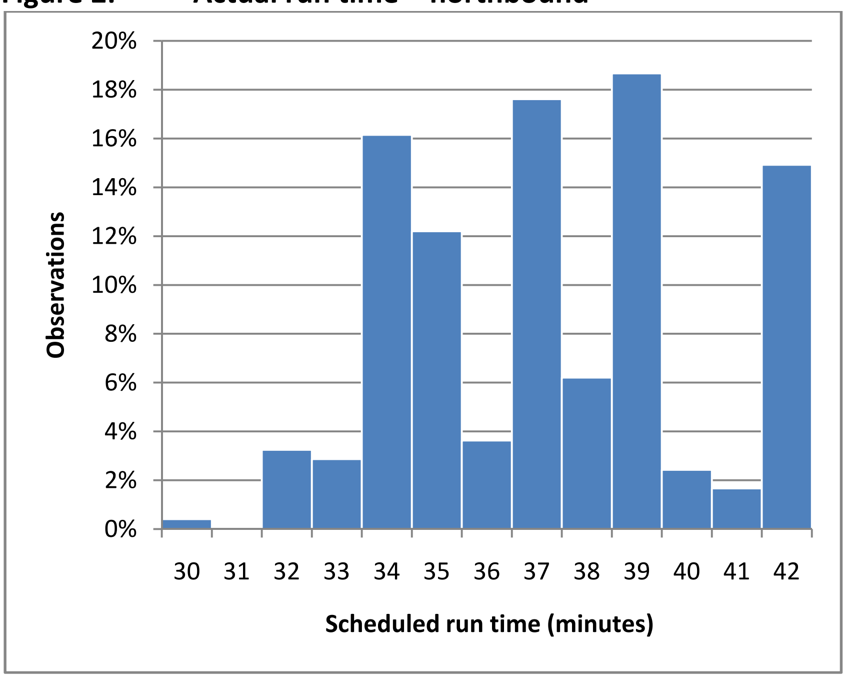

Figure 3: Scheduled run time – northbound

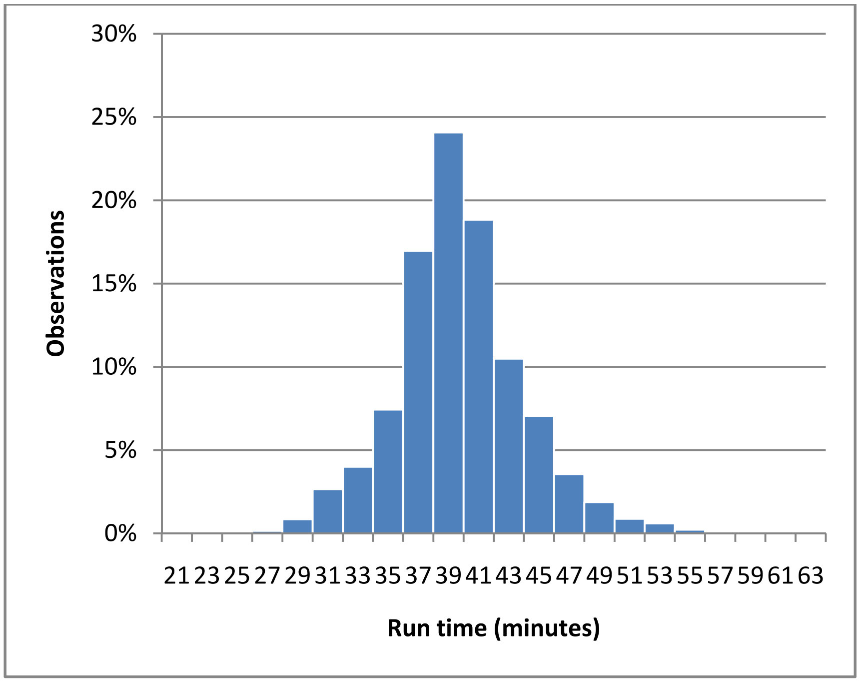

Figure 4: Actual run time – southbound

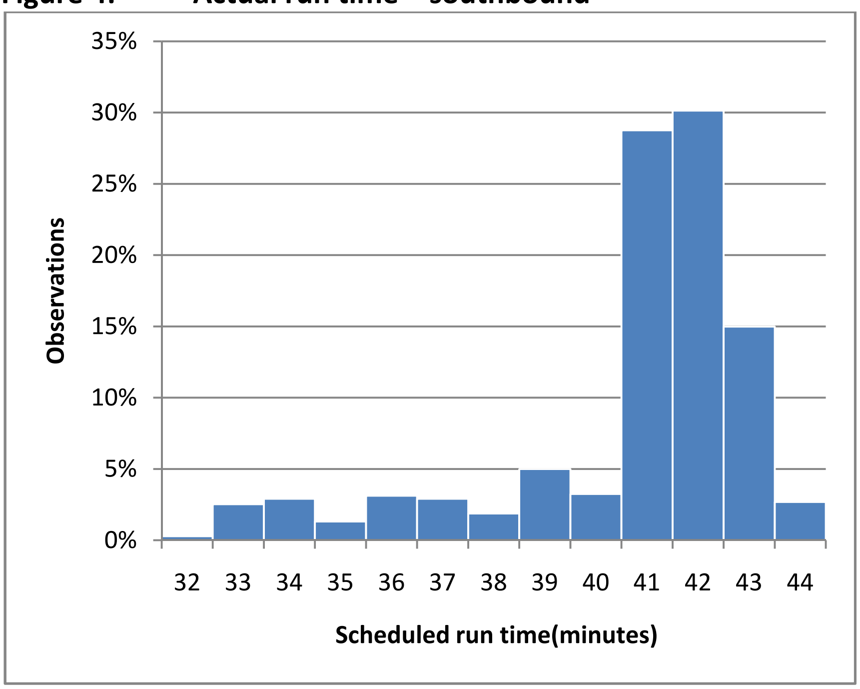

Figure 5: Scheduled run time – southbound

The delay at the start of the trip, the end of the trip and at the before last time-point were then analyzed. At the start of the route, the average run starts less than a minute late (see table 6). The standard deviation (1.89 minutes southbound and 2.10 minutes northbound) is also low which suggests that most trips are starting close to the scheduled trip start time. This can also be seen in the distribution of the delays (see figures 6 and 7).

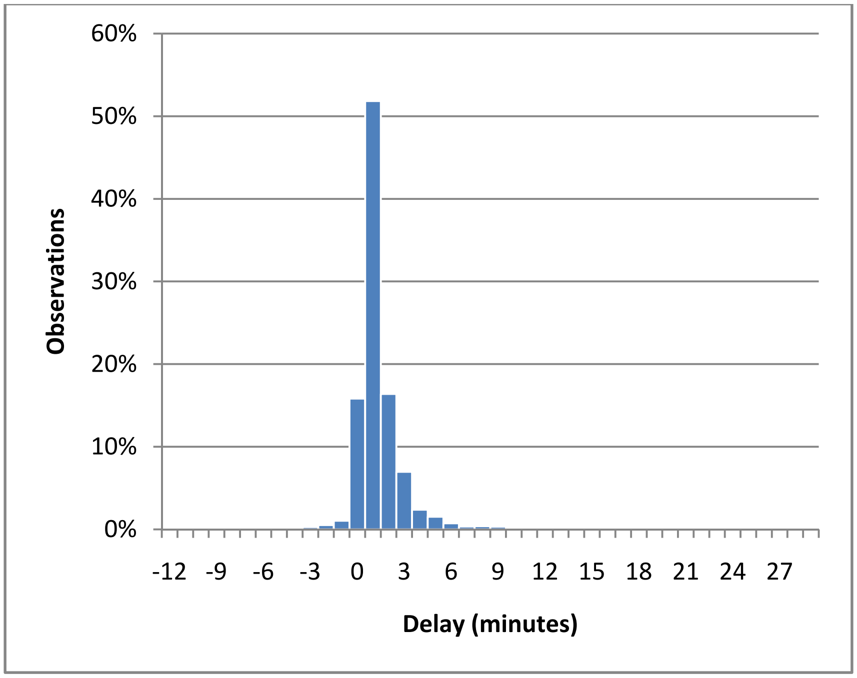

Figure 6: Delay at start of trip – northbound

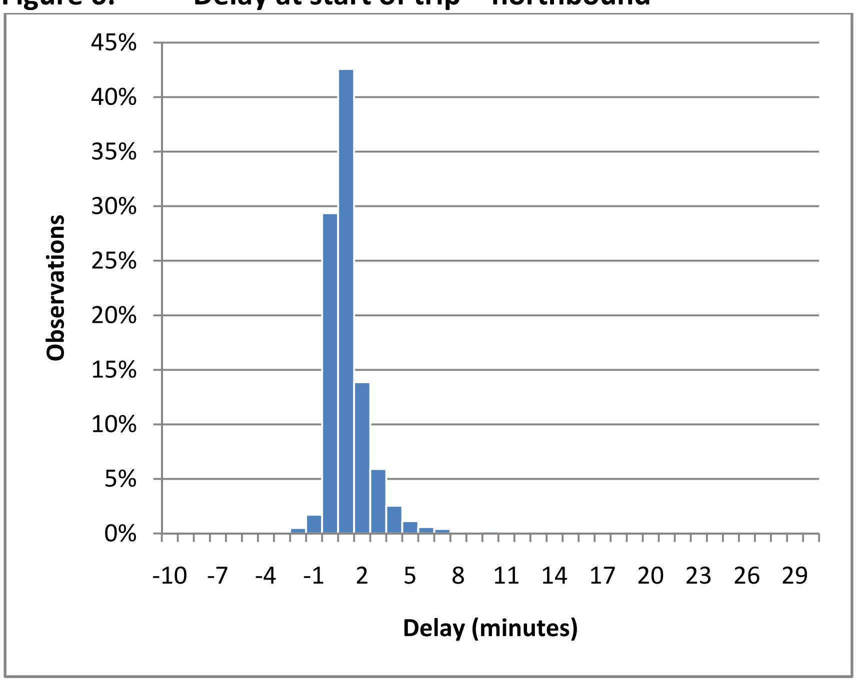

Figure 7: Delay at start of trip - southbound

Since there does not appear to be a problem with the drivers' ability to start on time, the delay at the end of the run is analyzed. On average buses arrive at the Joliette métro station 0.22 minutes early while they arrive 4.15 minutes late at Henri-Bourassa and Saint-Michel. When looking at the histograms, we notice that the run times are distributed around the mean value with a higher proportion of delays being above than below the mean (see figures 8 and 9). Buses are probably arriving consistently late in the northbound direction because many drivers have been observed to take their layovers at the previous stop to the south of Henri-Bourassa Boulevard.

Because many layovers are not taken at the last stop, the schedule adherence at the previous time-point was analyzed. For the southbound direction, this time-point is at the intersection of boulevard Saint-Michel and boulevard Saint-Joseph. In the northbound direction, the time-point is at the intersection of boulevard Saint-Michel and de Louvain Street East. In the northbound direction, buses are on average late by just over a minute. This confirms that the problem with the schedule is occurring between the end of the route and the previous time point. For the southbound direction, buses are leaving 1.46 minutes late on average from the intersection of Saint-Michel and Saint-Joseph, but drivers are arriving on-time at the next time point. Histograms of the delay at the before last time-point are given in figures 10 and 11.

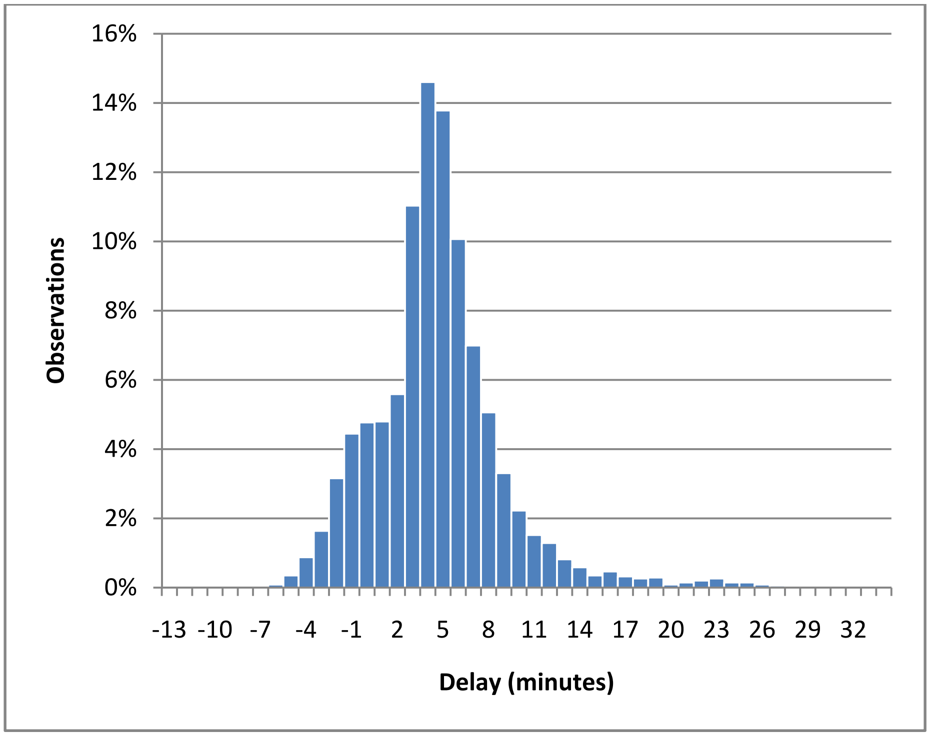

Figure 8: Delay at end of trip – northbound

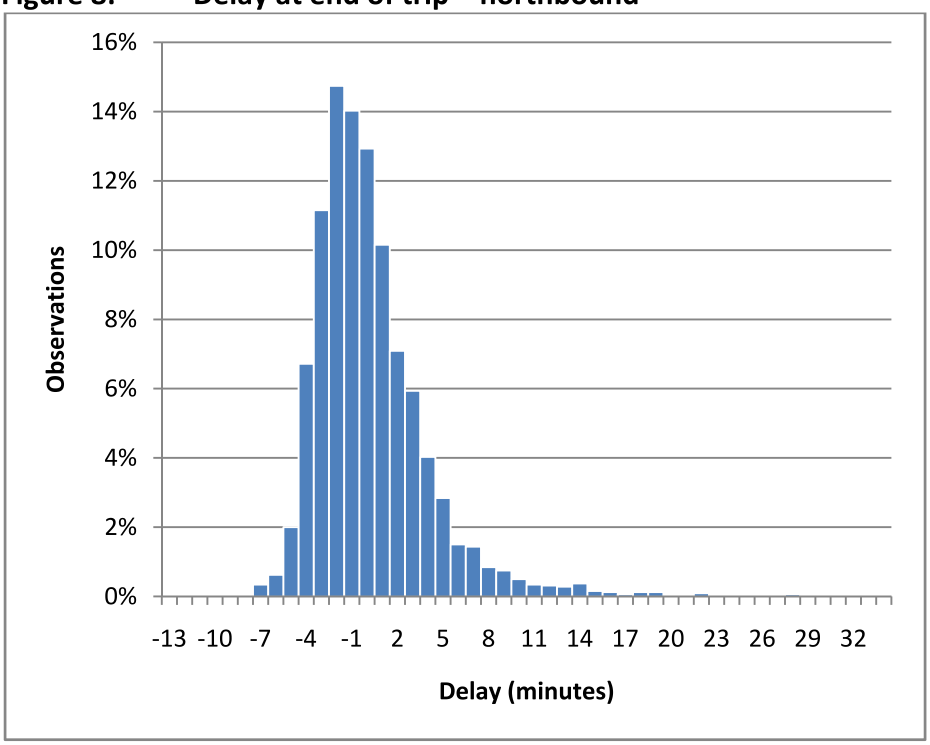

Figure 9: Delay at end of trip – southbound

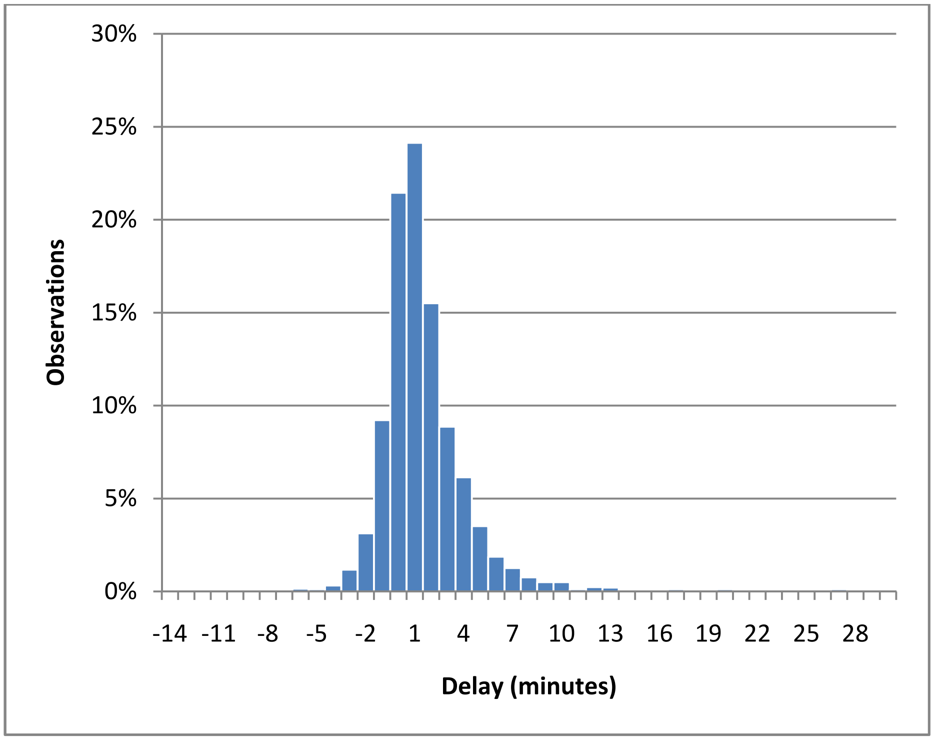

Figure 10: Delay at the before last time-point (Saint-Michel and de Louvain) – northbound

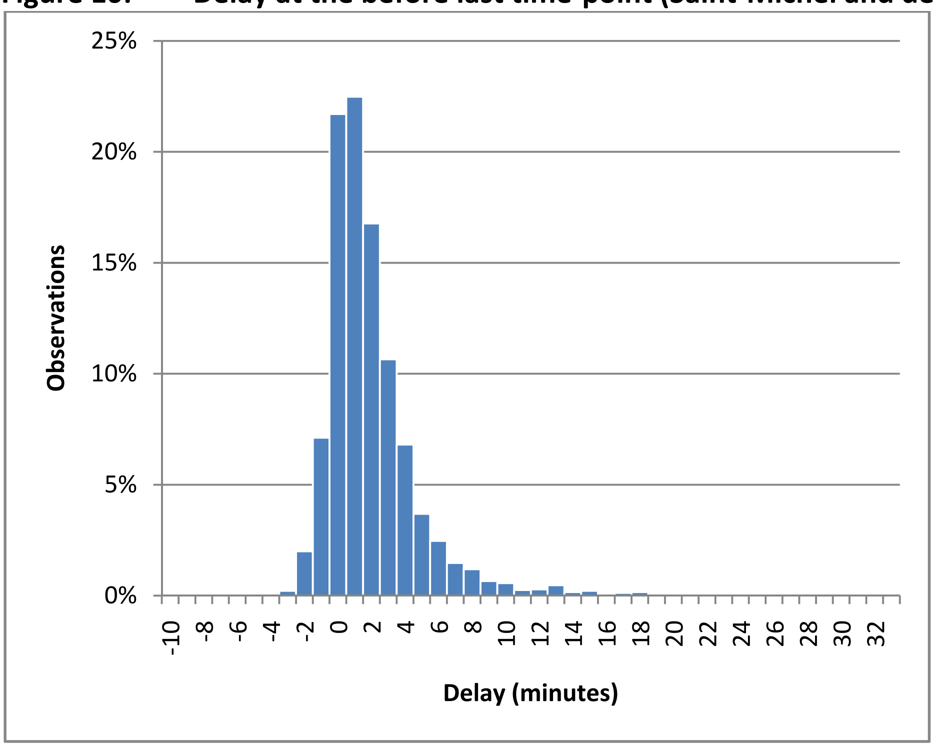

Figure 11: Delay at the before last time-point (Saint-Michel and Saint-Joseph) - southbound

Run time model

Since this is the first time that archived STM AVL and APC data has been used for this type of analysis, the first step is to develop a generalized run time model to assess the data. The characteristics of this model are well known. Checking the effects of independent variables on run time and to what extent it follows the theory of transit planning is used as a benchmark for assessing the quality of the collected data. A general multivariate linear OLS regression model for run time was derived using the archived trip data and is given in the following table.

Table 7: Run Time Model

Variable	B	t
Constant	1443.48	82.51**
Average Load	-2.34	-4.05**
Boardings + Alightings Front Door	2.11	8.22**
(Boardings + Alightings Front Door)^2	-0.003	-3.82**
Boardings + Alightings Back Door	-0.99	-2.38*
(Boardings + Alightings Back Door)^2	0.02	8.47**
Weekday	39.45	9.26**
Southbound	151.39	37.56**
Low Floor	-98.31	-15.50**
TD Early AM	-136.41	-14.55**
TD Peak AM	51.40	8.26**
TD Midday	90.83	16.47**
TD Peak PM	180.15	28.61**
Actual Stops	12.89	15.89**
Rain (mm)	1.81	3.81**
Snow (cm)	2.87	4.37**
Snow Ground (cm)	2.26	12.90**
Delay Start	-0.05	-3.91**
R^2	0.603	
N	6620	

Dependent Variable: Run Time (seconds)

* 95% significant or higher | ** 99% significant or higher

As expected, the run time decreased (-2.34 seconds/passenger) as average passenger loads increased. Passenger activity (boardings and alightings) at the front door increases the running time by 2.11 seconds per passenger, but since the activity at the front door squared is negative, the time per passenger decreased as the overall passenger activity increased. At the back door, each passenger decreases the run time by 0.99 seconds. This shows that use of the back door has a benefit on the run time, but since the passenger activity squared is positive, the time used by passenger increases as activity increases. The type of bus used for the route also has some benefits; low-floor buses are 98 seconds faster than high-floored buses if all other values are kept to their means. Weekday trips were longer by 39 seconds. Southbound trips were also longer by 151 seconds, which accounts for the additional distance, intersections and traffic signals. The time of day also has an important influence on run time. It is interesting to note that the coefficient associated with mid-day trips is greater than am peak trips. Of course, trips in the AM peak would still be longer when accounting for increased passenger activity, but this might be due to waiting at time points or other factors apart from traffic conditions. PM peak trips are much longer (180 seconds), probably due to the effects of congestion. The number of stops actually made also increases the run time and mostly accounts for deceleration and acceleration time (12.9 seconds per actual stop). Buses starting their runs late are faster than on time or ahead of schedule buses. Drivers seem to be adjusting their behaviour based on whether they are ahead or behind schedule since run times decrease by 0.05 seconds for every second of delay. As Montréal is also known for its winters, the weather variables had a statistically significant impact on run time. For every millimetre of rain on a given day, the trip took an additional 1.81 seconds if all other values are kept to their mean. Snow also has an important impact on run time. For every centimetre of snow, the run time would increase by 2.87 seconds. The snow on the ground which accounts for lower temperatures and delays in snow clearing also has an impact on the travel time (2.26 seconds per centimetre of snow on the ground). The previous model shows us that it compares to previous research and can be used further for analysis which establishes the robustness of the STM collection and archival system.

Selection of stops

For limited-stop bus service, four different scenarios were generated. Scenario 1 selects stops based on transfer-points. The second selected stops based on passenger activity as measured by the SCAD system. The third scenario selected stops based on the OD survey. The last scenario combines the results of the first three scenarios. Another limited-stop service was also analyzed after the initial results were presented and are available in a separate section (see page 44).

Run time models are generated for each scenario isolating the actual stops skipped and passenger activity.

Scenario 1

In scenario 1, all stops that were transfer points are selected for the limited service. This scenario does not adjust for the frequency of intersecting routes. As can be seen in figure 12, intersecting routes are numerous and are often clustered together. This suggests that not all transfer points should be served by limited service. This scenario was developed to prove that a suggestion from theory and practice that just providing limited service at transfer points only is suboptimal.

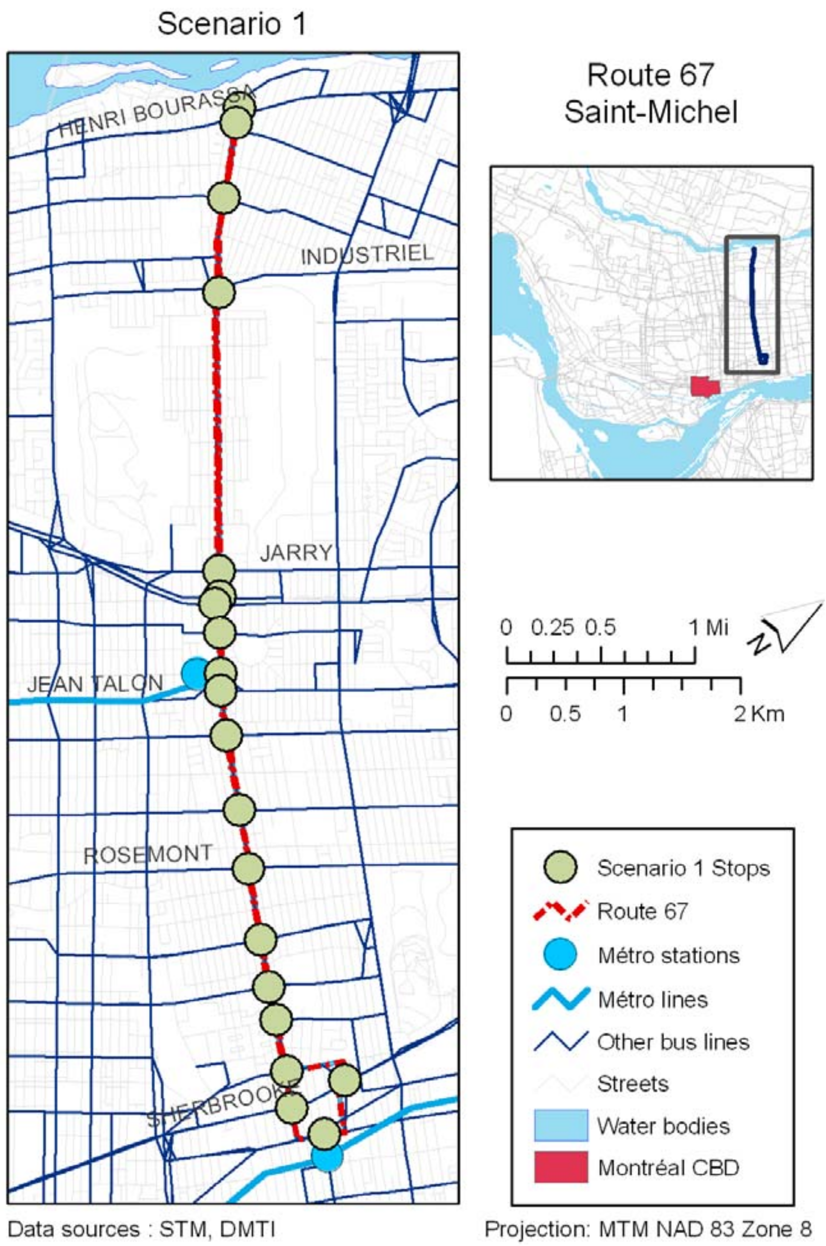

Figure 12: Selected stops for scenario 1

Table 8: Selected stops for scenario 1

Stop Number	Location	STM Stop Num.		Stop sequence	
		North	South	Nord	South
1	Hochelaga et Joliette (Métro Joliette)	120142	120142	1	40
3	Davidson et Sherbrooke	119261	--	3	--
4	Saint-Michel/Davidson et Rachel	118491	118495	4	36
6	Saint-Michel et du Mont-Royal	117461	117293	6	34
7	Saint-Michel et Saint-Joseph	116671	116673	7	33
9	Saint-Michel et Masson	115581	115583	9	31
12	Saint-Michel et Rosemont	114101	114103	12	28
14	Saint-Michel et Beaubien	112971	112973	14	26
16	Saint-Michel et Bélanger	111761	111763	16	24
18	Saint-Michel et Jean-Talon	111071	111073	18	22
19	Saint-Michel et Everett (Métro Saint-Michel)	110916	110913	19	21
21	Saint-Michel et Villeray	110321	110323	21	19
22	Saint-Michel et Crémazie (Sud)	--	110068	--	18
23	Saint-Michel et Crémazie (Nord)	110061	110063	22	17
24	Saint-Michel et Jarry	109591	109593	23	16
34	Saint-Michel et Charland	106161	106168	33	7
37	Saint-Michel et Fleury	1800221	1800223	36	4
39	Saint-Michel et Henri-Bourassa (Sud)	1802171	1802198	38	2
40	Saint-Michel et Henri-Bourassa (Nord)	1802186	1802186	39	1
42	Valois et Sherbrooke	--	119473	--	38

Scenario 2

Scenario 2 involved selecting stops based on passenger activity (alightings and boardings) at every stop along the route. As can be seen in Figure 13, many stops in the middle of the route have high passenger activity without being transfer points. The highest passenger activity, by far, was at métro stations as seen in Figure 13 and Table 9. Although the stops with the most activity are at transfer points, some stops in the middle part of the route, such as Saint-Michel and Legendre, have higher passenger activity than certain transfer stops such as Davidson and Sherbrooke.

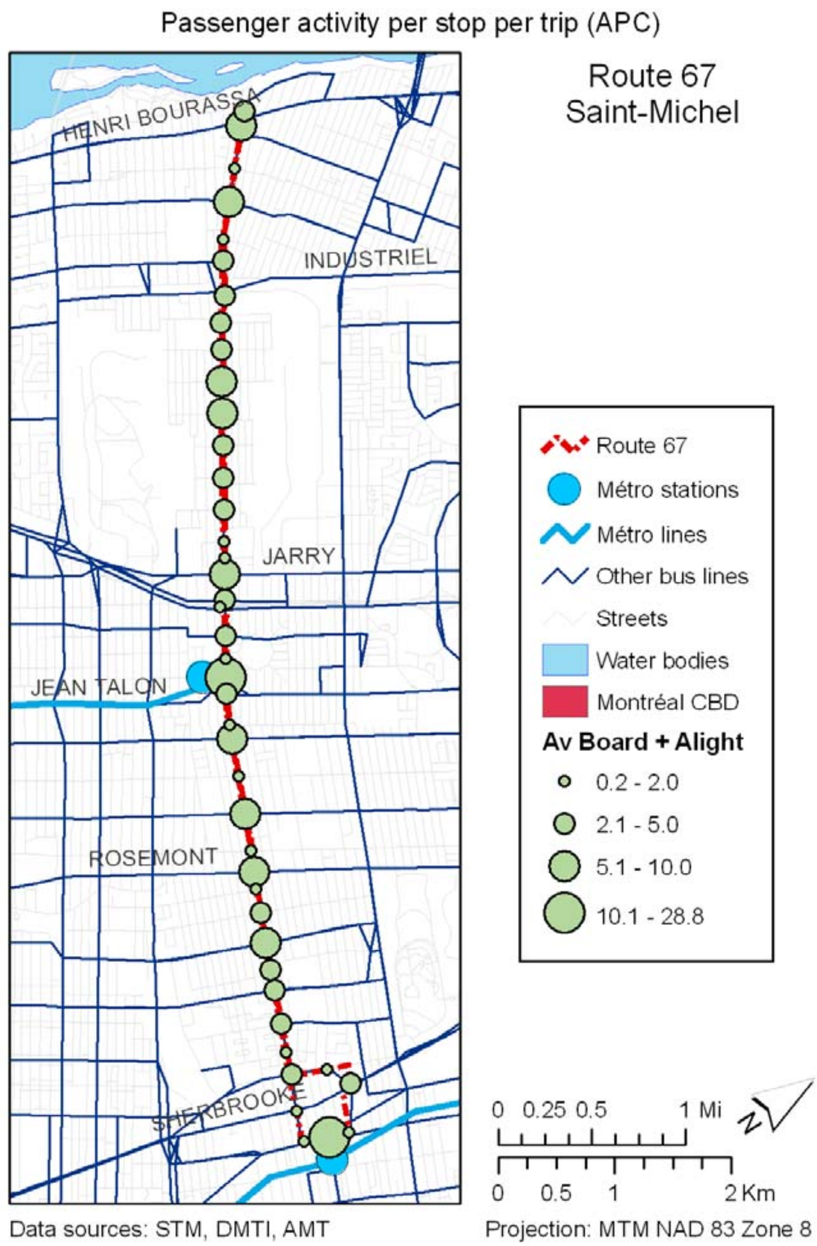

Figure 13: Passenger Activity by Stop

Table 9: Passenger Activity by Stop

Stop	Location	Boardings		Alightings		Boardings and Alightings	
		Mean	Std.	Mean	Std.	Mean	Std.
1	Hochelaga et Joliette (Métro Joliette)	11.99	15.23	9.11	11.9	21.10	12.77
2	Hochelaga et Davidson	0.81	1.39	0.15	0.45	0.96	1.48
3	Davidson et Sherbrooke	0.93	1.55	0.63	0.98	1.56	1.92
4	Saint-Michel/Davidson et Rachel	0.90	1.38	1.10	1.41	2.01	2.08
5	Saint-Michel et William-Tremblay	0.76	1.25	1.11	1.49	1.87	2.05
6	Saint-Michel et du Mont-Royal	1.31	1.83	1.18	1.62	2.49	2.42
7	Saint-Michel et Saint-Joseph	1.96	2.22	1.79	1.92	3.75	3.07
8	Saint-Michel et Laurier	1.03	1.53	1.00	1.46	2.03	2.13
9	Saint-Michel et Masson	4.64	3.75	4.86	3.82	9.50	5.96
10	Saint-Michel et Dandurand	1.57	2.08	1.41	1.71	2.98	2.66
11	Saint-Michel et Holt	0.41	0.89	0.43	0.88	0.84	1.27
12	Saint-Michel et Rosemont	2.64	2.92	2.62	2.45	5.25	4.32
13	Saint-Michel et de Bellechasse	0.86	1.36	0.97	1.47	1.83	2.16
14	Saint-Michel et Beaubien	4.12	4.28	4.01	3.55	8.13	6.20
15	Saint-Michel et St-Zotique	0.74	1.15	0.71	1.11	1.46	1.61
16	Saint-Michel et Bélanger	2.62	2.68	2.48	2.27	5.10	3.92
17	Saint-Michel et Bélair	0.76	1.17	0.88	1.25	1.64	1.85
18	Saint-Michel et Jean-Talon	1.84	2.74	1.00	1.97	2.84	4.07
19	Saint-Michel et Everett (Métro Saint-Michel)	13.66	10.16	15.19	10.3	28.85	14.57
20	Saint-Michel et Puccini	0.13	0.50	0.13	0.52	0.27	0.79
21	Saint-Michel et Villeray	2.20	2.74	2.45	3.08	4.65	4.41
22	Saint-Michel et Crémazie (Sud)	0.48	1.04	0.74	1.22	1.22	1.72
23	Saint-Michel et Crémazie (Nord)	1.63	2.30	1.38	1.89	3.01	3.17
24	Saint-Michel et Jarry	4.37	3.88	4.50	3.49	8.87	5.90
25	Saint-Michel et d'Hérelle (Sud)	0.42	0.84	0.35	0.77	0.77	1.22
26	Saint-Michel et d'Hérelle (Nord)	0.83	1.34	0.96	1.48	1.79	1.94
27	Saint-Michel et Deville	0.95	1.43	1.09	1.49	2.04	2.14
28	Saint-Michel et Robert	1.71	2.09	1.83	2.02	3.54	2.84
29	Saint-Michel et Denis Papin	2.29	2.77	2.20	2.42	4.49	3.55
30	Saint-Michel et Émile Journault	2.71	3.23	2.62	2.80	5.33	3.84
31	Saint-Michel et Legendre	3.73	3.63	3.88	3.59	7.61	4.84
32	Saint-Michel et de Louvain	2.38	3.08	2.46	3.48	4.84	4.43
33	Saint-Michel et Champdoré	1.80	2.93	1.86	2.53	3.66	3.99
34	Saint-Michel et Charland	0.95	1.71	1.72	2.27	2.68	2.78
35	Saint-Michel et Sauvé	2.37	3.51	1.86	1.97	4.23	4.24
36	Saint-Michel et de Mont-Joli	0.58	1.23	0.64	1.20	1.22	1.87
37	Saint-Michel et Fleury	2.63	3.12	2.84	3.00	5.48	4.35
38	Saint-Michel et Prieur	0.80	1.49	0.77	1.40	1.58	1.96
39	Saint-Michel et Henri-Bourassa (Sud)	3.38	5.24	5.67	7.52	9.05	8.01
40	Saint-Michel et Henri-Bourassa (Nord)	3.00	4.84	0.29	1.52	3.29	4.92
41	Rachel et de Chambly	0.46	0.92	0.72	1.08	1.18	1.48
42	Valois et Sherbrooke	0.69	1.32	2.34	3.82	3.03	4.34
43	Nicolet et Hochelaga	0.11	0.91	1.53	4.54	1.64	4.98

Since not all transfer points have high passenger activity, this suggests that there would be a smaller impact on users by excluding some transfer points. This scenario still has the disadvantage of having a few successive stops clustered together. A 1 in 4 ratio was used to select stops (i.e. the top 12 stops in terms of passenger activity along the route were selected [see Figure 14]).

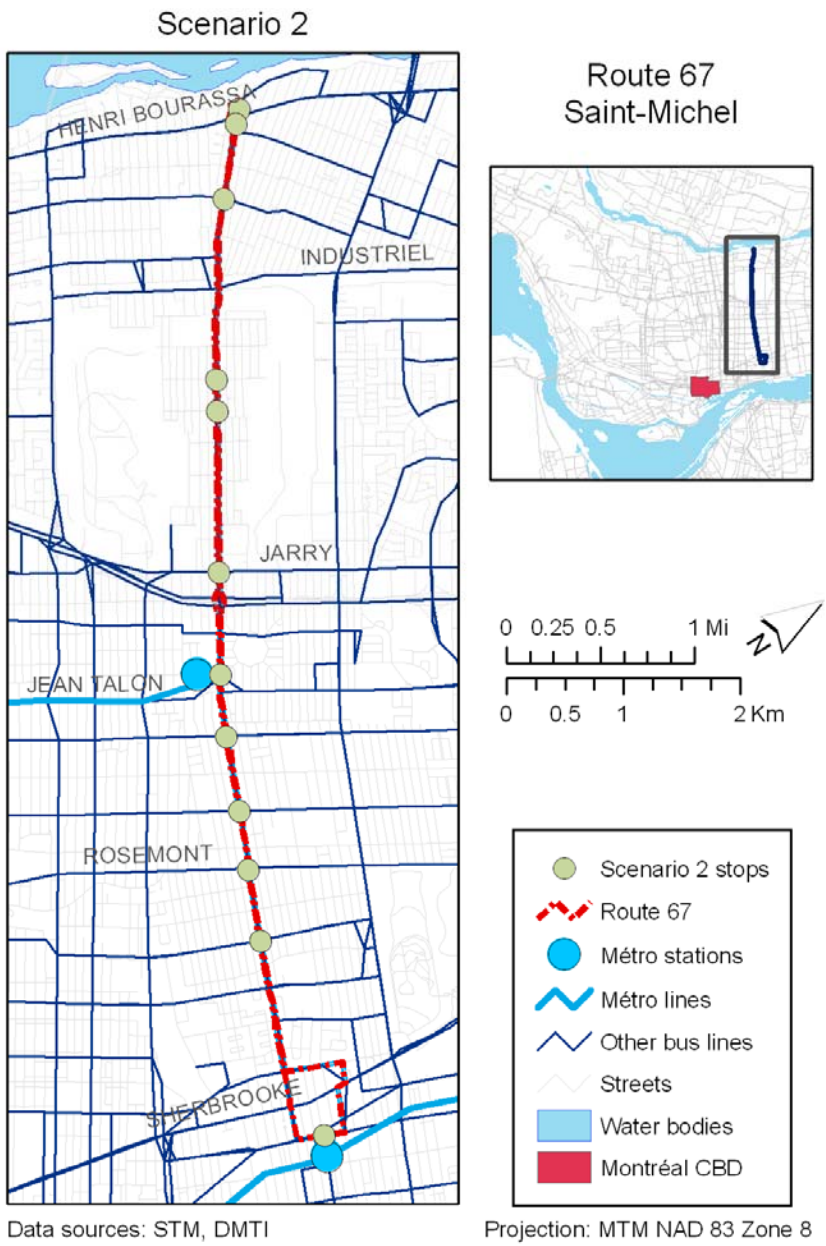

Figure 14: Selected stops for scenario 2

Table 10: Selected stops for scenario 2

Stop Number	Location	STM Stop Num.		Stop sequence	
		North	South	Nord	South
1	Hochelaga et Joliette (Métro Joliette)	120142	120142	1	40
9	Saint-Michel et Masson	115581	115583	9	31
12	Saint-Michel et Rosemont	114101	114103	12	28
14	Saint-Michel et Beaubien	112971	112973	14	26
16	Saint-Michel et Bélanger	111761	111763	16	24
19	Saint-Michel et Everett (Métro Saint-Michel)	110916	110913	19	21
24	Saint-Michel et Jarry	109591	109593	23	16
30	Saint-Michel et Émile Journault	107616	107613	29	11
31	Saint-Michel et Legendre	107181	107183	30	10
37	Saint-Michel et Fleury	1800221	1800223	36	4
39	Saint-Michel et Henri-Bourassa (Sud)	1802171	1802198	38	2
40	Saint-Michel et Henri-Bourassa (Nord)	1802186	1802186	39	1

Scenario 3

For the third scenario, data from users that declared that they used this bus route in the Montréal origin-destination were used. Trips from the survey were assigned to the transferring stop or the closest stop from their origin/destination based on whether users transferred from another route or walked to the route. This was done using the closest facility tool in ArcGIS's Network Analyst extension with scenario 3 stops as "facilities" and origins/destinations as "incidents". A road network from DMTI of the Montréal region was used to do this analysis. Recreational paths were included to this network while freeways were removed for the purpose of this analysis.

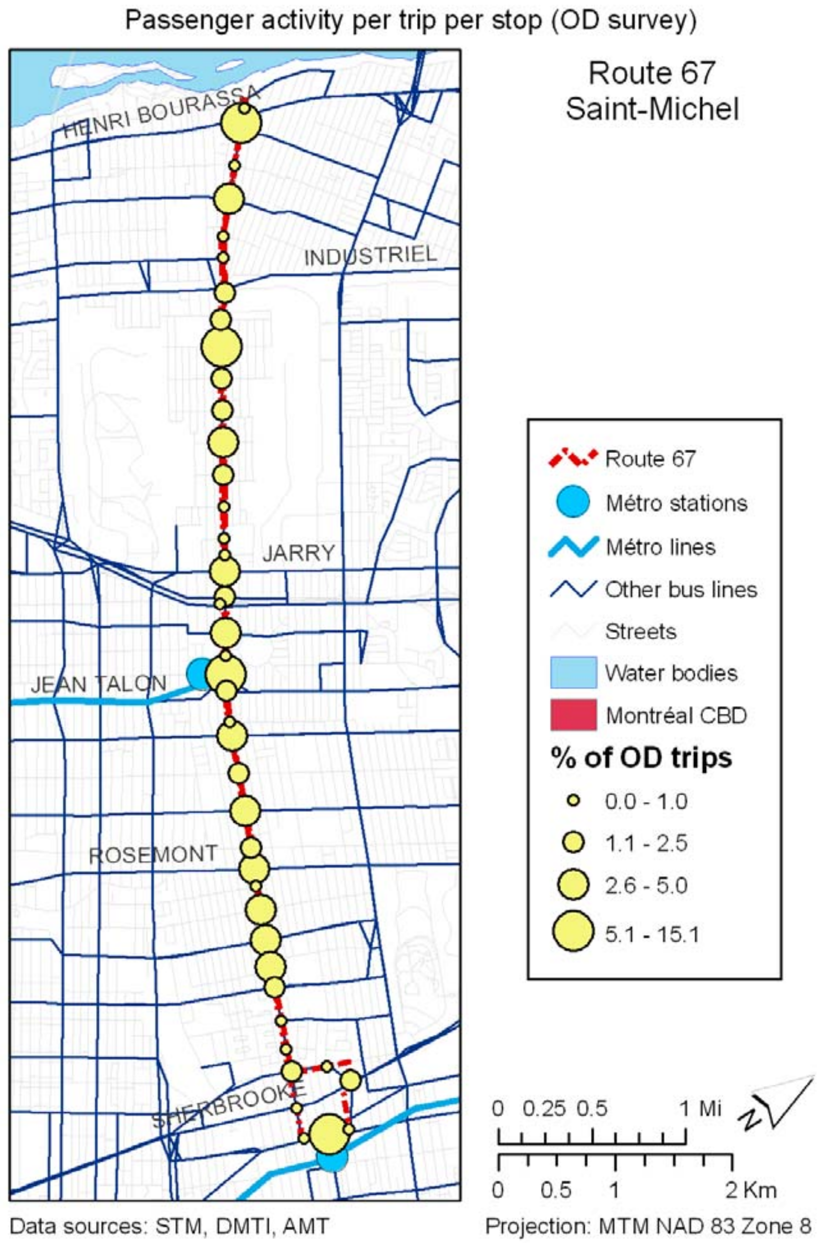

Figure 15: Passenger activity by stop (OD)

Table 11: Passenger activity by stop (OD)

Stop Number	Location	Number of passengers using the stop as first stop	Number of passengers using the stop as last stop	Total number of passengers using the stop
1	Hochelaga et Joliette (Métro Joliette)	157	145	302
2	Hochelaga et Davidson	7	8	15
3	Davidson et Sherbrooke	6	4	10
4	Saint-Michel/Davidson et Rachel	16	21	37
5	Saint-Michel et William-Tremblay	13	13	26
6	Saint-Michel et du Mont-Royal	9	11	20
7	Saint-Michel et Saint-Joseph	31	33	64
8	Saint-Michel et Laurier	35	37	72
9	Saint-Michel et Masson	59	55	114
10	Saint-Michel et Dandurand	33	35	68
11	Saint-Michel et Holt	3	3	6
12	Saint-Michel et Rosemont	57	62	119
13	Saint-Michel et de Bellechasse	32	26	58
14	Saint-Michel et Beaubien	54	49	103
15	Saint-Michel et St-Zotique	20	21	41
16	Saint-Michel et Bélanger	41	29	70
17	Saint-Michel et Bélair	7	10	17
18	Saint-Michel et Jean-Talon	20	20	40
19	Saint-Michel et Everett (Métro Saint-Michel)	196	210	406
20	Saint-Michel et Puccini	0	0	0
21	Saint-Michel et Villeray	49	49	98
22	Saint-Michel et Crémazie (Sud)	5	5	10
23	Saint-Michel et Crémazie (Nord)	32	32	64
24	Saint-Michel et Jarry	55	54	109
25	Saint-Michel et d'Hérelle (Sud)	1	1	2
26	Saint-Michel et d'Hérelle (Nord)	2	2	4
27	Saint-Michel et Deville	11	11	22
28	Saint-Michel et Robert	18	20	38
29	Saint-Michel et Denis Papin	44	44	88
30	Saint-Michel et Émile Journault	31	32	63
31	Saint-Michel et Legendre	29	27	56
32	Saint-Michel et de Louvain	67	69	136
33	Saint-Michel et Champdoré	28	25	53
34	Saint-Michel et Charland	30	30	60
35	Saint-Michel et Sauvé	4	5	9

Stop Number	**Location**	**Number of passengers using the stop as first stop**	**Number of passengers using the stop as last stop**	**Total number of passengers using the stop**
36	Saint-Michel et de Mont-Joli	1	1	2
37	Saint-Michel et Fleury	36	35	71
38	Saint-Michel et Prieur	7	6	13
39	Saint-Michel et Henri-Bourassa (Sud)	70	68	138
40	Saint-Michel et Henri-Bourassa (Nord)	7	8	15
41	Rachel et de Chambly	5	7	12
42	Valois et Sherbrooke	15	18	33
43	Nicolet et Hochelaga	3	5	8

A 1 in 4 ratio was also used to select the stops with the most passenger activity and the most origin–destination pairs. The advantage of using this survey is that it contains approximate information on where passengers boarded and alighted which the APC data does not indicate. Using the stop selection in scenario 3, over 33% of users would be able to board or alight at the same stop using the limited service without having to transfer to the regular route or walk to the closest limited stop.

As can be seen from the selection, using the APC and AVL data seems to be the best method to select stops based on passenger activity since the OD survey does not have information on which stops are actually being used by users. The major problem with the selection of stops criteria so far is that they do not account for stop spacing.

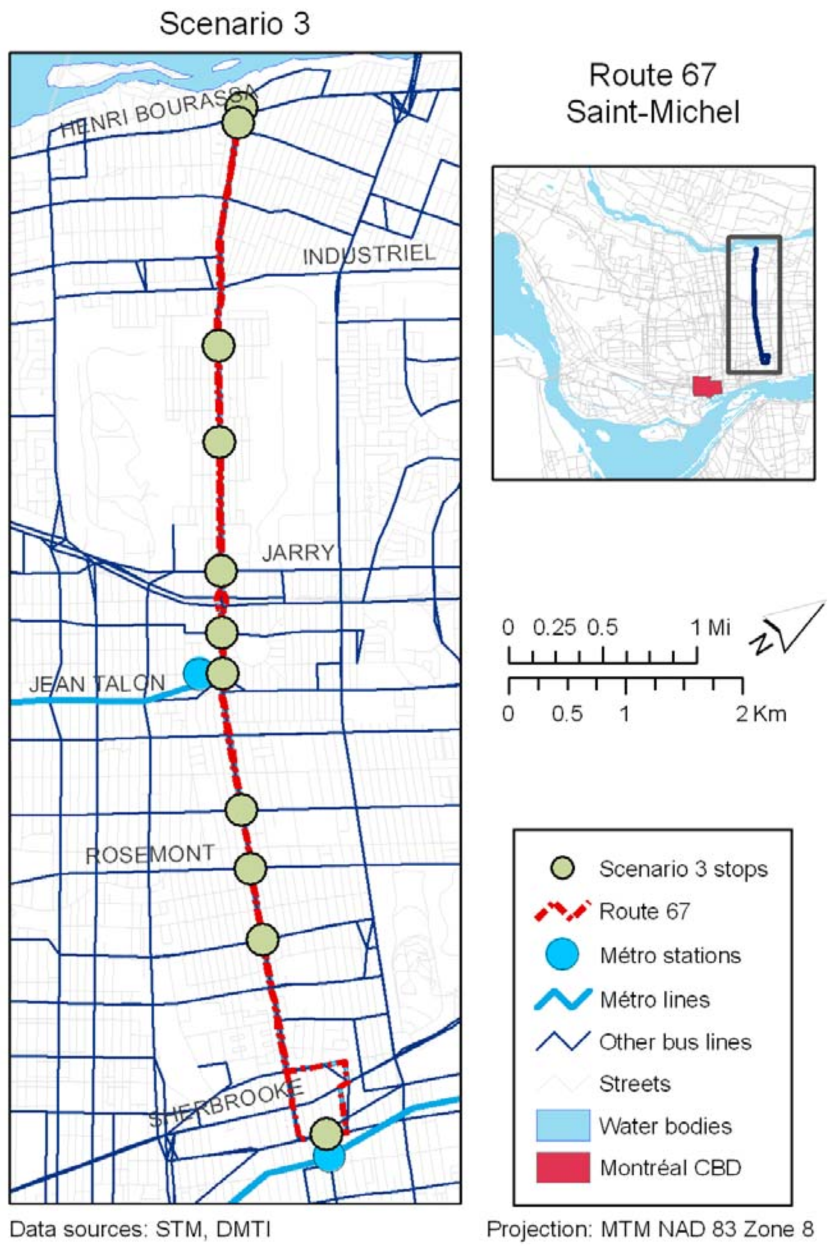

Figure 16: Selected stops for scenario 3

Table 12: Selected stops for scenario 3

Stop Number	Location	STM Stop Num.		Stop sequence	
		North	South	Nord	South
1	Hochelaga et Joliette (Métro Joliette)	120142	120142	1	40
9	Saint-Michel et Masson	115581	115583	9	31
12	Saint-Michel et Rosemont	114101	114103	12	28
14	Saint-Michel et Beaubien	112971	112973	14	26
19	Saint-Michel et Everett (Métro Saint-Michel)	110916	110913	19	21
21	Saint-Michel et Villeray	110321	110323	21	19
24	Saint-Michel et Jarry	109591	109593	23	16
29	Saint-Michel et Denis Papin	107971	107973	28	12
32	Saint-Michel et de Louvain	106781	106783	31	9
39	Saint-Michel et Henri-Bourassa (Sud)	1802171	1802198	38	2
40	Saint-Michel et Henri-Bourassa (Nord)	1802186	1802186	39	1

Scenario 4

In scenario 4, the same 1 in 4 ratio is used to obtain an average spacing between 800 to 1,600 meters. In this scenario, a number of criteria are used in order to select limited-service stops. The first criterion was the selection of stops that had the most activity. This led to the selection of major generators such as métro stations and important intersecting bus routes. After this initial criterion, stops were then selected in order to provide larger spacing and less clustering. In addition, to be selected, stops had to be paired with a stop in the opposite direction in order to not confuse users. The selected stops for scenario 4 are shown in figure 17.

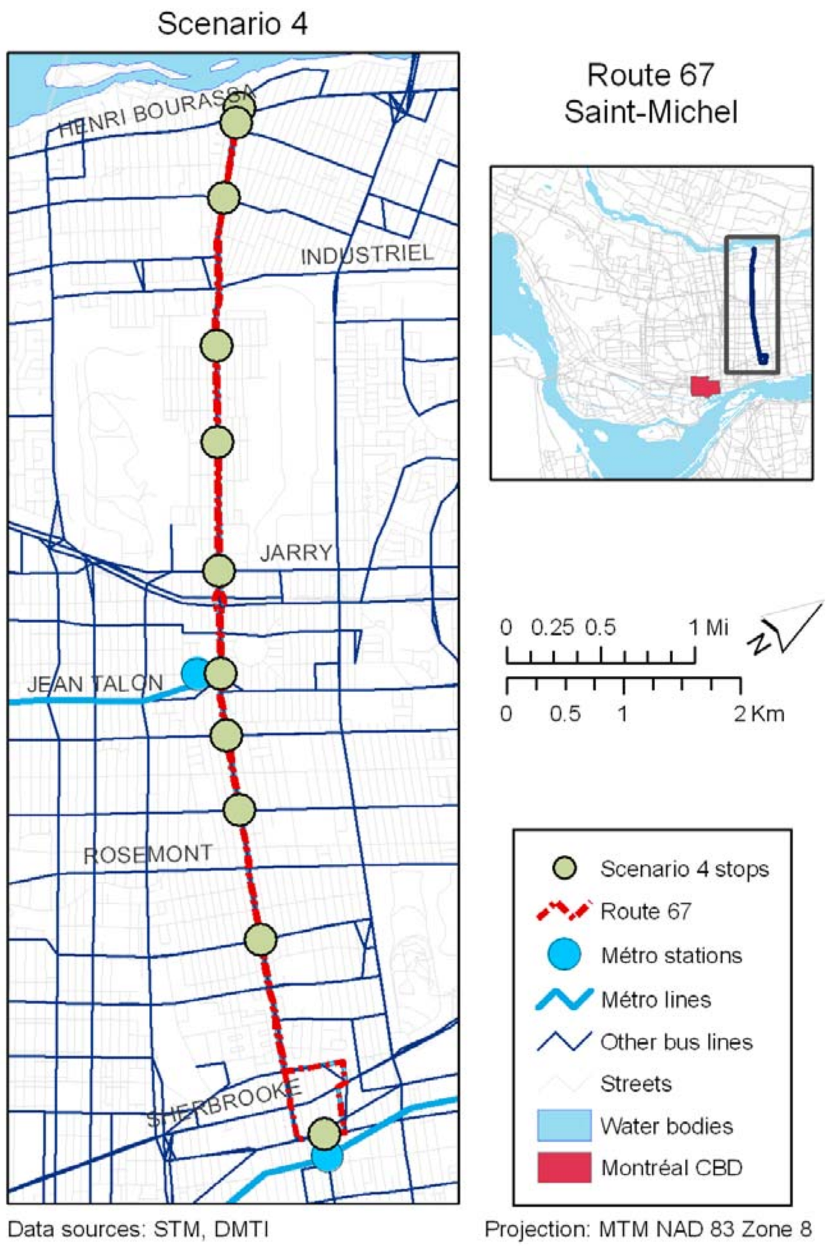

Figure 17: Selected stops for scenario 4

Table 13: Selected stops for scenario 4

Stop Number	Location	STM Stop Num. North	STM Stop Num. South	Stop sequence Nord	Stop sequence South
1	Hochelaga et Joliette (Métro Joliette)	120142	120142	1	40
9	Saint-Michel et Masson	115581	115583	9	31
14	Saint-Michel et Beaubien	112971	112973	14	26
16	Saint-Michel et Bélanger	111761	111763	16	24
19	Saint-Michel et Everett (Métro Saint-Michel)	110916	110913	19	21
24	Saint-Michel et Jarry	109591	109593	23	16
29	Saint-Michel et Denis Papin	107971	107973	28	12
32	Saint-Michel et de Louvain	106781	106783	31	9
37	Saint-Michel et Fleury	1800221	1800223	36	4
39	Saint-Michel et Henri-Bourassa (Sud)	1802171	1802198	38	2
40	Saint-Michel et Henri-Bourassa (Nord)	1802186	1802186	39	1

Estimation of bus run times

The run time for each scenario was estimated based on the model presented in table 7. Since it is difficult to give an exact run time, a range of travel times is given for both the limited and regular routes. These estimations assume that the route layout, traffic conditions and other conditions would remain unchanged. Three sets of travel times are given for each scenario. An optimistic running time, a pessimistic time and a realistic (or best estimate) were generated. The modified models separating passenger activity and actual stops into stops served by the limited service and stops not served by this service are presented in table 14. As can be seen, the magnitude of the coefficients has changed when compared to the model presented in table 7, yet the direction and statistical significance are around the same level in the model in table 7 except for the activity at the back door.

Table 14: Run Time Models to Estimate Mean Run Times by Scenario

Variables	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	B	t	B	t	B	t	B	t
(Constant)	1464.86	73.50	1445.03	58.01	1431.59	58.59	1459.20	59.34
Average Load	-3.21	-6.08	-3.30	-6.29	-3.23	-6.13	-3.32	-6.32
Weekday	39.63	9.19	39.31	9.13	38.01	8.76	39.71	9.22
Southbound	170.61	33.88	159.24	38.64	167.00	37.72	160.78	38.98
Low floor bus	-90.50	-13.57	-92.08	-13.98	-92.64	-14.14	-92.24	-14.05
TD Early AM	-120.24	-12.35	-131.34	-13.66	-122.38	-12.69	-127.65	-13.19
TD Peak AM	64.37	9.67	57.07	8.64	64.79	9.41	64.85	9.45
TD Midday	96.84	17.07	97.16	16.89	95.60	16.81	98.09	17.09
TD Peak PM	181.13	28.46	184.15	28.85	181.67	28.51	182.24	28.63
Rain (mm)	1.81	3.94	1.81	3.93	1.80	3.91	1.80	3.90
Snow (cm)	3.11	4.70	3.06	4.61	3.07	4.63	3.03	4.57
Snow ground (cm)	2.39	13.72	2.38	13.61	2.38	13.60	2.37	13.53
Delay Start	-0.05	-3.15	-0.05	-2.98	-0.05	-2.99	-0.05	-3.02
Actual stops	8.48	5.13	13.72	4.36	14.87	4.32	10.90	3.19
Actual stops skipped	13.28	12.87	11.14	12.48	11.35	12.97	11.50	13.27
Boardings and alightings front door	1.41	10.50	1.20	8.10	1.70	10.86	1.30	8.21
Boardings and alightings front door skipped	0.88	5.16	1.24	7.49	0.76	5.13	1.17	7.64
Boardings and alightings back door	1.27	4.89	1.35	4.71	1.59	5.77	1.10	3.74
Boardings and alightings back door skipped	3.41	12.28	3.19	11.74	2.88	11.11	3.22	12.51
R^2	0.602		0.600		0.601		0.601	
N	6620		6620		6620		6620	

Dependent Variable: Run Time (Analysis)

*All variables are significant at the 99% confidence level

By running separate run time models for each scenario, it is possible to generate run time estimates for both of the limited and regular services. Table 15 includes the estimates of run times for both limited and regular service. The realistic limited service removed the time components associated with passenger activity and actual stops that should not be served by the limited service to generate the run time estimates. The realistic regular service removed passenger activity at stops served by the limited service. The optimistic limited service removed all time components associated with passenger activity at all stops and the actual stops skipped. The optimistic regular service is the same as the current service because no time component was subtracted. The pessimistic express service removed time components associated with the number of actual stops skipped while the pessimistic regular service removed the time associated with passenger activity, since this scenario assumes that all passengers walk to the nearest stop with limited stop service. Assumptions used to estimate bus run times are explained on page 12.

Table 15: Estimated Analysis Segment Run Times for New Limited and Regular Service

Scenario	**1**	**2**	**3**	**4**
	Running Times (minutes)			
Current (Route 67)	34.8	34.8	34.8	34.8
Limited (Realistic)	29.3	28.4	28.5	27.9
Limited (Optimistic)	27.1	26.5	26.5	26.2
Limited (Pessimistic)	31.2	30.7	30.6	30.3
Regular (Realistic)	32.6	33.1	32.7	33.2
Regular (Optimistic)	34.8	34.8	34.8	34.8
Regular (Pessimistic)	30.7	30.6	30.7	30.7

Table 15 shows the expected range of bus run times in the analysis segment. Scenario 4 would yield to the most time savings (4.5 to 8.6 minutes) because the coefficients associated to activity at stops skipped is higher and the average number of passengers and actual stops skipped is higher than any of the other scenarios. It is also important to note that although scenario 1 (time savings ranging from 3.6 to 7.7 minutes) serves twice as many stops, the run time is only roughly 1.5 minutes more when compared to scenario 4. This is due to the fact that a large proportion of the time savings are associated with the actual stops skipped and with passenger activity. The time savings for scenarios 2 and 3 are almost the same (3.1 to 8.3 minutes and 3.2 to 8.3 minutes respectively). Selected stops in scenarios 2, 3 and 4 have the highest activity compared to scenario 1 stops. Since the activity squared terms were not included in this model, there might be additional time savings due to consolidating demand at certain stops.

The STM then asked for time estimates for a slightly modified limited-stop rush-hour service, route 467. The analysis and obtained run times are given in a separate section (see page 44). These run time estimates take into consideration the direction (north or south) and the time of day (peak AM or peak PM). Time savings for the entire route range from 4 to 11 minutes.

Limitations

Of course, using only AVL and APC data to estimate bus run times has its limitations. For instance, all variables that could have an impact on the bus run time are either not recorded or do not have access to the information. For example, the number of red lights, the time stopped in traffic, traffic incidents, and the driver's experience all probably have an impact on the bus run time. This information would give a more accurate diagnostic of the current situation.

In addition, the performance of buses on limited-stop service is not fully known. It is very probable that buses might not stop for as many red lights as is currently the case, but no information on this was available. Other factors which were not measured might have an influence on increasing or decreasing run times.

The major limitation of this study is that no information on passenger demand was available. This route does not operate in isolation from other routes on the STM network. If run times are decreased, one would expect that more passengers would be attracted to this route. This could either be existing users that use another route or new users that are currently using other modes or not making the trip at all. This potential increased ridership might have an effect on run times along this route due to the additional alightings and boardings, even though travel times would still be expected to be quicker than the current situation. Modelling the reallocation of passenger demand on the entire network based on the current travel time estimates would be useful. Macro scale transit modelling software packages could be used to generate these passenger increase estimations. This modelling technique would also be useful to estimate the percentage of users using the regular or the express routes.

Walking distances

Offering a limited stop service should have an effect on passenger walking distances if users choose to walk further to use the limited service. Accordingly, it was important to measure the effects on walking distance associated with each scenario using the data from the O-D survey. Table 16 shows the average walking distance to the nearest stop served by limited service. Scenario 4 has the advantage of having the smallest change in walking distances which would impact around 60% of users. This suggests that a number of users could walk to the next bus stop to access the limited service.

Table 16: Average Walking Distance to the Closest Stop Served by Limited-Service by Scenario

Scenario	1	2	3	4
Number of stops served	20	12	11	11
Average walking distance (meters)*	486.8	448.8	434.4	435.2
Average change in average walking distance (meters) for affected users only	426.4	284.9	297.8	276.0
Percentage of walking access trips with change in walking distance	52.4	65.1	57.5	62.3

*Note: The average walking distance for new service assumes that all users walk to the nearest bus stop served by the limited service even though the nearest stop is still served by a regular route. The current average distance is 263.2 m. The average walking distances do not include transfer trips whose walking distance would be close to zero in many cases.

Time savings per user

Another way of looking at the effects of implementing the limited service is magnifying the effects on personal travel time. Having the O-D survey enables estimating an average savings per person for current users.

In order to model this, if both the first stop and the last stop of O-D trips are selected in a given scenario, then users are assigned to the limited service. If not, users are assigned to the regular route. The distance between the first and last stops was then found using the Saint-Michel route as a network. Time savings per user were then found by applying the average time savings per run for the proportion of the route used by a particular user.

The average user travelled 2.5 km on route 67, not including walking distances. Because the route distance is considerably longer, the average time savings per user are less than that of a trip. The estimated average time savings per user are given in table 17 for both limited and regular service users. Time savings for limited service users are higher than for regular users. For scenario 4, average time savings would range from 1.5 to 2.9 minutes per trip. For regular service trips, it is expected that they would save up to 1.2 minutes in travel time. It is important to note that these are passengers who were already using these stops before the limited service is offered. The savings to passengers who might shift will be less since additional walking distances have to be taken into account. Yet these passengers might not need to shift since travel time savings are expected to occur along the regular route as well. It is expected that users that would shift to the limited service are travelling longer distances than average along this route.

Table 17: Time savings per user

		Time Savings (min.)		
Scenario	**Proportion of trips**	**Realistic**	**Optimistic**	**Pessimistic**
Limited service trips				
1	41.0%	1.86	2.62	1.21
2	28.5%	2.15	2.78	1.38
3	33.6%	2.04	2.71	1.35
4	30.3%	2.30	2.87	1.49
Regular route trips				
1	59.0%	0.60	0.00	1.15
2	71.5%	0.51	0.00	1.21
3	66.4%	0.61	0.00	1.22
4	69.7%	0.45	0.00	1.20

Scenario 4 is recommended for implementation because of the time savings and the selection of stops accounted for various criteria including demand, transfer points and savings in travel time. Also, the increase in walking distances for passengers interested in using this service is minimal compared to the other scenarios, yet passengers who would not like to use the new service can still walk the same distance and use the regular service which the STM is planning to retain. The savings from scenario 4 of limited service should be implemented with other measures along the route such as stop consolidation along the regular route, transit signal priority and adjusting the location of stops from near side to far side which could yield even more time savings for onboard passengers.

TIME ESTIMATES FOR ROUTE 467

The STM is going ahead with the implementation of limited-stop route service on Saint-Michel, route 467, starting on March 30, 2009. The implementation of limited service on this route is a first step towards implementing similar service on a number of other frequent bus routes. After presentation of the first four scenarios to the STM, they asked to estimate running times for an express service running along Saint-Michel only during peak periods (i.e. 6:30 AM to 9:30 AM and 3:30 PM to 6:30 PM). The STM also decided to use a 1 to 3 ratio when selecting bus stops, rather than the 1 to 4 ratio we proposed. They therefore slightly modified the stop selection and specified 15 stops that would be served by route 467 which is very similar to scenario 4. These stops are shown in the table and figure below. In the end, the STM decided to not only implement route 467 during rush-hours. Route 467 will operate between 6 AM and 6:30 PM with maximal headways of 10 minutes [26]. The general model presented earlier was used to estimate run times for off-peak weekday runs.

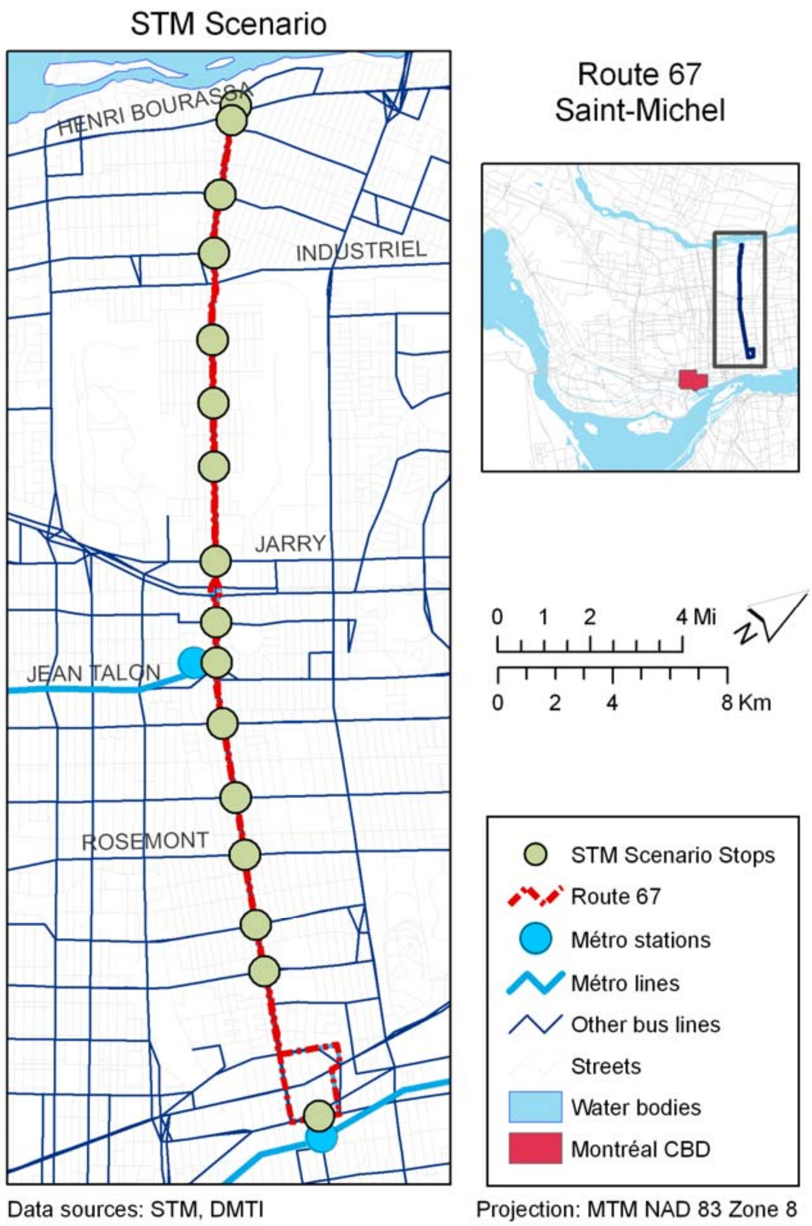

Figure 18: Proposed stops for route 467

Table 18: Proposed stops served by route 567

Stop number (report)	Location	STM stop number		Stop sequence number	
		North	South	North	South
1	Hochelaga and Joliette (Joliette métro)	120142	120142	1	40
7	Saint-Michel and Saint-Joseph	116671	116673	7	33
9	Saint-Michel and Masson	115581	115583	9	31
12	Saint-Michel and Rosemont	114101	114103	12	28
14	Saint-Michel and Beaubien	112971	112973	14	26
16	Saint-Michel and Bélanger	111761	111763	16	24
19	Saint-Michel and Everett (Saint-Michel métro)	110916	110913	19	21
21	Saint-Michel and Villeray	110321	110323	21	19
24	Saint-Michel and Jarry	109591	109593	23	16
28	Saint-Michel and Robert	135291	108413	27	13
30	Saint-Michel and Émile Journault	107616	107613	29	11
32	Saint-Michel and de Louvain	106781	106783	31	9
35	Saint-Michel and Sauvé	105681	105683	34	6
37	Saint-Michel and Fleury	1800221	1800223	36	4
39	Saint-Michel and Henri-Bourassa (South)	1802171	1802198	38	2
40	Saint-Michel and Henri-Bourassa (North)	1802186	1802186	39	1

To estimate rush-hour running times, another run time model was generated and given in table 7. This model is similar to the model used to produce run time estimates found in table 19 that separates passenger activity between stops served and not by the limited stop service. The time of day dummy variables using in the model present in table 14 have been replaced by four dummy variables representing each peak period and direction (i.e. southbound morning peak, northbound morning peak, southbound evening peak and northbound evening peak).

Table 19: Linear regression model for time estimate of route 467

Variables	B	t-stat
(Constant)	1483.830	76.41
Average load	-8.598	-17.52
Weekday	-14.623	-3.19
Southbound	117.913	20.93
Low Floor	-79.313	-11.75
Peak AM Southbound	83.506	9.99
Peak AM Northbound	-50.440	-5.38
Peak PM Southbound	72.949	6.94
Peak PM Northbound	180.065	21.91
Rain (mm)	1.903	4.05
Snow (cm)	3.240	4.81
Snow Ground (cm)	2.493	13.99
Delay Start	-0.041	-2.48
Actual Stops	15.636	7.33
Actual stops skipped	12.540	12.29
Boardings and alightings front door	2.578	19.32
Boardings and alightings front door skipped	2.346	11.74
Boardings and alightings back door	2.269	8.42
Boardings and alightings back door skipped	3.878	11.87
R^2	0.586	
N	6620	

Dependant variable : Run Time (Analysis)
*All variables are significant at the 95% level or higher

Estimated travel times are found for each scenario using the “optimist”, “pessimist” and “realist” methods presented earlier in this report on page 12. Since the analysis removed stops at the beginning and end of the route, ratios of the travel time for the entire run and the analysis are used to estimate the running time for the entire route. A ratio of 1.10 is used for northbound runs and a ratio of 1.14 is used southbound. These estimated run times are given in the following table.

Table 20: Estimated Run Times for route 467

	Run Time (analysis segment) (minutes)						
	Route 67	567 Limited Service			Route 67 with 567		
Scenario		*Optimist*	*Pessimist*	*Realist*	*Optimist*	*Pessimist*	*Realist*
Peak AM Southbound	40.4	29.2	36.3	33.7	40.4	33.2	35.9
Peak AM Northbound	36.9	25.4	32.8	30.0	36.9	29.6	32.3
Peak PM Southbound	40.2	29.0	36.1	33.5	40.2	33.0	35.7
Peak PM Northbound	41.3	29.7	37.1	34.3	41.3	33.9	36.7

APPLICATION TO OTHER ROUTES AND SITUATIONS

Many transit agencies throughout North America are collecting a wealth of information everyday through their automatic vehicle location and automatic passenger counting systems. Cases where this information is used towards anything more than simple transit performance measures such as on-time performance at time points and fleet management are far and few between. AVL and APC data is a rich source of information on transit operations. One of the important tools available to transit operators is the run-time regression model which is used in this paper to estimate run-times for a modified route. This model is an important tool, which can be used in order to understand which factors have an influence on run-times as well as their magnitude.

First and foremost, this research can be used to design and implement new limited-stop service in other cities. Many cities have a number of high-ridership bus routes that would be candidates for limited service. This technique could be used to evaluate whether or not it is worthwhile to implement these new services. In addition, this run time estimate technique is not only applicable to the implementation of a limited-stop service that was used as a case study for this project. Run-time models and the proposed time estimate technique could be used to a number of route changes. The same procedure would be ideal for run time estimates for routes on which stop consolidation is proposed. If the unit of analysis was changed to route segments, it would also be possible to evaluate the time savings (or increases) due to physical route changes such as route length or the implementation of traffic signals. These techniques could also be used to create better time estimates due to changes in the operational environment including congestion, fluctuations in passenger activity or weather. That being said, it is necessary that these conditions be present somewhere along the studied route or another similar route in order to evaluate the effects on run time. For example, it would be very difficult to estimate changes in run time using this technique for changing the placement of bus stops from the near side to the far side of intersections if very few far side stops are present on a particular (or similar) route.

The automation of run-time models could be beneficial to transit planners and operators to obtain information quickly and efficiently for as many routes as possible. A note of caution on the creation of these automatically generated models is that context-sensibility could be lost if they were applied across too many routes or cities. Before the generalization of this technique, one also needs to use judgement and experimentation to arrive at a final set of variables.

Of course, the major caveats with the use of this technique are the sample size, quality and availability of data. In this case study, it is reasonably safe to assume that other factors such as traffic incidents, the time spent waiting at red lights and driver experience probably have an influence on run times but this information was not available in our case. The availability of additional relevant data could lead to better models since their explanatory power might be higher.

CONCLUSION

The objective of this research was to recommend a limited-stop service that could yield substantial savings in run time for transit users along the limited and regular bus service. A new methodology is used in order to estimate run times savings for various scenarios. A run-time model based on current route conditions was derived from more than 6,000 trips. This run time model at the trip level incorporated variables that accounted for the direction of the route, actual stops, time of day, weekday, delay at the first stop, passenger activity, and climatic conditions. This is the first time that passenger activity by door and climatic conditions are used in run time models in transit operations and planning research. The activity through the back door shows that maximizing use of the back door can yield time savings. The model followed transit operations theory, which confirmed confidence in the accuracy of the STM AVL and APC data archival system. By separating passenger activity and number of actual stops between stops that are planned to be skipped as part of a new limited service and stops that are proposed to be served by the regular service, it was possible to estimate a range of mean run times. The recommended scenario (4) would yield time savings between 4.5 to 8.6 minutes for the limited service for the analyzed route segment keeping all other operating conditions constant at their mean values. When the number of bus runs on this route per weekday, in excess of 350, is also considered, this service can lead to considerable savings in operating time for the STM and travel time savings for users. By running a limited service in parallel to this route, there would also be time savings for the regular route, though not as much as the limited, because part of the passenger activity would be shifted to the limited service. For the recommended scenario, there could be savings over the segment analyzed of up to 4 minutes. Run time savings during for a rush-hour service could be even greater. The expected time savings for the rush-hour route range from 4 to 11 minutes for the entire route.

Future research for the selection of limited-service stops should also incorporate the variance of usage at the stops as a factor. In this study, a large enough sample of trips beginning at the same time of day was not available in order to evaluate the variance in passenger activity. The STM is in the process of implementing the findings from this research. Therefore, it is recommended that a post-implementation study to be undertaken in order to enable an accurate evaluation of the estimates proposed in this report and the effectiveness of the final scenario in reducing running time along both the regular and limited routes. This study was mostly concerned with the overall savings in run time along the studied route. A different approach would be to use a smaller unit of analysis (segment between time points) where other variables like number of signalized intersection could be incorporated in the model.

The introduction of limited-stop service along the route 67 Saint-Michel corridor will lead to considerable time savings for users as well as the STM. In order to maximize time savings and reduce operating costs, other strategies should be put in place including, but not limited to, implementing transit-signal priority, alternating between nearside and far-side stops and consolidating bus stops along the regular service. Bus bunching on the route was observed on this route and it often leads to the deterioration of service quality, but since the route Saint-Michel data is only a sample, accounting for headway deviations was not possible. It is expected that headway deviations would have an effect on run time. In order to analyze this phenomenon, it would be necessary to have all buses serving this route equipped with AVL and APC technology in order to analyze the effects of headway deviations on run time. The full implementation of AVL and APC systems would also be beneficial in order to provide better information for transit planning and operations. It is highly recommended that all STM buses be equipped with AVL and APC systems. Traffic condition information was not available when conducting this analysis, that being said, traffic congestion was accounted for with time of day variables. Finally, the impact on users would be the smallest as 60% of current users as measured by the OD survey will be required to walk an average 276 meters more to utilize the new express service. That being said, the savings in onboard time would offset loss in access time to these users.

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