Simulation-Based Methodology
for Improving Central Ottawa Transitway Performance

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Abstract

In North America and elsewhere around the world, there is a growing interest in bus rapid transit systems (BRTs) for serving the travel needs of middle size cities. Ottawa’s bus rapid transit model is well recognized for attracting and keeping riders in spite of competition from the private automobile mode. This specially designed facility enables OC Transpo, Ottawa’s transit agency, to provide fast and reliable bus service.

However, starting 2003, there was a growing concern among planners and transportation engineers in the City of Ottawa that bus travel time in the eastbound direction on the Central Transitway was showing a significant increase. It was recognized that field observations are useful for the identification of causes and patterns of delays in bus operations that increase travel time on the Slater eastbound bus corridor in Ottawa; a scientific method had to be used for a detailed investigation of problems and development of solutions.

Over a three- month period transit operations were observed in the field and compared with operations on the westbound Albert corridor. After some causes were identified, the Central Transitway within the road network in downtown Ottawa was also modeled and possible scenarios were examined using the microscopic simulation tool NETSIM. Based on the results derived from the field and from simulation, conclusions and recommendations were drawn to improve Central Transitway performance and reduce bus travel time. The results of this research project were brought to the attention of the OC Transpo and City of Ottawa engineers and planners. According to OC Transpo's technical personnel, the implementation of recommendations helped to improve the eastbound corridor performance.

This paper consists of five parts. Part 1 introduces the project background, objectives and methodology. In part two, literature is reviewed on transit operations on bus lanes, bus operating strategies, and headway based reliability control. Part three describes the study area, data collection and analysis of transit operations on the Central Transitway. In part four, the modeling and simulation of the Central Transitway is covered and highlights of results are presented. Finally, in part five conclusions and recommendations are noted.

1.0 Introduction

In order to enhance the sustainability of transportation, planners and engineers are looking for ways to enhance public transit performance and shift the modal split towards transit use. Without a doubt, for existing and future patrons, bus travel speed and time are the most important measures of effectiveness that will affect their decision regarding transit use. The passengers are likely to use it if it provides a quick trip. In order to define schedules, vehicles and operator requirements, transit agencies continuously measure and monitor bus speeds and travel times. City traffic engineers broadly use bus travel speed and time to determine and quantify congestion on the network and introduce appropriate traffic management measures.

As bus rapid transit (BRT) grows in importance in major North America cities and around the world, transportation professionals are committed to minimizing travel time and increasing bus travel speed in order to attract and retain transit users. The grade separated facilities and bus corridors on major arterials are managed in such a way to ensure minimal effect of traffic congestion on bus travel time. An appropriate traffic management and transit planning approach significantly contributes to travel time reduction and an increase in bus travel speed. If city policy is clearly aimed towards transit use and its growth, engineering measures can be implemented to increase levels of service for transit users and therefore increase ridership.

1.1 Background

Ottawa, Canada’s capital is a mid size city with a population of about 1,000,000. The transit system is based on BRT, which is well known around the world as a very efficient mode of public transportation. In the 1970’s Ottawa built one of the best busways, the so-called Transitway. The project was 75% senior-level government financed and it introduced a rapid transit system to Ottawa. It was found that travel demand could be accommodated with less cost by introducing a bus rapid system rather than light rail transit (LRT).

The Transitway was built on major corridors in Ottawa. The design enables a cruise speed of 80km/h and stations are very well designed to provide comfort and security for passengers during the entire service period. However, due to the estimated high capital cost to build bus tunnels through the Central Business District (CBD), it was found that buses could efficiently operate on “bus only” lanes, on arterials through the CBD. The buses are accommodated on Slater Street in the eastbound (EB) direction and on Albert Street in the westbound (WB) direction. The service is provided on these two parallel arterials with four transit stops in each direction.

The public transit is operated by OC Transpo transit agency, which is part of the City of Ottawa. OC Transpo is able to successfully provide a good service for commuters in both directions during peak periods. With more than 900 buses in their active fleet and more than 87 million annual trips made, the importance of efficient operations within Ottawa and through the CBD was always well maintained. As a result of close monitoring of bus operations in the CBD, the OC Transpo and City engineers realized that starting in September 2003 there was a significant increase in travel time through the CBD, particularly in the p.m. peak in the EB direction.

The City of Ottawa policy is to enhance an existing, already very efficient public transit. Since travel time through the CBD dramatically increased, it was necessary to undertake some effective measures to improve level of service for transit users that travel every day to and from downtown Ottawa. This was defined as a first priority for city transportation system management.

1.2 Study Objective

Following the priority set by City engineers and the OC Transpo planners to define and remove the causes for high travel time through the CBD, the interest was to explore the best approach that could be undertaken in order to solve this growing problem for the Ottawa transit system. The purpose of this study was to observe and analyze existing conditions in transit operations through the CBD. These findings later were used as an input for microscopic simulation of existing conditions and used to propose operational alternatives. Therefore, the objectives of this study were to:

1. observe transit operations during the p.m. peak period in both EB and WB directions and define the causes for travel time increases,
2. analyze transit operational data and define the parameters that will be used in micro-simulation,
3. conduct a micro-simulation on existing conditions and propose operational alternatives that were determined through the field observations, and
4. draw conclusions based on observations, data analysis and micro simulation output results.

The study was initiated following a discussion with the transit agency officials regarding the need to explore transit operations through the CBD and provide conclusions and recommendations for improvement.

2.0 Existing Research

Transportation sustainability calls for a reliable and efficient transit system could be a leading transportation mode in the near future. It seems that buses are not very attractive for users who have access to car, because buses travel at lower speeds and the service might be unreliable. However, bus transit level of service can be greatly improved through the construction of busway (11).

Ottawa has become a very good example of how a BRT system attracts more passengers and ensures increased levels of service and reliability as compared to bus transit operation in mixed traffic lanes. The Transitway in Ottawa was successful from the start. Over the years, it continues to provide the City with some of the best bus-based rapid transit in North America (5). The Ottawa rapid transit system includes “bus-only” lanes in the Ottawa CBD.

At the time of initiating this study, the Ottawa Central Transitway didn't provide reliable service on “bus-only” lanes along two arterials and this lack of reliability could have jeopardized increases in ridership. Previous investigations on this subject were based on determining effects on bus lane speeds. Using various study tools, it was found that the level of service, defined through bus lane speed and travel time, highly depends on the number of buses per hour per lane, bus stops locations and number of stops per kilometer, dwell time at stops and service patterns, schedules, and headways (10). Past research conducted on bus lane operations showed that an increase in the number of buses and an inappropriate service pattern reduces bus lane speed, travel time and level of service.

One common research tool used in recent years is NETSIM, a micro-simulation tool which simulates bus lane speeds and enables the estimation of level of service. The result can be compared to the level of service guidelines in the Highway Capacity Manual (HCM) 2000 (8).

2.1 Transit Operations on Bus Lanes

Transit agencies are interested in improving speed and reliability of service with maximum capacity needed to adequately respond to the demand. However, the bus speed and travel times are highly influenced by stop locations, time spent at the stop, traffic conditions related to signal timing plans and overall traffic management along the arterial. Passenger activities at the stops are defined through dwell time variations. It is important to adopt a strategy which would minimize dwell time and its variation, especially during peak hours. If there is no possibility to introduce dual bus lanes, it is recommended to group buses in such a manner that local and express buses do not interfere with each other's dwell time (10). Dwell time is also affected by concentration of passengers at the stops, which may be designed with insufficient space to accommodate passenger concentration prior to boarding. Therefore, stop design, spacing and location are parameters that definitely affect increasing travel time.

In most central areas with bus lanes, the competition for curb lane has always been an issue (8). However, appropriate traffic management measures that strictly define curb lane use and restrictions can improve bus travel time.

High demand corridors, from the transit agency point of view, offer challenges as well opportunities to increase the efficiency of service provided. Of course in these corridors, a large number of buses are required in order to respond to demand and it is a challenge to serve a high volume of transit vehicles. However, over the years transit agencies have managed to successfully implement well thought out strategies (2).

As mentioned earlier, the goal is to increase average operating speeds with minimal cost. Thus, for peak periods, most transit agencies adopted express routes and peak routes services. The OC Transpo also provides service in peak periods offering peak and express routes to and from the central part of Ottawa. Peak route services successfully manage the imbalance within different directions. In the case of Ottawa, Albert and Slater, the two bus corridors are strictly defined directional corridors where peak routes operate during these periods. Express routes are introduced to provide fast and reliable service, and are defined as being used “to operate non-stop between a designated collection area and a downtown area of distribution” (2). As they use the fastest paths during their long-haul portion of a trip, their travel speed is considered high and travel time is minimized.

As demand increases during peak hours there are numerous express and peak routes that cover the central area at the same time. The routes are defined with their headways. However, as the number of buses increases on the particular corridor this might affect headway reliability for other more frequent routes. The problem of service reliability is an on-going concern among transit agencies. Schedule adherence and running times are closely monitored to ensure that common problems such as bunching of vehicles, missed trips, late or early departures do not occur (1). Therefore, headway control is one widely adopted strategy to ensure service reliability, which affects transit attraction for potential users and indirectly supports transit growth management.

3.0 Study Area and Data Description

The first step in the process of data collection was to define the study area and methodology used to collect the data. It was found that essential data needed to accomplish this study was transit related data. However, in order to proceed further with traffic simulation, some traffic data was needed as well. Transit and traffic operations on Central Area corridors were observed and the findings were compared with data available from OC Transpo and other departments within City of Ottawa. Due to high cost and time constraints associated with data collection, there were certain limitations in this process.

The Ottawa Transitway, which is 25.8km long, passes through the downtown on two major arterials. These previously referred to bus or transit corridors are Slater Street in the eastbound direction and Albert Street in the westbound direction. The study area was defined with two corridors (i.e., Albert and Slater) from Bronson Avenue in the west to Elgin Street in the east (Figure1). During the initial period of this research project, the field observations were performed from Lebreton station in the west and Mackenzie Bridge in the east due to the presence of most express routes and p.m. peak routes, which originate from the Lebreton station. The highest passenger activity in downtown Ottawa is at the Mackenzie King station.

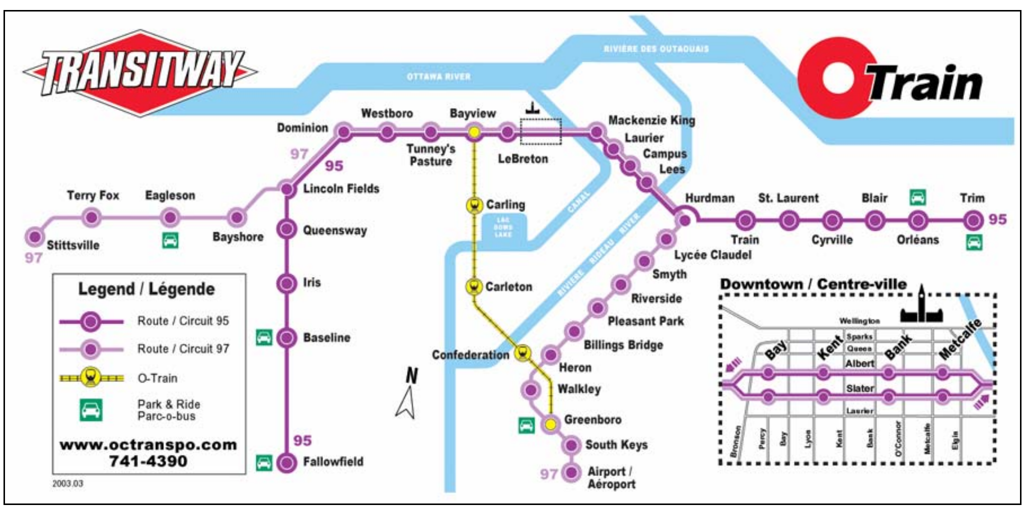

Figure1. Ottawa Transitway (source: OC Transpo)

As each downtown area, Ottawa has numerous high-rise commercial buildings and hotels located in the central core, which create high pedestrian and passenger activity rates in this area. Small businesses located along these particular two corridors, Slater and Albert, create a high competition for the right curb where buses operate on the “bus only” lane. Thus, along these corridors there are on-street and surface parking facilities, parking garages, taxi and loading zones. All these factors highly influence everyday transit operations on transit corridors during the p.m. peak.

The buses approach the Central area from the west (i.e. from or through the Lebreton station). They traverse in the eastbound direction for about 1.3 km from Bronson crossing another seven intersections on: Bay, Lyon, Kent, Bank, O’Connor, Metcalfe and Elgin. From the east, they traverse the same distance approaching the Central Transitway from Elgin, crossing the same intersections. There are only three two-way roads, Bronson, Elgin and Bank. The other five are one-way streets. The traffic volumes are not heavy enough to create major congestion during the p.m. peak hours. The traffic is composed of automobiles, trucks, buses and a small number of bicycles and motorcycles during warmer days. Within this research study area, there are four stops in each direction along Albert and Slater streets that were of particular interest in this research. These stops are identified as Bay, Kent, Bank and Metcalfe, as shown in Figure 1.

3.1 Transit Related Data

Transit related data was collected to analyze transit operational parameters, which determine its effectiveness. The transit planners use this data to closely monitor transit operations within the city. Their database contains data retrieved from APC (Automatic Passenger Counting) and AVL (Automatic Vehicle Location) systems.

Data collected using its APC are retrieved in the form of passenger movements and vehicle running times. The system captures many trips, multiple times and this produces over 21,000 trips for the database each day. Thus, passengers are counted when they enter or exit at each stop and time spent on dwell is also recorded. More importantly, there is a connection with the vehicle odometer so time-utilization at the stops and within the stops can also be retrieved from this database. This data is used to determine passenger activities at specific stops, as well as vehicle running times, distribution, and utilization.

AVL system data are used to track vehicles’ travel time between two points as well as their headways and headway adherences. This data was used to determine travel time through the Central Area in both directions.

3.2 Traffic and Geometric Data

The traffic related data was used for simulation purposes since bus corridors were modeled as part of the central area network. Therefore, the following data was collected: traffic volumes, pedestrian volumes, roadway geometry, and traffic signal timings. The network within the study area contains two major arterials and eight crossing streets. Five of these streets are one-way streets. Therefore, there were 8 nodes of interest within the network in each direction.

Some of the intersections have prohibited left or right turns during the p.m. peak hour and these restrictions were applied later in the model. The data was collected for the period between 17:00h and 18:00h when most of the congestion on the Slater bus corridor occurs. Traffic operations at the intersections were studied in terms of influence of pedestrian movements. Also, traffic signal timings were analyzed and imported into the simulation model. Signal coordination was provided on the corridor to allow transit operations with minimal delays.

Detailed analysis of the geometry of the roadway network was necessary as an input for the simulation model. From the observations in the field and from the City of Ottawa drawings the following information was made available: number of lanes, their length and width; right and left turning pockets, lane-use restrictions; pavement markings. The length of the observed east or west corridor was about 1.3 kilometers as mentioned earlier. It was observed that there was no southbound right turning pocket from Slater to Bank. Therefore, the right turns are being performed from the right-most lane where on street parking is also allowed during p.m. peak periods. During the p.m. peak hour there was a northbound left turning movement restriction from Slater onto Bank due to the traffic volume on Bank in the northbound direction. Pavement markings clearly demonstrate "bus-only" lane use. However traffic signs regulate restrictions during period between 6.a.m and 6 p.m. Outside of this time frame the same lane can also be used by taxis.

3.3 Traffic Operations on the Corridor

Since the traffic simulation model required detailed information about traffic operations including parking spaces and loading zones on the network during the specific period of time that was being simulated, this data was obtained directly from the site. The biggest concern for City officials was transit operation distractions caused by high competition for the right curb. This was also confirmed by observations. On-street parking is allowed during the p.m. peak period with a parking duration of one or two hours. There are parking garages where vehicles enter and exit from and onto the EB corridor. No data was available for parking use and frequency in the underground garages, however transit operations were partially delayed due to parking operation on the corridor. At some segments of the corridor, the vehicles exiting the parking garages had to use the "bus-only" lane in order to perform right turning movements, because parked vehicles were taking up the right curb. These actions were justified because using the "bus-only" lane was the only way to access the right-turning lane. Thus the highest number of "bus-only" lane violations was observed in this segment. In the WB direction on street parking is also allowed during the p.m. peak period with the same duration of one or two hours. The private and public parking garages also have an entrance and exit from Albert Street but there were not as many "bus-only" lane violations as observed on the EB corridor.

Since the area of interest is located in the central core of Ottawa, there was a need for taxi and loading zones serving business buildings and hotels. The taxi spaces are also located on the right curb, near the hotels. Loading zone restrictions apply for the p.m. peak period on Albert and Slater streets within the bus stop zones, which are clearly marked with traffic signs. Nevertheless, loading zone violations were observed on congested corridors. These violations were specifically animated in the simulation to obtain a situation that was close to reality.

3.4 Transit Operations Analysis

There were four stops of interest on each of the observed corridors. The length of each stop bay is between 55m and 71m. The length of passenger loading platforms was not clearly defined and was a subject of analysis. It was observed that the shortest bus stop bay on Slater had the highest concentration of passengers and high pedestrian volume. The loading platform width, because it is used for pedestrians as well, did not correspond to passenger activities at this specific stop. The shape of the curb obstructs and limits the sight distance of the waiting passengers so that they are unable to recognize the number and destination of oncoming buses. Consequently, same buses had to make two stops in order to ensure that all waiting passengers recognize their desired buses and board them. The conditions present at this bus stop were contributing to development of bus queue upstream in the westbound direction. The bus queue was also accumulated because the buses were unable to proceed at green lights at this intersection and green time allocated for them was not properly utilized. These conditions perpetuated the bus queue formation further upstream as it was addressed in this study.

The shortest stop bay on Albert Street also had an impact on bus queue formation in this specific area, but the problem was not nearly as severe as the one observed in the opposite direction. The sight distance was appropriate at each stop on Albert and regardless of the passenger concentration and distribution smooth operations were allowed at these stops. The capacities of each stop on the observed corridors were between three and five buses, depending on bus type combination at the time. Bus operations on the Central Transitway are performed in the platoon manner.

The analysis of bus operations and passenger activities was performed using the transit data from September 2003 when the problem was first identified. The operations during two p.m. peak periods were observed and data were collected. However, simulation was performed for the second peak hour between 17:00h and 18:00h when congestion on the corridor occurred.

3.5 Level of Service (LOS) for Transit

According to the Transportation Research Board, Transit Capacity and the Quality of Service Manual there are different measures of effectiveness that define the level of service for transit services. The transit manual defines reliability as one of the very important characteristics of transit systems. There are several measures of effectiveness for reliability. One of them, chosen in this research was headway adherence as “the consistency” or “evenness” of the interval between transit vehicles (7). The headway adherence is defined with a coefficient of variation of headways c_{vh} as follows:

c_{vh} = standard deviation of headway deviations/mean scheduled headway,
where headway deviations are calculated as the actual headway minus the scheduled headway. For a fixed route, headway adherence LOS is defined as shown in the following table.

Table1. Fixed-Route Headway Adherence LOS
(Source: TRB Transit Capacity and Quality of Service Manual- 2nd Edition, 2000)

LOS	c_{vh}	$P(h_i > 0.5h)$	Comments
A	0.00-0.21	≤1%	Service provided like clockwork
B	0.22-0.30	≤10%	Vehicles slightly off headway
C	0.31-0.39	≤20%	Vehicles often off headway
D	0.40-0.52	≤33%	Irregular headways, with some bunching
E	0.53-0.74	≤50%	Frequent bunching
F	≥0.75	>50%	Most vehicles bunched

OC Transpo was monitoring the most frequent route on the corridor in both directions, route 95**.** Using AVL data, the coefficient of headway adherence for route 95 in the EB direction was calculated for period between 17:00h and 18:00h. Comparing the results for an average coefficient of variation of headways with Table 1, it was found that the level of service was at Level E (c_{vh}=0.66) and level F (c_{vh}=0.76), meaning that there was frequent bunching of buses or most vehicles were bunched. The findings from this analysis of levels of service confirmed the actual transit operations on corridor.

Until 1994, the procedures used by the HCM 2000 to define the level of service for bus operations were passengers per bus and buses per hour. However, more recent research has introduced a criterion that is now widely used: bus speed. The HCM 2000 contains "the suggested speed-related level of service values for local bus service" (6). According to this source, since buses experience not only traffic delays but also delays associated with passenger activities at the stops, this criterion is believed to be appropriate for bus operations on arterials. To use this criterion, it was necessary to determine bus speeds using the reports on bus travel times in the EB and the WB direction between Lebreton and Campus stations. There were 34 routes that operate on Slater in the eastbound direction and 37 routes on Albert in the westbound direction during the p.m. peak period. Most express and p.m. peak routes on Slater originated at Lebreton station and mostly single buses were assigned for these routes. An average travel time for route 95, the most frequent, from Lebreton to Campus was 19 minutes between 16:00h and 17:00h and 24 minutes between 17:00h and 18:00h. Depending on overall traffic or weather conditions, the travel time increased up to 33 minutes in the EB direction. In the opposite direction average travel time for the same route from Campus to Lebreton ranges between 12 and 14 minutes between 16:00h and 17:00h as well as between 17:00h and 18:00h. The buses travel approximately 3 kms. It was found that bus speed during the p.m. peak hour on Slater is approximately 10 km/h yielding a level of service D. On some days this level of service would drop to level E and even level F. For the same distance in opposite direction, bus speed was approximately 15kms/h, yielding a level of service C. Most of the time, bus speeds in the WB direction were maintained at this level of service.

3.6 Bus Volumes

To respond to the passenger demand, the bus volume was different in the EB and the WB direction. On average, 183 buses per hour operated in the EB corridor between 16:00h and 17:00h. In another p.m. peak hour (17:00h to 18:00h) that was later simulated, there was an average of 177 buses per hour. The maximum scheduled number of buses was 203 buses per hour. To respond to specific demands, some routes had been assigned articulated low floor buses through the downtown area during the afternoon peak hours. Thus, in the EB direction there were about 21% articulated buses during two observed peak periods

The bus volume in the WB direction corresponded to lower passenger demand in this direction during the p.m. peak period. Therefore, there was an average of 147 buses per hour scheduled on Albert Street between 16:00 and 17:00. In another p.m. peak hour (between 17:00h and 18:00h), there were about 123 WB buses per hour, compared to 145 regularly scheduled WB buses for this p.m. peak hour with 28% assigned articulated buses.

3.7 Bus Running Times

Most of the p.m. peak and express routes in the EB direction originate from Lebreton (Figure1). However, the regular routes heading towards the east end of the city pass through Lebreton station as well. It was necessary to determine the scheduled and actual running times for p.m. peak and express routes as they were assigned. According to data it was found that scheduled running time between Lebreton and Mackenzie station (Figure1) for these routes is between 5 and 9 minutes. However, actual mean running time for most of these routes was twice as high. Scheduled running times from Lebreton to Mackenzie station for some regular routes in transit were between 9 and 11 minutes. However, mean running time was on average 15-40% higher than the scheduled running time. Based on the revenue time utilization report, it was found that for the majority of express and p.m. peak routes on the EB corridor more than 50% of the total running time was spent as “stop and go time”, “idle time” and “excess time” which is again a result of the bus operations on the corridor.

3.8 Passenger Activities

The possibility of passenger demand increase causing an increase in travel time due to operations at the stops was explored as well. The analysis of daily average passenger volumes at the stops shows significant difference between stop activities in both directions. During the p.m. peak hour boarding dominated vs. alighting on both corridors. Between four stops analyzed on Slater, the highest passenger activity between 16:00h and 17:00h was at the Metcalfe stop (Figure1) with 1,769 passengers/hour and at the Bank stop with 1,688 passengers/hour. In the opposite direction the highest passenger activity was between 1,291 and 1,332 passengers/hour.

One of the objectives of this study was also to determine if there were significant changes in the passenger activities on the corridor which may have caused significant increase in travel time. Analyzing data related to passenger activities at these four stops of particular interest, it was found that there was no significant changes in number of passenger activities yielding some other causes of travel time increase.

3.9 Vehicle Load Profiles

The analysis determined an average, minimum and maximum load per stop on Slater and Albert during two p.m. peak hours (16:00h and17:00h and 17:00h and 18:00h). It was found that the maximum average load at departure was at the Metcalfe stop on Slater, with 25 passengers/vehicle in the period 17:00h-18:00h. The maximum load at departure from the same stop was 99 passengers/vehicle. With the same methodology, analysis was conducted for the Albert corridor. The maximum average load on Albert was at the Bay stop, with 36 passengers during both p.m. peak hours that were observed. The maximum load at departure from the last stop on Albert was 97 passengers/vehicle. Comparing the average loads at arrival on Slater with the average load at arrival on Albert, it was found that average arrival loads are higher on Albert than on Slater. However, the vehicle loads increase as buses travel towards the last stop on Albert confirming that there is a similar pattern in vehicle load profiles in both directions. The reason behind relatively low load profiles was that many express and peak routes originated at Lebreton, only two stops further West from the corridor.

Bus stopping patterns as well as service at the stops has an effect on reducing speeds and capacity of the facilities. The service at the stops is best defined by dwell time, as time needed for passenger boarding and alighting. However, sometimes buses spend more time at the stops due to slow operations at the stops downstream or traffic operations at the corridor. Thus, a dwell time analysis was conducted for four stops of interest on Slater and Albert. The interest was to compare dwell time with the number of passengers boarding and alighting at these stops. Also, it was interesting to see what percentage of time buses spend at the stops in so called “excess time”, when buses cannot proceed from the stops due to traffic congestion or slow operations at the stops downstream. This analysis was needed for simulation purposes as well.

From the available data, it was found that average dwell time by stops on Slater varied from 6.9 sec up to 15.8 sec where the highest number of passengers was boarding. During the period of time between 17:00h-18:00h dwell time slightly decreases as passenger activities at all stops decrease. However the excess time, which is defined as “excess time = time spent at the stop - dwell time” (4), increased during this period. This was due to the bus queue formed on Slater at that time over the entire corridor when there were significant delays at all stops. The maximum dwell time found was 2.2 minutes at the Bank stop during the busiest hour between 16:00h and 17:00h.

Dwell time by stops on Albert varied from an average of 7 sec up to 19 sec at the one of the busiest stops on Albert. However, excess time at stops averaged 15 sec during both p.m. peak periods (16:00h-17:00h and 17:00h-18:00h) due to slower operations at stops over the observed period of time.

The bus queue starts to build between 16:45h and 17:00h and about that time the queue spreads over the entire corridor on Slater. Thus, the buses spent more time in “excess” time and moved very slowly. Interestingly, a different pattern in time utilization was observed at stops on Albert, where most of the stop time was spent for passengers boarding and alighting as dwell time. As passenger activities decreased moving along the WB corridor dwell time and excess time decreased as well. This is a confirmation that dwell time and excess time values are a result of operations at the stops, since there were no significant delays of operations between stops.

Transit agencies introduce articulated buses on some routes to respond to passenger demand during peak hours and speed up transit operations at the stops. As it was stated previously, one of the findings related to articulated buses was that most boarding on the Central Transitway occurs at the front door. Although proof of payment (POP) operations are designed to reduce dwell time, if all doors on articulated buses are not fully utilized then there may be less benefits of assigning articulated buses on some routes. More detailed analysis was also conducted to identify dwell time profiles by bus types at each stop on Slater. According to these findings, passenger activities on articulated buses were lower than on single buses at each stop on Slater, however, dwell time per vehicle was not significantly lower indicating that dwelling time may have not been fully utilized by POP operation. This was confirmed by field observations.

4.0 Central Transitway Modeling Using NETSIM

Data analysis as previously described provided an indication that transit operations were delayed due to different causes. Some questions still remained and required an answer. To complete the results of analysis and to provide some recommendations, a simulation was performed for two possible cases representing different scenarios of operations on the Central Transitway. For that purpose the NETSIM simulation tool was chosen as part of the TSIS 5.1 simulation software package.

The "base case" was defined with existing conditions regarding transit parameters. The number of buses on the bus corridors was defined as actual number of buses observed on site. All other transit parameters were used as results of data analysis, such as average dwell time, travel time, travel speed, bus routes and headways. Since the worst conditions on Slater corridor occurred between 17:00h and 18:00h this time period was chosen for a simulation period.

Two other cases were later created and analyzed. Scenario 1 was modeled as a case with maximum scheduled number of buses that are supposed to travel on bus corridors. The effects of these transit operational conditions were analyzed and compared with "base case" to identify what impact that would have on central area operations. Scenario 2 was created to model transit corridors with the same number of buses as existing conditions, however traffic operations on the corridor were changed. On-street parking and parking garages dwelling as well as right turning movements were restricted on the corridor during the simulation period 17:00 to 18:00. The effects of these operational measures were compared with the base case as well. The input data were segregated into three main categories as they were in the data collection process. These categories were: network data (link, nodes, geometry, lanes, turning bays); transit data (bus routes, headways, dwell time, stops); and traffic data (traffic volumes, pedestrian volumes, traffic signals, parking zones, parking garages).

The network in the simulation model is described with nodes and links. The nodes are defined with user specified numbers and there are internal and external nodes. Internal nodes are intersections within the network (Figure 2). However, the network is "filled" with vehicles through the external nodes. Two consecutive nodes are connected with links that are specifically defined as well. The links are defined with their length, number of lanes and lanes chanelization where all lanes are specified. The length of a link is considered as a distance between two stop lines of the consecutive intersections. The links are defined as three lane facilities with right or left turning pockets, if any. The rightmost lane on Slater and Albert was defined as a bus only lane of 3.5m width. The speed was defined as a 50km/h free flow speed on the entire network. The grade was set as 0%. Therefore, there was no influence of grade level on speed. Another specific input data was the distance from the stop line to the curb measured on site.

Before the simulation was performed the transit data was analyzed in detail as described earlier and the results were used to define the transit input parameters for a base case and Scenario 1. The number of buses that operated in "bus only" lanes was a very important parameter to define, since Scenario 1 was based on an increase in the number of buses in this lane. The actual number of buses on Slater and Albert was simulated by identifying all routes operating on these two corridors.

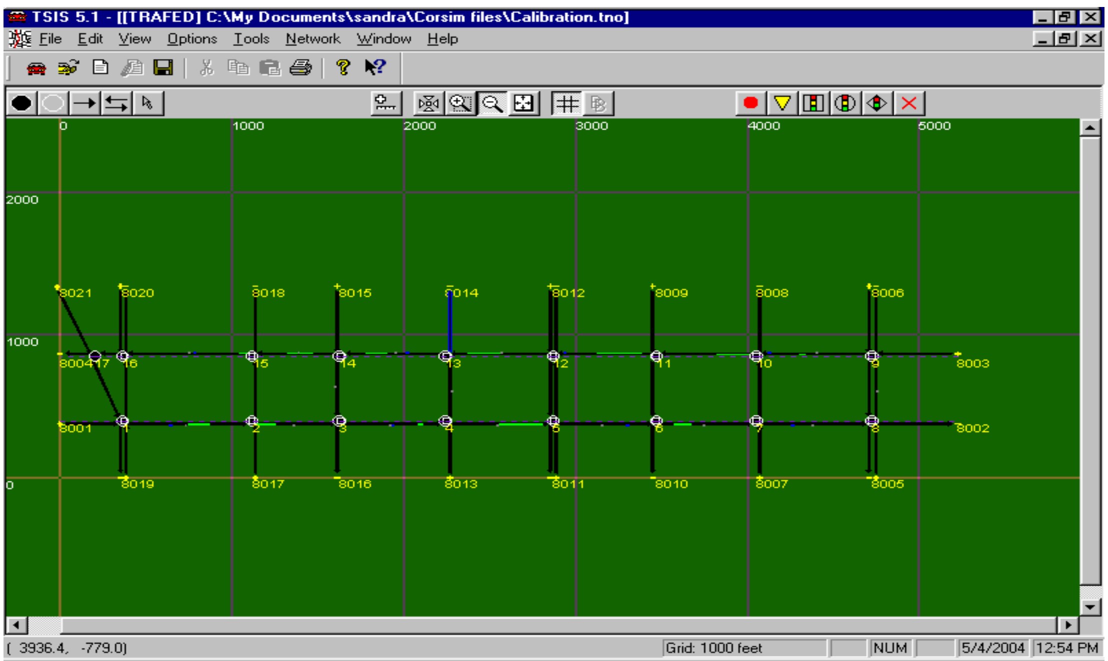

Figure2. The Central Area Network defined using TRAFED

The bus stop numbers were defined by NETSIM specification and each stop was defined with an average dwell time, bus type and capacity. The bus stop capacity was determined by length of each bus bay with an average of 4 buses per stop. The bus stop location was defined as the distance from the downstream stop line and that indicated type of stop by its location, near side, far side or mid block stop. The bus stops were modeled in such a way that they did not allow bus bypass, meaning that buses are assigned to perform as platoons as it was defined by Central Transitway operations. Bus routes and their headways were also modeled to best represent an actual picture of the transit operations. Therefore, all routes were identified and headways were modeled as they were scheduled. These headways were adjusted and used in a base case, since the actual number of buses did not correspond to scheduled number of buses. The routes were assigned to stop at each of the stops on Slater or Albert. Some routes had the same path and same headway, therefore the offset time was defined in such a way to properly generate proposed numbers of buses on the network.

Traffic parameters that were used for simulation purposes were taken mostly from City of Ottawa traffic surveys. The roadway geometry parameters were taken from the City drawings or on site. Due to limited resources for this project, there were no observations performed to determine traffic volumes that would be updated for this research. Traffic signal timings were obtained from the City of Ottawa for all 16 intersections that were of particular interest. The cycle length for most intersections on Slater is 55 sec, except Metcalfe with 80 sec and Elgin with 90 sec. Similar signal operations were on Albert. The cycle length is 55 sec. at each intersection except Elgin with 90 sec. cycle. The control type is pre-timed on all intersections except for Elgin NB left turns, which is actuated phase. The sensors are passage type and they are installed on two left turn lanes, with sensing zone of 7m on two left turning lanes on Elgin NB. The signal timings on each corridor were adjusted in such a way to enhance transit operations with no possibility to introduce preemption signals for transit vehicles on the corridor. Further examination of existing signal timings on this corridor was not the scope of this study. Therefore, signal timings were taken as they were set according to the City of Ottawa existing signal-timing plan at the corridors. g/C ratios varied from 0.27 up to 0.62. The highest g/C ratio (0.62) was set for the Metcalfe intersection on Slater to enhance bus travel speed. It was found in the field, as stated before, that green time allocated for the EB through movement at this intersection, was not properly utilized by buses. The field observations confirmed that about 15-40% of the allocated green light time for each cycle during the afternoon peak periods was unutilized by buses due to delayed transit operations at the Metcalfe stop.

Parking data for frequency and duration were not available, but most parameters were defined and based on field observations. NETSIM has the ability to model number of vehicles entering or exiting these facilities through so called “source/sink” locations. In this case these locations were specified on links where there are parking garages and public parking areas.

Once all the above described parameters were entered into the model, some adjustments were needed before the model was calibrated. These adjustments were also part of the calibrations to enhance the model’s accuracy. For example, NETSIM has different categories for vehicle types. However, it has very limited abilities to model different types of buses. Some adjustments had to be made for vehicle acceleration rates, vehicle length and vehicle occupancy. As it was found on site there were “bus only” lane violations on Slater, mostly by drivers entering or exiting parking garages or public parking areas. NETSIM has an ability to animate short-term events as short lane blockages. For this purpose, short-term events were generated to animate this traffic disruption in “bus only” lanes. These events are defined by frequency and duration of an event.

The last and very important step in the process is model calibration. The model was calibrated mostly using driver behavior parameters and some vehicle performance parameters in a “trial and error” manner until the model was developed to match existing conditions on the network. The modeled network was very specific for calibration since there were congested conditions in only one direction in the “bus only” lane. The vehicles in all other lanes traveled at much higher speeds. That was the reason why the model had to be calibrated using a combination of several calibration parameters.

The already developed and calibrated model had to undergo the validation process. As differences between observed and simulated values are lower, the model better fits actual traffic conditions. In this particular case transit parameters were primarily of interest for model validation since there was data available for these measures of performance. Among other validated parameters, bus volumes as well as average bus speed on Slater and Albert were compared with simulated values to validate the model. For example, actual and simulated number of buses on the EB corridor are illustrated in Figure 3.

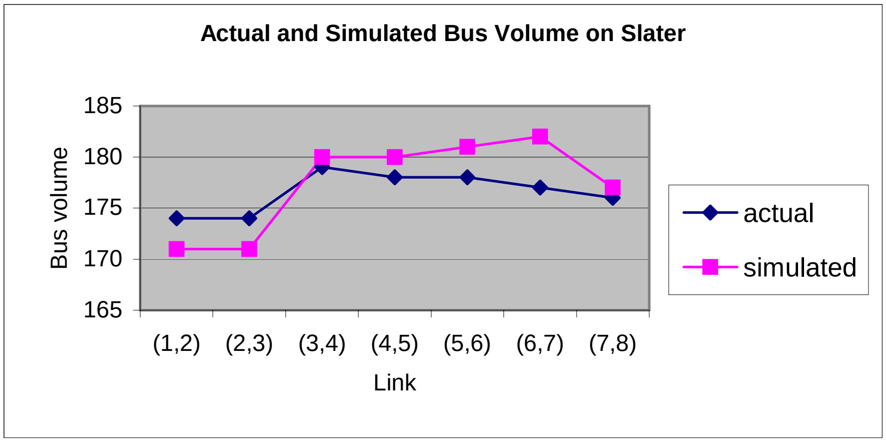

Figure3. Actual and Simulated Bus Volume on Slater (17:00h-18:00h)

Similarly, analysis was conducted for the mean bus travel speed. Data analysis and field observations showed that an average travel time on Slater was 15 minutes (0.25 hours). If buses traverse EB about 1.3 km between Bronson and Elgin it yields an average bus speed of 5.2 km/h. Bus traveling speed in the opposite direction was about 10 km/h. Average travel speed achieved by simulation was 8.6 km/h on Slater, while an average bus speed on Albert was 13.6 km/h. The process of validation showed acceptable results and further analysis was conducted.

4.1 Central Transitway Simulation Results

The analysis of the transit and traffic operations on the corridor provided some answers and explanations, which gave a solid ground for a recommendations proposal. However, two questions required answers: (1) How would the corridor handle the scheduled number of buses in both directions? (2) Would a proposal for short term traffic management measures contribute to improving Transitway performace on the corridor?

For this purpose the simulation procedure was selected as an appropriate method with the assumption that any findings would help in the decision-making process to enhance transit operations especially on the EB corridor. The first scenario was modeled with the same traffic conditions as in base case-existing conditions. However, transit operated with the maximum scheduled number of buses. The model animated 203 buses per hour in the "bus only" lane on Slater and 151 buses per hour in the "bus only" lane on Albert. Scenario 2 was an animation of proposed traffic management measure to improve transit operations in the "bus only" lane on Slater. It was found that there were distractions to transit vehicles particularly on Slater due to right curb parking operations, parking garage dwellings and right turning movements. Therefore, the second scenario was proposed to explore the effects of any parking operations and right turning movement restrictions during the p.m. peak hour. It was found that this proposed scenario would be a feasible and doable short- term measure for improvement of transit operations.

The measures of performance that were compared for the base case and Scenarios 1 and 2 in order to answer the previously posed questions were: bus speed on links (Slater and Albert), ratio of moving and delay time (M/T), maximum queue per link on bus only lane, and mean travel time and total travel time for Route 95.

Comparing average bus speeds in the base case and first scenario it was found that if more than 20 additional buses would travel in the EB direction as originally scheduled, the average bus speed would decrease by 14%. Since there was no significant increase in number of buses on the Albert corridor, no changes were found in average bus speed as expected. According to suggested speed related level of service criteria for buses on arterial roads and streets (10), the level of service on Slater would drop from level of service D to level of service F. In the WB direction, level of service would remain the same (i.e., level C) if the scheduled number of buses would traverse on Albert.

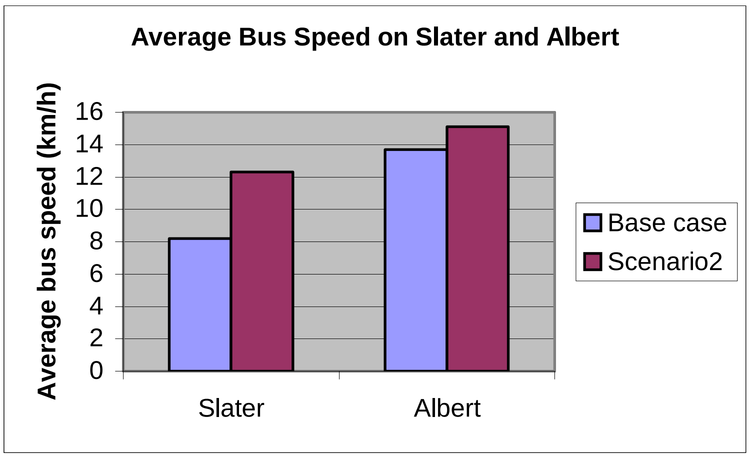

Figure4. Average Bus Speed Comparison for Albert and Slater in Scenario 2

When the results of Scenario 2 were obtained, it was found that bus speed on both corridors increased as shown in Figure 4. The increase in bus speed on Slater would be significant (54%) if right curb parking and right turning movements are prohibited between 17:00 and 18:00. Less, but still significant effects would be seen on the Albert corridor, where bus speed would increase by 19%.

Delays in “bus only” lanes were results of overall traffic operations on corridors. The buses are traveling through the intersections where there are delays due to signal timings, but also, as it was mentioned before, the competition for the rightmost curb on Slater is very high and yields delays. As was indicated earlier, most of total running time for express and p.m. peak routes on Slater was spent as ”lost time” (i.e., idle time, stop and go operations and excess time). The simulation provided the ratio of moving time and travel time (M/T) for all buses on the corridor. Therefore, it was interesting to explore how this ratio would change in these two scenarios. Adding more buses in the EB direction as per the first scenario would decrease M/T ratio on each link, meaning that buses are moving less in their total travel time. With Scenario 2, the changes in M/T ratios were even more obvious for both Slater and Albert as shown in Figure 5.

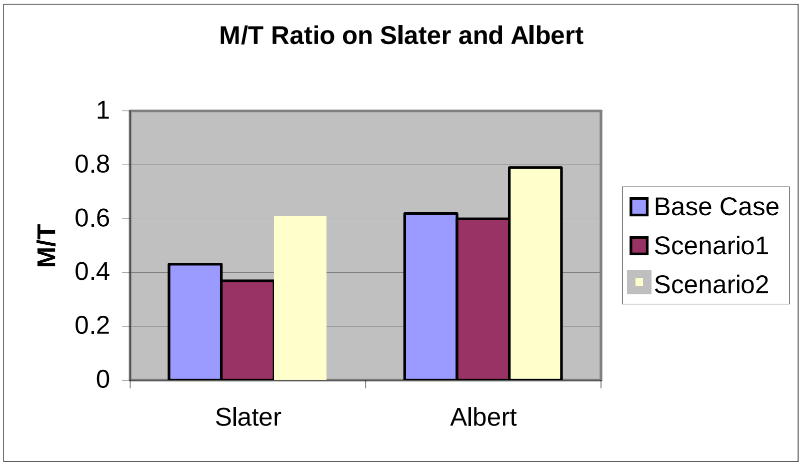

Figure5. Comparison of M/T Ratio for Buses on Slater and Albert

For the entire corridor on Slater, the ratio of moving time over total travel time increased from 0.43 to 0.61.On Albert, this ratio increased about 30%, meaning that buses would spend more time moving between stops than on "stop and go" operations, idle or excess time. Since there were no changes in dwell time and g/C ratios on intersections, the conclusion derived was that an increase in moving time was a result of restrictions of operations on the right curb, such as parking maneuvers or right turning movements. If the right curb parking and right turning movements were restricted at specific links on the corridor, a significant increase in moving time would be experienced, improving overall transit operations.

The field observations on Slater were recorded on video to determine the exact start time of the bus queue formation and its development. According to the APC database, peak passenger demand on Slater and Albert occurs between 15:45h and 16:45h. However, the queue starts to form around 16:45h and at about 17:00h the queue spreads over the entire corridor on Slater. The queue does not build up on Albert. There were several reasons why the queue formed, and one of them was distractions to transit operations due to vehicles merging with other traffic by crossing and traveling in the bus only lane. The stops and delays due to these operations occurred in the "bus only" lane and contributed to further queue formation. The NETSIM output provides network-wide cumulative statistics and one of the measures of performance that was interesting to use in this study was maximum queue length (maximum number of vehicles) per link. Analyzing the results derived from maximum queue per link in the "bus only" lane, it was found that maximum queue length per link would increase if the number of buses on Slater increased yielding an increase of up to 100% on some links.

Observing the headways and scheduled time of the most frequent route on the corridor, route 95, the particular interest was to determine the effects of the proposed scenarios on total travel time and mean travel time. Mean travel time is defined as sec/bus, while total travel time is defined for all vehicles assigned on a chosen route as bus-min. If the number of trips for route 95 would increase in the EB direction that would almost double the mean travel time for this route. On the other hand, Scenario 2 indicated a decrease in travel time for route 95 for about 30%, which would also decrease total travel time by 50 minutes. This measure of performance as total travel time in bus-minutes could be a good indicator for transit agencies if these values are converted to loss or gain in dollar values. An increase in the number of scheduled buses in the WB direction would also increase travel time for route 95 in this direction.

5.0 Conclusions and Recommendations

This project for the analysis of the Central Transitway in Ottawa was initiated in order to provide a possible solution which could improve transit operations through the Central core of Ottawa. The problem was identified in September 2003 when bus travel times in this area had been significantly increasing especially during the p.m. peak in the EB direction. The approach taken in this project was to observe these transit and traffic operations during the p.m. peak for a couple of months, analyze available transit performance data and finally conduct a simulation for two proposed scenarios. The following conclusions were derived from the above mentioned research processes:

- In the EB direction buses were traveling about 20 minutes in order to cover the distance of about 3 kms between 16:00h and 17:00h and about 24 minutes between 17:00h and 18:00h. For the same distance in the opposite direction, buses traveled between 12 and 14 minutes. 50% or more of the total running time for most routes was spent as “stop and go time”, “idle time” and “excess time” which was again a result of the operations on the corridor. During the next peak hour (17:00h to 18:00h) excess time increased, as there were delays between and at the stops during this hour.
- Coefficient of variation of headways for the most frequent route 95 confirmed frequent bunching of buses as well as conditions when most buses were bunched.
- Average dwell time by stops on Slater varied from 6.9 sec up to 15.8 sec at the stop where the highest number of passengers was boarding. The maximum dwell time found was 2.2 minutes during the busiest hour 16:00h-17:00h.
- The actual number of buses on the corridor didn’t correspond to the scheduled number of buses due to delayed operations. The simulation results derived from running Scenario 1 showed that if the scheduled number of buses actually went through Slater, the average bus speed would decrease by 14%.
- Due to operations at one stop with the highest concentration of passengers and specific design, green light time allocated for the EB direction at near intersection was thirty to fifty percent unutilized. Parking operations caused bus operation disruptions and led to further delays. The number of “bus lane” violations also contributed to bus operation delays. The right turning movements particularly from Slater were also performed using the bus-only lane further contributing to bus delays. The simulation results showed that removal of right turning movements and parking on the right curb would contribute to travel time decrease and travel speed increase by 54% in the EB direction. The buses would spend more time actually moving between stops and total travel time for the most frequent route would decrease 30%.

Based on the results and conclusions derived from the analysis, field observations and simulation procedure, the following recommendations for operations improvement were brought to the attention of the OC Transpo and City of Ottawa engineers and planners:

- Implement and enforce by-laws to eliminate bus-only lane violations during p.m. peak periods as well as loading zone restriction violations since they occur within bus stop designated areas in p.m. peak hours.
- In order to ensure vehicle travel in the right curb lane while exiting and entering parking garages on Slater Street it was recommended to pose further restrictions for "on-street" parking during the period between 15:00h-18:00h.
- To improve overall transit operations and reduce transit vehicle movement disruptions, it was suggested to implement right turning movement restrictions from Slater during the p.m. peak period. Further analysis was needed in order to determine a need for a.m. peak right turning movement restrictions.
- To improve POP (proof of payment) transit operations through the downtown and minimize dwell time, it was recommended to enhance public information and operators' training about transit operations on the Central Transitway. This was to ensure efficient passenger boarding operations through the downtown and minimize delays.
- To improve the passenger concentration and distribution at the stops, it was recommended to clearly mark loading areas for passengers to ensure utilization of bus stop capacity and improve operations at and between the stops. The markings should be performed on paved loading platforms or with two poles installed with a sign "no loading beyond this point". This could be an effective way for passengers to visually determine the loading area and therefore ensure passenger distribution at the stops according to bus arrivals if advanced information technologies are not available. The markings would compensate for an insufficient sight distance at Central Transitway stops
- The length and design of the Metcalfe stop with the highest concentration of passengers and pedestrian activities was recommended for further analysis. Due to design, the right curb was not appropriately utilized at this stop, reducing its actual capacity.
- Due to significant adherence of running times for express and p.m. peak routes with origin at Lebreton, it was recommended to revise headway control operations at Lebreton in order to ensure bus departure distribution according to operations at the corridor.
- The simulation results showed that further research was needed to revise and reconsider existing bus schedule patterns for the p.m. peak period, particularly in the EB direction. It was recommended to explore the possibility to compensate reduction in level of service regarding travel time by increasing number of transfers for some users and reducing the number of buses on the EB corridor. Enhancing runs of the most frequent, long haul central Transitway routes by reducing the headways would ensure better service on the corridor.

Starting September 2004, some of short-term measures were implemented including a reduction in the number of buses scheduled to travel through the corridor as well as bus-only lane use enforcement. The bus travel time observed through the most frequent route on the corridor increased about 40% and significantly improved overall operations on the corridor. It is contended that the operational and transit planning measures could be used as a tool for further transit growth.

References

(1) Abkowitz, D.M, Lepofsky, M. Implementing Headway-based Reliability Control on Transit Routes, Journal of Transportation Engineering, Vol.116, No1, 1999, pp 49-63.

(2) Federal Highway Administration (FHWA). U.S. Department of Transportation. Operating Strategies for Major Radial Bus Routes. DOT-1-84-27, Washington, D.C., 1984.

(3) Federal Highway Administration (FHWA). CORSIM 5.1 User's Guide. Office of Operations Research, Development and Technology, Washington, D.C., 2003.

(4) OC Transpo-Regional Municipality of Ottawa-Carleton. Operational Statistics. Ottawa, 1989.

(5) Rathwell, S., Schijins, S. Ottawa and Brisbane: Comparing a Mature Busway System With Its State of The Art Progeny. Journal of Public Transportation, Volume 5, No2, 2002, pp163-182.

(6) Transportation Research Board (TRB). Highway Capacity Manual (HCM), Chapter 27 Transit, Washington, D.C., 2000a.

(7) Transportation Research Board (TRB). Transit Capacity and Quality of Service Manual. Second Edition.Chapter3- Fixed Route Transit Service Measures. Washington, D.C., 2000b, pp3-48.

(8) Transportation Research Board (TRB). National Research Council. Synthesis of Transit Practice 34. Data Analysis for Bus Planning and Monitoring. National Academy Press, Washington D.C., 2000c.

(9) Transportation Research Board (TRB). TCRP Report 90. Bus Rapid Transit. Case Studies in Bus Rapid Transit. Vol1, Washington, D.C., 2003.

(10) Transportation Research Board (TRB)- National Research Council. Operational Analysis of Bus Lanes on Arterials, TCRP Report 26, National Academy Press, Washington, D.C., 1997.

(11) Vuchic, V. Transportation for Livable Cities. Center for Urban Policy Research, New Jersey, 1999.