ESTIMATING BUS RUN TIMES FOR NEW LIMITED STOP SERVICE USING ARCHIVED AVL AND APC DATA

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ABSTRACT

In recent years, several transit agencies have been trying to be more competitive with automobile to attract choice riders. Transit agencies can only be competitive if they can provide services that are reliable, have a short access and egress time, and have run times that are comparable to automobiles. Several transit agencies try to be competitive through offering faster services, such as limited-stop (express) bus service. This study uses AVL and APC data, in addition to a disaggregate data obtained from a travel behavior survey, to select stops and estimate run times for new limited-stop service that will run parallel to a heavily used bus route (67 Saint-Michel) in Montréal, Québec, Canada. 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 directions of the route, major activity points and stop spacing. This study shows that implementing a limited stop service would yield substantial time savings for both, the new limited service and the existing regular service running parallel to it.

Key Words: Run Time, Travel Time, Limited Stop Service, Express Service, Transit Planning, Transit Operations

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INTRODUCTION

In recent years, several transit agencies have been trying to be more competitive with the personal automobile 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 and egress time, and have faster or comparable run times to automobiles. Revising the current distribution of service based on travel needs can increase the competitiveness of transit agencies. Improving run-time is an important measure, yet it has to be significant enough for users to be able to perceive changes in service [1].

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 [2]. Yet they can also provide a comprehensive set of information about the state of existing services.

The *Société de transport de Montréal* (STM), the local transit agency providing service on the island of Montréal, Québec, Canada, is considering various measures to improve bus service. One such improvement is the introduction of limited-stop or express bus service parallel to heavily used routes to improve run times for existing riders.

This paper focuses on using archived AVL and APC data for route 67 Saint Michel, a high frequency route in the STM system, to select stops for implementing limited-stop bus service and to estimate run time savings along both the proposed and the existing service. The paper 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 bus run time for the new service and the existing. It is then followed by a discussion of those results and finally a conclusion section.

LITERATURE REVIEW

When passengers choose to use transit as a mode of transportation, a number of factors come into account. Passengers want to have a reliable service that arrives on-time, with a minimum in-vehicle time, [3] and minimum access and egress time [4]. AVL and APC systems have been implemented by a number of transit agencies [5, 6] and analyzed by a number of researchers with these goals in mind [5, 7, 8].

Run-Time

Reducing mean travel times is beneficial for the transit operator and users [9]. It reduces operating costs and the number of vehicles required. Transit users seek to minimize their total travel time because it is a cost. Minimization of travel time can thus attract new users to the system [10]. In order to reduce travel times, various strategies have been advanced. Vuchic [10] 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 [11] found that many factors influence the run 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 have an effect on bus run time [12] as well. The number of actual stops [8, 13-15] also has an influence on run time. Strathman et al. [8] also found that passenger demand increases run 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 run times [16]. Reducing the number of stops has always been discussed as an effective measure for reducing run time. This reduction can be achieved either by stop consolidation [7] 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 we have not seen 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 [1, 10, 17]. Express or limited buses stop at only a few stops along a route while 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 [10]. One of the drawbacks of express service is that wait times tend to increase after implementation [17], therefore they should be implemented parallel to high frequency routes (routes with short headways 8 minutes or less) and routes with high level ridership. To our knowledge, there is not any established criteria in the transit industry on how to select stops that will be served by new express service. Limited service should be serving stops with high level of passenger demand [10, 18]. In terms of limited service stop spacing, stops should be spaced several times greater than local stops [10], 800 to 1,600 meters apart [17, 19, 20] or 450 meters apart [18]. This spacing contrasts with "local" bus stop spacing in urban areas which generally ranges from 200 to 600 meters [21]. 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 [18]. The dilemma when designing a new limited-stop service is that the objective should be to minimize travel times – Ercolano [1] 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

Montréal, Québec, Canada is the second most populous metropolitan area in Canada with a population of 3.7 million. The STM operates bus and subway services on the island of Montréal which is home to about half of the inhabitants in 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 through 4 neighborhoods in 2 separate municipalities. 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 is mostly 3-storey triplexes mixed with some commercial buildings near major intersections. Table 1 includes a summary of route characteristics, while Figure 1 is a map of the studied route.

The experience with APC and AVL technology at the STM dates back to 1999. The current system is the third generation equipped on 220 buses out of 1,600 in the fleet. 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 the system. This system is mostly used by the STM for revising schedules and generating performance measures such as schedule adherence.

TABLE 1: Physical Characteristics of Route 67 Saint-Michel

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

1 km= 0.6214 miles

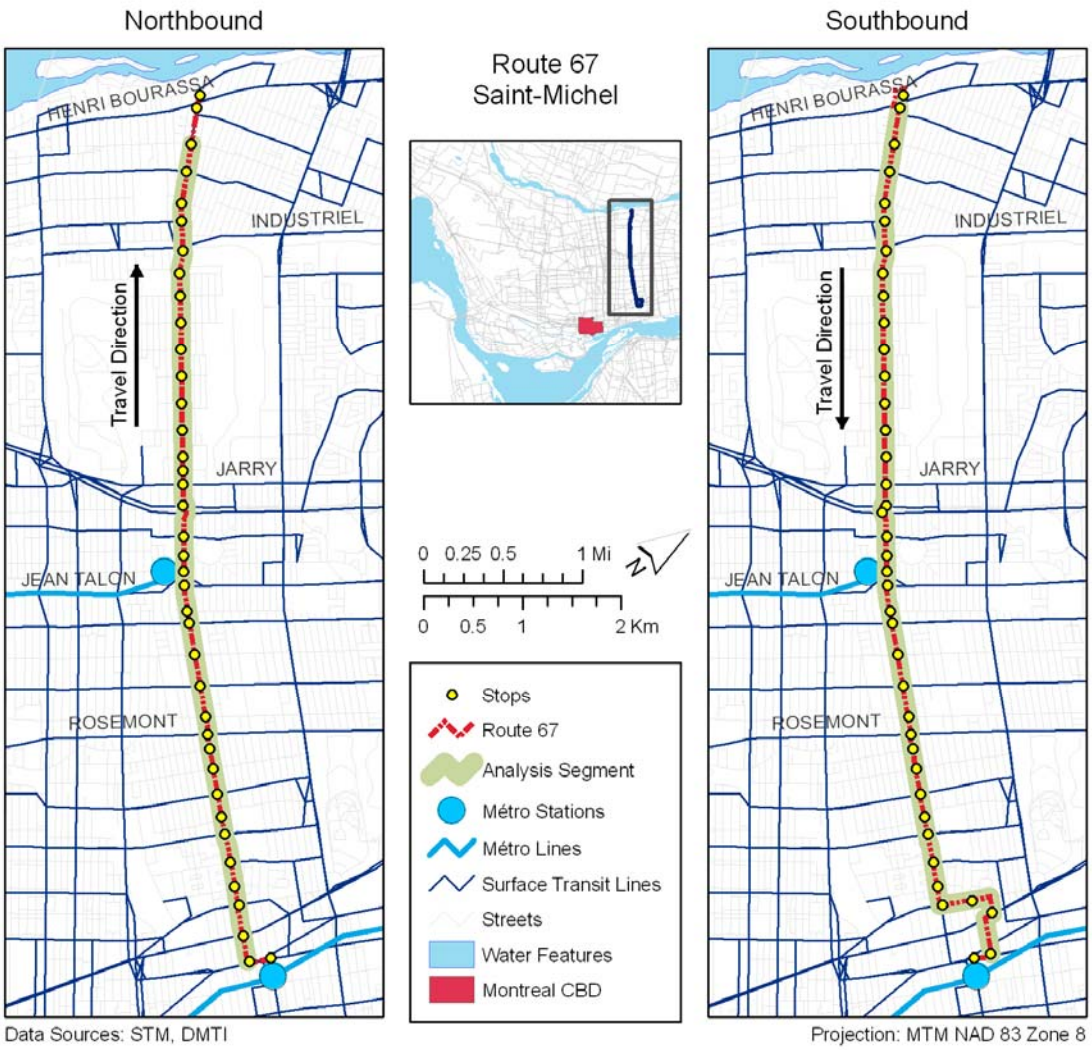

FIGURE 1: Route 67 Saint-Michel

METHODOLOGY

The objective of this paper is to select stops for a limited-stop bus service and to estimate the run time of the new service through 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 incomplete trips and recording errors. 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 eliminating short-turn runs, 6620 trips were used 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 2 is a list of variables prepared for conducting the analysis.

TABLE 2: 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 millimeters for the day of the trip at Trudeau Internation Airport (obtained from Environment Canada)
Snow (cm)	The amount of snow falling on the day of the trip in centimeters at Trudeau Internation Airport (obtained from Environment Canada)
Snow Ground (cm)	The amount of snow on the ground on the day of the trip in centimeters at Trudeau Internation 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

In order to asses the robustness of the obtained AVL and APC data, a run-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 [22] 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.

In order to design a limited-stop service, we first created 3 scenarios based on a single criterion. 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 [17, 19, 20].

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 behavior. 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.

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 generated 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, we are isolating the effects of passenger activity and actual stops made by the current service at skipped stops in order to estimate run time for the new limited service and local service that will be running in parallel. Since estimating actual number of passengers switching between regular and limited bus services is not possible 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, we subtracted the time associated with front and back door passenger activity and the actual stops skipped from the mean run time derived from the models. For the realistic regular route, we subtracted the time associated with passenger activity at the stops served by the limited service from the mean run 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 time associated with passenger activity and actual stops skipped is removed. The regular route would remain the same as the current route for this estimate. For the pessimistic run time estimate, it is assumed that all passenger demand would use the limited service by walking to the nearest stop served by the limited service. This is done by subtracting only the time associated with the actual stops skipped from the mean travel time. The pessimistic regular route, which in fact is the most optimistic run time for regular service, subtracts the passenger demand from the mean run time.

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 if we also consider that the average bus leaves 48 seconds later than the scheduled departure. Summary statistics are reported in Table 3.

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 to time savings. The frequency of stopping 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 3: Summary Statistics

Variable	Minimum	Maximum	Mean	Std. Deviation
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
(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
(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 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 run-time model. The characteristics of this model are well known in the transit literature [7, 11, 13]. Checking the effects of independent variables on run time and to what extent it follows the theory of transit planning is used as our benchmark for assessing the quality of the collected data. A general multivariate linear regression model for run time was derived using the archived trip data and is given in the table 4.

TABLE 4: Run Time Model

Variable	Coefficient	t-stat
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 would be 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 run 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 activity 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. Time of day also has an important influence on run time. What is curious is 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 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 behavior based on whether they are ahead or behind schedule since run time 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 millimeter 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 centimeter 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 centimeter 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 [7, 8, 11, 13, 23, 24].

Selection of stops

In scenario 1, all stops that were transfer points are selected for limited service. This scenario does not adjust for the frequency of intersecting routes. As can be seen in figure 1, intersecting routes are numerous and are often clustered together. This suggests that not all transfer points should be served by limited service. Yet we developed this scenario based on a suggestion from theory and practice to show the effects of just following the provision of limited service at transfer points only is not the most successful way.

Scenario 2 involved selecting stops based on passenger activity (alightings and boardings) at every stop along the route. 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). As can be seen in Figure 2, 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 the figure. In addition, not all transfer points have high passenger activity, which suggests that there would be less impact by excluding some transfer points. This scenario still has the disadvantage of having a few successive stops clustered together.

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. 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 we have 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/AVL data seems to be the best method to select stops, but all of these selection criteria are imperfect because they do not account for stop spacing. In scenario 4, we use the same 1 in 4 ratio to obtain an average spacing between 800 to 1,600 meters. 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. The selected stops for scenario 4 are shown in Figure 3 along with scenario 2 and 3.

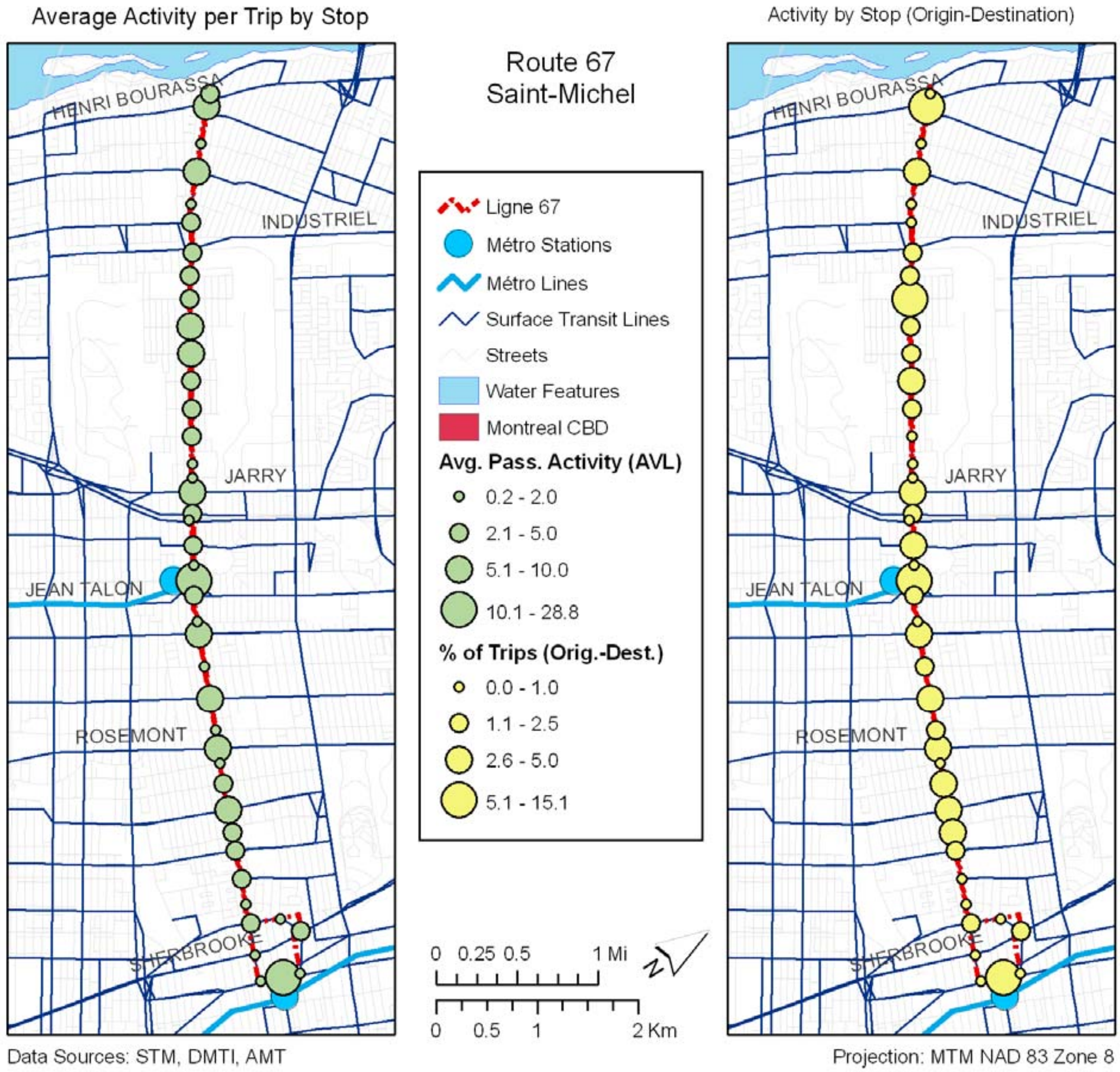

FIGURE 2: Passenger Activity Using APC data and the OD survey

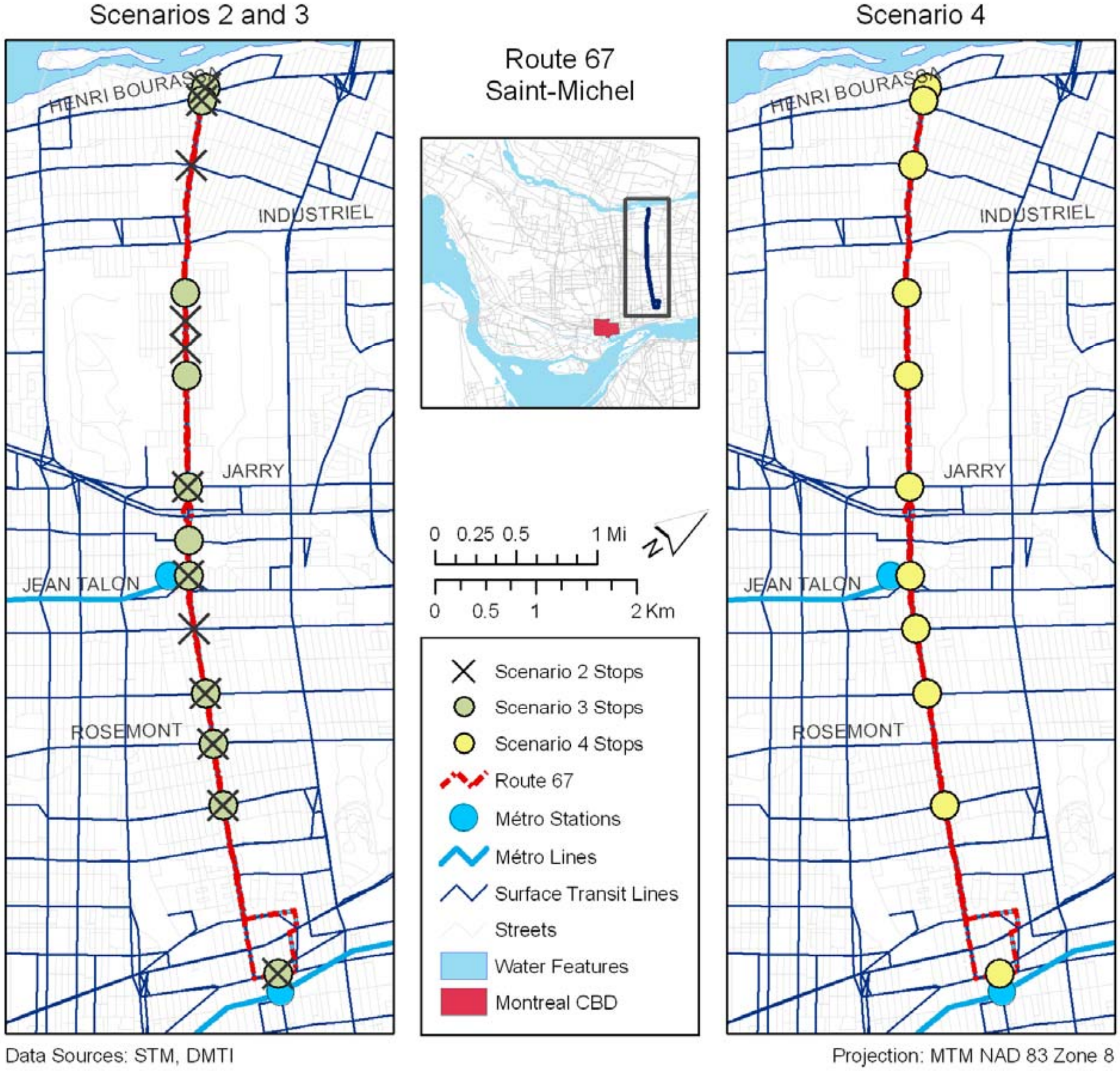

FIGURE 3: Selected Stops for each Scenario

Estimation of Bus Run Times

The run time for each scenario was estimated based on the model presented in table 4. 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 run 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 5. As can be seen, the magnitude of the coefficients has changed when compared to the model presented in table 4, yet the direction and statistical significance are around the same level in the model in table 5 except for the activity at the back door.

TABLE 5: Run Time Models to Estimate Mean Run Times by Scenario

Variables	Scenario 1		Scenario 2		Scenario 3		Scenario 4	
	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat	Coef.	t-stat
(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, we were capable of generating run time estimates for the limited and regular services. Table 6 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 time component of 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 only while the pessimistic regular service removed the time associated with passenger activity.

TABLE 6: Estimated Analysis Segment Run Times for New Limited and Regular Service

	Scenario 1	Scenario 2	Scenario 3	Scenario 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 6 shows the expected range of bus run times in the analysis segment. Scenario 4 would yield to the most time savings 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 serves twice as many stops, the run time only decreases by roughly 2 minutes when compared to scenario 4. This is due to the fact that a large proportion of the time component is associated with passenger activity and 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.

Offering a limited stop service should have an effect on passenger walking distances as well. Accordingly, it was important to measure the effects on walking distance associated with each scenario using the data from the O-D survey. Table 7 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 7: Average Walking Distance to the Closest Stop Served by Limited-Service by Scenario

	Scenario 1	Scenario 2	Scenario 3	Scenario 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.

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. Looking at the people who boarded and alighted at one of the limited stops in scenario 4, the expected time savings for passengers travel time using the optimistic approach is 2.8 minutes, while using the realistic approach is 1.02 minutes. 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.

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 the minimum compared to other scenarios, yet passengers who would not like to use the new service can still walk less and use the regular service which 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.

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. We used a new approach 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, type of day, delay at the first stop, passenger activity, and climatic conditions. To our knowledge, it 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 our 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, we were able 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 we also consider the number of trips on this route per weekday which is in excess of 350, this type of service can lead to considerable savings in operating time for the STM and travel time savings for users. By running a limited service along 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.

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, we did not have a large enough sample of trips beginning at the same time of day in order to evaluate the variance in passenger activity. STM is in the process of implementing the findings from this research accordingly a post-implementation will enable an accurate evaluation of the estimates proposed in this paper and the effectiveness of the final scenario in reducing running time along both routes (limited and regular). In this study we were concerned about the overall savings in run time along the studied route. A different approach is to use a smaller unit of analysis (stop-segment between time points) where other variables like number of signalized intersection can 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 farside stops and consolidating bus stops along the regular service. Since the STM 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. Finally traffic condition variables were not available when conducting this analysis, the effect of congestion was accounted for through time of day and direction coefficients, obtaining such information can help in generating a better estimate.

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