Effect of With-Flow Bus Lanes on Bus Travel Times

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Improvements in bus performance due to introduction of reserved bus lanes have traditionally been evaluated in terms of savings in total travel time. Little attention is usually paid to changes in individual segment times (i.e., travel times between consecutive bus stops along the bus route). An approach is presented that investigates the effect of an urban reserved bus lane on bus travel time on individual segments. Subsequently, the change in segment time is related to characteristics and traffic regulations at respective segments. Data were obtained by analysis of videotapes recorded before and after the introduction of exclusive curb bus lanes on a major arterial road in downtown Toronto. The data indicate that time savings are most likely to occur on segments where buses previously experienced considerable congestion, as well as at traffic signals, especially when bus stops are arranged with one on the near side and the next on the far side of their respective intersections. However, these time savings generate additional ridership, resulting in longer dwell times at stops and a corresponding overall increase in total travel time. Thus, the perception of transit service improvement may have more impacts on ridership change than any substantive change in performance. The results of the study suggest opportunities for using reserved bus lanes on a more selective basis along a particular route and the need to reconsider whether taxis should be permitted to use these lanes.

Throughout North America, reduced dependence on public transit has led to increased road congestion with corresponding delays and costs. For example, the daily cost of delay in the United States in 1984, on the freeway system alone, is estimated to have exceeded $1.2 billion (*1*). By contrast, for any reasonable load factor, buses contribute relatively little to congestion. According to one study, a bus can carry 20 times as many passengers as a car and contributes only 3 times as much to congestion (*2*). As a result, bus priority schemes have attracted attention as a means of reducing bus delays due to traffic congestion in order to enhance the attractiveness of transit.

Although there are a variety of bus priority schemes, this paper is concerned with urban streets along which curb lanes are devoted to bus use, referred to as "with-flow bus lanes." The implementation of such preferential treatment is generally believed to result in an improvement in total bus travel time, taken as the best single indicator of level of service. Previous applications of with-flow bus lanes have shown a wide range of changes in total travel time.

For example, a dual-width exclusive bus lane was introduced on Madison Avenue in midtown Manhattan and before and after observations were obtained for the entire length of this facility (*3*). During the p.m. peak hour, average total travel time decreased by 45 percent, from approximately 18 min to less than 10 min. Canadian examples include bus lanes on Albert/Slater and Rideau streets in Ottawa and Eglinton Avenue in Toronto, where changes in total travel time ranged from 0 to 15 percent, 5 to 25 percent, and 7 percent, respectively (*2*). Discrepancies in the results of these and other studies provide few guidelines for the expected change since, generally, the overall evaluations do not examine the impact on individual segments (i.e., sections between consecutive bus stops). An extensive overview of bus priority experiences in North American and European cities is presented elsewhere (*2,4*).

In this study, the impact of with-flow bus lanes is investigated by analyzing segments of a bus route individually. An attempt is made to relate changes in any one segment to traffic regulations and characteristics of the particular segment.

To study the effect of with-flow bus lanes on travel times, it is essential to analyze conditions both before and after implementation of the priority scheme. This can be accomplished by preparing time-space tables from which travel times for each segment can then be extracted. In obtaining the comparison results, statistical tests should be used to determine whether the difference is significant or whether the change could have occurred simply because of inherent variations. This is the approach used in comparing before and after observations for the Bay Street Urban Clearway in Toronto.

BAY STREET URBAN CLEARWAY AND DATA COLLECTION

Street and Service Characteristics

Bay Street, one of the central corridors in downtown Toronto, extends north-south from Davenport Road to Queens Quay, as shown in Figure 1. There are two lanes in each direction. Transit service consists of two overlapping bus routes, a main route supplemented by a "short turn" route during morning and evening peak periods. In the morning period, most riders board buses at Bloor Street, transferring from the subway to access employment activities to the south. In the afternoon, the direction of flow reverses.

Most of the 17 bus stops covered by the service are located on near sides of signalized intersections, and a few are located on far sides (Figure 2). Throughout this paper, bus stops are by default located on near side (at traffic signals), unless otherwise stated.

Project Implementation

On October 29, 1990, the city of Toronto initiated the dedication of curb lanes to buses, taxicabs, right-turning vehicles, and bicy

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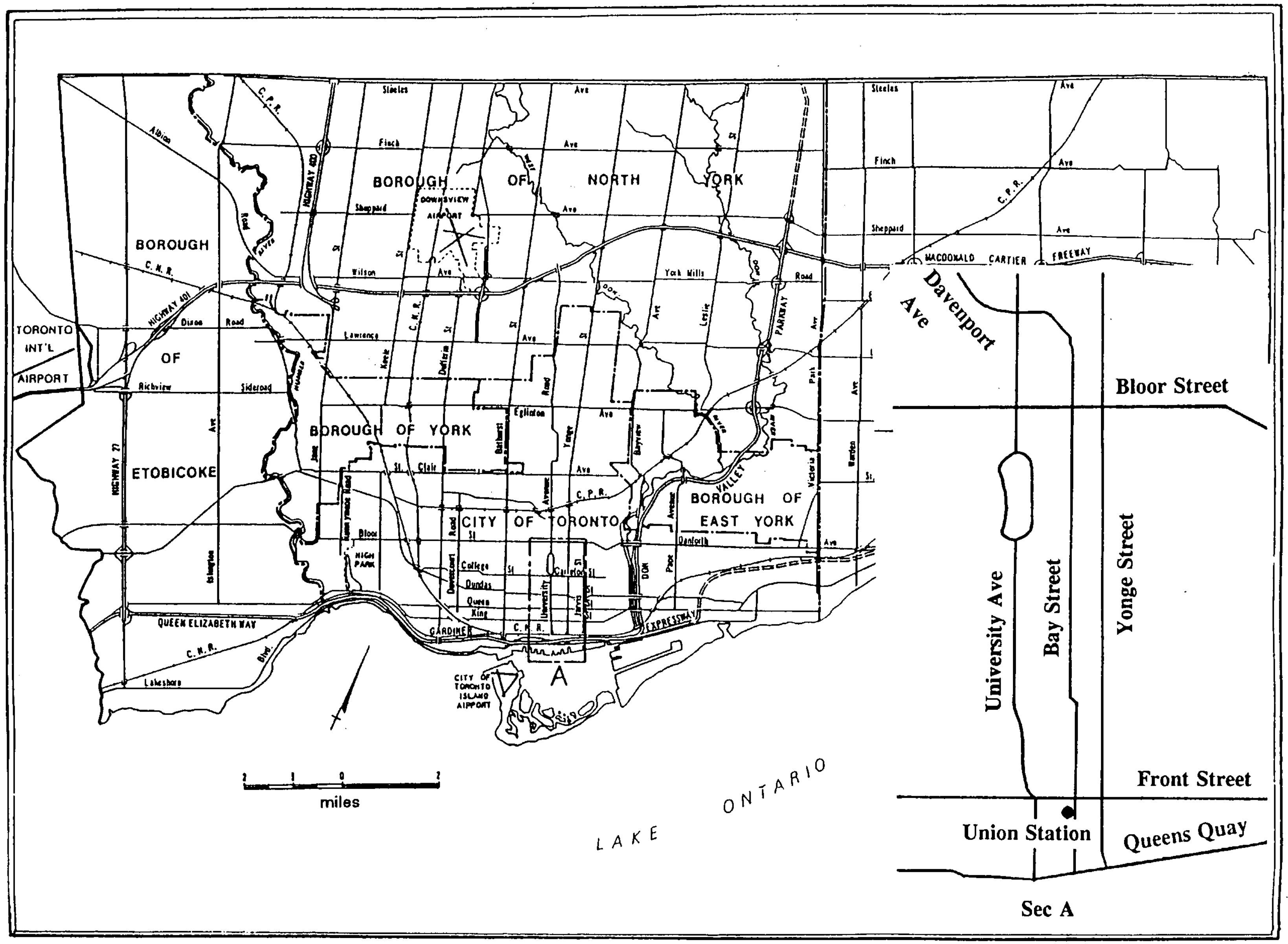

FIGURE 1 Bay Street in metropolitan Toronto.

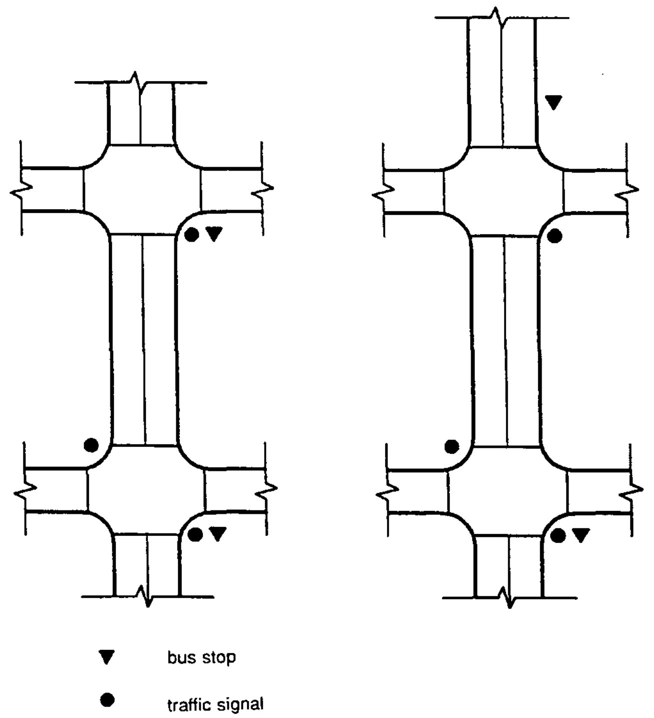

FIGURE 2 Illustration of segments with different bus stop locations.

cles. The project is documented by the Department of Public Works (*5*) and summarized as follows:

1. Almost 3 km of the southbound and northbound curb lanes on the Bay Street are reserved for public transit motor vehicles, taxicabs, right-turning vehicles, and bicycles only from 7:00 a.m. to 7:00 p.m. except on Saturdays, Sundays, and public holidays. Seventeen bus stops in each direction are served by the reserved lanes. There is no break during the off-peak period because bus delays during this period are of the same order as those during the afternoon peak period (*5*).
2. Stopping, except for transit vehicles, is prohibited from 7:00 a.m. to 7:00 p.m. except on Saturdays, Sundays, and public holidays. Parking is prohibited at all times on both sides of Bay Street. Stopping was permitted before implementing this project at all times, but parking was permitted during off-peak periods only.
3. Some new turn prohibitions were introduced.
4. The reserved lanes are identified by overhead signs and pavement markings of white painted diamonds with the message 7 A.M.–7 P.M., MON–FRI, NO CARS–TRUCKS.

Data Collection

Data were collected by continuous on-board video camera filming through the bus windshield. The camera is equipped with a stopwatch that indicates elapsed time, thereby allowing the travel time by segment to be determined.

Before implementation, the operation of traffic control devices (i.e., turn prohibitions and parking) varied throughout the day. Traffic flows and ridership also vary by time of day, as well as by direction. For these reasons, filming was carried out both before and after implementation at three fixed times, namely, 8:00 a.m., 2:00 p.m., and 4:30 p.m., to represent the morning peak, off-peak, and evening peak periods, respectively. For each period, one southbound and one northbound trip were filmed per day. Filming was carried out on Tuesdays, Wednesdays, and Thursdays to avoid irregularities usually associated with weekends, Mondays, and Fridays. The sample sizes for the before and after periods are presented in Table 1.

Data Preparation

From the data collected, each of the southbound and northbound trips during the three periods (i.e., morning, off-peak, and evening), before and after project implementation, was separated into individual dwell times (at each stop), individual travel times from each stop and/or traffic signal to the following stop and/or traffic signal, and individual signal times (i.e., delay time at each traffic signal). Finally, the data were entered for computer analysis.

ANALYSIS OF AGGREGATE TIMES

Before turning to the detailed analysis of segment times, this section examines the change in bus performance on the basis of total travel time. Total travel time for a southbound trip is defined as the time from the moment that doors open at the Bloor bus stop to allow for passenger boarding and alighting until the moment that doors are closed at the Union Station bus stop in the south. Most origins and destinations of passenger trips lie along this section. Total travel time for a northbound trip is defined similarly.

Total travel time includes total running and total dwell times. The change in total running time is considered a better measure of change in overall performance than total travel time because total travel time may increase because of increases in dwell time attributable to increased ridership (which itself, of course, is a positive result).

To study the change in any of these three time measures after project implementation, the *t*-test on two population means is

TABLE 1 Sizes of Before and After Samples

	Number of Trips					
	Morning		Mid-day		Evening	
Period	SB[a]	NB	SB	NB	SB	NB
'Before'	16	13	8	7	14	14
'After'	12	12	10	9	7	10

[a]SB = Southbound; NB = Northbound.

used. The *t*-test was carried out at a 5 percent level of significance as recommended for traffic studies (*6*). The results of all tests are given in Table 2 and discussed here by direction of travel. The mark (√) in the tables indicates that the null hypothesis tested is rejected at the 5 percent level of significance, implying that the random variable has either decreased or increased.

Southbound Direction

Table 2 indicates that the means of total travel time and total running time decreased significantly during the three periods studied. However, because of road construction activity that affected travel times at southern segments before project implementation, the changes in total travel and total running times for the southbound direction do not represent the effect of the reserved lane alone on bus performance. In other words, without this construction activity, travel times before project implementation would undoubtedly have been lower than those recorded.

As indicated in Table 2, the mean of total dwell time increased by 44.8 percent during the midday period, with no significant changes occurring during other periods. The increase in total dwell time is attributable to increased ridership. To investigate the increase in ridership, the numbers of passengers boarding and alighting at each stop were observed. Passengers board from the front door and alight from either the front or rear doors. Since filming was carried out from the front seat, passengers boarding and alighting from the front door were videotaped and subsequently counted when the tapes were viewed. The number of passengers alighting from the rear were counted manually at each stop and dictated into the camera microphone during taping. Figure 3 depicts the changes in ridership, measured by the total number of on-passengers per bus trip along the bus lane for four of the six cases studied; ridership in the other two cases is minimal. The exhibit shows a general increase in ridership that agrees with the findings of another study that reported an overall increase in ridership by 25 percent (*7*). During the midday period, ridership in the southbound direction increased by 45.7 percent, from 45.8 to 66.7 on-passengers per trip, as shown in Figure 3.

Northbound Direction

Since traffic in the northbound direction had not been affected by construction, the results shown in Table 2 for this case provide a more reliable measure of the impact of the reserved lane on the overall bus performance. As shown, during the morning and midday periods, none of the means of the three variables changed significantly after project implementation. During the morning period, traffic is very light in the northbound direction and parking along Bay Street was already prohibited before the bus lane was introduced. Thus, the results pertaining to this period agree with the a priori expectation of changes in the three variables.

Although parking was permitted during the midday period before project implementation, the expected improvement in bus performance after introducing the exclusive lane, accompanied by parking prohibition, did not occur. Total dwell time did not change significantly, yet ridership shows an increase comparable to the case of midday, southbound period, as shown in Figure 3.

During the evening period, the mean of the total travel time increased significantly by 7.4 percent, while the mean of the total running time remained unchanged. However, the mean of the total dwell time increased by 61.8 percent, which explains why the mean of the total travel time increased. Corresponding increase in ridership is shown in Figure 3.

Conclusions Related to Aggregate Times

The results for the northbound direction during the evening period reveal the weaknesses of studying the change in bus performance

TABLE 2 Results of *t*-Tests on Aggregate Time Means

	Morning							
	Southbound				Northbound			
	$\bar{x}_1$[a]	$\bar{x}_2$		Change (%)	$\bar{x}_1$	$\bar{x}_2$		Change (%)
Total Travel Time	18.2	17	✓	-6.7	15.1	14.8		
Total Running Time	13.9	12.2	✓	-12.2	12.3	11.9		
Total Dwell Time	4.3	4.8			2.8	2.9		
	Mid-day							
Total Travel Time	21.5	18.2	✓	-15.3	17.4	173		
Total Running Time	18.2	13.4	✓	-26.2	14.2	12.6		
Total Dwell Time	3.3	4.8	✓	+44.8	3.3	4.6		
	Evening							
Total Travel Time	20.5	18.2	✓	-11.6	19.3	20.7	✓	+7.4
Total Running Time	17.1	14.1	✓	-17.8	15.5	14.6		
Total Dwell Time	3.4	4.1			3.7	6.1	✓	+61.8

[a]$\bar{x}_1$ and $\bar{x}_2$ are sample averages (in minutes) 'before' and 'after', respectively.

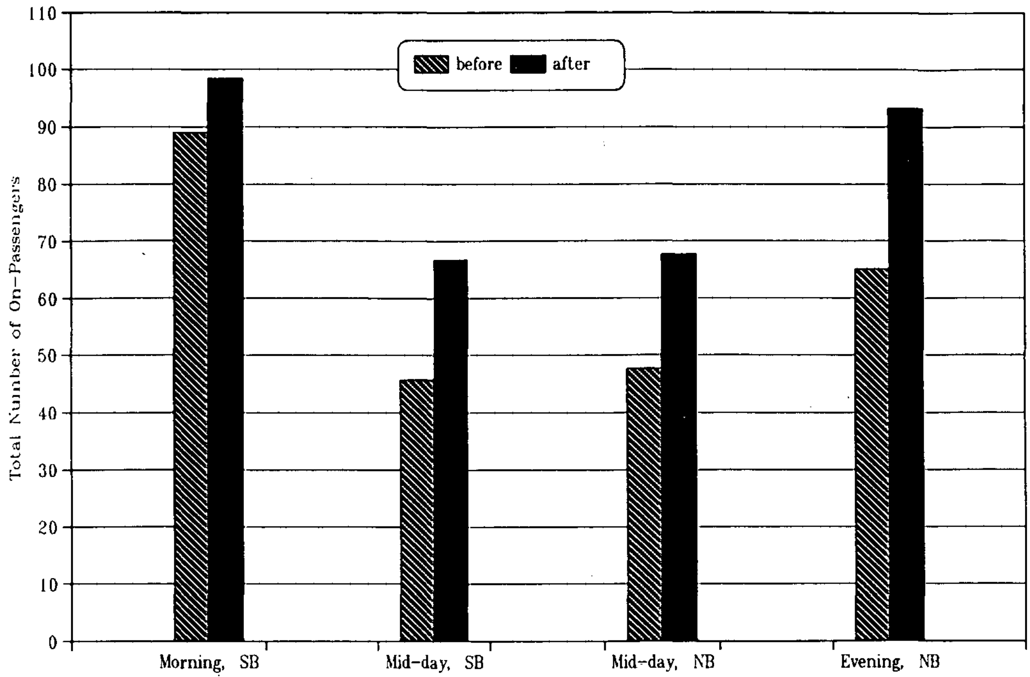

FIGURE 3 Average total number of on-passengers per trip along the bus lane.

on the basis of total travel time change. According to the analysis, bus performance during the evening period deteriorated significantly, after introducing the bus lane, whereas the mean of the total running time, a more precise measure of bus performance, did not change.

For the northbound direction, results indicate that total running time did not change after project implementation during any of the periods studied. The reasons for this result are unclear since, thus far, the impacts of the reserved bus lane on individual segment running times have been ignored. Clearly, measuring total travel time alone does not help explain differential changes in the two basic components (total running and total dwell times). Moreover, total running time does not account for different segment characteristics along the entire route.

CHANGES IN SEGMENT TIMES

Segment time is the time taken to travel between two successive bus stops, excluding dwell time. For a single segment, it is the elapsed time from when the doors are closed at the upstream stop until they are opened at the next stop. Signal time (i.e., bus delay at a traffic signal) is included if encountered during this period. *t*-tests are carried out for all segment times of southbound and northbound trips during the three periods studied. The results for segment time means that changed at the 5 percent significance level are presented in Table 3. The detailed analysis and results are presented more fully elsewhere on a segment-by-segment basis, for each direction, and by the three basic periods (A. S. Shalaby, unpublished data). Only a few of the more general observations are summarized herein.

Construction, as noted previously, was taking place at a southern intersection on the Bay Street before lane introduction. As a result, the four southbound segments that were affected are discarded from the analysis, except for the morning period when southbound traffic is relatively light at that particular section of Bay Street.

Bus time mean, in the southbound direction during the morning period, decreased significantly after project implementation at only 5 of the 15 segments studied, as indicated in Table 3. Parking and turning prohibitions at these five segments were already in force before lane introduction. Inspection of these segment times shows that most savings occurred at four traffic signals. Examples include signal times, which decreased from 21.7 to 3.2 sec and from 12.1 to 0.4 sec.

TABLE 3 Results of *t*-Tests on Segment Time Means

	Sample Average (sec)		
	'Before'	'After'	Change (%)
Southbound, Morning	48.6	38.2	-21.4
	26.7	23.1	-13.5
	47.7	28.1	-41.1
	23	19.4	-15.6
	70	61.7	-11.8
Southbound, Mid-day	86.5	51.5	-40.5
	44.7	26.6	-40.5
	45.2	58.5	+29.4
Northbound, Evening	66.1	85.6	+29.5
	68.2	31.4	-53.9
	121.1	77.4	-36.1

At one signalized intersection, where the bus stop is on the near side, before lane introduction, buses would usually encounter large queues that would prevent buses from boarding passengers during the red signal. As a result, buses would generally join the queue until it dissipated, board and alight passengers during the green signal, and were then forced to wait during the following red time. After lane introduction, queues are much shorter than before and formed by light-volume, right-turning vehicles Thus, buses can make use of the red signal to board and alight passengers; consequently, the need to wait for more than one red signal becomes less likely.

The phenomenon of time savings at traffic signals is more pronounced when the location of bus stops is such that one on the near side with the following stop on the far side of their respective intersections, an arrangement known as Von Stein's law of transit stop locations (*8*). The bus stops at four consecutive intersections to the north of Bay Street constitute a series of alternative stops. The results show that time means at two of the three segments decreased significantly, mainly because of shorter delay times at traffic signals, as noted earlier. This phenomenon also occurred at the second series of alternative stops at three intersections south of the Bay Street. It is more pronounced when right-turning traffic is either prohibited or very light.

During the midday period, travel time mean decreased at one segment and increased at another, as shown in Table 3. Inspection of the first segment indicates that the significant decrease in segment time mean is due to parking prohibition after lane introduction. Although traffic congestion due to parking was also pronounced at another segment during the before period, change in the segment time mean was obscured by illegal parking and stopping because of ineffective police enforcement after lane introduction at that segment. When delays due to illegal parking and stopping (by cars, taxis, etc.) were eliminated from observations (e.g., waiting time for a bus behind a vehicle stopping or parking was excluded from observations), segment time mean decreased significantly by 40.5 percent.

The significant increase in time mean in the other segment, during the midday period in the southbound direction, is attributed to the considerable increase in signal time mean at the upstream intersection (2.2 to 17 sec), which may be a result of the increase in dwell time at the near-side bus stop, causing buses to wait more often during the red signal after using the green time for boarding. Automobile volume, measured for both directions combined at that segment, was reported to have increased after project implementation by 13 percent, from 1,310 to 1,480 (*7*).

In three of the six cases studied—namely, southbound-evening, northbound-morning, and northbound-midday—buses at the 16 segments of the route experienced no significant change in travel time mean. In one case, although parking prohibitions were applied after lane introduction, there was no effect on bus performance, largely because of relatively light traffic. In the other two cases, parking and stopping regulations were similar before and after, while some new turn prohibitions were introduced after lane introduction. However, no improvement occurred because of light traffic. It is concluded, therefore, as might be expected, that dedication of the curb lane for transit use has no effect on segment times when traffic volume is light, even though turning movements, stopping, and parking prohibitions favor bus performance.

As noted earlier, traffic flow in the northbound direction represents the peak flow during the evening period. Most riders board buses at the southern stops, where major employment centers are located, and alight at the northern segments, especially at the Bloor stop, which is a transfer point between bus and subway services. The results given in Table 3 indicate that bus time mean increased at 1 and decreased at 2 of the 16 segments studied. The increase in segment time mean is due to considerable increase in time mean (44.2 to 61.3 sec) for the traveled distance of this segment (i.e., the segment time excluding the signal time at the upstream intersection). In fact, thorough inspection showed that the number of right-turning vehicles at the downstream intersection increased considerably, leading to longer queues that delayed buses after lane introduction. The increased number of right-turning vehicles is possibly due to the prohibition on right turns at the Bloor intersection and, consequently, the shift of right-turning movements to other intersections. Furthermore, according to one study, the number of taxis increased by 8 percent on the Bay Street to take advantage of the reserved lane (*7*). Thus, taxis attracted from alternatives to the Bay Street cause high delays at intersections where they leave for their destinations.

Introduction of the bus lane, together with the prohibition of right turns at one intersection, relieved to a large extent the considerable delays experienced by buses in the two northern segments where significant decrease in time mean occurred. The bus stops in the two consecutive segments are alternate, which also contributed to time savings, as explained earlier.

Effect on automobile times in non-bus-lanes as well as surrounding streets was reported to be insignificant, except in six sections, one in Bay Street and five in neighboring streets, where travel time decreased significantly (*7*).

SUMMARY AND RECOMMENDATIONS

Change in bus performance, following the introduction of with-flow bus lanes on urban streets, has usually been evaluated on the basis of total travel time change. This paper shows that total travel time is not the best measure of change in bus performance because its components (i.e., running times and dwell times) may vary considerably. Total running time also attributes the change in performance to the overall characteristics of the street, with no focus on individual segments having different characteristics and traffic regulations. As a result, reasons for changes, if any, are not fully explained.

The analysis carried out in this study leads to the following conclusions:

- The bus lane has little impact on bus performance during off-peak periods and when traffic is light.
- Prohibition of parking, only at previously congested segments, improves bus performance at those segments.
- Time savings occur at traffic signals (especially at segments accommodating alternative stops) and on previously congested segments.
- Right-turn prohibitions improve bus performance considerably. However, caution should be paid to the adverse impact of diversions of traffic to alternative intersections at which right turns are permitted
- Police enforcement is an important factor in achieving improvements to bus performance, particularly on congested segments.
- The use of reserved lanes by taxis diverted from other streets contribute to bus delays.

- Ridership generally increases after introducing the lane, even without improvements in travel time.

The last finding is noteworthy, since it appears that ridership increased because of the perception of an enhanced service by establishing an exclusive lane, even though total travel time, in one case, increased. In a user attitudinal survey, for example, 91 percent of the respondents expressed positive views of the project and 85 percent claimed they have a reduced transit travel time (*7*).

For future projects the following should be taken into consideration:

- Dedicating curb lanes to bus use during peak periods only;
- Dedicating curb lanes to bus use on a selective basis, at congested segments only, preventing right turns where possible, and revising stop locations, to be alternative at those segments. Police enforcement, however, should be strict at those particular segments;
- Allowing taxis to use the "jumping" lanes (i.e., curb lanes at the segments at which buses are favored) should be considered more carefully because of potential adverse impacts on bus performance; and
- Allowing parking on lightly congested segments.

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