Introduction of Reserved Bus Lane

Impact on Bus Running Time and On-Time Performance

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This paper evaluates the impact of adding a reserved bus lane on the running times and on-time performance of two parallel bus routes, one of them a limited-stop bus service and the other a regular bus service. By means of automatic vehicle location and automatic passenger count data, statistical models were built to estimate running time and on-time performance. The reserved bus lane yielded savings of 1.3% to 2.2% in total running time, and benefits were more significant for northbound afternoon peak trips than for southbound morning peak trips because of congestion levels northbound. The introduction of a reserved lane increased the odds of being on time by 65% for both routes. A decline in the variability of running time and delay at the end was noticed after implementation of the reserved lane; the decline indicated that the reliability of the service being offered along the corridor had improved. The analysis showed that the more affected a bus service was by adverse traffic conditions, the more it benefitted in running time from improvements introduced by reserved lanes while keeping schedules constant. Reserved lanes had a substantial effect on both service reliability and on-time performance, two key variables in customer satisfaction that justified such implementation. This study will help transit planners and schedulers to understand the effects of implementing reserved lanes on running time, on-time performance, and transit schedules.

Boulevard Saint-Michel in Montreal, Quebec, Canada, is a high-frequency bus corridor east of the central business district. Every weekday, 43,000 public transit users travel on it, while the Société de transport de Montréal (STM, the transit agency providing service on the island of Montreal) carries 1 million passengers on its four metro (subway) lines and 202 bus routes. To improve transit service on Boulevard Saint-Michel, STM decided in 2008 to implement a series of improvements, including a limited-stop bus service (express bus service) running parallel to the regular bus service. Tétreault and El-Geneidy analyzed four scenarios—by means of historical data obtained from automatic vehicle location (AVL) and automatic passenger location (APC)—related to placement of stops along a new route (*1*). STM used the same methodology to introduce a new limited-stop service (Route 467), implemented on March 30, 2009, that serves 60% fewer stops than the regular service (Route 67), yielding an average stop spacing of 615 m (0.382 mi). The Express 467 runs from 6:00 a.m. to 7:00 p.m., with a maximum headway of 10 min (*2, 3*).

El-Geneidy and Surprenant-Legault estimated that trips made after March 30, 2009, were 1.5% faster for Route 67 and 10% to 11% faster for Route 467 (*4*). Route 467 proved to be even more efficient during peak hours, with savings up to 14.2%. In addition, El-Geneidy and Surprenant-Legault measured riders' perceptions of running time gains (*4*). Seventy-two percent of users noticed a decrease in running time that they overestimated to be around 5 min when the actual running time decrease was 1.5 min per rider on average.

Thanks to the improvement in bus service, STM observed a 4% increase in total ridership on Boulevard Saint-Michel between November 2008 and November 2009, and an 8% increase in ridership during peak hours. Meanwhile, on August 3, 2009, STM continued its series of improvements along the studied route by implementing a reserved bus lane during peak hours. This paper evaluates the impact of the reserved bus lane on running times, on-time performance (OTP), and schedule adherence of Routes 67 and 467.

LITERATURE REVIEW

Bus service reliability, waiting time, and short in-vehicle time are valued characteristics that affect riders' perception of the existing service (*5, 6*) and can notably be improved with the implementation of a reserved bus lane. A simple and efficient method to evaluate the success of a reserved lane is to generate running time, OTP, and schedule adherence models from before-and-after data sets to distinguish the impacts of different factors on the time required to complete a trip between two points on a route and to determine whether the bus finishes the studied segment on time. Running-time models that look at before-and-after implementation of a strategy are well-known and commonly used in the transit literature (*4, 7, 8*). The factors affecting running time include trip distance, passenger activity, number of stops made, period of the day, driver's characteristics, delay at the start of the trip, weather conditions, and congestion (*4, 9–14*). Furthermore, OTP and schedule adherence are affected by the same variables (*14*). Achieving a smaller running time and improving OTP are likely to increase ridership on a transit line (*15*) while also improving users' satisfaction of the service (*16*). OTP has a direct impact on waiting time, which represents the most onerous time component of the transit journey. The marginal value of waiting time exceeds in-vehicle time (running time) by approximately a factor of three (*17*).

The simple question, "How does a reserved lane influence running time of buses and OTP?" is seldom asked or answered in the literature. Thamizh Arasan and Vedagiri created a simulation in which bus

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running time would decrease by around 15% for a reserved lane 10 km long in Chennai City, India (*18*). In this simulation, average bus speed, including stops, was 39.5 km/h. Buses were continuously separated from the rest of traffic, including at intersections, and did not benefit from transit signal priority. Shalaby studied the implementation of a reserved bus lane on Bay Street in downtown Toronto, Ontario, Canada, by using a microsimulation tool (*19*). The reserved lane was bidirectional and located on curbsides. This reserved lane was active between 7:00 a.m. and 7:00 p.m. on weekdays. It was 3 km long and served 16 bus stops. Shalaby reported running time savings between 0 and 17% after the reserved lane began operating (*19*). In relation to delays, he found a 14% improvement in delay during the afternoon peak period. However, Shalaby's findings were derived from descriptive statistics tables and affected by an increase in ridership as well as an increase in the number of bus trips. As a result, it is impossible to measure which proportion of the observed change could be attributed to the reserved lane. Tanaboriboon and Toonim analyzed four reserved bus lanes implemented in 1980 in Bangkok, Thailand (*20*). These lanes ranged between 1.2 and 6.3 km long, with running time between 5 and 15 min. With reserved lanes, running time was 0.7% to 23% shorter; running time standard deviations and coefficients of variation also decreased, indications that bus service was more reliable. Similar to those in Shalaby's study, these findings came from descriptive statistics and no reserved lane effect is assessed or isolated from other factors. It is also clear that the range of savings varies between 0 and 23%. This is generally considered a big range. So a more accurate estimation of the effects of reserved lanes on running time is needed.

Hence, for correct evaluation of the impact of a reserved bus lane on bus running time and OTP, it is necessary to build statistical models for which the effect of the reserved lane would be isolated. In addition, the Boulevard Saint-Michel corridor offers a unique unit of analysis, measuring about 7 km, with bus running times of about 30 min in the initial situation. Moreover, the service of both the regular bus route and a limited-stop bus route would benefit from the same reserved lane. No previous paper has studied a reserved lane that is as long in distance or has such a long running time. Furthermore, this study is unique because it is investigating the effects of a reserved lane on more than one bus service, using archived AVL and APC data from both before and after periods, and not relying on simulations as did previous studies.

METHODOLOGY

The data used in the analysis came from AVL and APC systems, which are installed on 306 of the 1,680 buses in STM's fleet. AVL and APC data are widely used in transit research when changes in a service need to be measured or estimated (*4, 7, 8, 21*). As only 18% of STM's buses are outfitted with AVL and APC systems, the STM samples all its routes at different moments to obtain a complete picture of its network. The data recorded at both the stop and the trip levels can then be used to adjust schedules or to generate performance measures. After the data were cleaned and incomplete trips, recording errors, and trips with insufficient passenger activity were removed, information on 4,384 trips was kept.

As Figure 1 shows, the reserved lane on Boulevard Saint-Michel stretches between Rue Rachel to the south and Boulevard Henri-Bourassa to the north [8.25 km (5.13 mi)]. The segment evaluated in this study was limited to the interval between Boulevard Saint-Joseph to the south and Rue Fleury to the north [6.82 km (4.24 mi)] because of Route 467's limitations. Indeed, its first stop in the southern portion of the reserved lane was at Boulevard Saint-Joseph, whereas Rue Fleury's stop was adjacent to Boulevard Henri-Bourassa's stop in the northern section. Boulevard Henri-Bourassa's stop had to be excluded because the first and last stops of each route may cause counting errors in passenger activity, errors caused by layovers, and errors caused by the overlap between the end of a trip and the beginning of another. In addition, it was necessary to select the section to be analyzed in such a way that there was a stop for each route at both ends. There was a reserved lane on the curbside in each direction, leaving two lanes for cars in the middle of the street, one in each direction.

To analyze the effect of the implementation of a reserved bus lane on Boulevard Saint-Michel, a running time model was used. Meanwhile, to analyze OTP, a binary logit model was used to determine whether the bus arrived on time at the end of the route. Table 1 lists the variables used in the statistical analysis. "Running time" is defined as the difference between the leave time of the last stop of a segment and the leave time of the first stop of the segment. Here, the portion of the reserved lane analyzed was divided into a northbound and a southbound segment.

In addition to having a space component, the reserved lane had a time component. It was functioning between 6:30 a.m. and 9:00 a.m. southbound and between 2:30 p.m. and 6:30 p.m. northbound. Hence, all the trips kept in the database were completely made on the reserved-lane segment during operation hours of that lane in the appropriate direction, either before or after its implementation on August 3, 2009. A dummy variable distinguished the trips made on or after August 3, 2009, from the ones made before this date. A second dummy variable, Year 2009, characterized periods and accounted for two changes made in 2009: the full implementation of (*a*) a new smart card payment system (named OPUS) and (*b*) of Route 467, the limited-stop bus service on Boulevard Saint-Michel. There was also a dummy variable for the trips made on Route 467. According to the findings of El-Geneidy and Surprenant-Legault, Year 2009 should slow trips by 2.5% whereas Route 467 should accelerate them by 12.6% (*4*).

Finally, four additional variables were included to account for variations in running time. A delay before the start of a trip compared with the schedule should decrease running time when that delay increases, because bus drivers generally try to compensate for such an initial delay (*4*). Snow precipitation was used by Tétreault and El-Geneidy and was expected to increase running time, as buses may have to go slower, congestion may be higher, and passenger activity may be slower (*1*). Naturally, passenger activity, or the number of passenger movements through one of a bus's two doors, should increase running time. It is rare that passengers board through the rear door. This occurrence may indicate that the bus is near capacity and that the driver may let people enter by the rear door, as the rear of the bus is often less crowded. Trips that include boardings by the rear door should thus be slower, so a dummy variable was included to differentiate them from others.

Figure 2 shows graphically the different periods of data collection, represented by the vertical lines and labeled in the upper section of the figure, whereas the bold arrows indicate routes for which data were collected. Average running times are noted in parentheses beside route numbers. For consistency, data were collected in 2008 and 2009 only between April and December, as Route 467 began operating on March 30, 2009. Figure 2 shows that northbound trips tend to be slower than southbound trips, Route 467 is faster than Route 67, and running time tends to decrease with the addition of improvements to bus service.

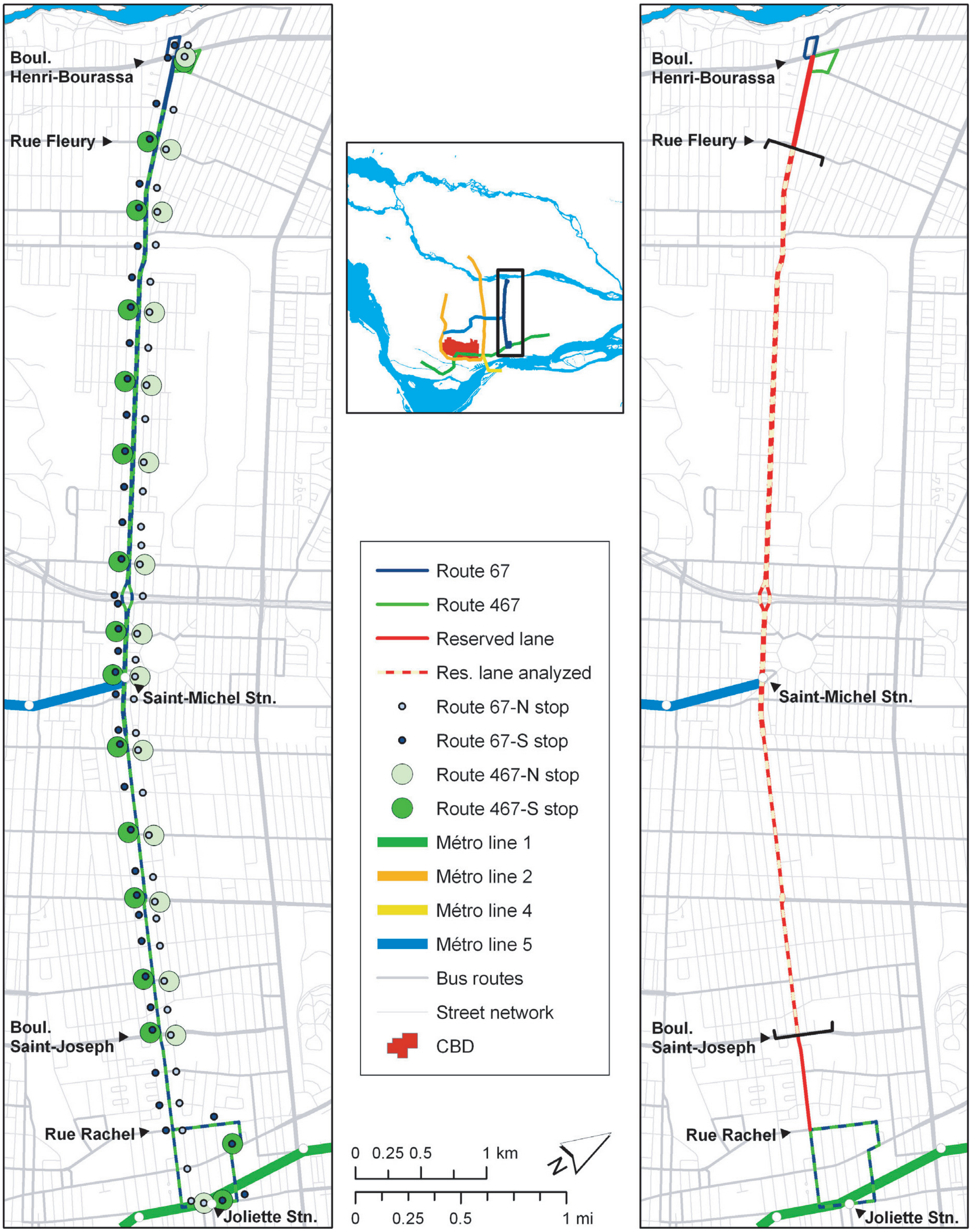

FIGURE 1 Study area. (Source: STM and DMTI Spatial, Inc., Markham, Ontario, Canada; Projection: NAD 1983 MTM8 coordinate system.)

TABLE 1 Definitions of Variables Used in Regression Model

Variable	Definition
Running time (s)	Difference between the leave time of the last stop of a segment and the leave time of the first stop of a segment.
On time	Dummy variable that equals to 1 if the trip arrived more than 3 minutes late at the end of the study segment.
Northbound trip	Dummy variable that equals to 1 if the trip is northbound. All northbound trips are realized during the afternoon peak hour whereas the southbound trips are realized in the morning peak hour.
Year 2009	Dummy variable that equals to 1 if the trip is made between April 6, 2009, and December 31, 2009. It equals to 0 if the trip is made between April 7, 2008, and December 31, 2008. Year 2009 sees the full implementation of a new smart card payment system (named OPUS) and of Route 467, the limited-stop bus service on Boulevard Saint-Michel.
Reserved lane in operation	Dummy variable that equals to 1 if the trip is made between August 3, 2009, and December 31, 2009. It equals to 0 between April 7 and December 31, 2008, and between April 6 and August 2, 2009. When equal to 1, the variable means that the reserved bus lane is now implemented.
Route 467	Dummy variable that equals to 1 if the trip is made by Route 467, a limited-stop bus service. If it equals to 0, the trip is made by Route 67, a regular bus service.
Delay at the start (s)	Difference between the leave time of the first stop of a segment and the scheduled leave time for this stop.
Snow precipitations (cm)	Snow precipitations in centimeters that occurred during the day when the trip was made.
Passenger activity	Total number of passengers who boarded or alighted by the front or the rear door during a trip.
Rear door boardings	Total number of passengers who boarded by the rear door during a trip. Boarding by this door is exceptional, as passengers have to pay their fare at the front door.

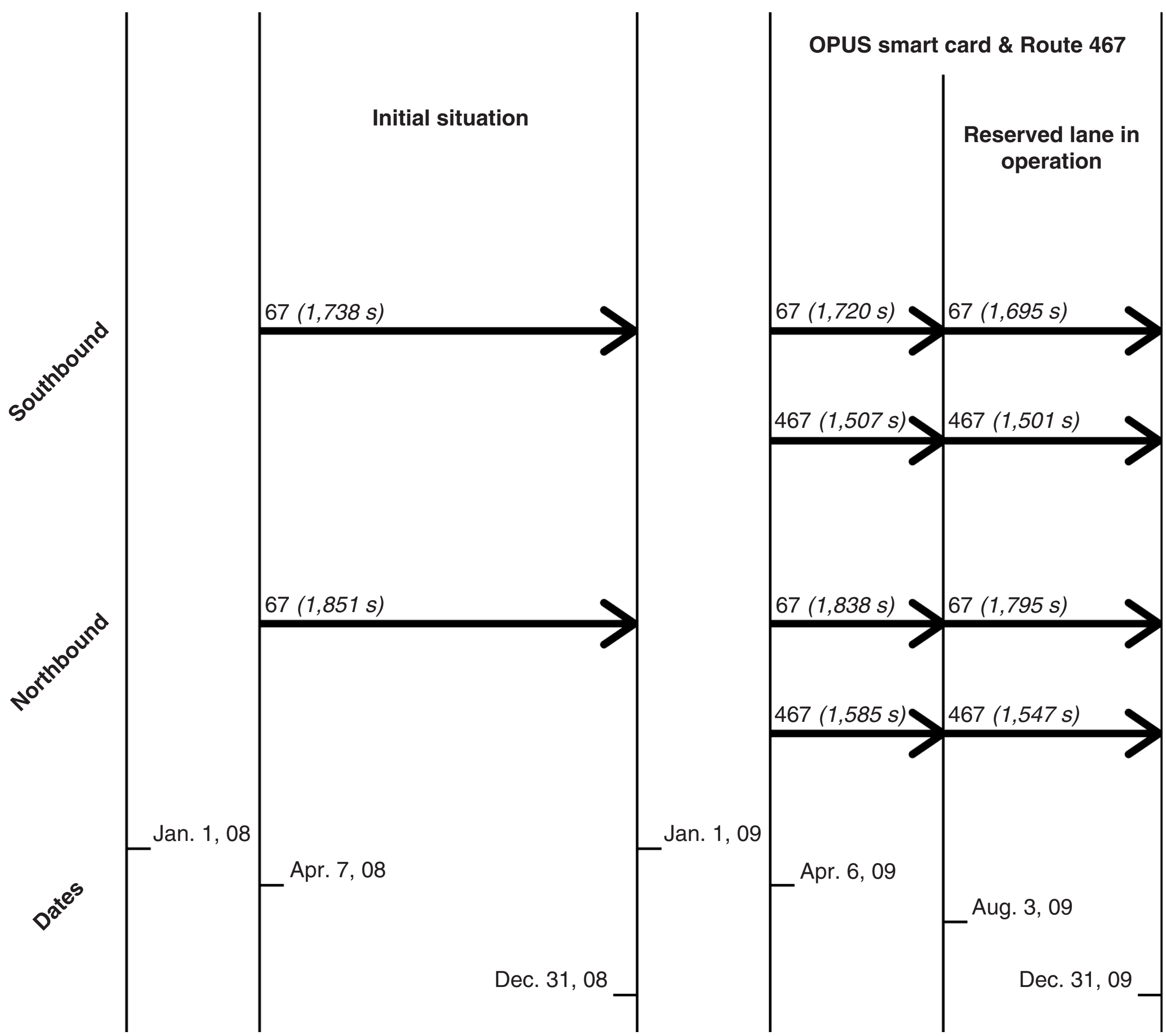

FIGURE 2 Timeline of changes to bus service on Boulevard Saint-Michel.

DESCRIPTIVE STATISTICS

The first part of this section compares the following five variables: running time, delay at the start, snow precipitation, passenger activity, and boardings by the rear door. Table 2 shows summary statistics for southbound trips made during the morning peak hour, whereas Table 3 includes statistics for northbound trips made during the afternoon peak hour. In each table, statistics are separated by period and route.

In Figure 2, on average, running time decreases each period, running times of Route 467 are shorter than those of Route 67, and northbound trips take more time than southbound trips. In addition to a decrease in average running time, a decrease in standard deviation is generally observed between periods. The coefficient of variation, the ratio of the standard deviation to the mean, is at its lowest in the period designated OPUS smart card and Route 467 for southbound trips and in the period designated Reserved Lane in Operation for northbound trips. Typically, a higher variance (or standard deviation) in running times is observed when bus bunching occurs. A low coefficient of variation eases the preparation of a schedule and maximizes schedule adherence and reliability, which are important factors in transit demand (*6*). As addition of a limited-stop bus service (Route 467) and a reserved bus lane provides for more fluidity in the buses' movements, it is expected that coefficients of variation decrease with implementation of these measures. However, it is not the case for southbound trips. A possible explanation for this discrepancy is that traffic conditions before implementation of the reserved lane maintained a regular distance between buses on consecutive trips.

In many cases, delay at the start is close to or more than a minute. Route 467 southbound seems to suffer the most from delays, starting 83 to 103 s later than the scheduled time. Meanwhile, the same route ends earlier than scheduled by 68 to 235 s. An explanation may be that Route 467 had an excess of recovery time between the northbound and the southbound trips. Schedules did not change except after implementation of the limited-stop service. It is also clear from observing Route 67 that implementation of the reserved lane has led to improvements in schedule adherence as well. During the morning peak (southbound), Route 67 was to end, on average, 81 s late, whereas northbound finished its trip 54 s late during the afternoon peak. After the implementation of the reserved lane, the morning peak southbound became 26 s late and the afternoon peak northbound became 10 s early. This finding indicates an improvement of 67% in the southbound morning peak and of 118% in the northbound afternoon peak. The standard deviation of running time and the delay at the end have declined during the reserved-lane period compared with the initial state. This finding indicates improvements in the reliability of the service being offered.

Passenger activity per trip decreases by around 20% after the initial situation, which is expected, as there are about 50% more trips during peak hours, when Route 467 is implemented. Small increases for southbound trips are observed after the reserved lane comes into operation, and Route 67 carries slightly more passengers in this direction. No differences exist between routes or periods (after the initial period) in passenger activity for northbound trips, except for Route 467 after the reserved lane implementation that counts about 18% less passenger activity per trip, without any particular reason. Last, snow precipitation and boardings by the rear

TABLE 2 Descriptive Statistics, Southbound Trips: Morning Peak Hour

Period	Route	*N*	Variable	Median	Mean	SD	Coeff. of Variation
Initial situation (Route 67 only)	67	732	Running time (s)	1,725	1,738	128	0.0735
			Delay at the start (s)	28	40	80	
			Delay at the end (s)	52	81	134	
			Snow precipitation (cm)	0	0.3	1.3	
			Passenger activity	165	173	58	
			Boardings rear door	0	1.3	2.7	
OPUS smart card and Route 467	67	206	Running time (s)	1,720	1,720	100	0.0581
			Delay at the start (s)	16	26	61	
			Delay at the end (s)	26	29	88	
			Snow precipitation (cm)	0	0.0	0.2	
			Passenger activity	130	138	46	
			Boardings rear door	0	0.3	0.8	
	467	29	Running time (s)	1,523	1,507	102	0.0679
			Delay at the start (s)	71	83	74	
			Delay at the end (s)	−233	−235	79	
			Snow precipitation (cm)	0	0.0	0.0	
			Passenger activity	129	130	37	
			Boardings rear door	0	0.2	0.4	
Reserved lane in operation	67	231	Running time (s)	1,700	1,695	106	0.0628
			Delay at the start (s)	34	41	66	
			Delay at the end (s)	16	26	80	
			Snow precipitation (cm)	0	0.1	0.5	
			Passenger activity	139	144	43	
			Boardings rear door	0	0.2	0.7	
	467	333	Running time (s)	1,513	1,501	103	0.0684
			Delay at the start (s)	95	103	88	
			Delay at the end (s)	−121	−104	118	
			Snow precipitation (cm)	0	0.2	0.7	
			Passenger activity	128	132	43	
			Boardings rear door	0	0.3	0.9	

NOTE: SD = standard deviation.

TABLE 3 Descriptive Statistics, Northbound Trips: Afternoon Peak Hour

Period	Route	N	Variable	Median	Mean	SD	Coeff. of Variation
Initial situation (Route 67 only)	67	1,431	Running time (s)	1,823	1,851	162	0.0876
			Delay at the start (s)	25	54	112	
			Delay at the end (s)	19	62	197	
			Snow precipitation (cm)	0	0.4	1.9	
			Passenger activity	175	178	57	
			Boardings rear door	0	0.9	2.1	
OPUS smart card and Route 467	67	316	Running time (s)	1,822	1,838	158	0.0858
			Delay at the start (s)	30	47	120	
			Delay at the end (s)	15	43	175	
			Snow precipitation (cm)	0	0.0	0.2	
			Passenger activity	138	145	43	
			Boardings rear door	0	0.4	1.0	
	467	58	Running time (s)	1,601	1,585	138	0.0870
			Delay at the start (s)	–31	–4	104	
			Delay at the end (s)	–78	–68	143	
			Snow precipitation (cm)	0	0.0	0.0	
			Passenger activity	146	145	42	
			Boardings rear door	0	0.4	0.9	
Reserved lane in operation	67	469	Running time (s)	1,786	1,795	127	0.0706
			Delay at the start (s)	28	39	81	
			Delay at the end (s)	–28	–10	121	
			Snow precipitation (cm)	0	0.1	0.5	
			Passenger activity	144	147	39	
			Boardings rear door	0	0.4	0.9	
	467	579	Running time (s)	1,543	1,547	123	0.0795
			Delay at the start (s)	3	11	76	
			Delay at the end (s)	–105	–91	114	
			Snow precipitation (cm)	0	0.1	0.5	
			Passenger activity	119	121	36	
			Boardings rear door	0	0.2	0.5	

door are rare occurrences (all medians are equal to 0); nonetheless, these phenomena have an important impact on running time when they occur.

Figure 3 shows the distribution of running times for all southbound morning trips (including both Routes 67 and 467) in contrast to the distribution of running times for all northbound afternoon trips. In each case, the distribution is fitted with a quadratic function whose maximum is reached in the middle of the peak period, which is around 7:30 a.m. and around 4:00 p.m. However, trips made in the afternoon (northbound) generally take more time than trips made in the morning (southbound). In addition, afternoon (northbound) trips display more variation in running time than morning (southbound) trips, an observation that is confirmed by the coefficients of variation, which range between 0.0706 and 0.0876 in the afternoon against a range of 0.0581 to 0.0735 in the morning (Tables 2 and 3).

ANALYSIS AND DISCUSSION

The regression model presented in Table 4 compares running times between Boulevard Saint-Joseph and Rue Fleury for Routes 67 and 467 during the three periods noted in Figure 2. Standard errors in this model are robust to heteroscedasticity, and the model does not suffer from multicollinearity.

Although both northbound and southbound trips are the same distance, northbound trips are slower by 113 s (6.8%), which could be explained by traffic conditions. In this database, southbound trips are made during the morning peak hour, whereas northbound trips are made during the afternoon peak hour. It is possible that on Boulevard Saint-Michel, traffic conditions are better during morning peak hours than during afternoon peak hours. As expected, trips made in 2009 were slower, in this case, by 26 s. This effect is probably due to the smart card payment system, which requires users to wait a few seconds before the machine can read their card. This finding is consistent with previous studies (*4*).

The model's main goal is to measure the effect of the new reserved bus lane. Trips made since the implementation of the reserved bus lane appear to be faster by 22 s (1.3%) southbound and by 40 s (2.2%) northbound. This value is derived from the combination of two variables: the first is the reserved lane in operation, and the second is the interaction variable reserved lane in operation multiplied by northbound trips (both shown in bold in Table 4). The effect of the reserved lane could possibly be mitigated by cars waiting in this lane to turn right at a traffic light, as they cannot turn right on red lights on the island of Montreal. Limited-stop service (Route 467) is faster than Route 67, by 162 s (2 min 42 s) southbound and by 232 s (3 min 52 s) northbound. These gains represent, respectively, 9.4% and 12.6% of the average Route 67 running times in each direction.

The delay at the start of a trip is expected to decrease running time. Bus drivers would compensate for 37% of the delay that they have when they start. The data used in this analysis include trips made in the winter, which involves snow. Indeed, at least 1 cm of snow was on the ground for 9.6% of all trips. For every centimeter of snow falling during a given day, running times of all trips made during that day increase by 14 s. The coefficient affecting passenger activity (passengers who board and leave the bus) seems low; in fact, part of

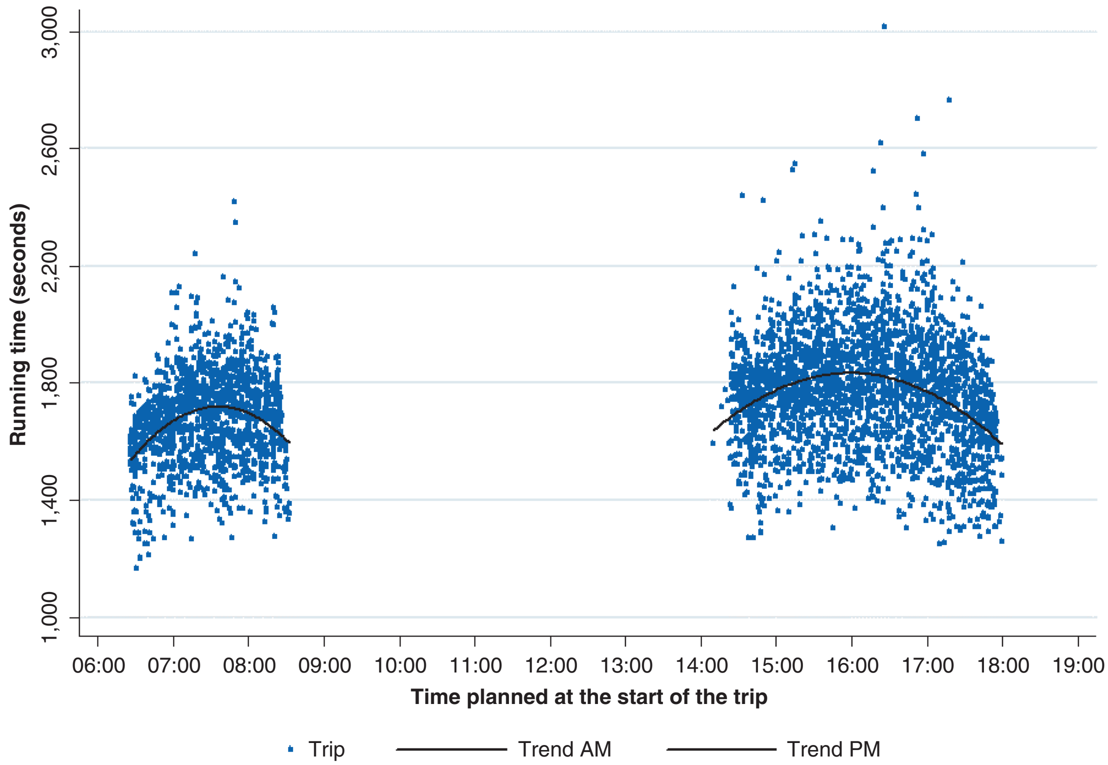

FIGURE 3 Distribution of running times in relation to time planned at start of trip.

the effect of passenger activity may be embedded in the constant of the model. As mentioned earlier, drivers may allow rear-door boarding when the bus is full. Each passenger boarding by the rear door adds 7.90 s to running time than another passenger movement; this time difference could mean that, when passengers are boarding by the rear door, boardings in general take more time, as the bus is reaching capacity.

The interaction variables involving the northbound variable are of particular interest. Indeed, northbound trips made during the afternoon peak hour are slower than southbound trips made during the morning peak hour by 113 s. The more-adverse traffic conditions in the afternoon could be explained by a higher trip demand for all modes because of the simultaneous events of the end of the school day, the end of the workday, and the beginning of the work night and of many shopping trips. Once it is said that northbound trips are penalized compared with southbound trips, it is necessary to look at the differential impact of the new measures introduced by STM.

The first impact is the limited-stop bus service. This service provides an additional 70 s of savings for northbound trips, which is 43% more than the savings for southbound trips. It is possible that, in situations with high traffic levels, making a stop with passenger activity requires more time than with less traffic. With increased car traffic, all these actions may be more time-consuming. As a result, the limited-stop service (Route 467), which makes 15 stops instead of 39 for the regular service (Route 67), is less affected by traffic conditions because of the smaller number of stops. However, the difference between northbound and southbound trips made on Route 467 seems to hold even when the reserved lane is in operation. As noted earlier, cars are allowed to enter the reserved lane if they need to turn right. It is possible that these cars have a stronger negative impact on running times of northbound trips than of southbound trips, but this hypothesis needs to be verified.

The second impact is the reserved lane, which decreases running time by 18 s more northbound than southbound (81% more). Again, the additional savings for northbound trips support the hypothesis that these trips are realized in a more-congested environment, which the reserved lane lessens at least partially. Nevertheless, the reserved lane's impact on running time is only –1.3% southbound and –2.2% northbound, which is significant, although marginal. Aside from cars turning right at intersections, two other points can

TABLE 4 Linear Regression Model, Running Time Between Boulevard Saint-Joseph and Rue Fleury During Times of Reserved Lane Operation

Variable	Coefficient	*t*-Statistic
Constant	1,533	199.61***
Northbound trip	113	23.67***
Year 2009	26	4.63***
Reserved lane in operation	**−22**	**−2.94****
Reserved lane in operation * northbound trip	**−18**	**−2.08***
Route 467	–162	–20.96***
Route 467 * northbound trip	–70	–6.73***
Delay at the start (s)	–0.37	–7.65***
Snow precipitation (cm)	14	5.08***
Passenger activity	1.19	22.57***
Rear door boardings	7.90	3.31***

NOTE: N = 4,384, R^2 = .5868.
*Significant at 99.9%, **significant at 99%, ***significant at 95%.

explain the depression of the savings from the reserved lanes. The first is that STM did not change schedules after implementing the reserved lanes. When one notices the delays at the start and the end in Tables 2 and 3 for the reserved-lane periods, it becomes clear that buses start late and end early. These factors indicate an excess in recovery time in the schedules used during this period. Such excess explains the reasons for the amount of delay at the start. For a driver to adhere to schedule that contains excess time, he or she would have to start late, go slower, hold at some stations—practice a combination of those actions—to avoid being too early at the end of the route. Finally, the levels of congestion along Boulevard Saint Michel are not extreme, especially southbound during the morning peak when compared with other sections in the region; this factor makes the savings from the reserved lanes appear minor.

As the summary statistics show (Tables 2 and 3), delay at the end of the study segment during the reserved-lane period declined compared with the initial-situation period. In the STM system, a bus is considered on time if it is between 1 min early and 3 min late, measured at the time point and compared with the announced schedule. The following model concentrates on the impact of the various measures implemented by STM to reduce the probability of arriving late at the end of the study segment. Arriving late at the end of the segment (more than 3 min late) is coded 1, whereas being on time (less than 3 min late) is coded 0. This variable is used as the dependent variable in a binary logistic model. The findings from this model are reported in Table 5.

Two main policy variables have a negative and statistically significant effect on the probability of being late. The reserved lane decreases the odds of being late by 65%, whereas Route 467 decreases it by 66%. Northbound trips increase the odds of being late by 75%. This finding is consistent with the running-time model, for which running times for northbound trips were much slower than those of southbound trips. The introduction of the OPUS smart card system (2009 variable) increases the odds of being late by 69%. Delay at the start increases the odds of being late by 0.9% for every second late at the beginning of the route. As expected, the amount of snow increases the odds of being late by 20% for every centimeter of snow. For the activity of every passenger, the odds of being late increase by 2%. Finally, the odds of being late increase by 6% for every boarding by the rear door.

To summarize, the various measures used by STM seem to benefit northbound trips more than southbound trips, whereas northbound trips are, on average, the slowest. The total savings on the northbound trips is 272 s (14%), whereas the savings for southbound trips is 184 s (11%). More savings could have been observed, 16% northbound and 12% southbound; yet, because of implementation of the smart card system, the current savings are lower than these values. Of the total efforts by STM to improve service along Route 67, the reserved lane represents 12% to 15% of total savings in bus running time on Boulevard Saint-Michel. In addition to savings in running time, a decrease of 65% in the probability of being late occurred with implementation of the reserved lane and 66% along Route 467. Finally, the decline in the variation in service (running time variation and variation in the amount of delay at the end) is apparent from the summary statistics, indicating a third and extremely important benefit to transit riders from implementation of the reserved lane.

TABLE 5 On-Time Performance Model

Variable	Coefficient	*Z*	Odds Ratio
Constant	–6.637	–22.430***	
Northbound trip	0.561	4.380***	1.752
Year 2009	0.525	3.150**	1.691
Reserved lane in operation	–1.023	–4.810***	0.359
Route 467	–1.070	–3.830***	0.343
Delay at the start (s)	0.009	14.300***	1.009
Snow precipitation (cm)	0.187	5.550***	1.206
Passenger activity	0.021	15.690***	1.021
Rear door boardings	0.064	2.310*	1.066

NOTE: N = 4,384, pseudo-R^2 = .341, log likelihood = –1,068.642.
*Significant at 99.9%, **significant at 99%, ***significant at 95%.

CONCLUSION

The objective of this paper was to assess the impact of a reserved bus lane along Boulevard Saint-Michel in Montreal on bus running times. Although the reserved lane is in operation only during the morning peak period southbound and the afternoon peak period northbound, these two cases appear to be different in relation to running times and possibly traffic conditions. Northbound trips take about 7% more time than southbound trips, which is likely due to higher congestion in the afternoon going north than in the morning going south. Implementation of a limited-stop bus service yields running time gains of 9.4% southbound and 12.6% for the more-congested northbound trips, results that are consistent with previous research (*1, 4*). These results could mean that limited-stop bus service is even more effective in difficult traffic conditions than it is in light traffic conditions. As for the reserved lane, its effect on running time seems small, with 1.3% gains southbound and 2.2% gains northbound. It is possible that cars waiting in the reserved lane to turn right weaken the benefits of the reserved lane on bus running time. Hence, forbidding right turns at some intersections could provide additional running-time gains for buses. In addition, moving from nearside bus stops to farside bus stops is expected to help in increasing the benefits from the reserved lane and bypass the delays caused by right turns, especially with the implementation of transit signal priority. The fact that STM did not change the schedules of Routes 67 and 467 until January 2010, combined with levels of delay at the start and early arrivals at the end of the route, can also explain the depression in the reserved-lane savings in running time. The presence of excess in recovery time is reflected in the driver's decision to leave the first stop late and arrive early at the end. In January 2010, STM applied several changes to Routes 67 and 467, including changing the schedules and implementing articulated buses to serve Route 467. A second study after the schedules were tightened is recommended so that the effects of the reserved lanes on both changes can be measured. Both limited-stop service and reserved lanes provide more time savings to northbound afternoon peak trips than to southbound morning peak trips. The direct implication of these findings is that the more a bus route is affected by adverse traffic conditions, the more it will benefit from improvements such as limited-stop service and reserved lanes. Although the savings in running time are small, the changes in OTP are clear and of a high magnitude. A reserved lane and limited-stop service lead to a decrease in the odds of being late by 65% and 66%, respectively. OTP has a direct impact on customer satisfaction (*17*). This finding explains the high levels of customer satisfaction noticed in previous studies that concentrated on limited-stop services (*4, 22*). In addition to the benefits in OTP, the summary statistics show a decline in running-time variation and variation in delay at the end of the route. These findings are clear indications of the increase in transit service reliability along the studied corridor. Finally, no difference is observed between the limited-stop service and the regular service after implementation of the reserved lanes. This factor indicates that, in this study, the reserved lane has a similar impact on both types of service.

This study showed the direct benefits from implementing various strategies to improve bus transit service in an urban environment. The findings from this study can help designers to understand the benefits of these changes and to account for them in future scheduling plans so that excess operating time can be avoided. More research is needed to assess the detailed factors affecting the efficiency of implementing a reserved lane. To collect detailed data, installation of video cameras at the front of buses may be one possible method. As the main effect of a reserved lane is isolation of a bus corridor from other traffic lanes, efforts should be made to quantify the effects of actual traffic on bus running times and OTP with different scenarios related to the location of the reserved lane. The location of the reserved lane on the curbside or in the middle of the road is expected to affect the lane's efficiency as well. Because only 10% of STM buses are implemented with AVL and APC systems, it is not possible to perform a reliability analysis to confirm the findings from the summary statistics.

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