**Microscopic Simulation Approach to
Capacity Analysis of Public Transit Corridors**

by

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ABSTRACT

Traffic congestion in urban areas is an everyday occurrence. Realizing the fact that increasing travel demands are unlikely to be met through expansion of the transportation system for automobile use, transportation professionals are resorting to transit services to increase mobility. The strategy of using high volumes of buses in urban corridors is receiving policy attention. However, detailed studies of corridor capacity have been scarce. In this research, using NETSIM as a microsimulator, bus transit corridors were investigated in terms of capacity. Selected scenarios incorporating year 2021 traffic were analyzed for choke conditions and the results obtained were compared with base case conditions representing year 2001 traffic environment. Based on the results of network performance, conclusions are drawn on the capacity of transit corridors. This research is believed to benefit City policy makers, planners and transit operators.

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GLOSSARY OF ACRONYMS AND TERMS

AADT	Annual Average Daily Traffic
APCS	Automatic Passenger Counting System
CB-900	First Bus Station on Albert Street (from East to West after Elgin Street)
CB-910	Second Bus Station on Albert Street (from East to West)
CA-920	Third Bus Station on Albert Street (from East to West)
CA-930	Fourth Bus Station on Albert Street (from East to West)
CA-940	First Bus Station on Slater Street (from West to East after Bronson Street)
CA-950	Second Bus Station on Slater Street (from West to East)
CB-960	Third Bus Station on Slater Street (from West to East)
CB-970	Fourth Bus Station on Slater Street (from West to East)
CBD	Central Business District
CORSIM	(CORridor SIMulation) A Microscopic Traffic Simulation Tool Supported by the TSIS Environment
DOT	Department of Transportation
FFS	Free Flow Speed
FHWA	Federal Highway Administration, Sponsor for the Development of the TSIS Suite of Traffic Analysis Tools.
FRESIM	(FREeway SIMulation) Part of the CORSIM Simulation that Models Freeway Operations
FTA	Federal Transit Administration
GUI	(Graphical User Interface) An Interface Between a User and A Software Tool, Consisting of Graphical Elements and Controls, e.g., windows, dialogs, buttons
HCM 2000	Highway Capacity Manual 2000
HOV	High Occupancy Vehicle

Km/hr	Kilometre per Hour
LOS	Level of Service
MOE	Measures of Effectiveness
NETSIM	(NETwork SIMulation) Part of the CORSIM Simulation that Models Surface-Street Operations
OC-Transpo	Ottawa-Carleton Transpo
Script Tool	The TSIS Script Tool is a Combined Script Editor and Tool for Executing Visual Basic Scripts
Sec/veh	Seconds per Vehicle
TMP	Transportation Master Plan
TRAFED	TRAFED is a graphical user interface-based editor that allows easily creating and editing traffic networks and simulation input for the CORSIM model.
TRAFVU	TRAFVU (TRAF Visualization Utility)
Transit Street/ Corridor	Wherever transit street or transit corridor is mentioned in the text, it is meant for either Albert or Slater or both streets.
Translator	A TSIS Tool Used to Translate Between the TRF and TNO File Formats
TRF	A file that contains the input data used to define a CORSIM network and to drive the CORSIM simulation for a single simulation case.
TSP	Transit Signal Priority
Veh/hr	Vehicles per Hour
Veh.-min	Vehicle Minutes
'T'	Symbol shown in figures representing standard deviation of 10 simulation results.

CHAPTER 1

INTRODUCTION AND RESEARCH OBJECTIVES

1.1 Introduction:

Addressing the problem of traffic congestion, especially in urban areas is the responsibility of transportation engineers and planners since it is an everyday occurrence that affects general public. This problem is not limited to large metropolitan areas. Even back in 1980s public opinion surveys in many North American urban areas indicated that traffic congestion was of higher concern than crime, housing and pollution (ITE 1986). Increasing demand for using roadway facilities, rising volume of traffic and growing number of passenger-kms travelled every year are causing traffic congestion problems all over the world. Delay, unreliability of travel time, increased fuel consumption and diminished air quality are the offshoots of congestion that extend into economic and social problems of a country.

Realizing the fact that increasing travel demands are unlikely to be met through expansion of the transportation system alone, provincial/state and local governments are becoming more interested in exploring transit services that can increase mobility. Transportation engineers and planners are, therefore, keen on improving the efficiency of public transit. Innovations such as preferential treatments to transit operation, Bus Rapid Transit (BRT) and other transit improvements offer the potential to enhance transit services so that riders can reach their destinations more quickly and easily. Further, improved service enhances ridership and improves the revenue picture. In turn, quality

transit services become affordable. However, reliable and well researched information on capacity and service factors of bus corridors is not available.

1.2 Background of and rationale for this research:

Ottawa is the capital of Canada and is known in the world for having a very good transit system. According to the Transportation Master Plan published by the City of Ottawa, its population is expected to grow from 800,000 people in 2001 to 1.2 million in 2020- an increase of 50%. During this period, the overall demand for afternoon peak hour passenger trips on its transportation system will grow by 58% (City of Ottawa 2003). According to the City of Ottawa, "Transit ridership has been growing at a significant rate (average 5 %) since 1996, and Ottawa's residents take transit, on average, more than those of any city of comparable size in North America" (City of Ottawa 2003). Supporting a vibrant downtown by preserving multi-modal access, with a focus on walking, cycling and transit is one of the principles set for growth management by the Ottawa transportation planners. Keeping in view the growing travel demand and increasing trends of transit ridership, City of Ottawa has set an ambitious transit modal split objective for 2021. It is planned that 50% of motorized passenger trips to and from Ottawa's dense urban core will be served by public transit. This reflects an increase of 28% from 2002. It includes 80% of downtown work trips during the after noon peak hour. To achieve the benchmark set for year 2021, the City of Ottawa has also planned to increase the size of transit fleet from just over 900 vehicles in 2003 to 1,800 vehicles in 2021 – an increase of exactly 100% as compared to 2003 figures (City of Ottawa 2003).

From the preceding information that emphasizes the importance of transit operations in Ottawa's future growth, there definitely seems to be a need to determine the conditions beyond which the two very important public transit corridors namely Albert and Slater Streets in the downtown of Ottawa, will no longer be able to accommodate any more buses without making facility design changes such as dedicating another lane for buses in the system, making these transit corridors an exclusive facility for transit operations, grade separation, etc. Authorities in the City of Ottawa also confirmed that there had been no such study carried out showing microscopic level details under projected 2021 traffic conditions along these two corridors.

Figure 1.1 shows the Ottawa Transitway while Figure 1.2 displays its traversing through the downtown area via Albert (East – West) and Slater (West – East) Streets. Figure 1.3 shows a complete network with all links and nodes falling within the study area and facilitating traffic operation through the downtown area.

1.3 Purpose and Objectives of Research:

The main purpose of this research is to simulate microscopically public transit corridors (Albert and Slater) of downtown Ottawa and analyze different case scenarios representing future traffic conditions for year 2021 with an intention to maximize throughput of transit buses along these streets.

The main objectives of this research are to:

1. find choke level in the network under current and changed operating conditions incorporating year 2021 traffic,

2. determine how many buses can be accommodated under various scenarios of traffic and operating conditions,
3. compare the results of choke level condition with the existing condition, and
4. draw conclusions which could help policy makers, researchers, city planners, transit operators and other stake holders in their decision making process.

Figure 1.1 Ottawa Transitway – Key Map

Figure 1.2 Ottawa Transitway via Albert and Slater Streets

1.4 Choke level:

A choke level is defined as a state under which most of the traffic movements in the network selected for this study are operating at a Level of Service of 'E or F' and / or the throughput of transit buses can not be increased further under a set of well defined operating conditions.

1.5 Different approaches to determine choke level:

There can be two different approaches to determine choke levels in the system.

1. One approach is to keep on projecting traffic (auto and transit) at their normal growth rate and determine in which year the system will no longer be able to accommodate more traffic under a set of operating conditions.
2. The second approach is to project the auto traffic to a certain year (in this case 2021) and maximize the supply of transit buses by providing low mean headways along with additional green time to transit corridors only until delays experienced by auto traffic movements on links intersecting transit streets reach a level that is represented by Level of Service 'E or F'.

Since this research is transit oriented, therefore, second approach is followed in which throughput of transit buses has been maximized.

1.6 Beneficiaries of this research:

This research will help the following:

1. Policy makers in devising a policy when to go for an exclusive transit or grade separated facility along Albert and Slater Street.
2. City planners in planning future growth of downtown Ottawa by making the downtown core more accessible for businesses and people within the city.
3. Researchers in finding ways to improve the efficiency of the system as a whole.
4. Transit operators in planning and meeting future transit demands to and from the downtown core in particular and the city in general.

1.7 Thesis Organization:

This thesis is organized in seven chapters, details of which are as follows:

Chapter 2 covers literature review. The growing importance of transit buses in terms of their role in mitigating traffic congestion in urban areas is described. Prior work on the subject of this research is reviewed. Also relevant work carried out by researchers showing various measures of transit priority is also presented in literature review chapter.

Chapter 3 explains in detail the methodological framework including extensive data requirements for this research. The approach used to collect data from various departments of the City of Ottawa as well as from direct field measurements is described. Salient features of the study area are also described in the end of this chapter.

Chapter 4 highlights the role of computer simulation in this research and describes various aspects of the simulation tool (NETSIM) that was selected to carry out this research. It includes an overview of the simulation tool, its theory of operation, logic under which it works in order to simulate traffic environment and the variety of output measures it produces in the form of MOE (Measures of effectiveness).

In **Chapter 5** a complete methodology for network modelling and its calibration is presented. Step by step procedures for modelling and calibrating base case scenario referred to in this research as Case-A representing year 2001 traffic conditions are described. The operating characteristics established for base case were later used for future case scenarios.

Chapter 6 is dedicated to the simulation of future case scenarios and the impacts of projected traffic conditions were analyzed and compared with base case scenario.

Finally in **Chapter 7**, based on the analyses of results described in previous chapter, conclusions are noted and recommendations made to assist concerned authorities in decision makings.

CHAPTER 2

LITERATURE REVIEW AND SCOPE OF THIS RESEARCH

2.1 Background:

Traffic congestion is one of the most severe problems that urban areas of almost every size are facing these days. According to a Texas Transportation Institute report (Schrank and Lomax 2002), “The average annual delay per peak road traveller climbed from 16 hours in 1982 to 62 hours in 2000” in 75 urban areas of USA that were covered under the study. Increasing demand for using roadway facilities, rising volume of traffic with low average occupancy of vehicles and growing number of passenger-km travelled every year have created traffic congestion problems in urban areas all over the world. On the other hand there has been a marginal increase on the supply side which is constrained by economic, social and environmental related barriers (Ewing 1993). According to US Federal Highway Administration, congestion is expected to continue increasing at a significant rate not only in major urban centers but also in medium and small urban areas. Delay, unreliability of travel time, increased fuel consumption and air pollution emissions are the offshoots of congestion that extend into economic and social problems of a country (Al-Masaied 1995 and Lintelo 1991). Statistics show that (24) % of Canada’s total energy consumption occurs in Ontario and (55) % of Ontario’s total energy use is consumed by transportation sector which is producing 42% of all hydrocarbons and 63% of all nitrogen oxides (Zargari 1996).

In response to the growing recognition of these problems, transportation engineers, planners, researchers and policy makers are making their efforts to contain these adverse effects within limits and prevent further degradation of the environment. Realizing the difficulties in increasing supply of roadway facilities and expanding roadway capacity in urban areas, most of the efforts to relieve congestion have been focused on improving system efficiency through traffic control and demand-side strategies.

2.2 Role of Transit Bus:

Role of transit bus in mitigating traffic congestion and transporting passengers especially in dense core of urban areas has been under discussion since long but its importance has increased significantly in recent years. There is an increasing emphasis on efficient transit operations and strategies for transit priority. The U.S. Federal Transit Administration (FTA 1998) initiated a program called 'Bus Rapid Transit program', which involves the development and demonstration of improved transit operations in several areas. In an article published in Australia, authors state "One way of improving the efficiency of the road network for the movement of people, where there is limited road space, is to provide priority treatments for HOVs and buses" (Government of Western Australia 1997). In another article entitled "A new vision for Urban Transportation", published by Transportation Association of Canada (TAC) (1993), emphasis has been laid on enhancing knowledge base and taking action in thirteen subject areas among which transit is one. In some other literature sources, as a public policy, commuters have been encouraged to use public transit instead of depending

totally on private autos for making trips (Reynolds and Hixson 1992). Preferential treatments and other incentives are given to public transit and high occupancy vehicle users in order to help maximize person movement capacity through the facilities at acceptable levels-of-service. This is accomplished by system design, operation and management initiatives.

Realizing the importance of high occupancy vehicles in an urban environment, transportation engineers and planners are focusing to improve the efficiency of public transit since it is viewed as a reliable travel demand management measure. Various steps are being taken in order to reduce travel time, improve travel time reliability and predictability of transit buses, thus encouraging motorists to shift away from single occupant vehicles. Studies show that higher travel time of bus is primarily caused by delays at a control (congested) facility and dwell time at bus stations. Making use of the recent developments in signal controller technology and communication and surveillance systems, several efforts are underway to improve transit performance throughout the North America (Transit Signals Systems Committee 1999). However, there have been relatively few successful implementations of transit priority measures on urban networks with signalized intersections in coordinated signal system (Skabardonis 2000).

Under interrupted flow conditions of traffic, "Capacity of an urban street is related primarily to the signal timing and the geometric characteristics of the facility as well as to the composition of traffic on the facility" (Transportation Research Board 2000). Before moving forward, it is, therefore, necessary to have an understanding of

transit priority measures implemented successfully in some parts of the world with an intention to improve the efficiency of transit operations and its person carrying capacity.

2.3 Transit Priority Measures:

Transit priority measures in an urban environment are broadly characterized into two types: one based on facility design while the second rely on traffic control (Skabardonis 2000). Facility design measures which are site specific usually consist of exclusive lanes for transit on arterials, as well as street designs that facilitate transit movement. Examples include bus bays and bus bulbs (widened sidewalks at bus stations) to facilitate safe loading and unloading of passengers and reduce conflicts with other vehicles and on-street parking management.

Under the second category, transit priority measures that rely on traffic control are implemented through 'Transit Signal Priority' (TSP) which is an operational strategy that facilitates the movement of in-service transit vehicles, either buses or streetcars, through traffic-signal controlled intersections (Management Systems Committee 2002). Review of literature reveals that the concept of transit priority is not new. In fact, as early as 1962, an experiment was conducted in Washington, D. C. in which the offsets of a signalized network were adjusted in such a manner that could increase the average speed of transit buses (Sperry 1972). Further, the first bus-actuated signal priority experiment was carried out in Los Angeles in 1970 which was later demonstrated in other parts of USA (Evans 1970). At this point, it is also imperative to recognize the difference between signal priority and signal pre-emption which are different processes, but often

used synonymously. Signal priority and signal pre-emption are two different methods of giving preference to special vehicles over other vehicular traffic. Signal priority modifies the normal signal operation process to better accommodate transit vehicles. Whereas signal pre-emption interrupts the normal process for special events such as approaching train or responding to emergency vehicles (Management Systems Committee 2002). At some places in literature, the terminology of signal pre-emption has been used inappropriately with transit operation. One example is found in an article where it is stated, "Signal pre-emption may hold green until the bus clears the intersection" (Skabardonis 2000). Similarly, in some other articles it is stated, "Pre-emption techniques are designed to provide preferential treatment to buses at signalized intersections" (Khasnabis et-al. 1999, 1996, 1993, 1997).

Objectives of transit signal priority include schedule adherence, improved transit efficiency, contribution to enhanced transit information and increased road network efficiency. Signal priority treatments are further divided into two: passive and active priorities (Sunkari 1995). In 'Passive priority', predetermined timing plans are used to provide some benefits to the transit movements but do not require the presence of transit vehicle to be active. Treatments such as Adjustment of Cycle Length, Splitting Phases, Area wide timing plans and metering vehicles are provided under this category. The second type is 'Active priority' in which right of way is given only when the bus is actually present. Types of treatment in this category are Phase Extension, Early Start, Special Phase, Phase suppression and unconditional priority. Several functions are needed in order to provide active priority. First a vehicle must request priority treatment,

then this request must be detected or communicated, and finally, the traffic signal must respond to the request if necessary (Huffman et-al. 1998).

Skabardonis (2000) studied the impacts of transit priority measures for 60 buses/hr. This appears to be a very low volume level. However, in this study an hourly bus volume of 225/hr was modelled for base case scenario which was further increased to almost twice in future case scenarios.

2.4 Factors Affect Transit Priority Measures:

It is not out of place to mention that in spite of having a preferential treatment through signal priority measures, the overall efficiency of transit operation is affected by dwell time – the time required to service passengers at the busiest door plus the time required for opening and closing the doors. As stated in HCM 2000, dwell time has greater influence on the capacity of transit facility than the ratio of the green time to the cycle length (g/C). The problem is further aggravated with the increase in volume of buses.

Negative impacts of transit priority consist of impacts to other traffic, generally on cross streets, which face the potential of increased delays at signals thus causing increased average travel times and reduced average speeds to such vehicles. Transit priority strategies become complex if there are conflicting bus movements at an intersection (Skabardonis 2000).

2.5 Previous Work Done On Bus Corridor Capacity:

Although, providing an efficient transit service is seen since long as a measure to mitigate traffic congestion problems in urban areas and for which various steps are also proposed, yet, there was present relatively little information on the bus flow capacity of an arterial that has an exclusive bus lane where buses have partial or exclusive use. This deficiency was addressed to some extent when a research “Operational Analysis of Bus Lanes on Arterials” under Transit Cooperative Research Program (TCRP) was carried out and its report published in 1997 (TCRP-Report 26). The report contained guidelines for estimating bus lane capacities and speeds along arterials (St. Jacques and Levinson 1997).

In addition to it, transportation professionals have always lacked a consolidated set of transit-capacity and quality of service definitions, principles, practices, and procedures for planning, designing and operating vehicles and facilities. This lacking was overcome with the publication of TCRP Web Document 6, Transit Capacity and Quality of Service Manual (TCQSM) - First Edition, which appeared in January 1999 (Kittelson & Associates 1999). Some material of this report that was relevant to traffic engineers was later incorporated in HCM 2000 Manual. This recent effort showed that it was a start toward providing the transportation industry with a transit companion to the HCM. The author of the report states that this companion document “is in contrast to the Highway Capacity Manual (HCM) that defines quality of service and presents fundamental information and computational techniques related to quality of service and capacity of highway facilities.” This statement emphasized the difference between transit capacity and highway capacity which needs to be clarified. As stated in HCM 2000, “Transit

capacity differs from highway capacity in that it deals with the movement of both people and vehicles, depends on the size of transit vehicles and how often they operate, and reflects the interaction between passenger traffic concentrations and vehicle flow”.

Passenger carrying capacity is another measure through which operational characteristic of a transit system is gauged. During the course of literature review, it was noticed that some corridors are transporting huge volume of passengers during peak hour everyday. As mentioned in an article, “During phase 1, the system moved an average of 770,000 passengers/day with 34,000 passengers per hour per direction on the busy section of the system” (Leal, M.T. and Bertini, R.L., 2003). In another article (Harkness, R.C., 2003), the author compares the passenger carrying capacity of Link light rail versus Bus Rapid Transit and quotes the statistics shown in Figure 2.1. Again, the case of

Figure 2.1 Statistics of Passenger Transportation in Different Systems.

Bogota, Columbia is presented where 25,000 passengers/hr/direction are currently being transported at peak load point. However, in case of New York City, based on current bus volumes (all seated) 44,000 passengers/hr/direction is estimated which the system can transport. The following relevant quotes are extracted from Samuel, P. (2002).

“Thomas Rubin, a California based consultant and former senior transit agency official in Los Angeles, says that spacing of buses at 264 feet (80.5 m) with 3-second headways at 60 mph (100 km/hr) is safe. That would yield 1200 buses/hour and passenger flows of up to 70,000/lane/hour.” In the same article the author refers to another veteran academic and states that according to Vuchic “it is possible to run buses safely at 6 to 8 second headways or 450 to 600 buses per hour per lane. If the buses carry 60 seats, that’s a seated capacity of 27,000 to 36,000/hour”.

It should be noted here that the above quoted references, in most instances, are referring to the uninterrupted flow conditions that can be experienced on BRT links. These information items are included in this literature review chapter for reference purposes only.

2.6 Shortcoming in Previous Work:

In spite of making efforts to review transit capacity-related principles, procedures and practices, during the course of literature search, it was noticed that the procedure for calculating bus lane capacity reported in the above mentioned references is somewhat vague that does not provide reliable and well researched information on capacity of bus corridors because most of these researches were based on uninterrupted flow conditions

and are site/case specific. There are other discrepancies as well. For example, the actual volume of buses observed on exclusive bus lanes in at least one case i.e. of Bogota, Columbia, was far higher (630 buses/hr in two lanes) than the maximum number of buses calculated during simulation results reported by references noted above (City of Bogota, 1996).

The case of City of Bogota (Columbia) is a real life example where as mentioned earlier a total of 635 buses/hr are actually operating on surface streets. According to a report, such a high volume of transit buses in the City of Bogota is achieved despite poor operating conditions and a generalized lack of maintenance due to absence of a city busway management and operation authority. There is little police control, no systems management, and scarce information for users (City of Carolina, 2002).

Other references report actual throughput of buses on dedicated facilities. In the New Jersey's Lincoln Tunnel, 735 buses are reported to have operated during morning peak hour in peak direction (Kittelson & Associates 1999a). However, such a high volume of buses is achieved on exclusive rights of way where buses make no stops. The second highest volume of buses reported in literature is on Troncal Ave. Caracas in Bogota, Columbia, where 630 buses/hr/direction are successfully traversing through the corridor (City of Bogota, 1996). In Bogota system, the busway has two lanes per direction for the exclusive use of buses. In the case of Ottawa, the Transitway is operating much below capacity. A volume of 225 buses/hr is handled on the West Transitway.

Real life North American examples of bus lanes in interrupted flow environment operating at or above capacity are not available.

From a capacity analysis perspective, there is little information on high volume of buses operating in the form of a platoon in a CBD environment. Regarding capacity of a bus lane, there is not much literature available except the one referred earlier (TCRP-Report 26) in this section. The authors of the TCRP-Report 26 note the practical problems associated with high volume transit operations that have to be resolved while calculating capacity of a bus lane operating under interrupted flow conditions and passing through CBD areas. The Highway Capacity Manual procedure due to its rather coarse nature is of limited use in the study of capacity and level of service of bus transit corridors in a CBD environment.

2.7 Scope of this Research:

In this study, transit operation is studied under passive priority measures in which fixed time plans of traffic signals are used. Further, this research does not describe the procedure for calculating bus lane capacity where transit buses are operating on exclusive bus lanes in the CBD of a city. However, it does provide a fair idea of maximum number of buses that can be accommodated under a certain set of conditions as found through simulations of different case scenarios.

CHAPTER 3

METHODOLOGICAL FRAME WORK AND

DATA COLLECTION

The question this research is expected to answer cannot be addressed through the use of coarse macroscopic types of methodology. The methodology described in the HCM 2000 for calculating capacity of exclusive bus lanes in urban corridors is very coarse in nature. It provides a range of values for many factors such as the clearance time (t_c), failure rate (z_a) and the co-efficient of variation of dwell time (c_v) etc. Since in some cases these values are very broad in range, their use would result in highly divergent capacity estimates. Also, in the HCM 2000, capacity of a bus lane is calculated by taking into account only the critical bus station along a corridor. All other operating conditions at the up and downstream sides of a corridor are completely omitted. This procedure may produce inappropriate results, as downstream traffic conditions depend much on traffic operating conditions at upstream side. In addition, the impacts of high volume of buses in an exclusive lane on the network as a whole cannot be identified using HCM 2000 procedure. All these difficulties can be overcome using microsimulation techniques of analyzing a network. Further, using a microsimulation approach, once the model is calibrated, the effects of making changes to the network can be determined efficiently. However, there are some limitations associated with the microsimulation approach as well which include extensive data needs, time required to input all information into the model, inability to define average occupancy and dwell time of buses according to the routes etc.

3.1 Research Methodology:

For reasons noted above, this research adopted the microsimulation approach to study the capacity and related problems of the transit corridors. To facilitate complex problem-solving such as one dealt with in this research, various traffic models have been developed by researchers and many of these models are incorporated in computer software (Transportation Research Board 2000a). Easy access to microcomputers has increased the importance of these computerized traffic modelling and simulation tools many folds.

Simulation is a term that is used to describe “any model which attempts to represent or mirror actual traffic behaviour” (Taplin, 2003). A simulation tool is considered ideal for public presentation, evaluation of before and after studies, routine planning and operations analysis. It offers users the opportunity to observe animated traffic conditions, and evaluate alternative scenarios for roadway and signal system improvements in various traffic environments. Further, a simulations tool is considered more practical than a field experiment for the following reasons (Federal Highway Administration 2001).

- In situations such as the present research, a field experiment is impossible.
- Significantly less cost is involved.
- Yield results much more quickly.
- Comprehensive nature of results generated as simulation output Measures of Effectiveness (MOE) are not easy to collect from direct field measurements.
- No disruption in traffic operations takes place.

- Effects of any significant physical changes to the facility can be analyzed without spending much money just for experimental purposes.
- Impact of future traffic demand can easily be analyzed.
- Many variables can be held constant.

Thus, if a traffic system is simulated on a computer by means of a simulation model, it is possible to predict the effect of planning and operational strategies on the system performance (Papacostas 2001).

Figure 3.1 shows the components and linkages of the overall research methodology followed in this study. The first step of the research framework involved defining the problem and stating the purpose and objective of this study. In the next step a decision needed to be made about the choice of grain of analysis. Many approaches were considered for addressing the stated problem outlined in this research. These included the macroscopic approach, the microscopic level and a combination of both these approaches which is known as a mesoscopic approach. After examining the different strategies that are used to address traffic engineering problems, it was decided that a microscopic approach can better address the problem identified for this research study. The very next step was to determine the choice of methodology that could appropriately deal with the stated problem and the objectives of this study. As mentioned earlier, it was impossible to carryout a field experiment that could replicate future traffic environment in the network for year 2021 under different case scenarios intended to be examined in this study. Since microcomputers are easily accessible these days to almost

Figure 3.1 Research Study Framework

all transportation professionals throughout the world, and a number of simulation tools are within the reach of traffic engineers, it was therefore, decided to run microscopic simulations and analyze future traffic operations in the CBD of the City of Ottawa. The fourth step was to investigate the research area thoroughly and determine the data requirements of this study. In the fifth phase of this study, the selected network was modelled and the data collected from various departments of the City of Ottawa were defined as an input into the simulation model. Later it was calibrated in order to reflect as closely as possible the traffic operating conditions prevailing in the year 2001. During the sixth phase of this study, the calibrated model was used and different scenarios representing future traffic operating conditions in the network were tested and results obtained from them were analyzed and compared with the base case scenario. Finally conclusions were drawn and recommendations made that will help city policy makers, planners and transit operators in decision making.

3.2 Brief Overview of the Research Study Area:

The research study area is located in Central Business District (CBD) of City of Ottawa – the capital of Canada. It is bounded in the North and South directions by Albert and Slater Streets respectively and in the East-West directions by Elgin and Bronson streets. A total of eight streets namely Elgin, Metcalfe, O'Connor, Bank, Kent, Lyon, Bay and Bronson are crossing transit corridors. Albert and Slater streets are two major streets of the downtown, Ottawa, running across the heart of the CBD and facilitating mixed traffic operations of private autos, transit buses and heavy vehicles. Traffic movement on both streets is permitted in only one direction. These streets are connected with the

Exclusive Bus Transit-way from the east side through Mackenzie King Bridge approaches and from the west side by an extension of Albert and Slater streets beyond Bronson street thus forming a part of Ottawa Transit-way which is serving a huge volume of transit buses throughout the day. Traffic runs on Albert Street in East-West direction while on Slater Street the direction of traffic flow is West-East. Out of the eight streets crossing Albert and Slater streets in North South directions, only three streets viz. Elgin, Bank and Bronson serve two-way traffic movements. The other five crossing streets allow only one-way operation of traffic through them.

Both Albert and Slater streets represent typical CBD environment of any modern city comprising closely spaced traffic signals. Most of these traffic signals are equipped with a cycle length of 60 sec with the exception of only two operating at a cycle length of 120 sec. These traffic signals help smooth operation of high volume of traffic composed of private autos, heavy vehicles and a significant number of transit buses. The efficiency of bus operation is further enhanced by dedicating an exclusive bus lane throughout the length of these streets. A large number of high-rise buildings - mostly commercial in nature, are located alongside the streets. Each of these streets is provided with a total of four on-line bus stations spaced almost equally along the street length. These stations serve a huge number of transit passengers throughout the day, especially in peak hours. On the Ottawa Transit-way map (Figure 1.1), these bus stations are named as Metcalfe, Bank, Kent and Bay. Further, for internal data processing, OC-Transpo identifies these bus stops as CB-900, CB-910, CA-920 and CA-930 on Albert Street and CA-940, CA-950, CB-960 and CB-970 on Slater Street. The presence of a large number of shops,

restaurants, hotels and offices generates a very high volume of pedestrians crossing the streets particularly at intersections located in the middle of Albert and Slater streets. High volume of pedestrian traffic often disrupts smooth operation of right and left turning vehicles at intersections. On and off-street parking, loading and unloading zones, taxi stands and surface and underground parking lots are also located within the research study area. The presence of these land use and transportation features is to be studied in simulating traffic flow.

3.3 Data collection:

It is easily understandable from a cursory look at 'brief overview of research area' mentioned above that substantial volume of data was essential for this study. As a first step, a thorough investigation of the site was undertaken in which a detailed inventory of the existing features was prepared along with a comprehensive list of data required to initiate the study. Since the data required for this study were varied in nature, they were grouped into the following main categories:

- Traffic volume
- Transit information
- Roadway information
- Traffic signal information
- Parking, loading/unloading and Taxi zones
- Pedestrian volume

Data collection is associated with obvious costs. It is neither free nor painless. It demands considerable amount of time and efforts. Because of the financial and time

constraints for this research, a strategy was devised to gather as much information from the departments already undertaking collection of large volume of data on a regular basis for their day to day needs. Two departments namely OC-Transpo and Transportation, Utilities and Public Works working under the City of Ottawa were contacted. In the subsequent meeting, representatives of these departments were briefed about the objective of the study and the data requirements for this research. They all extended their cooperation generously by providing access to their information resources and making all the existing data available for the study. However, some of the information that did not exist with these departments was collected on site through field surveys. A conceptual flow chart is shown in Figure in 3.2 showing availability of data in different sources and the methodology adopted to collect it for this study.

Following is a brief description of the data collected under each category from the concerned departments.

3.3.1 Traffic volumes:

The network under study is composed of several links representing roadway sections between consecutive intersections. Most of the roadway sections offer only one-way traffic operation. However, few sections limited to north or southbound traffic only are open to two-way traffic. All these two-way sections are undivided except one that is Elgin Street on which a divided roadway facility is provided for north and southbound traffic. Traffic flow into or out of the network is facilitated by either entry or exit link having a composition of different sized vehicles in the traffic stream. The presence of

Figure 3.2 Logistics of Data Collection

intersections within the network help vehicles change their directions thus associated with turning movements.

Under this category, traffic volume data along all roadway sections within the network were collected from Transportation, Utilities and Public Works Department of City of Ottawa. As a general practice, traffic data are collected at intersections and all turning volumes are recorded in data sheets. Traffic flow along intersections is segregated into four main directions as North, South, East and West bound traffic and movement along each roadway section approaching an intersection is further split into left or right turning or straight moving vehicles. Figure 3.3 shows the statistics of a traffic volume data collected at one of the intersections in the network. A cursory look at this data sheet reveals that traffic volume counts have been made for three different periods of the day. First period contains data for three hours between 07:00 and 10:00 and is called morning peak period. Second period spans for 2 hours from 11:30 until 13:30 and is referred as off-peak hour. Similarly, duration of third period is three hours i.e. between 15:00 and 18:00 and is also known as evening peak period. Traffic movement in each direction has been reported in data sheets for every 15 minute interval covering a total of eight hours counting period during the whole day. Traffic volume data for all sixteen intersections covering morning and evening peak hours and off-peak hours were collected from the department concerned. Some other information such as the day and date of the year during which the survey was carried out, weather conditions, the AADT factor etc. are also shown in data sheets. All these facts have further been summarized on hourly basis as shown in Figure 3.4 with traffic volumes in AM and PM peak periods grouped

Transportation, Utilities and Public Works Department

Count ID 10851

Vehicular Turning Movements (15 Min. Volumes)

ALBERT ST and BAY ST

(ULRS Listing ALBERT & BAY)

Survey Date: Monday 20 August 2001

Conditions: Wet

Start Time: 07:00

Total Observed U-Turns

Northbound: 0 Southbound: 0

Eastbound: 0 Westbound: 0

AADT Factor

Monday in August is

1

Time Period	BAY										ALBERT										GRAND TOT	
	Northbound					Southbound					STR TOT	Eastbound					Westbound					
	LT	ST	RT	SUB TOT	LT	ST	RT	SUB TOT	LT	ST		RT	SUB TOT	LT	ST	RT	SUB TOT					
07:00-07:15	8	30	0	38	0	0	0	0	38	0	0	0	0	0	90	12	102	102	140			
07:15-07:30	2	49	0	51	0	0	0	0	51	0	0	0	0	0	108	10	118	118	169			
07:30-07:45	13	73	0	86	0	0	0	0	86	0	0	0	0	0	122	18	140	140	226			
07:45-08:00	15	75	0	90	0	0	0	0	90	0	0	0	0	0	138	24	162	162	252			
08:00-08:15	11	85	0	96	0	0	0	0	96	0	0	0	0	0	129	21	150	150	246			
08:15-08:30	18	94	0	112	0	0	0	0	112	0	0	0	0	0	125	18	143	143	255			
08:30-08:45	13	92	0	105	0	0	0	0	105	0	0	0	0	0	111	33	144	144	249			
08:45-09:00	10	72	0	82	0	0	0	0	82	0	0	0	0	0	67	22	89	89	171			
09:00-09:15	15	75	0	90	0	0	0	0	90	0	0	0	0	0	100	19	119	119	209			
09:15-09:30	10	62	0	72	0	0	0	0	72	0	0	0	0	0	81	11	92	92	164			
09:30-09:45	4	59	0	63	0	0	0	0	63	0	0	0	0	0	73	15	88	88	151			
09:45-10:00	5	41	0	46	0	0	0	0	46	0	0	0	0	0	75	16	91	91	137			
11:30-11:45	10	47	0	57	0	0	0	0	57	0	0	0	0	0	55	25	80	80	137			
11:45-12:00	9	61	0	70	0	0	0	0	70	0	0	0	0	0	61	19	80	80	150			
12:00-12:15	8	63	0	71	0	0	0	0	71	0	0	0	0	0	74	14	88	88	159			
12:15-12:30	8	50	0	58	0	0	0	0	58	0	0	0	0	0	69	23	92	92	150			
12:30-12:45	4	48	0	52	0	0	0	0	52	0	0	0	0	0	67	22	89	89	141			
12:45-13:00	6	50	0	56	0	0	0	0	56	0	0	0	0	0	63	22	85	85	141			
13:00-13:15	5	51	0	56	0	0	0	0	56	0	0	0	0	0	65	16	81	81	137			
13:15-13:30	11	51	0	62	0	0	0	0	62	0	0	0	0	0	68	13	81	81	143			
15:00-15:15	10	72	0	82	0	0	0	0	82	0	0	0	0	0	92	28	120	120	202			
15:15-15:30	10	111	0	121	0	0	0	0	121	0	0	0	0	0	113	41	154	154	275			
15:30-15:45	7	153	0	160	0	0	0	0	160	0	0	0	0	0	113	35	148	148	308			
15:45-16:00	6	141	0	147	0	0	0	0	147	0	0	0	0	0	105	32	137	137	284			
16:00-16:15	11	192	0	203	0	0	0	0	203	0	0	0	0	0	146	86	232	232	435			
16:15-16:30	12	156	0	168	0	0	0	0	168	0	0	0	0	0	166	68	234	234	402			
16:30-16:45	9	169	0	178	0	0	0	0	178	0	0	0	0	0	136	58	194	194	372			
16:45-17:00	18	157	0	175	0	0	0	0	175	0	0	0	0	0	162	48	210	210	385			
17:00-17:15	5	132	0	137	0	0	0	0	137	0	0	0	0	0	135	63	198	198	335			
17:15-17:30	7	161	0	168	0	0	0	0	168	0	0	0	0	0	165	41	206	206	374			
17:30-17:45	14	109	0	123	0	0	0	0	123	0	0	0	0	0	136	29	165	165	288			
17:45-18:00	12	80	0	92	0	0	0	0	92	0	0	0	0	0	109	22	131	131	223			

Figure 3.3 Vehicular Turning Movements (15 Min. Volumes)

separately. Such tables provide an insight of the direction of traffic flow through any intersection during different times of the day. These tables are further supplemented by a diagram shown in Figure 3.5 that describes the total volume of traffic approaching the intersection through crossing streets and its subsequent split in different directions. These different directional movements of vehicles at each intersection were taken separately as a percentage of the total traffic volume on that link for subsequent input into the simulation model. Through these data, we also come to know about the types of the vehicles and their proportions in the traffic stream. Traffic on each roadway section is broadly divided into two categories as private autos and heavy vehicular traffic. Buses are counted in the category of heavy vehicular traffic. Traffic counts shown in Figures 3.3 and 3.4 include heavy vehicles as well. However, data for heavy vehicles have been collected separately and compiled in another data sheet for morning and evening peak and off-peak periods.

3.3.2 Transit information:

Another category of data is relevant to Transit Bus operations - one of the main objectives of this study as well. All data relevant to this category were provided by OC-Transpo – another department of the City of Ottawa. It is not out of place to mention that being a part of the Ottawa Transitway, a significant volume of buses are operating along Albert and Slater streets, thus serving a large number of passengers to and from the CBD. Data under this category were further divided into three sub-categories

- Bus routes and schedules,
- Passenger boarding and alighting information and
- Fleet size and proportion of different sized buses in it.

Vehicular Turning Movements - Summary

ALBERT ST and BAY ST
 (ULRS Listing ALBERT & BAY)

Survey Date: Monday 20 August 2001
 Conditions: Wet
 Start Time: 0700

Total Observed U-Turns
 Northbound: 0 Southbound: 0
 Eastbound: 0 Westbound: 0

AADT Factor
 Monday in August is
 1

Time Period	BAY										ALBERT									
	Northbound			SUB TOT	Southbound			SUB TOT	STR TOT	Eastbound			SUB TOT	Westbound			SUB TOT	STR TOT	GRAND TOT	
	LT	ST	RT		LT	ST	RT			LT	ST	RT		LT	ST	RT				
07:00-08:00	38	227	0	265	0	0	0	0	265	0	0	0	0	0	458	64	522	522	787	
08:00-09:00	52	343	0	395	0	0	0	0	395	0	0	0	0	0	432	94	526	526	921	
09:00-10:00	34	237	0	271	0	0	0	0	271	0	0	0	0	0	329	61	390	390	661	
11:30-12:30	35	221	0	256	0	0	0	0	256	0	0	0	0	0	259	81	340	340	596	
12:30-13:30	26	200	0	226	0	0	0	0	226	0	0	0	0	0	263	73	336	336	562	
15:00-16:00	33	477	0	510	0	0	0	0	510	0	0	0	0	0	423	136	559	559	1069	
16:00-17:00	50	674	0	724	0	0	0	0	724	0	0	0	0	0	610	260	870	870	1594	
17:00-18:00	38	482	0	520	0	0	0	0	520	0	0	0	0	0	545	155	700	700	1220	
8.0 HR TOTAL	306	2861	0	3167	0	0	0	0	3167	0	0	0	0	0	3319	924	4243	4243	7410	

EQU. 12 HR TOTAL 425 3976 0 4401 0 0 0 0 4401 0 0 0 0 0 4613 1284 5897 5897 10298

Note: These values are calculated by multiplying the totals by the appropriate expansion factor.

AVG. 12 HR TOTAL 425 3976 0 4401 0 0 0 0 4401 0 0 0 0 0 4613 1284 5897 5897 10298

Note: These volumes are calculated by multiplying the Equivalent 12 hr. totals by the AADT factor.

AVG. 24 HR TOTAL 556 5208 0 5764 0 0 0 0 5764 0 0 0 0 0 6043 1682 7725 7725 13489

Note: These volumes were calculated by multiplying the Average Daily 12 hr totals by 1.31.

AM TOTAL (0700-0900) 90 570 0 660 0 0 0 0 660 0 0 0 0 0 890 158 1048 1048 1708

PM TOTAL (1530-1730) 75 1261 0 1336 0 0 0 0 1336 0 0 0 0 0 1128 431 1559 1559 2895

Figure 3.4 Vehicular Turning Movements - Summary

ALBERT ST and BAY ST
(ULRS Listing ALBERT & BAY)

Survey Date: Monday 20 August 2001
Conditions: Wet
Start Time: 0700

Total Observed U-Turns
Northbound: 0 Southbound: 0
Eastbound: 0 Westbound: 0

AADT Factor
Monday in August is 1

Approved by: DM

Printed on : 28/05/2002

Figure 3.5 Diagram – Vehicle Movements at Intersection

3.3.2.1 Bus routes and schedules:

All bus schedules operating on the streets of network were obtained along with their routes from OC-Transpo office. As mentioned earlier, a total of 384 transit buses are serving Albert and Slater corridors only in morning peak hour. Out of these 384 buses, 225 are traversing through Albert Street thus yielding an average headway of 16 sec. Similarly, 159 buses are passing through Slater Street with an average headway of 23 sec in one-hour period. These buses provide easy access to Ottawa's dense urban core from most parts of the city. Transit operations for some of the routes start early in the morning and continue till late at night. A few routes offer only express service while a few more operate only in peak periods. There are many routes that offer bus service throughout the day with varied frequency of operation. Table 3.1 and Table 3.2 show numbers of buses that are serving each bus station along Albert and Slater Streets during morning peak hour.

Table 3.1 Bus Stations and No. of Buses on Albert Street

<u>Albert Street</u>		
(Morning Peak hour 7:30 am to 8:30 am)		
S. No	Bus Station #	No. of buses
1	CB-900	218
2	CB-910	217
3	CA-920	225
4	CA-930	214

Table 3.2 Bus Stations and No. of Buses on Slater Street

<u>Slater Street</u>		
(Morning Peak hour 7:30 am to 8:30 am)		
S. No	Bus Station #	No. of buses
1	CA-940	159
2	CA-950	147
3	CB-960	149
4	CB-970	148

Route diagrams of buses contain a wealth of information including the origin and destination points of the route, name and location of bus stations being served, if early morning service is provided, areas that are served in selected time periods only, etc. These route diagrams also provided information about the schedule of bus operation during twenty-four hour period. Some of the routes start operation early in the morning and continue to operate till late at night. Further, the frequency of most of the bus routes is increased during morning and evening peak periods of the day.

As far as transit bus operation on streets crossing Albert and Slater in North-South direction is concerned, not all these streets are served by transit routes. However, data for those streets, which are facilitated by transit operation, were also collected from the department. Highest number of buses operating on any of these streets during morning peak hour is found to be 46 on Bank Street out of which 25 are South Bound and the rest 21 North Bound.

3.3.2.2 Passenger information:

Another set of data collected from OC-Transpo is relevant to passenger information. Passenger activities at all the eight transit stations in the study area were obtained. It was made possible through the Automatic Passenger Counting System (APCS) installed in the transit buses keeping a complete record of passengers boarding or alighting from transit buses at each bus stop location. Bus stations that are in high or low demands during different periods of the day can be studied through this data. Figures 3.6 and 3.7 show passenger activity at each bus station within the network that is served during morning peak hour by routes along these corridors. It can easily be noticed from these figures that a significant volume of passengers use these bus stop locations. The total number of passengers served on both Albert and Slater streets is more than 11,500 in one hour period. Out of these 11,500, more than 9,000 passenger trips are destined towards the CBD area from other parts of the city. Further, transit stations on Albert

Figure 3.6 Passengers Activity at Bus Stations on Albert Street

Figure 3.7 Passengers Activity at Bus Stations on Slater Street

Street caters around 58 % of the total passenger volume with a total of 6823 passengers. Of all the eight stations, stations # CB-900 and # CB-910 on Albert Street serve a very high demand of transit passengers during morning peak hour with a total throughput of 2183 and 2180 passengers, respectively. Minimum volume of passenger traffic observed for any single bus station is 430 at station # CA-940 on Slater Street.

Through these data, we also come to know about the routes that are in high demand of passengers moving towards or out of the CBD area during different times of a day. Average occupancies of buses while entering or leaving Albert and Slater streets are calculated with the help of these data and are shown in Figures 3.8 and 3.9 respectively.

Data about average dwell time of a transit bus on each of these bus stations are also collected from OC-Transpo office for input into simulation model.

Figure 3.8 Average Occupancies of Transit Buses at Bus Stations on Albert Street

Figure 3.9 Average Occupancies of Transit Buses at Bus Stations on Slater Street

3.3.2.3 Fleet size and proportion of buses:

The conventional transit fleet operating in the City of Ottawa has different types and models of buses. Some buses are equipped with low floor facility while those with comparatively old models have high floors. A major portion of the fleet is composed of 12 meter standard buses in which 578 buses have high floor and 160 have low floor. Whereas all the 177 buses in 18 meter articulated type are equipped with low floor facility. OC-Transpo has planned to replace all high floor buses in the transit fleet with low floor models by 2015. Figure 3.10 shows the growth in transit bus fleet operating in Ottawa in past 10 years. It can be noticed from Figure 3.10 that the standard equivalent buses in transit fleet has grown from 858 in 1990 to 926 in year 2000, showing an increase of approximately 8%. OC-Transpo is planning to further increase the size of the fleet up to 1800 buses - an increase of about 100% by the year 2021 (City of Ottawa). Such a high expected increase in fleet size clearly describes the importance of and dependence on transit operations in future in the city of Ottawa.

The proportion of 12 meter and 18-meter size buses operating within the study area is reported by the OC-Transpo office as 84% and 16%, respectively.

3.3.3 Roadway information:

Third category of data is relevant to roadway information that includes details about roadway geometric design, pavement markings and road side facilities. This information contains data about length of each roadway section, number of lanes available in it, width of each lane and the corridor as a whole, presence of any turning

SYSTEM OPERATING STATISTICS A-3											
BUS FLEET	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	BUDGET 00
Mini Buses	0	0	3	3	4	4	6	7	9	0	2 ^(a)
Mid Sized Buses	56	53	18	0	0	0	0	1	1	1	1
Standard	567	593	649	669	668	682	676	671	680	727	752
Articulated Buses	164	163	161	161	148	108	110	114	120	120	116
Total Active Fleet	787	809	831	833	820	794 ^(b)	792 ^(b)	793	820 ^(b)	857	871
Standard Equivalent Buses	858	880	907	913	893	847	846	848	870	907	926
Reserve Fleet	0	0	0	0	0	0	14	15	0	0	0
Low Floor Standard Buses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	110	160
Low Floor Articulated Buses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0	0
High Floor Standard Buses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	617	582
High Floor Articulated Buses	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	120	116
Max. Peak Scheduled Fleet	715	715	717	712	699	695	642	663	662	710	736
Midday Scheduled Fleet	281	287	272	270	265	272	249	227	243	255	263
Average Age/Mini Bus	N/A	N/A	0.3	1.7	4.1	5.2	4.9	5.7	6.1	7.1	3.0
Average Age/Mid Sized Bus	8.6	9.6	10.4	N/A	N/A	N/A	N/A	N/A	2.0	3.0	4.0
Average Age/Standard Bus	10.0	10.0	10.0	10.5	11.3	12.3	13.5	14.4	12.2	13.2	12.0
Average Age/Articulated Bus	3.6	4.6	5.6	6.5	7.4	8.4	9.5	10.4	11.3	12.3	13.0
Average Age/Active Fleet	8.6	8.9	9.0	9.7	10.6	11.7	12.8	13.7	12.1	13.1	11.0
Buses less than 5 years old	329	275	253	253	193	138	90	92	105	235	265
Buses 6 to 10 years old	117	186	209	236	252	240	265	252	254	210	189
Buses 11 to 15 years old	293	169	146	74	69	91	86	109	197	210	226
Buses more than 16 years old	48	179	223	270	299	325	351	341	264	192	188
Road Calls	9,988	8,770	8,474	8,965	8,247	7,552	6,139	7,468	6,131	7,859	7,900
GARAGE CAPACITY (St. Bus Equiv.)											
Design	780	788	788	788	908	908	908	908	908	908	908
Overload	880	888	888	888	1,008	1,008	1,008	1,008	1,008	1,008	1,008

NOTE: 24 day strike, Nov. 25 - Dec. 10, 1996

Figure 3.10 Statistics of Transit Fleet Operating in Ottawa City.
Source "Operating Statistics - OC-Transpo, 2000"

pockets supporting left or right turning movements, vertical gradient of the links, pavement markings for smooth operation of traffic, distance of stop lines from near side road curb, bicycle lane if any, etc. Drawings for all the sixteen intersections in the study area were provided by the City of Ottawa. Following information was extracted directly from the drawings provided for onward input into the simulation model:

- No. of lanes in each roadway section approaching and leaving an intersection,
- Left/ Right turning pockets, if any
- Pavement markings on links approaching intersections,
- Lanes dedicated for bus operations,

Total number of lanes on the up and downstream sides of any intersection varies between 2 and 4. Bank Street within the domain of study area is served by only two lanes, each one of them dedicated for North and Southbound traffic. However, most of the roadway sections serving only one-way traffic are provided with a facility of two to four lanes. Number of lanes on Albert and Slater streets is four with the exception of those sections equipped with transit stations which are provided with a three lane facility on most locations.

Data about overall curb to curb roadway length between two adjacent intersections, total corridor width, width of each lane and distance of stop line from near side road curb were collected manually with the help of odometer. Lengths of all bus stations within the network and number of buses they can accommodate were also

gathered at site manually. Information about turning restrictions at intersections during day time was obtained during the course of site data collection. A vertical gradient of zero is defined into the simulation model for the whole network for the purpose of simplicity.

3.3.4 Traffic signal information:

Traffic signals play a vital role in smooth operations of traffic during any time of the day. Their importance increases many folds especially in a dense urban environment like CBD of any city where high volume of traffic is experienced throughout the day, particularly in peak periods.

Fourth category of data for this study relates to traffic signals. Under this category, information about the operating characteristics of a traffic signal such as signal offset timings; cycle lengths; green, red and yellow times; phasing sequences and the time allocated for each phase operation is collected. All the traffic signals in the study area are pre-timed signals having different timing plans for morning and evening peaks and off-peak periods of the day. As mentioned earlier, there are a total of sixteen traffic signals operating within the study area. It is noticed that with the exception of only two traffic signals, one at Albert/Elgin intersection and the other at Slater/Elgin intersection which are operating at a total cycle lengths of 120 sec, all other traffic signals (which are fourteen in number) have been assigned a cycle length of 60 sec during morning peak hour. Yellow interval for all the traffic signals is set to 3 sec whereas all red time is set at 2 sec. All these information items were provided by the department concerned in the City

of Ottawa.

Figure 3.11 contains all data for one of the sixteen intersections in the network. Different timing plans, phasing sequences and schedule of operation are shown in this figure for smooth flow of traffic during different periods of the day.

3.3.5 Parking, loading/unloading and taxi zones:

Since the area under study is located in dense urban core, a large number of shops, restaurants and hotels are around in the region. To facilitate their business, many spaces have been provided along roadside for on-street parking, loading/unloading zones and taxi stands. A number of other surface as well as underground parking lots are also available in the area.

Most of the information under this category of data was collected on site during field surveys. Roadway sections providing these facilities were identified at site and their lengths measured manually with the help of an odometer. Duration and timings during which facility is available were also noted. All the roadway sections within the study area that are facilitated with such zones provide it only on one side of the street. However, exact information about the frequency and average duration of time vehicles spend in such zones during morning peak hour was not available from all departments contacted. Therefore, a default frequency of 15 vehicles per hour (minimum) normally used in simulations is taken as an input for running different case scenarios. This default value is

Traffic Signal Timing									
Intersection:		Main: Elgin St.		Side: Albert St.					
Controller Type:									
Prepared By:		Adam Woolfrey			Date:		6/17/02		
Existing Timing Plans									
	AM Peak	Off Peak	PM Peak	Night Plan					
	(TP 1)	(TP 2)	(TP 3)	(TP 4)					
	Phase 1	Phase 2	Phase 1	Phase 2					
Cycle	120	100	110	75	Ped Minimum Time				
					W	DW	A+R		
NB Thru	75	65	75	44	15	7	3.3+2.8		
NB LT	25	15	25	12			3.3+3.7		
SB Thru	50	50	50	32	15	7	3.3+2.8		
SB LT									
WB Thru	45	35	35	31	17	6	3.3+4.1		
WB LT									
Notes: time for each direction includes amber and all red intervals									
Phasing Sequence 1									
Phasing Sequence 2									
Notes: Start of first phase should be used as reference point for offset									
* Indicates that phase is actuated									
◄...► Ped Signal									
Schedule (weekday)					Comments				
Time	Plan								
0:15	TP4								
6:30	TP1								
9:30	TP2								
15:00	TP3								
18:30	TP2								
22:30	TP4								
Cost is \$26.75 (\$25 + GST)									

Figure 3.11 Traffic Signal Timing Plan.

applied to all the zones regardless of their nature in the network. Similarly location of parking lots whether surface or underground was also identified at site and their distances from nearest intersections noted.

3.3.6 Pedestrian volume:

Information about pedestrian traffic is also important in any network especially when its volume is significantly high. High pedestrian traffic often impedes movement of right or left turning vehicles at intersections. In this study, some intersections are observed with very high pedestrian traffic. Such volumes are causing high disruption to smooth operation of right and left turning movements thus forming a long queue of vehicles unable to be discharged in one green phase of signal cycle.

Under the sixth category, pedestrian data at each intersection was obtained from the Transportation, Utilities and Public Works Department of the City of Ottawa. Pedestrian movements in all directions of an intersection were recorded for a period of 8 hours. This pedestrian traffic has been further summarized into 15 minute counts. Pedestrian volume in morning peak hour varies from as high as 2177 at Bank/Slater to as low as 130 on Bronson/Slater. Figure 3.12 shows pedestrian volumes at all the sixteen intersections within the network. It is clear from this figure that around 17,900 pedestrians are crossing the streets in the network at different intersections during morning peak hour. It is also noticeable that approximately 62% of the whole pedestrian activity is concentrated on only three streets viz. Metcalfe, Bank and Kent.

Figure 3.12 Pedestrian Volumes at Intersections

3.4 Salient Features of Study Area (Base Case – year 2001):

Salient features of the study area are as follows:

- **Length of street *:** Albert/Slater = 1.3 km (approx.)
- **No. of crossing streets:** 8
- **No. of traffic signals:** 16
- **Cycle lengths:** 60 sec and 120 sec.
- **Pedestrian volume at intersection:** - Highest 2177
- Lowest 130

- **Transit bus volume:**
 - 225 buses/hr.(Albert Street)
 - 159 buses/hr. (Slater Street)
- **Bus Fleet composition**
 - 12 m (40 ft) size 84%
 - 18 m (60 ft) size 16 %
- **Passenger activity at any bus station:**
 - Highest 2183 (On + Off)
 - Lowest 430 (On + Off)
- **Total passenger activity:**
 - Albert Street 6823 (On + Off) passengers
 - Slater Street 4841 (On + Off) passengers
 - Total** **11,664**
- **No. of bus stations:**
 - 4 (Albert Street)
 - 4 (Slater Street)

* This length is shown for the roadway section between Elgin and Bronson intersections along Albert and Slater Streets.

CHAPTER 4

SIMULATION TOOL – NETSIM

Before describing data input procedures, the methodology adopted for network modelling, analytical techniques used in this study and how results were prepared, it is appropriate to have a better understanding of the simulation environment and the simulation tool itself that was used to carryout this research. A brief description of the Simulation Environment (TSIS) and the Simulation Tool (CORSIM) is provided in sections 4.1 and 4.2, respectively.

4.1 Overview of the Simulation Environment:

CORSIM is a windows-based simulation tool that works in the integrated development environment of TSIS. TSIS includes seven pre-configured tools viz. TShell, CORSIM, TRAFED, TRAFVU, TSIS Text Editor, TSIS Script Tool and TSIS Translator. All these tools enable users to model any complex traffic environment and conduct a detailed microscopic level traffic operations analysis. A brief description of all these tools is provided next.

4.1.1 TShell:

TShell is the container of all pre-configured and any additional tools that enable us to manage TSIS projects.

4.1.2 CORSIM:

It is a microscopic traffic simulation tool that models movement of individual vehicles while taking into account the influences of driver behaviour. It has two components namely NETSIM and FREESIM that are designed to simulate traffic operations on Surface Network and Freeways, respectively.

4.1.3 TRAFED:

It is a graphical user interface-based editor through which traffic networks are created and edited. Simulation input for any CORSIM model is also provided using TRAFED.

4.1.4 TRAFVU:

TRAFVU - abbreviated for TRAF Visualization Utility is a graphics post-processor for CORSIM microscopic traffic simulation system. It displays traffic networks as well as simulation output measures of effectiveness (MOE). It also animates simulated traffic flow operations along with MOE.

4.1.5 TSIS Text Editor:

This is a standard text editor with an additional feature of 'understanding' the CORSIM TRF file format. When editing a TRF file with this editor, the output window displays text describing the entry field and record type at the current cursor position. This makes manual editing of the text file much easier.

4.1.6 TSIS Script Tool:

This tool is a combined script editor and a tool for executing Visual Basic Scripts. This tool has two built-in scripts. One is a multi-run script that repeatedly runs CORSIM on a test case applying different random number seeds to each run. The other script runs CORSIM on many different test cases.

4.1.7 TSIS Translator:

This translator performs the operations of converting TRF files for use by TRAFED as well as translating the TRAFED native format (TNO) files into TRF files for use by CORSIM and other tools.

4.2 Overview of the Simulation Tool – NETSIM:

NETSIM, a microscopic traffic simulation tool widely used by Traffic engineers all over the world, was employed to model and conduct traffic operations analysis for the road network chosen for this research. In a microscopic simulation a vehicle is taken from its network entry point to final exit (Liu et-al. 1996). As mentioned earlier, NETSIM is one of the two microscopic simulation tools that are incorporated in CORSIM (Corridor Simulation). The other tool is FREESIM, which stands for Freeway Simulation. Both these tools are capable enough to represent the entire traffic environment as a function of time. Traffic operations on surface streets are modelled in NETSIM, whereas on Freeways they are replicated in FREESIM. Any traffic environment representing a combination of surface streets and freeways can also be modelled in CORSIM using NETSIM and FREESIM together and the effects of both

these environments on each other can be analyzed.

NETSIM versions 5.0 and 5.1 were employed for this research to simulate different scenarios of traffic operations for the network chosen in Central Business District of Ottawa city. Initially all the data were input and some scenarios simulated in version 5.0. Later on, with the availability of release 5.1 in April 2003, all these data were transformed into the new version as it offers many new features. One of the major reasons of switching to version 5.1 was the inability of previous version to handle more than 256 transit buses in any network. From the point of view of this research having its focus on transit bus operations, the most important feature introduced in the new version of CORSIM was its capability to simulate transit bus operations up to a maximum of 2000 buses. Another important feature is the access to a new output data processor that CORSIM driver provides in new release. The output processor now enables to accumulate user-selected statistics and summary data during multiple runs of CORSIM. It writes the collected data to an Excel workbook, a comma-separated file, and/or a tab separated file. Among the other new features introduced in version 5.1 are the increase in maximum number of nodes, links, vehicles, detectors, actuated signals, etc (Federal Highway Administration 2003). A wealth of data in the form of MOE is also accumulated at the end of each run of simulation.

4.2.1 NETSIM - Theory of operation:

NETSIM is a fixed-step microscopic network simulation model in which interval-based simulation is applied to represent traffic operations. Each vehicle in it is treated as

a distinct object. Since a time-step is one second, therefore, the movement of each vehicle, each variable control device such as traffic signals and each event are updated every second. NETSIM is a stochastic model in which random numbers are assigned to driver and vehicle characteristics and decision-making processes. Behaviour of vehicles is governed by car following, queue discharge and lane switching logics. “In a car following model, drivers accelerate or decelerate in reaction to the vehicles ahead or drivers may try to maintain a minimum desired speed (hence, lane changing)” (Transportation Research Board 2000).

4.2.2 Vehicle identification and movement:

In NETSIM, vehicles in the system are identified according to the fleet type. Up to nine different types of vehicles (with different operating and performance characteristics) can be specified, thus defining the four vehicle fleets namely auto, carpool, bus and truck. It is the car-following logic that differentiates the operation of private vehicles from a bus that is supposed to service passengers at bus stations. Kinematic properties of each vehicle such as speed and acceleration as well as its status whether it is queued or moving are also determined. Same stochastic approach is applied to turn movements, as in free-flow speeds, queue discharge headways, and other behavioural attributes. As a result, each vehicle's behaviour can be simulated in a manner reflecting real-world processes. In addition, a “driver behavioural characteristic” (passive, aggressive) is also assigned to each vehicle. Each time a vehicle is moved, its position (both lateral and longitudinal) on the link and its relationship to other vehicles nearby are recalculated, as are its speed, acceleration, and status. Further, congestion can result in

queues that extend throughout the length of a link and block the upstream intersection, thus impeding traffic flow. Delays caused to the turning vehicles at intersections due to pedestrian traffic are also modelled in the network to represent real time traffic operations.

4.2.3 Simulations for each scenario:

Because of the stochastic nature of CORSIM, the MOE obtained from a simulation result are the outcome of a specific set of random number seeds. This particular set of random number seeds may yield very conservative or avant-garde results. Consequently, simply relying on the results generated in MOE from a single run of simulation of a scenario might be misleading. In order to gain a better understanding of network performance each scenario is simulated for at least ten (10) times using different sets of random number seeds. The results of all the simulations finally obtained were averaged out and taken for further calculations and analysis.

4.2.4 Simulation outputs:

As mentioned earlier, CORSIM accumulates data every time step. At the end of each time period the accumulated data are used to produce a wealth of output data in the form of MOE. These MOE are calculated on a link basis and used in conjunction with the Highway Capacity Manual (HCM) to estimate the performance of the network. Among the MOE are included vehicle trips and kilometre, total time (veh-min) that includes move and delay times which are also calculated separately, control delays (sec/veh), queue delays (sec/veh), average volume (veh/hr.), average speed (km/hr), phase failures,

maximum and average queue lengths, number of buses discharged, bus station data etc.

The results generated in the form of MOE at the end of each simulation also include person delay data. However, these data were not used in any analysis because of their inappropriateness for this research. In NETSIM, person delays are calculated keeping in view the average occupancy of a vehicle constant throughout the simulation process. Whereas in this study, a significant number of passengers are boarding or alighting from transit buses which is not accounted for anywhere in person delay calculations. In fact, in NETSIM only dwell time is defined at each bus station location that forces each transit bus to stop over there. However, passenger activity at bus stop locations is not logged anywhere in the model.

CHAPTER 5

NETWORK MODELLING AND CALIBRATION

After collecting all relevant information about the study area as discussed in Chapter 3 and choosing NETSIM as simulations tool to carryout this research, the next step was to feed all such information into the simulation model. The model thus created was later calibrated in order to replicate as closely as possible real world traffic conditions of base case scenario i.e. Case-A representing year 2001 traffic environment. Afterward, operating characteristics of calibrated model were changed and new scenarios developed representing traffic operating conditions for future year (2021). The process of developing base case model was grouped into following main categories:

- Road network
- Traffic volume
- Transit operation
- Traffic signal
- Pedestrian volume

5.1 Road network:

In this category, roadway features of the network were defined into the simulation model. Details are noted next:

- **Nodes and links:** All intersections in the network were modelled as nodes and each of them was assigned a specific number. List of all intersections in the network and the node number assigned to them are shown in Table 5-1. Flow of traffic into and out of the network is facilitated through entry and exit nodes. Such

nodes are automatically numbered by NETSIM assigning a series of 8000. Two consecutive nodes were connected by a link representing length of roadway section that was measured during field survey. Each link shows unidirectional

Table 5.1 Name and Number of Intersections in the Network

Intersection Names and No.			
Intersection No.	Albert Street	Intersection No.	Slater Street
1	Albert / Elgin	9	Slater/ Bronson
2	Albert / Met' Calf	10	Slater/ Bay
3	Albert / O' Connor	11	Slater/ Lyon
4	Albert / Bank	12	Slater/ Kent
5	Albert / Kent	13	Slater/ Bank
6	Albert / Lyon	14	Slater/ O'Connor
7	Albert / Bay	15	Slater/ Met'Calf
8	Albert / Bronson	16	Slater/ Elgin

movement of traffic. Segment of roadway with two way traffic operation was modelled with two separate links each in opposite direction. Number of lanes and width of each lane on a link was also defined under this category and a dummy node was provided where a change in number of lanes occurred as observed along transit corridors on roadway sections with a bus station facility. At such locations a three lane facility is provided in most of the cases for traffic operation. Free flow speed of 50 km/hr (30 mph) was set for all links in the network as suggested by HCM 2000 for urban streets in CBD area. Links in the network were assigned the respective street names. Overall curb to curb length between intersections # 1 and # 8 on Albert Street and intersections # 9 and # 16 on Slater Street is approximately 1.3 km on each street. All such information is shown in Appendix-

A in Table-A1 and Table-A2 describing the attributes of each link in the network. All links were modelled with a gradient of zero. Location of stop line from near side curb at links approaching intersections was also provided as an input into the model.

- **Bus stations:** After defining all links and nodes in the network, properties of bus stations were defined. Links with a bus station facility were identified and their identification number, distance from upstream nodes, capacity to accommodate number of buses, average dwell time to service transit passengers etc. were given as an input into the model. All bus stations in the network are online type. These details are shown in Table-A3 in Appendix- A.

- **Parking garages and on-street parking zones:** There are a number of surface and underground parking garages in the network besides on-street parking, loading and unloading zones and taxi stands which exist along curb side of transit corridors. During field surveys, locations of parking garage were identified and these were modelled as source/sink locations. Provided a parking lot, any loss or gain of traffic volume between two consecutive nodes on Albert or Slater Streets is modelled as source/sink location and their volumes picked up from traffic count data collected from City of Ottawa. Similarly on-street parking, loading and unloading zones and taxi stands were also modelled in the network and the lengths measured during filed surveys were defined in it. From a Delcan Corporation (1999) study, information was obtained about frequency and average

duration of parking in the study area; but no information for morning peak hour was available. Further, no information was available from any of the departments of the City of Ottawa as well. Therefore, a minimum parking frequency of 15 vehicles/hour as suggested by NETSIM was taken along each such segment in the network. These details are shown in Table-A4 in Appendix – A.

- **Extent of study area:** The extent of study area is 80 m (262 feet) in the North of Albert Street and 100 m (328 feet) in the South of Slater Street. At such locations, streets crossing transit corridors are intersected by other streets of the CBD. In the east-west direction, along Albert and Slater Streets boundaries of the network were extended further up to 187 m (613 feet) in the East direction beyond Albert/Elgin intersection (# 1) and 140 m (459 feet) in the West direction beyond Slater/Bronson intersection (# 9).

It is very relevant to mention here that the scope of this study was limited to the analysis of selected scenarios for a small network in the downtown of Ottawa that incorporates two public transit corridors. The MOEs derived from each case scenario relate to the study area selected for this research. Therefore, these MOEs should not be interpreted as the only effects in the downtown of Ottawa.

5.2 Traffic volume:

Traffic volume data that were collected from the City of Ottawa office was examined before using it as input into the simulation model. It was noticed that the dates

and year of data collection were not similar at the sixteen intersections in the network. Therefore, all such data that were collected in previous years were made compatible to year 2001 and following the advice of the City of Ottawa officials, a projection rate of 2.5% per annum along with respective AADT factor was applied to the traffic entering the network from various entry nodes. Hourly volumes during morning peak hour (7:30 – 8:30 am) were extracted from the data and were defined in the network representing year 2001 traffic conditions. Uniform distribution type of vehicle entry headway was chosen because of the typical downtown environment of the area. Traffic projections were made using the following equation:

$$\text{New traffic} = \text{Old traffic} (1 + r)^n \quad \text{Eq. 5.1}$$

Where r = growth rate (in fractional terms) and

n = no. of years

Heavy vehicle data were segregated from rest of the traffic and defined as a percentage of total traffic entering the network. Transit buses entering into the network were not included in the category of heavy vehicles and therefore, modelled separately. Percentage of turning movements at approach links of each intersection were calculated and given as an input into the network. These are shown in Table – A5 in Appendix A.

For traffic projections up to year 2021, the Transportation Master Plan for City of Ottawa was studied in which an overall increase of 21% in auto traffic is estimated in Ottawa's dense urban core (City of Ottawa 2003). Following these guidelines, 0.96% per

annum increase in auto traffic was calculated until year 2021 and later defined in the network to simulate future traffic conditions. Table 5.2 shows hourly volumes of traffic for year 2001 and 2021 along with percentage of heavy vehicles (without buses) in traffic stream.

Table 5.2 Hourly Traffic Volumes for Base Year and Projected Year

<u>Traffic volumes for base year (2001) and projected year (2021)</u>			
Entry Link	Hourly Volume (veh/hour) (year 2001)	Hourly Volume (veh/hour) (year 2021) *	Trucks (% age of hourly volume)
(8025, 215)	778	942	2
(8019, 209)	219	266	3
(8011, 201)	190	231	2
(8002, 111)	322	390	8
(8001, 101)	232	281	3
(8012, 202)	742	899	4
(8020, 210)	237	287	3
(8026, 216)	748	906	4
(8021, 211)	695	842	2
(8015, 205)	1029	1246	4
(8014, 204)	349	423	6
(8018, 208)	1186	1436	2
(8024, 214)	873	1057	4
(8003, 151)	631	764	1
* Volumes projected @0.96% per year. It includes truck traffic but not bus traffic.			

5.3 Transit operation:

In this category, transit bus operation along the streets of network was modelled. Buses operating on each street of the network were grouped under preferably one or a maximum of two routes and a mean headway of buses was defined accordingly that

yielded hourly volume of bus traffic in year 2001 on that street. Highest volume of buses served by any of the bus stations on respective transit corridor during morning peak hour was kept constant throughout the corridor. On Albert Street it was found to be 225/hr while on Slater Street 159/hr. Number of buses served by each bus station on Albert and Slater Streets are already shown in Tables 3.1 and 3.2 earlier in chapter 3.

Table 5.3 Routes No., Mean Headway and Hourly Volume of Buses in the Network

Transit buses in the network - Year 2001 Route #, Mean Headway and Hourly volume			
S. No.	Street / Route #	Mean Headway (sec)	Hourly volume (bus/ hr.)
	<u>Albert Street:</u>		
1	Route # 1	16	225
	<u>Slater Street:</u>		
2	Route # 21	24	150
3	Route # 22	400	9
	Total on Slater Street		150
	<u>Bank Street (NB):</u>		
4	Route # 51	171	21
	<u>Bank Street (SB):</u>		
5	Route # 52	144	25
	<u>Elgin Street (NB):</u>		
6	Route # 41	360	10
	<u>Elgin Street (SB):</u>		
7	Route # 42	327	11

Mean headway was calculated from following equation:

$$\text{Mean Headway (s/veh)} = 3600 / (\text{Flow rate veh/hr}) \quad \text{Eq. 5.2}$$

Table 5.3 shows route number assigned to transit buses operating on different streets of the network, their mean headway and hourly volumes.

Dwell time which is defined in HCM 2000 as “the time a transit unit (vehicle or train) spends at a station or a stop measured from stopping to starting” was also defined during transit operation modelling. Dwell time is calculated from following equation:

$$t_d = P_a t_a + P_b t_b + t_{oc} \quad \text{Eq. 5.3}$$

Where t_d = dwell time

P_a = alighting passenger/bus through busiest door during peak 15 min (passengers)

t_a = passenger alighting time (seconds/passenger)

P_b = boarding passenger/bus through busiest door during peak 15 min (passengers)

t_b = passenger boarding time (seconds/passenger)

t_{oc} = door opening and closing time (seconds)

Average dwell time data of buses on each bus station of transit corridor was provided by OC-Transpo which is shown in Table 5.4. Further, in Figures 5.1 and 5.2,

passenger activity through transit buses on all the eight bus stations along Albert and Slater Streets is shown. An examination of these figures show that a total of 11, 664 passengers are serviced on transit corridors in just one hour period. Out of these approximately 58% are serviced on Albert Street while rest (42%) on Slater Street.

Table 5.4 Dwell Times on Bus Stations along Albert and Slater Streets

Dwell Time (sec) of buses on bus stations -year 2001 (Morning Peak Hour - 7:30 am to 8:30 am)					
Albert Street			Slater Street		
S. No.	Bus Stop #	Average Dwell Time (sec)	S. No.	Bus Stop #	Average Dwell Time (sec)
1	CB- 900	11	1	CA- 940	5
2	CB - 910	12	2	CA - 950	10
3	CA - 920	10	3	CB - 960	9
4	CA - 930	3	4	CB - 970	9

Figure 5.1 Passengers Activity on Albert Street.

Figure 5.2 Passengers Activity on Slater Street.

Average occupancy of transit buses was calculated from the data provided by OC-Transpo. Buses operating on Albert Street have an average occupancy of 29.2 passengers/bus before serving first bus station (CB-900). Where as, on Slater Street it was 35.8 passengers/bus before serving first station (CA-940). These two figures were averaged out as 32.5 passengers/bus because of the limitations of NETSIM that allows only one value of average occupancy for all the buses operating in the system.

5.4 Traffic signal:

Traffic signals facilitating flow of traffic through the network were modelled under this category. All traffic signals in the network are pre-timed with various timing plans for different periods of the day. For morning peak hour (7:30 – 8:30 am), two

different types of Cycle Length (C) are functioning in the network - one with 120 sec and the other with 60 sec. Intersections # 1 (Albert/Elgin) and # 16 (Slater/Elgin) are equipped with 120 sec cycle length whereas all other intersections in the network are assigned a 60 sec cycle length. All red time of 2 sec and an amber time of 3 sec are allocated to all signals in the network. Signal cycle lengths and the offsets along Albert and Slater Street are shown in Figure 5.3 and Figure 5.4 respectively with green times allocated for transit corridors. Further along transit corridors, (g/C) ratios at all signals are also shown in Figures 5.5. Details of traffic signals operating in the network are shown in Table – A6 in Appendix – A. Links approaching each intersection and the time allocated to each link for traffic operation are shown in this table.

Figure 5.3 Cycle Lengths (C) and Green Time (g) on Albert Street

Figure 5.4 Cycle Lengths (C) and Green Time (g) on Slater Street

Figure 5.5 (g/C) Ratios along Albert and Slater Streets.

5.5 Pedestrian traffic:

Since study area represents CBD of the City of Ottawa, therefore a significant volume of pedestrian traffic is experienced. Under this category, pedestrian traffic was modelled which is classified in NETSIM as no (less than 100/hour), light (between 100 and 250/hour), moderate (between 250 and 500/hour) and heavy (above 500/hour). Pedestrian data collected from City of Ottawa were examined and the entire pedestrian activity during morning peak hour was grouped together along each intersection of the network according to the classification of NETSIM. These were later defined as an input into the model.

Further, projected pedestrian volumes for year 2021 for intersections along transit corridors were not available; therefore, the year 2001 data were used in simulations. However, it should be mentioned that increased bus volume along Albert and Slater corridors is likely to result in increased pedestrian activity. The increased interaction between pedestrians and turning vehicles would add to increased delays to road traffic.

5.6 Model calibration:

After defining all the inputs in the network, the model was calibrated to reflect a traffic environment approximately similar to the real world traffic conditions. Therefore, some of the calibration parameters that include driver behaviour and vehicle performance were changed and through trial and error method a match of real world traffic conditions was developed. All these calibrating parameters are shown in Table – A7, Table – A8 and Table – A9 in Appendix A.

Further, there is only one type of transit bus i.e. 12 m (40 ft) size that has been defined in NETSIM. However, in our network almost 16% of the bus fleet is composed of 18 m (60 ft) size buses. Therefore, following the advice of TSIS officials one of the vehicle types predefined in NETSIM was redefined as transit bus and its size changed to 18 m. More over its operating characteristics were also made similar to that of 12 m size bus as the operating characteristics of 18 m size bus were not available. Vehicle type specifications are shown in Table – A10 of Appendix – A.

Finally, two measures of performance namely link volumes and average speed were chosen and the difference between observed and simulated figures was compared in order to validate model calibration. Figure 5.6 shows observed and simulated volumes on all the links in the network. Statistical analysis of the difference in volumes between observed and simulated results was also performed and it is reported in Table 5.5. For average speeds on Albert and Slater corridors, ten (10) field tests were also carried out in a car on Wednesday, the March 19th 2003 during morning peak hour and its data collected for comparison with simulated speeds. Results of observed and simulated average speeds are presented in Table 5.6.

Average speed from field observations was calculated using space mean speed (SMS) (McSHane et-al., 1998) which is as follows:

$$\text{Space mean Speed (km/hr)} = n \cdot d / \sum t_i \quad \text{Eq. 5.4}$$

Where n = no of travel time observed

$d =$ distance traversed (km)

$t_i =$ travel time for the i th vehicle (sec or hr)

Figure 5.6 Observed and Simulated Volumes on Links

Table 5.5 Statistical Analysis Results

Statistical Analysis Results (% difference of volume)	
Mean	0.16
Median	(0.13)
Standard Deviation	5.17
Skewness	1.00
Minimum	(12.62)
Maximum	20.35
Sum	11.42
Count	70.00
Confidence Interval (95%)	{1.37, -1.05}

Table 5.6 Average Speed Results

Average Speed results (km/hr.)		
	Observed in field	Simulated
All traffic :		
- Albert Street	24.4	22.36
- Slater Street	24.7	24.02

5.6.1 Initialization Period:

At the start of a simulation, the roadway network contains no vehicles. The period of time called the initialization or "fill time" is used to load vehicles on each sub-network so that statistics can be gathered on a network with meaningful results. An initialization period of 5 minutes was defined during each simulation in order to load vehicles in the network. Initialization results are shown in Table – A11 in Appendix A.

5.7 Statistical analysis of the model output:

Due to the stochastic nature of CORSIM, a total of 10 simulations were run in each case varying the random numbers. Performance measures that were derived from 10 simulation results were analyzed statistically in which mean, standard deviation, minimum and maximum values and (+/-) 95% confidence interval were calculated. The Standard deviation is a measure of how widely values are dispersed from the average value. However, confidence interval is a range on either side of a mean. These results were compiled for:

- Albert and Slater corridors (between Elgin and Bronson intersections) and
- Each link.

Results of some of the performance measures on transit corridor only are shown in Table 5.7.

Table 5.7 Statistical Analysis of Model Output Results

Statistical Analysis Results (Year 2001)				
	Stops	Trips	Km Traversed	Speed (km/h)
<u>Albert Street:</u>				
Mean	3,036.1	9,710.1	941.65	22.49
Standard Deviation	58.3	251.7	23.1	0.1
Minimum	2,932.0	9,351.0	909.3	22.3
Maximum	3,126.0	10,172.0	982.7	22.8
Confidence Int.*	{3072.2, 3000}	{9866.1, 9554.1}	{955.9, 927.4}	{22.6, 22.4}
<u>Slater Street:</u>				
Mean	3,428.5	14,075.6	1,092.8	24.2
Standard Deviation	94.9	374.0	28.1	0.3
Minimum	3,264.0	13,445.0	1,044.9	23.8
Maximum	3,534.0	14,466.0	1,121.1	24.5
Confidence Int.*	{3487.4, 3369.7}	{14307.4, 13843.8}	{1110.2, 1075.4}	{24.3, 24.0}
* (+/- 95% Confidence Interval)				

CHAPTER 6

DESCRIPTION OF SCENARIOS AND ANALYSIS OF RESULTS

As outlined in Chapter 1, the objectives of this research are to:

- find choke level in the network under current and changed operating conditions incorporating year 2021 traffic,
- determine how many buses can be accommodated under various scenarios of traffic and operating conditions,
- compare the results of choke level condition with the existing condition, and
- draw conclusions which could help policy makers, researchers, city planners, transit operators and other stake holders in their decision making process.

It is clear from the objective statement that one of the purposes of this research is to maximize transit bus volume on Albert and Slater Streets along with year 2021 traffic under different case scenarios until capacity is reached and/or control delays of traffic movements in the network climb to a Level of Service (LOS) 'E or F'.

6.1 Capacity and Level of Service (LOS):

6.1.1 Capacity:

According to Highway Capacity Manual 2000, capacity is defined as “The maximum sustainable flow rate at which vehicles or persons reasonably can be expected to traverse a point or uniform segment of a lane or roadway during a specified time

period under given roadway, geometric, traffic, environmental and control conditions; usually expressed as vehicles per hour, passenger cars per hour, or persons per hour”.

6.1.2 Level of Service (LOS):

In the HCM (2000), Level of Service (LOS) is defined as, “A qualitative measure describing operational conditions within a traffic stream, based on service measures such as speed and travel time, freedom to manoeuvre, traffic interruptions, comfort and convenience.”

6.1.3 LOS ‘E’:

LOS ‘E’ is characterized by significant delays and average travel speeds of 33 percent or less of the Free Flow Speed (FFS).

6.1.4 LOS ‘F’:

LOS ‘F’ is characterized by urban street flow at extremely low speeds, typically one-third to one-fifth of the FFS. Intersection congestion is likely at critical signalized locations, with high delays, high volumes, and extensive queuing.

A link or intersection is said to have a Level of Service (LOS) ‘E or F’ when Control Delays > 55 and 80 sec/vehicle respectively.

6.2 Criteria for selecting number of transit buses:

Number of buses discharged from Mackenzie King Bridge off ramp represented by link 101 – 1 at intersection No 1 in Figure 6.1, was taken as ‘Buses Arriving’ Albert

Street. However, buses discharged at link 109 - 8 representing west bound approach at Albert/Bronson intersection (No. 8) were taken as 'Buses Departing' Albert Street. Similarly number of buses discharged by link 151 - 9 representing east bound approach at Slater/Bronson intersection (No. 9) is defined as 'Buses Arriving' Slater Street. Whereas, buses discharged by link 161 - 16 denoting east bound approach at Slater/Elgin intersection (No. 16) were taken as 'Buses Departing' Slater Street. Figure 6.1 shows all the links and nodes of the network under study.

In order to proceed with this objective, the study was divided into different categories, which are described in following section.

6.3 Description of Scenarios:

All the scenarios intended to be examined were grouped into three main categories. These categories are shown in Figure 6.2. Further, Figure 6.2 in conjunction with Figure 6.3 describes a complete methodology for comparing performance measures (MOE) of the network under different case scenarios. A brief description of these scenarios is presented below:

6.3.1 Case-A:

Case-A represents Base-Case scenario in which traffic operations for conditions prevailing in year 2001 is simulated. Year 2001 was taken as the base year and all traffic data were made compatible (if not already) to it. After running the simulations, performance characteristics of the network were measured and results taken as a base case for comparison of MOE from other cases.

Figure 6.1 Link/Node Diagram of Network

Figure 6.2 Scenario Categories and Description

Figure 6.3 Methodology for Selecting Scenarios for MOE Comparison

6.3.2 Case-B:

Case-B is designated to scenario for projected traffic conditions in year 2021 in which throughput of transit buses was maximized keeping all the operating characteristics of the network same as were defined in Case-A. The purpose of running this scenario was to check the potential of the network to meet future transit demand under projected traffic conditions and without making any changes in the network. It was achieved by incrementally reducing the mean headway of transit buses along Albert and Slater Streets. A series of simulations were run under this category however, only the results of scenario with the highest yield of transit buses were compiled for comparison of MOE from other cases. In this scenario it was noticed that a mean headway of 7 sec/bus or less generate approximately same number of buses which are around 442 and 449 on Albert and Slater Streets, respectively. Any mean headway below 7 sec/bus cannot bring any significant number of more buses on these corridors under conditions defined for this scenario. This has been discussed in detail in section 6.7 under “Impact of exclusive bus lane”. Potential influences of maximizing number of transit buses on individual links as well as on the whole network were calculated and are presented later in this chapter.

Figure 6.4 shows number of buses arriving and departing Albert and Slater Streets in Cases “A and B” according to the criteria set out in section 6.1 above. Case-A represents year 2001 figures while Case-B shows the maximum bus volume that can be accommodated on transit corridors along with projected traffic for the year 2021 under same operating conditions defined in base case scenario. Statistical analysis of these

Figure 6.4 No. of Transit Buses on Albert and Slater Streets in “Cases A and B”

* Note: Symbol ‘I’ shown in this figure and throughout this chapter represents Standard Deviation of 10 simulation results.

Figure 6.5 Percentage of Buses Increased on Albert and Slater Streets.

results was also performed and standard deviations (symbolized as ‘I’) have been shown in the same figure. An examination of Figure 6.5 discloses that as of year 2001 Albert and Slater Streets are operating well under capacity with enough room available to

accommodate 96% more buses on Albert Street and approximately 182% additional buses on Slater Street without making any changes to the system. These percentages are shown separately in Figure 6.5.

6.3.3 Case-C:

Case-C also depicts scenarios for projected traffic in the year 2021 with changes made in operating conditions. Effective green time of traffic signals along Albert and Slater Streets were changed and this change was kept limited to transit corridors only. No change in green time was made for streets crossing Albert and Slater corridors. Scenarios under this category were studied with an intention to further increase the throughput of buses by providing additional green times to transit corridors. A series of simulations were run in this category and different combinations of green time were applied along transit corridor. However, scenario representing the highest yield of transit buses along with the most severe traffic operating conditions on other links in the network was selected for onward calculations and comparison of MOE with other two cases i.e. Cases A and B.

6.4 Selection of scenario from Case-C:

Each scenario in Case-C was provided with an additional effective green time increasing progressively by a 5 sec interval (in addition to original green time as in Base case scenario). The increment (along transit corridors only) was applied simultaneously to all the intersections in the network. This green time was continued to be increased until control delays of most of the traffic movements in the network swelled to 55 sec/vehicle

i.e. a LOS 'E' or above. Any further increase in effective green time along transit corridor beyond this limit will result in additional delays to the traffic operating on such streets without contributing significantly to the throughput of buses. Results of five scenarios of this series are shown in Figure 6.6 and Figure 6.7 in which transit buses traversing through Albert and Slater Streets are shown along with Case-B scenario for comparison purposes. It can be easily noticed from the figures that even an increase of 20 sec in the effective green time on Albert and Slater Streets could not attract any significant number of more buses on these corridors. Any appreciable raise is seen at 40 sec increase in green time when the number of transit buses swells to over 7% on Albert as well as on Slater Streets as compared to the figures calculated in Case B. Similarly a 50 sec increase in green time increases the throughput of buses by approximately 10% on both Albert and Slater Streets. Many other scenarios including the one with maximum

Figure 6.6 Transit Buses on Albert Street at Different Green Times

Figure 6.7 Transit Buses on Slater Street at Different Green Times

maximum allowable effective green time of 120 sec and another with a reduction of 5 sec along transit corridors were also examined. However, in order to reduce quantum of work, all such scenarios were not selected for detailed analysis as they could not increase the supply of buses through transit streets. Since scenario C5 yielded the highest number of transit buses, therefore, it was selected for further calculations and comparison of MOE from other cases. Finally, in scenario C5, minor adjustments were made in the green times of three traffic signals in the network in order to reduce control delays along intersecting streets already operating at very high control delays.

A separate analysis was also carried out to examine why such a high increase in green time is not increasing significantly the throughput of transit buses along Albert and Slater Streets. This analysis is discussed in detail in Section 6.7 of this chapter.

6.5 Cycle lengths (C) and g/C ratios:

Details of traffic signals showing total cycle lengths (C), green times (g) and g/C ratios for Cases A, B and C are shown in Figures 6.8 to 6.11. Signal details for Albert Street are shown in Figures 6.8 and 6.10, whereas for Slater Street these are shown in Figures 6.9 and 6.11.

It is evident from the above discussion that there were a total of three major cases viz. Case-A, Case-B and Case-C (representing scenario C5) selected for this study. With the exception of one i.e. Case-A representing base case for year 2001, the objective of other two cases was to determine maximum throughput of transit buses along with projected traffic for the year 2021 until capacity is reached and/or control delays climb to a LOS 'E' or above on most of the links in the network.

6.6 Statistical Analysis of Cases A, B and C:

A total of ten simulations were run in each case to reflect diverse behaviour of driver types in the network. Statistical significance of the buses generated during these simulations was also checked and measures such as minimum, maximum, mean, standard deviation and (+/-) 95% confidence interval were calculated in each case. The same two links (mentioned in Section 6.2 above) representing entry and exit points of buses on transit corridors were chosen and statistical analysis of buses discharged by these links was carried out. Results of this analysis are reported in Table 6.1.

Figure 6.8 Cycle Lengths and Green Times along Albert Street in Cases A, B and C.

Figure 6.9 Cycle Lengths and Green Times along Slater Street in Cases A, B and C.

Figure 6.10 (g/C) Ratios along Albert Street in Cases A, B and C.

Figure 6.11 (g/C) Ratios along Slater Street in Cases A, B and C.

Table 6.1 Statistical Analysis Results of Transit Buses Discharged.

Statistical Analysis results of buses discharged in Cases A, B and C					
S. No.	Description	Buses on Albert Street		Buses on Slater Street	
		Arriving Link (101-1)	Departing Link (109-8)	Arriving Link (151-9)	Departing Link (161-16)
1	<u>Case A:</u>				
(i)	Mean	225.0	219.3	159.0	158.4
(ii)	Standard Deviation	0.0	2.1	0.0	0.7
(iii)	Minimum	225.0	217.0	159.0	157.0
(iv)	Maximum	225.0	222.0	159.0	159.0
(v)	Confidence Int.*	-	{221, 218}	-	{158.8, 158.0}
2	<u>Case B:</u>				
(i)	Mean	442.4	419.9	448.6	440.5
(ii)	Standard Deviation	31.0	30.7	17.2	13.3
(iii)	Minimum	395.0	371.0	421.0	413.0
(iv)	Maximum	486.0	459.0	474.0	456.0
(v)	Confidence Int.*	{461.6, 423.2}	{438.9, 400.9}	{459.3, 437.9}	{448.7, 432.3}
3	<u>Case C:</u>				
(i)	Mean	486.4	462.1	493.7	483.4
(ii)	Standard Deviation	21.6	20.3	20.9	21.7
(iii)	Minimum	452.0	432.0	455.0	451.0
(iv)	Maximum	521.0	498.0	523.0	519.0
(v)	Confidence Int.*	{499.8, 473}	{475, 449.2}	{506.6, 480.8}	{496.8, 470}
* (+/- 95% Confidence Interval)					

6.7 Impact of exclusive bus lane:

Here, it is very relevant to mention that number of buses generated in all the three cases is a result of exclusive bus lane operation. NETSIM does not allow more than one exclusive bus lane on any roadway section in a network. This exclusive bus lane operation forces transit buses to follow the designated lane only.

As described earlier, at a mean headway of as low as 7 sec/bus, Case-B could generate only 442 and 449 transit buses on the upstream side of Albert and Slater Streets, respectively, instead of discharging 514 buses in one hour simulation period. Similarly in Case-C, at a mean headway of 5 sec/bus along with a significantly high green time (+50 sec in base case) along Albert and Slater corridors, the number of buses discharged at the upstream links of these corridors were only 486 and 494, respectively, as opposed to 720 buses in one hour period. The total discharge being well below the flow rate of buses defined as input revealed that the capacity of exclusive bus lane was reached. This situation has been described in detail in "Operational Analysis of Bus Lanes on Arterials - TCRP Report 26" (St. Jacques and Levinson 1997). The authors state, "Two measures of performance output indicated the point at which capacity was reached: (1) simulated average bus speeds dropped significantly and (2) the number of buses serviced at the bus stop was less than the number of buses input as the bus flow rate. These two measures indicated a point at which no greater flow rate of buses would be achieved along the arterial and where buses queued excessively at the bus stop or at upstream signals."

When animation results generated by NETSIM for these cases were observed on screen, it indicated a long queue of buses on links 101 – 1 (Mackenzie King Bridge off ramp) and 151 – 9 (East bound approach to intersection No 9). One hour simulation results also showed that the average queue on both these links was 10 and 8 vehicles, respectively, spread over the entire length of the links. These queues of buses were unable to be served completely during a green phase of signal cycle thus impeded traffic

flows and caused lower speeds and higher delays and travel times. It is imperative to mention that these links are serving as a main supply source of transit buses to Albert and Slater Streets. Having these upstream links operating at capacity, supply of transit buses cannot be increased at the downstream side of transit corridors in order to let them choke.

6.7.1 NETSIM Results of exclusive bus lane:

In order to supplement the understanding of saturated state of transit bus operation in exclusive lane at upstream links of Albert and Slater streets, results generated by NETSIM in all the three cases were analyzed. Among the measures selected for analysis and comparison were average speed, average delays, travel time (sec/bus) and average and maximum queues which are commonly used in estimating effectiveness at signalized intersections (McShane, et.al. 1998). These are shown in Figures 6.12 to 6.21. Results shown in each of these figures represent output in two different patterns. Under the first pattern results are compiled for the first 10 minutes period in which output data are collected at every 10 sec interval. In this way we get a complete understanding of the fluctuations happening in traffic flows due to the presence of control signals in the network. In the second pattern, results are compiled for rest of the 50 minutes simulation period in which data are gathered at every ten minute interval. It can be easily observed from Figures 6.12 and 6.13 that in Case-A, average bus speeds along links (101 – 1) on Albert and (151 – 9) on Slater Streets get stabilized within first three/four minutes period and continue to operate around 29 km/hr and 26 km/hr respectively, throughout the one hour simulation period. The same situation is seen (in Case-A) for Bus Total Delays and Bus Travel Time which are shown in Figures 6.14 to 6.17. In addition, the average

queues of buses drop down with the passage of time from 3 to 2 on link (101 – 1) of Albert Street and from 1 to 0 on link (151 – 9) of Slater Street. However, in Cases B and C, it is entirely opposite to base case and a sudden drop in average bus speeds is seen during the first ten minutes period. The overall decrease in average speeds in Cases B and C is more than 70% (as compared to base case) on both Albert and Slater Streets. The obvious outcome of this reduction in average speeds is higher delays, longer travel times and excessive average and maximum queues of buses in the lane. These are shown in Figures 6.14 to 6.21. It is very important to understand that these queues of buses had already occupied the entire length defined for links (101 – 1) on Albert and (151 – 9) on Slater Streets. Regarding bus delays, we can notice from Figures 6.14 and 6.15 that these are continuing to increase in Cases B and C as opposed to Case-A with the passage of time. Similar pattern is observed in bus travel times which are shown in Figures 6.16 and 6.17. However, average and maximum queues along these links are shown in Figures 6.18 to 6.21. Speed results were also plotted against bus delays as well as bus travel times and are shown in Figures 6.22 to 6.25. A regression analysis was also run in each of these cases and the regression equation and correlation coefficient (R^2) between two parameters (speed and bus delays or bus travel time) were calculated. These are shown in respective figures. A negative slope of regression equation in all the four figures is evident showing an inverse relationship between the two parameters. Similarly a higher value of R^2 represents strong correlation between the two parameters. The whole phenomenon is in complete accordance with the traffic flow theory according to which increase in delays and a reduction in speed defines traffic flow operations beyond saturation point.

Figure 6.12 Bus Mean Speed (in Cases A, B & C) on Link Approaching Albert Street.

Figure 6.13 Bus Mean Speed (in Cases A, B & C) on Link Approaching Slater Street.

Figure 6.14 Bus Delays (Cases A, B & C) on Link Approaching Albert Street.

Figure 6.15 Bus Delays (Cases A, B & C) on Link Approaching Slater Street.

Figure 6.16 Bus Travel Time (Cases A, B & C) on Link Approaching Albert Street.

Figure 6.17 Bus Travel Time (Cases A, B & C) on Link Approaching Slater Street.

Figure 6.18 Average Queues of Buses (Cases A, B & C) on Link Approaching Albert Street.

Figure 6.19 Average Queues of Buses (Cases A, B & C) on Link Approaching Slater Street.

Figure 6.20 Maximum Queues of Buses (Cases A, B & C) on Link Approaching Albert Street.

Figure 6.21 Maximum Queues of Buses (Cases A, B & C) on Link Approaching Slater Street.

Figure 6.22 Bus Speed v/s Bus Delay Relationship in Case-B on Links Approaching Albert and Slater Streets

Figure 6.23 Bus Speed v/s Bus Travel Time Relationship in Case-B on Links Approaching Albert and Slater Streets

Figure 6.24 Bus Speed v/s Bus Delay Relationship in Case-C on Links Approaching Albert and Slater Streets

Figure 6.25 Bus Speed v/s Bus Travel Time Relationship in Case-C on Links Approaching Albert and Slater Streets.

Figure 6.26 Percentage Changed (from Case-A) in Cases B & C (under saturated conditions) along Link (101 - 1)

Figure 6.27 Percentage Changed (from Case-A) in Cases B & C (under saturated conditions) along Link (151 - 9)

6.7.2 Comparison of Capacity from HCM 2000 and Microsimulation:

Before presenting performance measures generated under each case scenario, a comparison of exclusive bus lane capacity computed from HCM 2000 method and through microsimulation was also carried out for future case scenarios i.e. B and C. For conditions taken in this study, HCM 2000 suggests, “The bus lane vehicle capacity is simply the vehicle capacity of the critical bus stop along the bus lane”. According to HCM 2000, capacity of exclusive bus lane is determined by the equation 6.1 shown below:

$$B = B_{bb} * N_{eb} * f_r \quad \text{Eq. 6.1}$$

where B = Exclusive bus lane capacity (veh/hr),

B_{bb} = Bus loading area vehicle capacity at critical bus stop,

N_{eb} = Number of effective loading areas at critical bus stop

f_r = capacity adjustment factor for right turns at critical bus stop (in this case, right turns at critical bus stations on Albert and Slater Streets are prohibited).

We know that B_{bb} is given by:

$$B_{bb} = 3600 (g/C) / \{t_c + [(g/C) t_d] + z_a * c_v * t_d\} \quad \text{Eq. 6.2}$$

where t_c = clearance time between successive buses = 7.5 sec (Mean of 1st range). Two ranges 5 – 10 and 10 - 15 sec suggested by HCM 2000.

- t_d = average dwell time (sec)
 z_a = failure rate for CBD stop type 1 = 1.27 (Mean)
 (range 1.440 – 1.040 as suggested by HCM 2000)
 c_v = co-efficient of variation of dwell time = 60% (Mean)
 (40% - 80% suggested by HCM 2000)

For this research, CB-910 on Albert Street and CB-950 on Slater Street were identified as critical bus stations because of the highest dwell time along respective corridor. Details of the two bus stations are as under:

Critical bus station along Albert Street = CB-910

$$\begin{aligned}
 t_d &= 12 \text{ sec} \\
 g/C &= 26/60 = 0.43 \text{ (In Cases-A and B)} \\
 g/C &= 76/110 = 0.69 \text{ (In Case-C)} \\
 N_{eb} &= 4
 \end{aligned}$$

Critical bus station along Slater Street = CB-950

$$\begin{aligned}
 t_d &= 10 \text{ sec} \\
 g/C &= 27/60 = 0.45 \text{ (In Cases- A & B)} \\
 g/C &= 67/100 = 0.67 \text{ (In Case-C)} \\
 N_{eb} &= 4
 \end{aligned}$$

Case-A (Year 2001)

Since this case represents the existing situation, the HCM (2000) method is not used to calculate capacity of corridors in Case-A.

Case-B (Year 2021)**Bus station CB-910 – Albert Street:**

$$B_{bb} = 3600 (g/C) / \{t_c + [(g/C) t_d] + z_a * c_v * t_d\}$$

$$B_{bb} = 71 \text{ buses/hr.}$$

$$\text{Capacity} = B = B_{bb} * N_{eb} * f_r$$

$$\text{Capacity} = B = 284 \text{ buses/hr}$$

Volume (simulated)/capacity (HCM 2000) ratio:

$$v/c = (442/284) \text{ or}$$

$$v/c = 1.55$$

Case-B (Year 2021):**Bus station CB-950 – Slater Street:**

$$B_{bb} = 3600 (g/C) / \{t_c + [(g/C) t_d] + z_a * c_v * t_d\}$$

$$B_{bb} = 83 \text{ buses/hr.}$$

$$\text{Capacity} = B = B_{bb} * N_{eb} * f_r$$

$$\text{Capacity} = B = 332 \text{ buses/hr}$$

Volume (simulated)/capacity (HCM 2000) ratio:

$$v/c = (449/332) \text{ or}$$

$$v/c = 1.35$$

Case-C (Year 2021)**Bus station CB-910 – Albert Street:**

$$B_{bb} = 3600 (g/C) / \{t_c + [(g/C) t_d] + z_a * c_v * t_d\}$$

$$\text{Here } g/C = 76/110 = 0.69$$

$$B_{bb} = 100 \text{ buses/hr.}$$

$$\text{Capacity} = B = B_{bb} * N_{eb} * f_r$$

$$\text{Capacity} = B = 400 \text{ buses/hr}$$

Volume (simulated)/capacity (HCM 2000) ratio:

$$v/c = (486/400) \text{ or}$$

$$v/c = 1.22$$

Case-C (Year 2021):**Bus station CB-950 – Slater Street:**

$$B_{bb} = 3600 (g/C) / \{t_c + [(g/C) t_d] + z_a * c_v * t_d\}$$

$$\text{Here } g/C = 67/100 = 0.67$$

$$B_{bb} = 111 \text{ buses/hr.}$$

$$\text{Capacity} = B = B_{bb} * N_{eb} * f_r$$

$$\text{Capacity} = B = 444 \text{ buses/hr}$$

Volume (simulated)/capacity (HCM 2000) ratio:

$$v/c = (494/444) \text{ or}$$

$$v/c = 1.11$$

In concept, a v/c ratio greater than 1.00 can exist where a forecast demand flow rate is used to compare an existing or estimated capacity. However, it should be noted that in all v/c ratios shown above, 'v' is representing simulated volumes of each case and these are the bus volumes which have been discharged at links (101-1) and (151-9) representing entrance links of Albert and Slater Streets, respectively. Further, 95% of this discharged volume crosses the entire corridor after serving all the bus stations including the critical bus station (in HCM 2000 terminology) along respective street. Therefore, this volume should not be interpreted as the volume showing demand for using that facility. Demand for using the facility is represented by the arrival rate which was defined as the mean headway of buses during each simulation. As described earlier in this chapter, the existing facility did not cater the demand when a mean headway of 7 sec or less was defined in the network. As shown in Figures 6.28 and 6.29, representing Cases B and C, respectively, arrival rate of buses (at mean headway of 7 sec) is higher than the discharge capacity of entrance links on Albert and Slater Streets. Thus in Case-B as shown in Figure 6.28, the gap between arrival rate (@7 sec mean headway) and departure keeps on growing with the passage of simulation time which at the end of 1 hour simulation period becomes significantly wide. This difference between arrival and departure rates represents queue of buses that pile up on the upstream side of entrance links. However, when a mean headway of 8 sec is defined, the discharge curves of both the entrance links are falling just over the arrival curve representing optimum conditions where the demand is almost fully met by the supply. In fact, there is a slight queue formation that appears at the end of 1 hour period and which is not visible in Figure 6.28. However, it can be observed in Figure 6.4 where 442 and 449 buses have actually been discharged against a

Arrival/Discharge of Buses - (Case-B)
Albert Street (Link 101 - 1) & Slater Street (Link 151-9)

Figure 6.28 Arrival and Discharge of Buses at Different Headways (Case-B) – Albert Street Link (101 – 1) & Slater Street Link (151-9).

Figure 6.29 Arrival and Discharge of Buses at Different Headways (Case-C) – Albert Street Link (101 – 1) & Slater Street Link (151-9).

Figure 6.30 Arrival and Discharge of Buses at Different Headways - Link (101 - 1) at Albert Street (Case-B).

Figure 6.31 Arrival and Discharge of Buses at Different Headways - Link (151 - 9) at Slater Street (Case-B).

Figure 6.32 Arrival and Discharge of Buses at Different Headways - Link (101 - 1) at Albert Street (Case-C).

Arrival/Discharge of Buses - Link (151 - 9) on Slater Street
Case-C (20 Minute Simulation Results)

Figure 6.33 Arrival and Discharge of Buses at Different Headways - Link (151 - 9) at Slater Street (Case-C).

total arrival of 450 at a mean headway of 8 sec. Figure 6.29 shows same phenomena for Case-C in which an additional curve representing arrival of buses at 5 sec mean headway is also drawn. This was the mean headway defined to simulate Case-C. It can be noticed in Figure 6.29 that when the arrival rate at a mean headway of 8 sec is defined for transit operation, the roadway facility is capable enough to meet the entire demand and no queue formation exists. However, at a mean headway of 7 sec as well as 5 sec, scarcity in supply is evident which is continuously increasing during 1 hour simulation period. These results have also been shown in Figures 6.30 to 6.33 for 20 minute simulation period providing a closer look of supply and demand of transit operation.

In reality volume discharged cannot exceed the capacity of a facility. Any volume in excess of discharged volume will pile up on the upstream side of entrance links thus causing queue formations and representing that there is a high demand of using the facility.

When the capacity of bus lane obtained from simulation results in Cases B and C, is compared with the one calculated from the procedure described in HCM 2000, we come to understand that the two capacities are not identical. In Case-B, capacity resulted from microsimulation is 55% and 35% higher on Albert and Slater Streets, respectively, as compared to the figures calculated from HCM 2000. Similarly, in Case-C, it is 22% and 11% higher on Albert and Slater Streets, respectively, as compared to HCM 2000 results.

Although, this research is not intended to reinvestigate the HCM 2000 procedure for calculating capacity for bus lane, however, following reasons are noticed that may affect capacity calculations following HCM 2000 practice.

- i) In HCM 2000 methodology, it is noticed that instead of providing certain values for many factors such as the clearance time (t_c), failure rate (z_a) and the co-efficient of variation of dwell time (c_v), a range of values is suggested that are used to calculate capacity of a bus lane. For instance in case of clearance time, HCM 2000 suggests, “Depending on acceleration and traffic conditions” two different ranges can be used – one 5-10 sec and the other 10-15 sec. The statement “Depending on acceleration and traffic conditions” is itself vague with an inherent difficulty to estimate these parameters correctly during field observations. Further, the difference between the two extremes (5 and 15 sec) of both the ranges is 200%. It is not difficult to understand that the obvious outcome of using different set of values is a different capacity figure.
- ii) In case of failure rate (z_a) which is defined in HCM 2000 as “The probability that a queue of buses will not form behind a bus stop,” again a range is provided which is also hazy and it is not easy for a designer to estimate this figure with certainty.
- iii) While selecting co-efficient of variation of dwell time, suggested values range between 40-80% with 60% recommended for most of the cities in USA.
- iv) In addition, as mentioned in the manual, HCM 2000 provides only a guideline of calculating bus lane capacity. Therefore, such guidelines do not tell about the

results with any degree of certainty. However, in case of computer simulations after replicating the base case conditions close enough to real time traffic conditions, we are much more confident about the results.

- v) In HCM 2000, capacity of a bus lane is calculated taking into account only critical bus station along a corridor. All other operating conditions at the up and downstream sides of a corridor are completely omitted which may end up with inappropriate results, as downstream traffic conditions depend much on traffic operating conditions at upstream side.
- vi) HCM 2000 methodology does not take into account vehicle characteristics and drivers behaviour in its calculations. However, simulation techniques do incorporate such factors.

6.8 Compilation of Results:

In Figure 6.34 a methodology is shown describing how results of all the three cases i.e. A, B and C are presented in this section. In the beginning, all the three cases were compared according to the Level of Service (LOS) criteria. LOS criteria are discussed separately in section 6.9.

In the first stage, LOS for the links approaching an intersection is calculated for each case. These are shown separately for Albert and Slater Streets. Additionally, turning movements were also determined and are tabulated to describe each turning movement on individual links for the scenarios selected in this study. In the second stage, MOE obtained from different case scenarios were grouped into two main categories.

Figure 6.34 Methodology for Comparing MOE from Different Cases.

Under the first category, each scenario was studied at network level and the impacts of traffic operations on performance measures were determined. These MOE were finally put together and results of Cases B and C were compared with Case-A representing base case traffic conditions for year 2001. In the second category, results were compiled for transit corridors only and the merits and demerits of each case were studied from transit point of view and are presented for comparison. A discussion is also made on the results obtained in both the categories on the basis of which conclusions are drawn and recommendations made for this study.

6.9 Level of service (LOS) criteria:

According to HCM 2000, “LOS is evaluated on the basis of control delay per vehicle (in seconds/vehicle)” (Transportation Research Board 2000b). It further states that control delay is the portion of the total delay attributed to traffic signal operation for signalized intersections. Control delay includes initial deceleration delay, queue move-up time, stopped delay and final acceleration delay. In NETSIM control delay is determined by the following equation:

$$D_{icd} = D_s + D_d + D_a \quad \text{Eq. 6.3}$$

where

D_{icd} = Intersection control delay

D_s = Stopped delay

D_d = Delay incurred while a vehicle is decelerating while approaching the stop bar or the end of the queue

D_a = Delay incurred while a vehicle is accelerating to gain its full operating speed after the signal indication turns green.

LOS criterion for signalized intersection is shown in Table 6.2 as follows:

Table 6.2 (source HCM 2000)

LOS	Control Delay per vehicle (s/veh)
A	≤ 10
B	$> 10 - 20$
C	$> 20 - 35$
D	$> 35 - 55$
E	$> 55 - 80$
F	> 80

Figure 6.35 and Figure 6.36 illustrate traffic operations in Case-A at link levels. All links approaching an intersection along Albert Street are shown in Figure 6.35 whereas along Slater Street these are shown in Figure 6.36. In Case-A, except one link that is facilitating North bound traffic operation at Slater/Kent intersection (#12) showing to have a LOS 'D', all other links in this case have a LOS 'C' or below on both Albert and Slater Streets.

Similar analysis was carried out for Case-B and the impact of projected traffic and maximizing transit bus volume on Albert and Slater Streets were assessed. Figures 6.37 and 6.38 are showing traffic operating conditions on each link of an intersection in the network. Links approaching Albert Street are shown in Figure 6.37, whereas for Slater Street these are shown in Figure 6.38. Again it is very obvious that in Case B only one

link facilitating north bound traffic operations has reached a LOS 'F' and that too on Slater/Bronson intersection (#9). Rest of the links are functioning well at a LOS 'D' or below accommodating a significant volume of additional buses along transit corridors beside meeting the projected demand of auto traffic for the year 2021. Among the links that are operating at LOS 'D', highest delays are found at Albert/Elgin intersection (#1) on West bound approach that is representing Mackenzie King Bridge Off ramp link. The Control Delay figures for this link shows that it is very close to a LOS 'E'. The highest Control Delays on Slater Street are found to be at Slater/Kent intersection (#12) on a link that is serving north bound traffic. It can be noticed from the Figures shown above that the total amount of Control Delays when aggregated on directional basis is higher for north bound traffic as opposed to south bound traffic. Similarly these Control Delays are higher in case of west bound traffic as compared to east bound traffic.

Case-C was also analyzed on the same lines followed in Cases A and B. LOS of all links approaching Albert and Slater Streets in Case C is shown in Figures 6.39 and 6.40 respectively. The impact of increasing green times along transit corridors until choke conditions appear on links approaching these corridors from north/south directions is apparent in these figures. It is obvious in the figures that in case of Albert Street as shown in Figure 6.39 at least four links are already operating at a LOS 'E or F' out of which two are serving north bound traffic while the other two are for south bound traffic. Among the rest, two links are very close to attaining a LOS 'E'. The picture of Slater Street is even worse as a total of seven links are functioning at a LOS 'E or F'. And among the rest, one link is almost at the verge of LOS 'E'. This can be seen in Figure 6.40.

Figure 6.35 LOS - Approach Links at Intersections on Albert Street (Case-A)

Figure 6.36 LOS - Approach Links at Intersections on Slater Street (Case-A)

Figure 6.37 LOS - Approach Links at Intersections on Albert Street (Case-B)

Figure 6.38 LOS - Approach Links at Intersections on Slater Street (Case-B)

Figure 6.39 LOS - Approach Links at Intersections on Albert Street (Case-C)

Figure 6.40 LOS - Approach Links at Intersections on Slater Street (Case-C)

In addition to above, all turning movements (left, right or through) at each link were also examined for a through understanding of traffic operation within the network under different case scenarios. These movements have been summarized in Table 6.3 showing only those movements operating at a LOS 'E' or above. These critical movements have also been presented graphically in Appendix-B.

A cursory look at Table 6.3 shows that in Cases A and B, there are only a few traffic movements operating at a LOS 'E' or above. In fact, there were only two critical movements observed in Case-A, one identified as left turning movement at north bound link of Albert/Metcalf intersection (# 2). While the second was a right turning movement on north bound link of Slater/Kent intersection (# 12). In Case-B such movements rose to five as a result of projected traffic for the year 2021 and increased transit volume. All other movements in both these cases were operating at a LOS 'D' or below. However, in Case-C a number of turning movements can be seen operating at a LOS 'E or F'. This is understandable because the green times along transit corridor were increased significantly in this case, thus causing excessive delays to traffic operating on intersecting streets. Number of turning movements operating at a LOS 'E or F' is higher at intersections along Slater Street as compared to the ones along Albert Street.

Figure 6.41 Move, Delay and Total Times in Cases A, B and C

Figure 6.42 (Move/Total) Ratio in Cases A, B and C

Figure 6.43 Total Vehicle Kilometres in Cases A, B and C

Figure 6.44 Percentage Comparisons of MOE in Cases A, B and C

Figure 6.45 Average Speeds in Cases A, B and C

Figure 6.46 Minutes/Km of Delay and Total Times in Cases A, B and C

Figure 6.47 Percentage Comparisons of MOE in Cases B and C

Figure 6.48 Fuel Consumption in Cases A, B and C

Figure 6.49 Emissions (CO, HC, and NOx) in Cases A, B and C

(Note: In the emission results, data for buses is not included as NETSIM does not calculate emission results for transit buses).

Figure 6.50 Comparisons (%) of Fuel Consumption and Emission - Cases A, B and C

Figure 6.51 Stop and Queue Delays in Cases A, B and C

Figure 6.52 Kilometres Traversed in Cases A, B and C

Figure 6.53 Mean Travel Times of Buses on Transit Corridors in Cases A, B and C

Figure 6.54 Time Empty – Bus Stations on Albert Street in Cases A, B and C

Figure 6.55 Time Empty – Bus Stations on Slater Street in Cases A, B and C

Figure 6.56 Trips on Transit Corridors in Cases A, B and C

Figure 6.57 Kilometres Traversed on Transit Corridors in Cases A, B and C

Figure 6.58 Travel Time on Transit Corridors in Cases A, B and C

Figure 6.59 Average Speeds on Transit Corridors in Cases A, B and C

CHAPTER 7

CONCLUSION AND RECOMMENDATIONS

7.1 Summary

This research was carried out for a road network in the downtown of Ottawa, Canada along which a very high volume of transit buses is operating through two public transit corridors viz. Albert and Slater Streets. This network was studied for morning peak hour under projected auto traffic conditions for year 2021. The main purpose of this research was to investigate choke levels in the network beyond which point supply of transit buses through public transit corridors cannot be increased without making facility design changes in the network such as dedicating another bus lane in the system, reserving entire corridors for exclusive transit operations or grade separation. Apart from base case conditions referred to here as Case-A representing 2001 traffic conditions, other scenarios in this research were broadly categorized into two. Under the first category that was named Case-B, operating conditions of the system were kept same as are followed in base year of 2001 and the supply of transit buses was maximized until choke conditions appear in the network. In the second category referred to here as Case-C, changes were made in operating characteristics and additional green time was provided to transit corridors and its impact on supply of transit buses was again analyzed. MOE obtained from these categories were compared with base case conditions under Case-A. The network was modelled microscopically and NETSIM was used as a simulation tool for this purpose. The author believes that this research will benefit city policy makers, planners and transit operators in their decision makings.

7.2 Conclusions:

Following are the conclusions of this research:

1. Having the same set of operating conditions as in year 2001, referred to here as Case-B, a total of 442 and 449 buses can be accommodated in exclusive bus lanes during morning peak hour (7:30 – 8:30) on Albert and Slater corridors, respectively, along with year 2021 auto traffic passing through other lanes of these corridors. This shows an increase of approximately 96% on Albert Street and 182% on Slater Street as compared to transit bus volume in year 2001 during the same period. At this level of bus volume exclusive bus lanes will saturate at upstream sides of Albert and Slater Streets represented by links (101 – 1) at intersection # 1 and link (151 – 9) at intersection # 9, respectively.
2. Capacity of Albert and Slater Streets can be increased by providing additional green time of up to +50 sec (in addition to original signal time as in year 2001) along transit corridors at which (+50 sec) most of the traffic movements on links intersecting transit streets will be operating at a LOS 'E' or 'F' representing choke conditions in the network. Increase of +50 sec in green time (as simulated in Case-C) will attract a total of 486 and 494 buses on exclusive bus lanes of Albert and Slater Streets respectively. This shows an additional boost of 10% buses on Albert as well as on Slater Streets as compared to Case-B. Any further increase in green times along transit corridors will result in additional delays to traffic operating on intersecting links of the network.

3. At saturated conditions, average speeds on upstream link (101 – 1) along Albert Street in Cases B and C will drop by 75%, bus total delays and bus travel time will increase by more than 135% and 96%, respectively, and average queues will rise by 400%. In addition maximum queues will grow from 8 to 15 or above on same link. Similarly on upstream link (151 – 9) along Slater Street, in Cases B and C, average bus speed will reduce by more than 72%, total bus delays and bus travel time will increase by more than 578% and 264%, respectively, and maximum queues will rise by 450%. Further, average bus queues will grow from '0' to 8 buses on same link.
4. Increase in green times up to +30 sec (in addition to original signal times) along transit corridors attracts less than 6% of additional bus volume on transit corridors, as compared to Case-B.
5. In order to further increase the capacity of Albert and Slater Streets, facility design changes such as dedicating another exclusive bus lane in the system, reserving both the corridors for an exclusive transit bus operation or grade separation will have to be introduced. However, a detailed study for each of these options will be required outlining the net benefits of such improvements.
6. Capacity figures of exclusive bus lane obtained from simulation results and from HCM 2000 procedure are not identical. In Case-B, capacity resulting from microsimulation is 55% and 35% higher on Albert and Slater Streets, respectively, as

compared to the figures calculated from HCM 2000. Similarly, in Case-C, it is 22% and 11% higher on Albert and Slater Streets as compared to HCM 2000 results.

7. In HCM 2000 methodology for calculating bus lane capacity, a range of values is suggested for many factors such as the clearance time (t_c), failure rate (z_a) and the coefficient of variation of dwell time (c_v). Therefore, the resulting capacity of bus lane will vary for each set of values taken by the user.
8. Slater Street because of low volume of buses in year 2001 has a higher potential to accommodate more transit buses as compared to Albert Street.
9. Based on year 2001 average occupancy figures of transit buses which is 32.5 persons/bus at the upstream links of Albert and Slater Streets, up to 28,958 passengers in Case-B and 31,850 passengers in Case-C can be transported to downtown core through transit operation at Albert and Slater Streets only. This shows an increase of 132% in Case-B and 155% in Case-C as compared to figures in year 2001. Based on the statistics mentioned in Chapter-2 showing passenger carrying capacity of exclusive bus lane in many parts of the world, this figure seems reasonable.
10. When comparing Case-B with Case-C, some advantages of Case-B are evident. These are as follows:
 - It has 15.2% higher Move and 47% lower Delay Times as compared to Case-C. Total Time is also lower by 36.3%.

- Move/Total ratio is 82.3% higher.
 - Total Vehicle Km traveled in one hour period on network level is 15.2% higher.
 - Average speed on the network level is 80.7% higher.
 - Minutes/Km of Delay and Total Times are lower by 53.3% and 45.2% respectively.
 - Total fuel consumption is lower by 12.8%.
 - Overall pollutant emissions are lower. Values of CO, HC and NOx are less by 10.6%, 18.2% and 2.3% respectively.
 - Stop Delays are lower by 54% whereas Queue Delays are lower by 54.4%.
 - Kilometres Traversed on network level are higher by 15.2%.
 - Trips along transit corridor are higher. Along Albert Street these are higher by 8.7% whereas on Slater Street these are higher by 11.4%.
 - Km Traversed along transit corridor are higher. On Albert and Slater Streets these are up by 8.2% and 11.4% respectively.
11. Case-C has following comparative advantages over Case-B:
- It can accommodate higher volume of transit buses. On Albert and Slater Streets transit bus volume is higher by about 10% in both cases. As a result its passenger carrying capacity is also higher by 10%.
 - Mean Travel Time of buses along Albert Street is lower by 4.8%.
 - Mean Travel Time (all vehicles) is lower on transit corridors. On Albert Street it is lower by 9.5% while on Slater Street it is lower by 2.3%.
 - Average speed on Albert Street is higher by 2%.

12. In year 2001, none of the links is operating at choke conditions (LOS 'E' or 'F'). There are only two turning movements, one at link 15-2 (left turning) and the other at link 208-12 (right turning) which are operating at LOS E and F, respectively. In year 2021 under Case-B, which is accommodating maximized transit volume along with projected demand of auto traffic, turning movements that are operating at a LOS 'E' or 'F' rose to five. However, in Case-C there are a number of turning movements that are operating at a LOS 'E' or 'F'.
13. Microsimulation is an appropriate approach to simulate and analyze traffic operations in any complex environment. NETSIM is a good tool for microsimulation type of research studies.

7.3 Recommendations:

Concerning the use and improvement of this microscopic model, following recommendations are made:

1. Dwell times at bus stations play an important role in the overall efficiency of transit operations. If average occupancy of transit buses and passenger activity at bus stations along Albert and Slater Streets are increased, impact of higher dwell times at bus stations should be examined.
2. Average dwell time of buses at each bus station may vary from real time situation as many buses have different dwell times. Routes with higher dwell time impede transit

traffic at upstream side. In NETSIM, the capability should be developed so that dwell times are defined according to the route demands instead of an average dwell time value applicable to all routes in the system.

3. Since increase in green time along transit corridor as in Case-C is not significantly increasing the throughput of transit buses as compared to Case-B, rather it is causing excessively high delays to traffic movements on intersecting streets, it is therefore, recommended to continue transit operations at existing cycle lengths.
4. Another analysis incorporating two bus lanes and additional bus stations located at suitable point across the width of the corridor should be carried out.
5. Skip Stop strategy can be applied in future but it needs further study about the effect on dwell times (which might increase on some bus stops) and how to educate people, etc.
6. In NETSIM, option of two or more bus lanes should also be provided.

REFERENCES

- [1] Advanced Traffic Management Systems Committee and Advanced Public Transportation Systems Committee of ITS America. *An overview of Transit Signal Priority*, 2002.
- [2] Al-Masaied and Hashem, R. "Performance of Safety Evaluation Methods", *Journal of Transportation Engineering*, Volume 123, Issue 5, 1995, pp 364-369.
- [3] City of Bogota. "Master Transportation Plan for Bogota", (JICA, 1996).
- [4] City of Carolina, Department of City and Regional Planning. "Carolina Transportation Program, 2001-2002 Report".
- [5] City of Ottawa. "Ottawa Transportation Master Plan", March 2003.
- [6] Delcan Corporation. 1999 / 2000 Central Area Parking Study Update – Final Report. Prepared for City of Ottawa, 2000.
- [7] Ewing and Reid. "TDM, Growth Management, and the Other Four out of Five Trips", Transportation Research Board, 72nd Annual Meeting, Washington, D.C., 1993.
- [8] Evans, H and Skiles G., "Improving Public Transit Through Bus Pre-emption of Traffic Signals, *Traffic Quarterly*, Vol 24, No. 4, October 1970 pp 531-534.
- [9] Federal Highway Administration (FHWA). *CORSIM User's Guide – version 5.0*. Office of Operations Research, Development and Technology, Washington, D.C., March 2001
- [10] Federal Highway Administration (FHWA). *CORSIM User's Guide – version 5.1*, Office of Operations Research, Development and Technology, Washington, D.C., 2003.

- [11] Federal Transit Authority (FTA) *Issues in Bus Rapid Transit*. Washington D.C., 1998.
- [12] Govt. of Western Australia. *High Occupancy Vehicle and Bus Priority Facilities for the Perth Metropolitan Region*. Discussion paper published by Transport, October 1997.
- [13] Huffman, B., Paquet, J., Weesner, J. and Pitstick, M. "Signal Priority Demonstration in Suburban Chicago", Proceedings of the 1998 Bus Operations, Technology and Management Conference, American Public Transit Association, 1998.
- [14] Institute of Transportation Engineers, *Urban Traffic Congestion: What Does the Future Hold?* ITE Publication No. IR-040, Washington, D.C., 1986.
- [15] Khasnabis, S., Reddy, G. V. and Hoda, S. K. "Evaluation of the Operating Cost – Consequences of Signal Preemption as an IVHS Strategy", Transportation Research Record (TRR) 1390, Transportation Research Board, Washington, D.C., 1993.
- [16] Khasnabis, S., Karnati, R. and Rudraraju, R. K. "A Netsim-based approach to Evaluate Bus Preemption Strategies", Transportation Research Board (TRB) 75th Annual Meeting, Washington D.C., 1996.
- [17] Khasnabis, S. and Rudraju, R. K. "Optimum Bus Headway for Preemption – A Simulation Approach", Transportation Research Record 1603, Transportation Research Board, Washington, D.C., 1997, pp 128-136.

- [18] Khasnabis, S., Rudraraju R.K. and Baig, M. F. "Economic Evaluation of Signal Pre-emption Projects", *Journal of Transportation Engineering*, March/April, 1999.
- [19] Kittelson Associates, Inc. TCRP Web Document 6 – Transit Capacity and Quality of Service Manual. Prepared for Transit Cooperative Research Program, Transportation Research Board, National Research Council, January 1999.
- [20] Kittelson Associates, Inc. TCRP Web Document 6 – Transit Capacity and Quality of Service Manual (Chapter-2). Prepared for Transit Cooperative Research Program, Transportation Research Board, National Research Council, January, 1999a.
- [21] Leal, M.T. and Bertini, R.L. "Bus Rapid Transit: An Alternative For Developing Countries", web.pdx.edu/~bertini/brt.pdf, viewed on web, August 19, 2003.
- [22] Lintelo and Martijn te. *Park and Ride, Hindsight and Foresight for Ottawa-Carleton*. Prepared at the Ottawa-Carleton Regional Transit Commission, Ottawa, 1991.
- [23] Liu, R., and Vliet, D. V. "DRACULA – a dynamic microscopic model of road traffic", *Proceedings of the International Transport Symposium*, pp 160-170, Beijing, 1996.
- [24] McShane, W. R., Roess, R. P. and Prassas, E. S. *Traffic Engineering*. 2nd Edition Prentice Hall, NJ., 1998.
- [25] Papacostas, C. S. *Fundamental of Transportation Engineering*. 3rd Edition. Prentice-Hall Inc., Englewood Cliffs, New Jersey, 2001.

- [26] Reynolds, Marilyn M. and Hixson, C. D. "Transit Vehicle Meets System: A Method for Measuring Transfer Times Between Transit Routes", Transportation Research Record 1349, Transportation Research Board, Washington D.C., 1992.
- [27] Samuel, P. Policy Update 16. "Busway vs. Rail Capacity: Separating Myth from Fact", February, 2002.
- [28] Schrank, D. and Lomax, T. *The 2002 Urban Mobility Report*, Texas Transportation Institute, The Texas A&M University, June 2002.
- [29] Skabardonis, A. "Control Strategies for Transit Priority", *Transportation Research Record (TRR)* 1727, paper No. 00-1584, Transportation research Board, 2000.
- [30] Sperry Rand Corporation. *Urban Traffic Control and Bus Priority System Design and Installation*. Sperry Systems Management Division, November 1972.
- [31] St. Jacques, K. and Levinson, H. S. *Operational Analysis of Bus Lanes on Arterials*. TCRP Report 26 Sponsored by The Federal Transit Administration and published by Transportation Research Board, National Research Council, 1997.
- [32] Sunkari, S. R., Beasley, P. S., Urbanic II, T. and Fambro, D. B. "Model to Evaluate the Impacts of Bus Priority on Signalized Intersections", Transportation Research Record (TRR) 1494, Transportation Research Board, Washington, D.C., 1995, pp 117-123.
- [33] Taplin J. Simulation Models of Traffic Flow. Department of Information Management and Marketing, University of Western Australia, (www.esc.auckland.ac.nz) viewed on web, May 2003.

- [34] Transportation Association of Canada (TAC). Briefing - *A New Vision fro Urban Transportation*. Ottawa, 1993.
- [35] Transit Signals Systems Committee. Transit Priority Workshop *Proceedings of Midyear Meeting*, Minneapolis, Minnesota. Transportation Research Board, 1999.
- [36] Transportation Research Board, "Traffic Analysis Software Tools", *Circular Number E-C014*, National Research Council, September, 2000a.
- [37] Transportation Research Board. Signalized Intersection (Chapter-16), Highway Capacity Manual (HCM), 2000, Washington, D.C., 2000b.
- [38] Transportation Research Board. Transit (Chapter-27), Highway Capacity Manual (HCM), 2000, Washington, D.C., 2000c.
- [39] Zargari, S. A. *Optimization of Integrated Multimodal Urban Transportation Corridors* Ph. D. Thesis, Department of Civil and Environmental Engineering, Carleton University, Ottawa, 1996.

APPENDIX – A

Table-A1

NETSIM LINKS

LINK	-LANES-			-CHANNEL-										LINK TYPE	R	B234567	DESTINATION			OPP. NODE	LOST TIME SEC	Q DIS HDWY. SEC	FREE SPEED MPH/KMPH	RTOR CODE	PED CODE	LANE ALIGN -MENT	STREET NAME	
	F			C			U			LEFT	THRU	RIGHT	DIAG															
	L	P	U	L	P	U	L	P	U																			
LENGTH FT / M	L	P	U	L	P	U	L	P	U	L	P	U	L	P	U	LEFT	THRU	RIGHT	DIAG	OPP. NODE	LOST TIME SEC	Q DIS HDWY. SEC	FREE SPEED MPH/KMPH	RTOR CODE	PED CODE	LANE ALIGN -MENT	STREET NAME	
(1, 215)	262/	80	3	0	0	0	1	0000000	0	8025	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Elgin St.
(2, 213)	262/	80	3	0	0	0	1	0000000	0	8023	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Metcalf St.
(4, 209)	262/	80	2	0	0	0	1	0000000	0	8019	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Bank St.
(5, 207)	262/	80	4	0	0	0	1	0000000	0	8017	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Kent St.
(7, 203)	262/	80	2	0	0	0	1	0000000	0	8013	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Bay St.
(8, 201)	262/	80	1	0	0	0	1	0000000	0	8011	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Bronson St.
(110, 111)	297/	91	3	0	0	0	1	0000000	0	8002	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Albert St.
(9, 202)	328/	100	2	0	0	0	1	0000000	0	8012	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Bronson St.
(11, 206)	328/	100	3	0	0	0	1	0000000	0	8016	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Lyon St.
(13, 210)	328/	100	1	0	0	0	1	0000000	0	8020	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Bank St.
(14, 212)	328/	100	4	0	0	0	1	0000000	0	8022	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	O'Connor
(16, 216)	328/	100	3	0	0	0	1	0000000	0	8026	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	0	0	1-1*	Elgin St.
(3, 14)	256/	78	4	0	0	0	1	0000000	160	212	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	O'Connor
(159, 14)	121/	37	4	0	0	0	1	4200000	0	160	212	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	1	1-1*	Slater St.
(1, 103)	443/	135	4	0	0	0	1	0200000	8301	2	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Albert St.
(13, 4)	256/	78	2	0	0	0	1	0000000	105	209	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	3	2-1	Bank St.
(4, 13)	256/	78	2	0	0	0	1	3000000	158	210	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	3	2-1	Bank St.
(10, 7)	256/	78	2	0	0	0	1	0000000	108	203	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Bay St.
(8, 110)	202/	62	4	0	0	0	1	0001000	9	111	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Albert St.
(9, 8)	258/	79	2	0	0	0	1	1100000	110	201	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Bronson St.
(109, 8)	374/	114	4	0	0	0	1	2000000	0	110	201	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Albert St.
(110, 9)	266/	81	3	0	0	0	1	0010000	8	152	202	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Comm. St.
(157, 13)	314/	96	4	0	0	0	1	0200000	4	158	210	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Slater St.
(12, 5)	256/	78	4	0	0	0	1	0000000	106	207	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Kent St.
(104, 4)	220/	67	3	0	0	0	1	2000000	13	105	209	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	3	1-2	Albert St.
(105, 5)	325/	99	4	0	0	0	1	0200000	0	106	207	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Albert St.
(107, 7)	255/	78	4	0	0	0	1	0200000	0	108	203	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Albert St.
(16, 1)	259/	79	3	1	0	0	1	0010000	103	215	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Elgin St.
(1, 16)	259/	79	3	1	0	0	1	0000000	162	216	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Elgin St.
(102, 1)	285/	87	2	1	0	0	1	2000000	16	103	215	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	1	1-2	M-Br. Off R
(154, 11)	223/	68	4	0	0	0	1	0200000	0	155	206	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Slater St.
(6, 11)	256/	78	3	0	0	0	1	0000000	155	206	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Lyon St.
(161, 16)	377/	115	4	0	0	0	1	7201000	1	162	216	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	2-1	Slater St.
(15, 2)	256/	78	4	0	0	0	1	0001000	3	213	0	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	3	1-1*	Metcalf St.
(103, 2)	223/	68	4	0	0	0	1	2000000	0	3	213	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Albert St.
(216, 16)	328/	100	3	0	0	0	1	0000000	0	1	162	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	2	1-1*	Elgin St.
(151, 9)	459/	140	3	0	0	0	1	2000000	8	152	202	0	0	0	0	0	0	0	0	0	0	2.0	1.8	30/ 48	1	0	1-1*	Slater St.

(8357, 161) 0/ 0 2 0 0 0 1 1100000 16 0 0 0 0 2.0 1.8 0/ 0 1 0 1-1*
 (16, 162) 287/ 87 2 0 0 0 1 2000000 0 8004 0 0 0 2.0 1.8 30/ 48 0 0 1-1* Mc-Br-On-R

LINK TYPE

LANE CHANNELIZATION

* INDICATES DEFAULT VALUES WERE SPECIFIED

RTOR

PEDESTRIAN

CODES

CODES

0 UNRESTRICTED 0 RTOR PERMITTED 0 NO PEDESTRIANS

1 LEFT TURNS ONLY 1 RTOR PROHIBITED 1 LIGHT

2 BUSES ONLY 2 MODERATE

3 CLOSED 3 HEAVY

4 RIGHT TURNS ONLY

5 CAR - POOLS

6 CAR - POOLS + BUSES

7 RIGHT TURNS + RIGHT DIAGONAL AND/OR THROUGH

8 LEFT TURNS + LEFT DIAGONAL AND/OR THROUGH

9 ALL PERMITTED MOVEMENTS WITH RESPECT TO

THE GEOMETRY AND ADJACENT LANE CHANNELIZATIONS

D DIAGONAL TRAFFIC ONLY

T THROUGH TRAFFIC ONLY

TOTAL LINKS: 86

TOTAL NON-ENTRY NODES: 55 (ALLOWED: 8999)

Table-A2

OPTIONAL LINK GEOMETRIC DATA

UP NODE	DOWN NODE	CURB LANE WIDTH FT / M	LANE 2 WIDTH FT / M	LANE 3 WIDTH FT / M	LANE 4 WIDTH FT / M	LANE 5 WIDTH FT / M	LANE 6 WIDTH FT / M	LANE 7 WIDTH FT / M	DISTANCE STOP- LINE TO CURB FT / M	FORWARD SIGHT DISTANCE FT / M	ANGLE OF LINK
2	213	15 / 5	14 / 4	15 / 5					* 4 / 1	*1000 / 305	0
4	209	9 / 3	9 / 3						* 4 / 1	*1000 / 305	0
5	207	12 / 4	11 / 3	11 / 3	12 / 4				* 4 / 1	*1000 / 305	0
7	203	13 / 4	15 / 5						* 4 / 1	*1000 / 305	0
13	210	13 / 4							* 4 / 1	*1000 / 305	0
14	212	13 / 4	12 / 4	12 / 4	12 / 4				* 4 / 1	*1000 / 305	0
159	14	8 / 2	12 / 4	12 / 4	12 / 4				16 / 5	*1000 / 305	0
1	103	10 / 3	10 / 3	10 / 3	10 / 3				* 4 / 1	*1000 / 305	0
13	4	9 / 3	9 / 3						* 4 / 1	*1000 / 305	0
4	13	8 / 2	13 / 4						8 / 2	*1000 / 305	0
10	7	13 / 4	15 / 5						15 / 5	*1000 / 305	0
9	8	* 12 / 4	* 12 / 4						15 / 5	*1000 / 305	0
109	8	10 / 3	10 / 3	10 / 3	9 / 3				15 / 5	*1000 / 305	0
110	9	* 12 / 4	* 12 / 4	* 12 / 4					16 / 5	*1000 / 305	0
12	5	12 / 4	11 / 3	11 / 3	12 / 4				15 / 5	*1000 / 305	0
104	4	13 / 4	13 / 4	13 / 4					15 / 5	*1000 / 305	0
16	1	* 12 / 4	* 12 / 4	* 12 / 4					8 / 2	*1000 / 305	0
1	16	* 12 / 4	* 12 / 4	* 12 / 4					15 / 5	*1000 / 305	0
102	1	* 12 / 4	* 12 / 4	* 12 / 4				* 12 / 4	15 / 5	*1000 / 305	0
6	11	* 12 / 4	* 12 / 4	* 12 / 4				* 12 / 4	15 / 5	*1000 / 305	0
161	16	11 / 3	11 / 3	11 / 3	11 / 3				16 / 5	*1000 / 305	0
15	2	10 / 3	11 / 3	11 / 3	10 / 3				15 / 5	*1000 / 305	0
103	2	12 / 4	11 / 3	14 / 4	9 / 3				16 / 5	*1000 / 305	0
216	16	* 12 / 4	* 12 / 4	* 12 / 4					15 / 5	*1000 / 305	0
151	9	* 12 / 4	* 12 / 4	* 12 / 4					16 / 5	*1000 / 305	0
3	14	13 / 4	12 / 4	12 / 4	12 / 4				15 / 5	*1000 / 305	0
208	12	12 / 4	11 / 3	11 / 3	12 / 4				15 / 5	*1000 / 305	0
2	3	12 / 4	11 / 3	10 / 3	13 / 4				16 / 5	*1000 / 305	0
209	4	13 / 4							8 / 2	*1000 / 305	0
215	1	* 12 / 4	* 12 / 4	* 12 / 4					15 / 5	*1000 / 305	0
201	8	* 12 / 4							15 / 5	*1000 / 305	0
210	13	9 / 3	9 / 3						15 / 5	*1000 / 305	0
15	161	11 / 3	11 / 3	11 / 3					* 4 / 1	*1000 / 305	0
214	15	15 / 5	14 / 4	15 / 5					15 / 5	*1000 / 305	0
106	6	11 / 3	12 / 4	12 / 4	12 / 4				16 / 5	*1000 / 305	0
153	10	9 / 3	12 / 4	12 / 4	13 / 4				6 / 2	*1000 / 305	0
205	6	* 12 / 4	* 12 / 4	* 12 / 4	* 12 / 4				15 / 5	*1000 / 305	0

211	3	13 / 4	12 / 4	12 / 4	12 / 4	15 / 5	*1000/ 305	0
156	12	10 / 3	12 / 4	11 / 3	10 / 3	16 / 5	*1000/ 305	0
108	109	12 / 4	10 / 3	10 / 3	10 / 3	* 4 / 1	*1000/ 305	0
160	15	11 / 3	11 / 3	11 / 3	11 / 3	16 / 5	*1000/ 305	0
204	10	13 / 4	15 / 5			15 / 5	*1000/ 305	0
202	9	* 12 / 4	* 12 / 4			15 / 5	*1000/ 305	0
3	104	9 / 3	12 / 4	13 / 4	13 / 4	* 4 / 1	*1000/ 305	0
155	156	12 / 4	11 / 3	11 / 3		* 4 / 1	*1000/ 305	0
152	153	12 / 4	10 / 3	10 / 3		* 4 / 1	*1000/ 305	0
7	108	10 / 3	12 / 4	10 / 3	10 / 3	* 4 / 1	*1000/ 305	0
14	160	11 / 3	11 / 3	11 / 3	11 / 3	* 4 / 1	*1000/ 305	0
5	106	13 / 4	12 / 4	12 / 4		* 4 / 1	*1000/ 305	0
13	158	8 / 2	12 / 4	12 / 4	12 / 4	* 4 / 1	*1000/ 305	0
9	152	10 / 3	10 / 3	10 / 3	10 / 3	* 4 / 1	*1000/ 305	0
11	155	10 / 3	12 / 4	11 / 3	11 / 3	* 4 / 1	*1000/ 305	0

* INDICATES DEFAULT VALUES WERE SPECIFIED

DEFAULT LINK GEOMETRIC DATA

WIDTH OF LANES
 LONGITUDINAL DISTANCE FROM THE STOP 12 FEET
 LINE TO THE NEAR CURB 4 FEET
 FORWARD SIGHT DISTANCE AT STOP LINE 1000 FEET

Table-A3

PROPERTIES OF BUS STATIONS

STATION NO.	LANE SERVICED	LINK	DISTANCE FROM UPSTREAM NODE FEET / METERS	CAPACITY (BUSES)	MEAN DWELL (SEC)	TYPE	PERCENT OF BUSES STOPPING
1	1	(1, 16)	236	1	10	1	100
11	1	(4, 13)	241	1	10	1	100
12	1	(210, 13)	263	1	10	1	100
CB900	1	(103, 2)	222	4	11	1	100
CB910	1	(104, 4)	219	4	12	1	100
CA920	1	(5, 106)	299	5	10	1	100
CA930	1	(108, 109)	156	3	3	1	100
CA940	1	(152, 153)	202	4	5	1	100
CA950	1	(155, 156)	219	4	10	1	100
CB960	1	(158, 159)	219	4	9	1	100
CB970	1	(15, 161)	256	5	9	1	100

THE TYPE CODE IDENTIFIES THE APPLICABLE STATISTICAL DISTRIBUTION OF DWELL TIME

Table-A4

PARKING ACTIVITY SPECIFICATIONS

LINK	DUR. OF PARK. MANEUVERS (SECONDS)	PARKING FREQUENCY (PER HOUR)	RIGHT CURB PARKING ZONE		LEFT CURB PARKING ZONE	
			LENGTH FEET / METERS	DISTANCE TO STOPLINE FEET / METERS	LENGTH FEET / METERS	DISTANCE TO STOPLINE FEET / METERS
(1, 103)	1	15	96 / 29	40 / 12	0 / 0	0 / 0
(109, 8)	1	15	0 / 0	0 / 0	136 / 41	56 / 17
(103, 2)	1	15	0 / 0	0 / 0	160 / 49	0 / 0
(2, 3)	1	15	0 / 0	0 / 0	288 / 88	208 / 63
(106, 6)	1	15	144 / 44	104 / 32	0 / 0	0 / 0
(153, 10)	1	15	304 / 93	24 / 7	0 / 0	0 / 0
(3, 104)	1	15	240 / 73	0 / 0	0 / 0	0 / 0
(7, 108)	1	15	88 / 27	96 / 29	0 / 0	0 / 0
(14, 160)	1	15	200 / 61	0 / 0	0 / 0	0 / 0
(13, 158)	1	15	152 / 46	0 / 0	0 / 0	0 / 0
(9, 152)	1	15	120 / 37	0 / 0	0 / 0	0 / 0
(11, 155)	1	15	64 / 20	8 / 2	0 / 0	0 / 0

Table-A5

NETSIM TURNING MOVEMENT DATA

LINK	TURN MOVEMENT PERCENTAGES		TURN MOVEMENT POSSIBLE		POCKET LENGTH (IN FEET/METERS)	
	LEFT	RIGHT	LEFT THROUGH	RIGHT DIAGONAL	LEFT	RIGHT
(1, 215)	0	100	NO	YES	0	0
(2, 213)	0	100	NO	YES	0	0
(4, 209)	0	100	NO	YES	0	0
(5, 207)	0	100	NO	YES	0	0
(7, 203)	0	100	NO	YES	0	0
(8, 201)	0	100	NO	YES	0	0
(110, 111)	0	100	NO	YES	0	0
(9, 202)	0	100	NO	YES	0	0
(11, 206)	0	100	NO	YES	0	0
(13, 210)	0	100	NO	YES	0	0
(14, 212)	0	100	NO	YES	0	0
(16, 216)	0	100	NO	YES	0	0
(3, 14)	22	78	YES	YES	0	0
(159, 14)	0	91	NO	YES	0	0
(1, 103)	43	57	YES	YES	0	0
(13, 4)	0	100	YES	YES	0	0
(4, 13)	0	100	YES	YES	0	0
(10, 7)	15	85	YES	YES	0	0
(8, 110)	0	100	YES	YES	0	0
(9, 8)	43	57	YES	YES	0	0
(109, 8)	0	99	NO	YES	0	0
(110, 9)	0	10	YES	YES	0	0
(157, 13)	0	87	YES	YES	0	0
(12, 5)	22	78	YES	YES	0	0
(104, 4)	1	99	YES	YES	0	0
(105, 5)	0	75	NO	YES	0	0
(107, 7)	0	81	NO	YES	0	0
(16, 1)	35	65	YES	YES	50/ 15	0
(1, 16)	5	95	YES	YES	50/ 15	0
(102, 1)	17	79	YES	YES	265/ 81	0
(154, 11)	0	74	NO	YES	0	0
(6, 11)	27	73	YES	YES	0	0
(161, 16)	28	34	YES	YES	0	0
(15, 2)	28	72	YES	YES	0	0
(103, 2)	0	98	NO	YES	0	0
(216, 16)	0	78	NO	YES	0	0
(151, 9)	14	86	YES	YES	0	0
(3, 104)	0	100	NO	YES	0	0
(6, 107)	0	100	NO	YES	0	0
(208, 12)	0	78	NO	YES	0	0

Table-A6

SPECIFIED FIXED-TIME SIGNAL CONTROL CODES

		NODE 1		CYCLE LENGTH 120 SEC	
INTERVAL NUMBER	OFFSET DURATION (SEC) (PCT)	+		-	
		(16, 1)	(102, 1)	(215, 1)	
1	45 37	7	2	1	
2	3 2	0	2	0	
3	2 1	2	2	2	
4	20 16	1	2	2	
5	3 2	0	2	2	
6	2 1	2	2	2	
7	40 33	2	1	2	
8	3 2	2	0	2	
9	2 1	2	2	2	
0			NODE 2		
		NODE 2		CYCLE LENGTH 60 SEC	
INTERVAL NUMBER	OFFSET DURATION (SEC) (PCT)	+		-	
		(15, 2)	(103, 2)		
1	25 41	1	2		
2	3 5	0	2		
3	2 3	2	2		
4	25 41	2	1		
5	3 5	2	0		
6	2 3	2	2		
0			NODE 3		
		NODE 3		CYCLE LENGTH 60 SEC	
INTERVAL NUMBER	OFFSET DURATION (SEC) (PCT)	+		-	
		(2, 3)	(211, 3)		
1	31 51	1	2		
2	3 5	0	2		
3	2 3	2	2		
4	19 31	2	1		
5	3 5	2	0		
6	2 3	2	2		
0			NODE 4		
		NODE 4		CYCLE LENGTH 60 SEC	
INTERVAL NUMBER	OFFSET DURATION (SEC) (PCT)	+		-	
		(13, 4)	(104, 4)	(209, 4)	
1	24 40	7	2	1	
2	3 5	0	2	0	
3	2 3	2	2	2	
4	26 43	2	1	2	
5	3 5	2	0	2	
6	2 3	2	2	2	
1					

0										
0										
	NODE 5									
	INTERVAL	OFFSET	5 SEC							
	NUMBER	(SEC)	DURATION (PCT)	(12, 5)	(105, 5)		APPROACHES		CYCLE LENGTH	60 SEC
	1	25	41	1	2					
	2	3	5	0	2					
	3	2	3	2	2					
	4	25	41	2	1					
	5	3	5	2	0					
	6	2	3	2	2					
0	NODE 6									
0										
	INTERVAL	OFFSET	15 SEC							
	NUMBER	(SEC)	DURATION (PCT)	(106, 6)	(205, 6)		APPROACHES		CYCLE LENGTH	60 SEC
	1	22	36	1	2					
	2	3	5	0	2					
	3	2	3	2	2					
	4	28	46	2	1					
	5	3	5	2	0					
	6	2	3	2	2					
0	NODE 7									
0										
	INTERVAL	OFFSET	10 SEC							
	NUMBER	(SEC)	DURATION (PCT)	(10, 7)	(107, 7)		APPROACHES		CYCLE LENGTH	60 SEC
	1	20	33	1	2					
	2	3	5	0	2					
	3	2	3	2	2					
	4	30	50	2	1					
	5	3	5	2	0					
	6	2	3	2	2					
0	NODE 8									
0										
	INTERVAL	OFFSET	40 SEC							
	NUMBER	(SEC)	DURATION (PCT)	(9, 8)	(109, 8)	(201, 8)	APPROACHES		CYCLE LENGTH	60 SEC
	1	27	45	1	2	1				
	2	3	5	0	2	0				
	3	2	3	2	2	2				
	4	23	38	2	1	2				
	5	3	5	2	0	2				
	6	2	3	2	2	2				
1	NODE 9									
0										
0										
	INTERVAL	OFFSET	35 SEC							
	NUMBER	(SEC)	DURATION (PCT)	(151, 9)	(202, 9)	(110, 9)	APPROACHES		CYCLE LENGTH	60 SEC
	1	27	45	2	1	1				
	2	3	5	2	0	0				

INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(153, 10)	(204, 10)	APPROACHES	CYCLE LENGTH 60 SEC
3	2	3	2	2	2	
4	23	38	1	2	2	
5	3	5	0	2	2	
6	2	3	2	2	2	
0				NODE 10		
0						

INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(154, 11)	(6, 11)	APPROACHES	CYCLE LENGTH 60 SEC
1	26	43	1	2		
2	3	5	0	2		
3	2	3	2	2		
4	24	40	2	1		
5	3	5	2	0		
6	2	3	2	2		
0				NODE 11		
0						

INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(156, 12)	(208, 12)	APPROACHES	CYCLE LENGTH 60 SEC
1	27	45	1	2		
2	3	5	0	2		
3	2	3	2	2		
4	23	38	2	1		
5	3	5	2	0		
6	2	3	2	2		
0				NODE 12		
0						

INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(157, 13)	(210, 13)	APPROACHES	CYCLE LENGTH 60 SEC
1	23	38	2	1	(4, 13)	
2	3	5	2	0	7	
3	2	3	2	2	0	
4	27	45	9	2	2	
5	3	5	0	2	2	
6	2	3	2	2	2	
0				NODE 14		
0						

INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(157, 13)	(210, 13)	APPROACHES	CYCLE LENGTH 60 SEC
1	23	38	2	1	(4, 13)	
2	3	5	2	0	7	
3	2	3	2	2	0	
4	27	45	9	2	2	
5	3	5	0	2	2	
6	2	3	2	2	2	
0				NODE 14		
0						

INTERVAL NUMBER	DURATION (SEC)	(SEC) (PCT)	(159, 14)	(3, 14)	APPROACHES	CYCLE LENGTH 60 SEC
1	29	48	1	2		
2	3	5	0	2		
3	2	3	2	2		
4	21	35	2	1		
5	3	5	2	0		
6	2	3	2	2		
NODE 15						
OFFSET 15 SEC						
INTERVAL NUMBER	DURATION (SEC)	(SEC) (PCT)	(160, 15)	(214, 15)	APPROACHES	CYCLE LENGTH 120 SEC
1	27	45	1	2		
2	3	5	0	2		
3	2	3	2	2		
4	23	38	2	1		
5	3	5	2	0		
6	2	3	2	2		
NODE 16						
OFFSET 35 SEC						
INTERVAL NUMBER	DURATION (SEC)	(SEC) (PCT)	(161, 16)	(216, 16)	(1, 16)	CYCLE LENGTH 120 SEC
1	50	41	2	1	1	
2	3	2	2	0	0	
3	2	1	2	2	2	
4	60	50	1	2	2	
5	3	2	0	2	2	
6	2	1	2	2	2	
INTERPRETATION OF SIGNAL CODES						
0	YIELD OR AMBER					
1	GREEN					
2	RED					
3	RED WITH GREEN RIGHT ARROW					
4	RED WITH GREEN LEFT ARROW					
5	STOP					
6	RED WITH GREEN DIAGONAL ARROW					
7	NO TURNS-GREEN THRU ARROW					
8	RED WITH LEFT AND RIGHT GREEN ARROW					
9	NO LEFT TURN-GREEN THRU AND RIGHT					

Table-A7

EMBEDDED DATA CHANGES IN EFFECT

SCALAR OR ARRAY	C O N T E N T S																CHANGED BY CARD TYPE
	100	81	69	40													
0	SPLPCT	15	0														141
0	LTLAGP	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	141
0	PDLIY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	146
0	PPER	1	9	21													146
0	DRVFAM	5	95														153

Table-A8

MODIFICATIONS TO ENVIRONMENTAL TABLES

TABLE PERFORMANCE SPEED		ACCELERATION (FT/SEC/SEC)															
INDEX	(FT/SEC)	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5
FUEL	0	14	14	14	14	14	14	14	14	14	14	14	30	52	91	130	166
HC	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CO	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NOx	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table-A9

MAXIMUM ACCELERATION TABLE

PERFORMANCE		0	10	20	30	40	50	60	70	80	90	100	110
INDEX	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC	FT/SEC
1	8.00	9.00	6.00	5.00	5.00	5.00	5.00	4.00	3.00	2.00	2.00	1.00	1.00
2	6.00	12.00	10.00	8.00	7.00	6.00	6.00	4.00	4.00	4.00	2.00	2.00	2.00
3	4.69	5.35	4.94	3.47	3.09	2.61	2.14	2.14	1.70	1.27	0.86	0.46	0.06
4	2.81	2.42	2.15	2.04	1.74	1.42	1.12	1.12	0.83	0.56	0.30	0.04	-0.23
5*	7.47	5.33	3.17	2.66	2.29	1.65	1.40	1.40	0.95	0.75	0.50	-0.33	-0.33
6	2.45	2.14	1.42	1.12	0.85	0.63	0.44	0.44	0.29	0.14	0.00	-0.14	-0.27
7	7.47	5.33	3.17	2.66	2.29	1.65	1.40	1.40	0.95	0.75	0.50	-0.33	-0.35

• INDICATES THAT ENTRIES WERE MODIFIED BY USER INPUT ON RECORD TYPE 173

Table-A10

NETSIM VEHICLE TYPE SPECIFICATIONS

VEHICLE TYPE	LENGTH FEET/METERS	Q DSCG HDWY FACTOR (PCT)	AVG. OCCUP.	FLEET COMPONENT AUTO TRUCK CARPOOL BUS	PERF. INDEX
1	16.0/ 4.9	100	1.3	50 0 0 0	2
2	35.0/ 10.7	120	1.2	0 50 0 0	3
3	16.0/ 4.9	100	2.5	0 0 84 0	2
4	40.0/ 12.2	120	32.5	0 0 0 84	7
5	14.0/ 4.3	100	1.3	50 0 0 0	1
6	53.0/ 16.2	120	1.2	0 25 0 0	4
7	60.0/ 18.3	120	32.5	0 0 0 16	5
8	64.0/ 19.5	120	1.2	0 25 0 0	6
9	14.0/ 4.3	100	2.5	0 0 16 0	1

Table-A11

INITIALIZATION STATISTICS

TIME INTERVAL NUMBER	SUBNETWORK TYPE	PRIOR CONTENT (VEHICLES)	CURRENT CONTENT (VEHICLES)	PERCENT DIFFERENCE
1	NETSIM	0	115	10000
2	NETSIM	115	159	38
3	NETSIM	159	198	24
4	NETSIM	198	187	5
5	NETSIM	187	201	7
ALL EXISTING SUBNETWORKS REACHED EQUILIBRIUM				
EQUILIBRIUM ATTAINED				

APPENDIX – B

Figure B1 Critical Movements at Intersection # 2 (Case -A)

Figure B2 Critical Movements at Intersection # 12 (Case -A)

Figure B3 Critical Movements at Intersection # 2 (Case -B)

Figure B4 Critical Movements at Intersection # 5 (Case -B)

Figure B5 Critical Movements at Intersection # 9 (Case -B)

Figure B6 Critical Movements at Intersection # 12 (Case -B)

Figure B7 Critical Movements at Intersection # 1 (Case -C)

Figure B8 Critical Movements at Intersection # 2 (Case -C)

Figure B9 Critical Movements at Intersection # 3 (Case -C)

Figure B10 Critical Movements at Intersection # 5 (Case -C)

Figure B11 Critical Movements at Intersection # 6 (Case -C)

Figure B12 Critical Movements at Intersection # 9 (Case -C)

Figure B13 Critical Movements at Intersection # 10 (Case -C)

Figure B14 Critical Movements at Intersection # 11 (Case -C)

Figure B15 Critical Movements at Intersection # 12 (Case -C)

Figure B16 Critical Movements at Intersection # 13 (Case -C)

Figure B17 Critical Movements at Intersection # 14 (Case -C)

Figure B18 Critical Movements at Intersection # 15 (Case -C)

Figure B19 Critical Movements at Intersection # 16 (Case -C)