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METHODOLOGY FOR PREDICTING BUS DELAYS AND ARRIVAL TIMES

by:

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Alexandria University
Alexandria, Egypt, 1989

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of

(MASTER OF ENGINEERING)

Department of Civil and Environmental Engineering
Carleton University, Ottawa, Ontario

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in partial fulfilment of the requirements
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Carleton University
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" TO THE SOUL OF MY FATHER AND MOTHER "

Who dreamed of highly educated and successful sons & daughters, sacrificed a lot and worked hard to raise them to the best of their abilities.

And

" TO MY NEW BORN SON: WASEEM "

ABSTRACT

Due to the fiscal constraints and the traffic congestion on urban roads and highways, there have been remarkable changes/delays in the public transportation services. The OC-Transpo (Ottawa-Carleton Regional Transit Commission) scheduling system is affected by these developments. These changes in the operational schedule vary from schedule timing to route choice, caused by the transit-way facility construction and the level of service on urban roads. Recognizing the need, a methodological framework for predicting bus delays and arrival times has been developed. Thus, the development of delay models has helped investigating precise transit delays and accurate prediction for bus arrivals.

Research has helped to identify the factors that cause bus delays and/or schedule disturbances. Also, the research investigated the actual bus delays due to the existing environment. A new approach was studied to minimize the bus delays at the road network intersections by creating a bus detection system to identify the bus before it approaches the intersection and giving it the right-of-way (**ROW**). In addition, a series of delay models were developed in order to estimate bus delay in minutes under various types of traffic conditions, i.e. normal traffic condition, accident occurrence, and bus flow without traffic disruption. These models enable an accurate prediction for bus arrival that could be announced to the public through the 560 system (telephone information system) and/or on-street information display system.

Bus route #2 in the Ottawa-Carleton Region was the route under research during the a.m. peak period only. Detailed analysis of bus operation was conducted through an extensive survey and video taping. Finally, recommendations were made to give serious consideration to enhance the public transportation system. The efficacy of such recommendations could be achieved through reduction in bus travel time, minimizing transit delays, reducing the number of traffic signal-related interruptions on transit routes,...etc. Transit system improvements will result in attracting more customers, and reducing the number of private vehicles using roadways (vehicle ownership), which will decrease emissions released into the environment.

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LIST OF SYMBOLS/ACRONYMS

SYMBOL/ ACRONYM:

DESCRIPTION:

560 System	Telephone Information System
AVLC	Automatic Vehicle Location and Control System
Bus.Mins	Bus Minutes
BUSTOP	Bus Stop
BUSTRIP	Bus Trip
CBC	Canadian Broadcasting Corporation
CBD	Central Business District
CO	Carbon-Monoxide
CO ₂	Carbon-dioxide
DENS.LT	Left turn vehicle density
DENS.RT	Right turn vehicle density
DENS.TH	Through vehicle density
FETSIM	Fuel Efficient Traffic Signal Management Program
FHA	Federal Highway Administration
HC	Hydro-Carbons
HCM	Highway Capacity Manual
HVDENSTY	Heavy-Vehicle density
ITE	Institute of Transportation Engineers
ITMS	Intelligent Transportation Management System
IVHS	Intelligent Vehicle Highway System
Km	kilometre
Km/h	kilometre per Hour
Km/h/L	kilometre per Hour per Lane
LOS	Level-Of-Service
MOE	Measures Of Effectiveness
M/T	The ratio between bus moving time and travel time
MTO	Ministry of Transportation of Ontario
NEMA	National Electric Manufacturers Association
NO _x	Nitrogen-Oxide
O	Optional
OC-Transpo	Ottawa-Carleton Regional Transit Commission
P.C.	Personal Computer
PTO	Public Transit Operation
R	Required
RMOC	Regional Municipality of Ottawa Carleton
R.O.W	Right-Of-Way

**SYMBOL/
ACRONYM:**

DESCRIPTION:

Sec/Bus	Seconds per Bus
Sec/Veh	Second per Vehicle
SIGNPKM	Number of traffic lights per kilometre
SO ₂	Sulphur-dioxide
SOAP	Signal Operation Analysis Package
SPSS	Statistical Package for Social Science
TRAF-NETSIM	Traffic Network Simulation
ULI	Urban Land Institute
UN	United Nation
Veh.Km	Vehicle kilometre
Veh.Mins	Vehicle Minutes

CHAPTER 1

INTRODUCTION

1.1 Background:

Transportation systems around the world are changing very rapidly. Changes are occurring in transportation technology, transportation demands and values, both public and private. With the increasing demand on private transportation and more freedom to travel everywhere, car traffic gets dense, congested and frustrating especially in peak hours. Public transportation was developed to accommodate the increasing demand of people to move within and between the different cities. In order to accommodate urban development, it has always been seen as one of the effective solutions to relieve the traffic jams occurring during rush hours.

Throughout the 20th century the world has faced a dramatic increase in population. As a matter of fact, the figures from the latest United Nation (UN) head count show that the world's population has more than doubled since the 1950's. Also, the UN projections show the world population reaching nearly 8.5 billion by the year 2025, despite the third world birth rate dropping since the 1960's [1]*. Accordingly, the number of automobiles has increased in order to accommodate these new users in their different daily activities.

Among the important problems arising from the population explosion is that of congestion. Although this overcrowding manifests itself in virtually every aspect of modern life, nowhere is it as dramatically exhibited in our society as on the streets and highways. The most vigorous attempt to reduce traffic congestion and delays was by

* Refers to references listed at end of thesis.

implementing traffic regulations and producing of control devices. Still, practically all major cities are troubled with severe peak-hour congestion even on newly completed freeways and especially in the downtown cores.

Bus transit is an important mode in urban areas of developed as well as developing countries. In industrially advanced countries, due to the high automobile ownership, there is much competition between public transit and the automobile. Service quality, as well as cost are important factors that influence mode choice decisions. Although cost to the user is a major concern, the level of service is also important to travellers within the urban areas of developing countries. In most of the third world countries, buses are the major mode of urban transport and often the only affordable choice for people with limited incomes.

The subject of this research covers a methodology for bus route analysis potentially applicable to OC-Transpo and/or other transit operators (i.e., bus operation & traffic optimization within a route, 560 interface system update, delay models, and better prediction for bus arrivals at target destinations). For example, OC-Transpo's operations include 825 buses, distributed over 140 routes, accommodated by 5,000 bus stops, and servicing about 75 million passengers annually [2].

In most North American cities, urban transit companies and operators are facing difficulties to increase and/or even to maintain their ridership market share. The existence of a large travel demand in a corridor does not assure that many people will use public transportation. Many of them may prefer to drive their own vehicles. The percentage of those people who depend on public transportation is usually lower in the suburbs than in

the central cities, and the vast majority of those who commute between the suburbs and the Central Business District (CBD) have the financial and the physical capability of driving if they choose to do so [3,4,5].

In most of the developing countries, public transit operators could not maintain the level of service due to augmented demand. For the last few decades, the crisis in public transportation has developed; bus services have deteriorated and the system efficiency and output have reduced, as passengers have turned to their private cars, and thus contributed to the traffic congestion. If more people use their automobiles, traffic congestion would increase and it will take longer to get to work. In the case of fewer people driving, the opposite effect might occur. Therefore, if enough people choose to travel by bus, the traffic congestion could be reduced; however, a drastic reduction in automobile use would decrease the total travel time. On the other hand, the forecast of rapid growth in the urban population and the consequences of developing the suburban areas will lead to expanded bus services and the public transit companies will have an opportunity to increase their share of the market [2,6,7].

Due to the expected increase in medium and large-size urban areas, in conjunction with no increase in the road capacity, traffic congestion is expected to rise. In Ontario, the annual travel growth in some corridors ranges between 3% and 6%, according to the Ministry of Transportation of Ontario (MTO), based on 1990 data analysis. Furthermore, by the year 2005, it is expected that traffic in Ontario could increase by 56% to 140% based on 1990 figures [8,9]. **Figure 1.1** shows the impact of the city population and the rate of automobile ownership on the urban transit usage. The figure includes different

cities around the world for comparison and identification of the actual relationship between public and private vehicle usage.

Although the cities included in the chart are unmatched in the social life style or in the natural resources, the comparison gives an example to explain the relationship between the auto ownership ratio and the public transit usage (Supply & Demand) compared to the city size of population. Also, the figure clearly shows that while the automobile ownership decreases within a society, the transit usage is expected to increase.

Also, the forecast of the increasing urban population, as well as the expansion of urban areas and development projects, suggests that more customers/users will be in need of bus services. As a consequence, public transit services will be in more demand in the years to come [7,10,11].

The transportation demand function which reflects consumer behaviour and attitude can be used to predict how the customer(s) will react to the different options of the transportation modes available. Also, relief of congestion is certainly a worthy objective for modern-day society because it reflects on the relative speed of each of the transportation facilities. In response to the changes in future conditions, public transportation must be more desirable than driving if it is to be successful in the travel market[12]. The most important factor in making it more desirable to the customers is to improve service. The Automatic Vehicle Location and Control System (AVLC) will facilitate and improve the service for public transportation since it will help in providing users a more reliable estimate of trip time from point (A) to point (B) [13,14].

Figure1.1: IMPACT ON THE URBAN TRANSIT USAGE
 Auto Ownership/100 People vs Percentage of Transit Share
 (Source: References # 7,10,11)

As a part of the development program for public transportation, and in order to improve the service and achieve customer satisfaction, the technology of automatic vehicle location was introduced and is still under development. The Automatic Vehicle Location and Control System is an assembly of advanced technology capable of locating & tracking vehicle (s) movements, real-time monitoring and determination, as well as management of the entire fleet/network area through a centralized control station [3,16]

The value of time is making people decide what type of transportation they should use. On a daily basis, commuters travelling to and from the CBD during peak hours found it easier to use the bus system in order to avoid traffic congestion, parking problems, higher parking rates, high stress level and frustration. Individuals usually have different feelings towards the different methods of transportation, and these feelings influence their behaviour. As long as people's perceived needs for mobility continue at the current rates, something obviously must be done to improve the current traffic situation [17,18,19]. Researchers noted that congestion relief can occur in a number of ways, i.e. traffic calming, grade separation, banning left turns,...etc. With the new technology, the public transportation can have the right-of-way or priority of traffic (that can be controlled by special detectors installed on the traffic signal or at the bus station) that will create a green-phase by the time transit vehicles approach the intersection [9,13]

In addition, assigning priority of traffic to transit vehicles tends to have the greatest initial impact on the regularity of service. The public transit operator's initial reaction towards decreasing delays encountered during servicing time at critical points within the street network should be to reduce the loss of mileage due to a slow speed or

in other words increase the operating speed. Since the overall benefits depend on the reliability of the transit vehicles, improvement in operating speed could be translated as an increase in the number of trips, increase in productivity, and that will contribute in a significant reduction in the operating cost. [20,21].

OC-Transpo has set-up a daily time table for each bus route within its service area. These time tables are to include an estimated arrival time at each bus stop location. Also, there is a telephone information system (the 560 system) for public use in order to update their schedule in case of emergency and expected delays. In this system, a recorded message informs the passengers and announces the estimated arrival time for each bus stop location

Scheduling of bus services takes place under uncertainty of arrival times considering traffic conditions (rush-hour congestion), harsh weather conditions (specially during winter time), recurring mechanical problems (bus breakdown), or non-recurring incidents, i.e. accidents, fire,...etc., which cause a detour for some routes. These delays and uncertainties have affected the OC-Transpo operation performance and may have been the cause of modal shifts away from the public transportation system. As a result, there is a significant increase in private vehicle ownership, which can be translated to a significant decrease in the public transportation revenue [22,23,24].

1.2 Literature Review:

The most important and common terminology within the traffic operation and analysis is **DELAY**. Delay is an important measure to describe traffic flow condition. Also, delay results in increased cost of fuel consumption and increased pollution released into the environment [25]. The Highway Capacity Manual (**HCM**) described delay as: "a complex variable that is sensitive to a variety of local and environmental conditions" [26]. Also, the HCM considers delay as the most important parameter of traffic flow and the main measure of effectiveness during the analysis of signalized intersections. Delay can define the level of service for a given street and/or intersection. It can be measured in the field, calculated from collected data (information), and estimated from simulation software packages [26,27].

Here, a review is presented of delay models which have been developed for the estimation of traffic delays and impact assessment. In 1934, Greenshields was first to publish the time-lapse photography; followed by many papers to identify and measure field delays i.e. Berry in 1956 and the Berry-Van Til method which sampled the stopped-time delay. Continuous research and studies have resulted in developing delay models. Among those was the famous Webster's delay model. The Webster model, originally developed in 1958, and was intended to estimate delays for one single approach. The model revealed that delay depends on traffic flow, the degree of traffic saturation, the cycle timing length, and the utilized green period. Although an assumption was made that traffic is arriving in a uniform fashion throughout the cycle period, the model considered the randomness of the vehicle arrivals during the cycle. A large amount of

information is required about the actual road condition, geometric design, traffic operation, and signal setting. The model shows that the average delay per vehicle will increase as a result of increasing volume, and will reach its peak as traffic approaches saturation level [12,28].

Further developments in delay models have been carried out by Whol and Martin in 1967, and then Blunden in 1971 to provide more details for intersection delays and the factors that could influence the model results. Other models have been developed in order to evaluate the operation of an intersection (based on the Webster delay model). These include the Signal Operation Analysis Package (SOAP), a model for system optimization and performance estimation analysis; TRANSYT, the PASSER II, for timing and optimizing the traffic signals; and many other intensive programs to estimate delays and provide measures of effectiveness on the traffic characteristics [29]. Also, the methodology included in the Highway Capacity Manual (HCM), of 1985 can be used to estimate delays caused by the arrival pattern of vehicles at different intersections, i.e. uniform or random, as well as stopped time delays caused by signal control devices [30,31,32]. Another delay model was developed by Helali (1990) for the estimation of delays in the road network or for multi-link streets. Equations were developed for different street types, classified according to geometric design, and traffic regulations [33].

All of the above referenced delay models were developed in order to help the transportation system management and planners to maintain, as well as to improve the quality, services, and efficiency of the existing transportation system. However, there is a lack of models for the estimation of public transit (bus) delays. Such a methodology,

if available, would give the public transportation managers and planners an accurate as well as real time for bus delays experienced in the field. Furthermore, the model development work can be a joint venture with the developing of the Automatic Vehicle Location and Control System (AVLC) technology. Both will result in enhanced transit ridership due to improved coverage of public transportation, improved service schedule, and reduced travel time. Also, there are environmental advantages as well, i.e. reduced fuel costs, reduced emissions, reduced noise level, and reduced levels of many other undesirable environmental impacts.

1.3 Objectives of The Research:

1.3.1 Objectives: The main objectives of this research are:

1. to identify and assess the factors that serve as a constraint to meeting the schedules of bus services;
2. to investigate and determine the actual delays experienced on the bus system due to the operating environment of buses;
3. to study and analyze the stopped-time-delays, their causes and their effects on the bus system operation and performance;
4. to determine and supply reliable information from the field, information on traffic count, accident occurrence, weather condition, fire,...etc.;
5. to develop a delay model to estimate the bus delays on the road network; and
6. to study the availability of all-green-time for buses approaching different intersections and the benefits gained by the system

1.3.2 Scope:

This thesis is expected to result in:

1. methodology to predict and estimate accurate bus arrivals at the different locations along routes. These predictions are to be based on a real-time monitoring system in order to calculate delays and/or bus arrivals at specific locations, as well as to update the 560 telephone system;
2. a real-time delay model based on the prevailing traffic conditions while the buses are in operation;
3. a determination of the bus arrivals at any location and any time under the existing traffic conditions;
4. identification of the conditions that are conducive to consideration of development of the Automatic Vehicle Location and Control System (AVL&C);
5. a methodology for minimizing delays caused by traffic signals (duration of the red-interval) at each intersection.

" Bus-delay for the purpose of this research is measured in minutes per link (Bus.Min) or any other specified distance within the developed delay models."

Finally, this research will be able to achieve its mission statement: "***TO IMPROVE THE IMAGE OF PUBLIC TRANSIT AND TO HELP TOWARDS MAKING PUBLIC TRANSIT AN ATTRACTIVE ALTERNATIVE TO THE PRIVATE AUTOMOBILE.***"

" This research is limited to the mixed traffic during peak-hour conditions, since peak-hour conditions are the key factors in planning and designing the improvement of the urban transportation system for transit operators as well as transit users."

1.4 Research Structure and Methodology:

From the literature review and a study of the different delay models developed over the last two decades, it can be observed that researcher's sole objective was to provide a safe, economic as well as efficient system for moving people on the existing road network facilities [34]. It is also noted that these models were always approached through sets of data gathering, information available from the past, historical traffic count, and survey results which give a close reckoning of the end results, depending on the degree of estimation and the assumption used to develop these models. Since researchers are still looking for an accurate methods to measure the actual field delays, using a methodology based on real-time information could be the answer. Attempts were made to develop the Automatic Vehicle Location & Control System (AVLC) in order to have full control over the vehicle fleet on the road system. The Ministry of Transportation of Ontario as well as the OC-Transpo, have tested the AVLC system on some bus routes, and the results were very impressive. This research will be among those studies that use actual data to measure delays encountered by the bus system and accurately predict the arrival times at different locations [35].

The research planning platform is shown in **Figure 1.2**. It contains the problem identification, understanding and recognition of the problem, and finally achievements and recommendations as a major foundation for the study plan.

Figure 1.2: RESEARCH PLANNING PLATFORM

1.4.1 Problem Identification:

The first part of the research will focus on assessing the problem with bus delays in the field with the possible consequences in every day traffic flow, existing and future. A survey was conducted and various data were collected to help identify the different types of bus delays. The information used during the model development was mainly collected from the operation of bus route #2 starting from the Bayshore (Bayshore Shopping Centre, Ottawa-West) and ending at Blair station (Blair & Ogilvie Road, Ottawa-East), **Figure 1.3** shows a layout for bus route #2. All data were collected during the a.m. peak-hours. Numerous problems were identified by OC-Transpo in the initial interview with the staff at the Planning Department and at the Operations Room, and included areas of concern, such as: constant delays, inaccurate delay messages sent to the public through the 560 system, and keeping track of buses not following the designed schedule. No attempt was made to document other bus routes during the study area nor any travel characteristics through either interviews and/or the distribution of questionnaires.

1.4.2 Understanding and Recognition:

The results from the bus survey and traffic count data collection, along with the information collected from the Regional Municipality of Ottawa-Carleton and the City of Ottawa, were analyzed. The second step was to put all the aspects of the research in proper perspective by making a rational framework to understand and solve any problem(s) on hand.

Data Analysis:

After the completion of the data collection, the next step was data reduction and analysis. Through the use of a computer simulated program, TRAF-NETSIM software, a coded road network program was available on campus. This program has created a complete data-base system for the proposed study area. Furthermore, NETSIM allowed the development of different cases and scenarios for the study area i.e. bus delays in case of accident occurrence, one lane blocked due to parked fire trucks or snow removal, possibility of giving the right of way to the bus system, and effect of traffic density. The results of analysis provided a determination for the actual impact on the existing traffic using the road network. The NETSIM software package has provided Measures of Effectiveness (MOE), which identify different parameters associated with the actual bus delays within the study area. By using the NETSIM output information and through a statistical software package, SPSS, a multiple regression analysis was performed to develop the best fit model.

1.4.3 Achievements and Recommendations:

The bus survey analyses were effective and successful in assessing the different components of delays. A delay model was developed to estimate bus delays. Road network traffic scenarios were created, i.e. road accident, snow removal which resulted in blocking one lane on the road. Also, another delay model was developed to estimate the delays caused by blocking a lane along a bus route.

Testing the Model:

As per the thesis objectives, ten equations were developed and used at the end of this research. In order to make sure that the model served the purpose it was designed for, a field test was carried out. Two video cameras were installed at two different intersections within the study area. These were selected according to the busiest traffic conditions at the survey time. These recorded actual traffic operations within the road network for one hour during the a.m. peak-hour period. Through close monitoring of the actual bus operation and its services i.e. travel time, moving time, stopping time (stopping due to servicing passenger, and/or traffic control devices), operating speed...etc., from one intersection to the other, it was possible to test the validity of the developed delay models, as well as comparing the model results with the NETSIM output and the actual field data. Furthermore, more than 95 bus observations were recorded on Slater Street (between Lyon, Bank, and O'Connor Streets) in order to estimate bus delays and predict bus arrival times at the different locations.

Finally, recommendations were made for the criteria for locating the bus prior to an intersection and giving it the right-of-way (Green light), enhancing the 560 system (Public Telephone Information System), and minimizing delays especially during peak-hour traffic.

1.5 Thesis Outline:

Figure 1.4 shows the research framework flow chart. It illustrates the steps which have been taken to reach the thesis objectives. The thesis consists of seven chapters and three appendices. These are organized in the following manner:

Chapter 2 includes data collection and bus survey analysis. Numerous types of data were collected and analyzed. Bus travel time and operation are also discussed.

Chapter 3 comprises the computer simulation, a brief introduction about the simulation package TRAF-NETSIM, development of a coded data base, and creating a case scenario for an accident on the bus route and another for giving the right-of-way to transit vehicles at the network intersections.

Chapter 4 discusses the different traffic regulations and its effect on transit vehicles. Also, a brief comparison of the different regulations used at some of major cities within Canada and around the world.

Chapter 5 deals with the experimentation process while developing the delay model and using NETSIM output in a statistical package SPSS for multiple regression analysis. Discussion of the different variables used in the equation are included. Description of each model and its use is also considered.

Chapter 6 describes the model validation and includes the various steps of testing the developed models. A comparison of the different model results with the NETSIM output results, as well as the actual field data.

Chapter 7 presents the thesis summary, conclusions and recommendations.

Appendix A contains all the data collected for research purposes and formulated for the use by TRAF-NETSIM simulation package (sample of input data & output results).

Appendix B lists detailed information (SPSS output) used during the regression analysis while developing the delay model.

Appendix C includes an introduction to the available technologies in the market for traffic analysis and management issues.

Appendix D contains miscellaneous data collection, i.e. accident data, bus observations at Slater Street.

CHAPTER 2

DATA COLLECTION

2.1 Data Preparations:

An important part of this research is the collection of data and the data base development. Usually for any transportation studies, the field-data information gathering is the only reliable option. Sometimes compiling such data is very difficult and sometimes almost impossible. This is because of a general constraint on resources; i.e. lack of money, time, and personal effort. Due to the difficulties aforementioned, the author's strategies were to collect as much information as possible and create a central-data-base within a computer simulation & software package which in turn have furnished a comprehensive description of the traffic network as it moves over the designated study area.

Data obtained during the course of this study not only form the foundation for future, more detailed studies, but identify, quantify and summarize the state of the existing bus operation associated with the every day traffic count on each bus route which will be the main source of developing the bus delay and arrival models. The developed delay model, as well as the assessment of the data obtained during the course of the study, will enable OC-Transpo to possibly implement remedial measures that would alleviate some of the existing problems and could mitigate the likely impact of the additional customers attracted to use the public transportation facilities in the future. **Figure 2.1** illustrates the study area including bus route #2 from Bayshore to its final destination at Blair station.

Varies types of data were collected through the course of study and they are listed as follows:

1. Data were collected for different parameters of traffic operation. These include traffic volume, vehicle classification, and the historical accident data along the designated bus route. These data were collected from the Transportation Department of the Regional Municipality of Ottawa Carleton (ROMC).
2. Recent delay data were acquired for the bus system; arrival time vs scheduled time, as well as the actual bus operation on a daily basis from OC-Transpo, Operation and Planning Department.
3. Information about different traffic signals within the study area was also obtained from the Traffic Department of the RMOC.
4. Data were collected through field measurements, such as measurements of the bus stop location (distance to/from the intersection), capacity of each bus stop (i.e. how many buses could be accommodated at one time), number of other bus routes using the same bus stop and their headway, geometric design, and street layout along bus route #2.

2.2 Data Collected from the Field:

In order to collect data from the field, a bus operation survey was conducted to collect information, as well as to assess bus operation during peak-hour. For the purpose of this study, the main target was to search for the busiest bus route, in particular throughout the day and especially one travelling through the down-town core.

Even before the commencement of the survey it was apparent that the bus operation at OC Transpo needed a very broad comprehensive study analysis in order to adequately address both the above mentioned issues and others, such as enhancing public transportation facilities, updating the 560 information system equipment requirement, etc.. However, due primarily to the time frame, the limited resources at present, and given the scope of the thesis research, it was not possible to conduct this detailed evaluation of the entire system at this juncture. Therefore, the researcher endeavoured to address the key areas of concern by conducting a detailed traffic count and general observation for bus #2 operation. (i.e. schedule adherence, time monitoring for bus schedule, and actual headway etc.) to determine how the bus schedule is currently being utilized.

The operation of the existing bus route was assessed by undertaking two days (only during the a.m. peak-hour period) traffic count and video taping the traffic operation and the bus service pattern at two major intersections within the bus route: Rideau & Charlotte Street and St. Laurent & Montreal Road. Although the intersection at Rideau & Charlotte Street is unique on its traffic regulation (no left-turn permitted and no right-turn during red-light), the choice of this intersection was made due to its proximity to the downtown area (to present the traffic count entering and exiting the downtown core). In addition, there were three observation points for monitoring and recording the arrival and departure of bus #2. These observation points were located at: Forest Street at the Lincoln Heights Galleria, Richmond Road at Churchill Avenue, and Somerset Street at Preston Street, at which time vehicle accumulation, arrivals patterns, schedule adherence and other criteria were recorded, and calculated for analysis purposes.

In combination with this traffic operation survey, general background data and information were collected from the Regional Municipality of Ottawa Carleton (RMOC) to verify, elaborate on and supplement the results of the traffic count and bus operation survey. Traffic data, collected from RMOC, City of Ottawa, and field measurements, were based on observations of the normal traffic pattern on a day-by-day basis. These survey results, as well as the research information gathered, will be used to build a data base case inside the simulator, NETSIM software package.

On Wednesday, August 10, 1994, Phase-I of the survey was conducted for bus route #2 in order to ascertain and document the bus characteristics, the operation schedule, and the associated traffic mix during the morning peak-hour period. This survey included:

- 1- Intersection video-taping and traffic count:** A video camera was installed at the corner of each intersection, Rideau & Charlotte Streets and Montreal Road & St. Laurent Boulevard.
- 2- Bus operation analysis and schedule adherence:** Five observation points were chosen in order to record and document the bus service performance, arrival & departure times, schedule adherence, actual head-way on the route, and also to compare the survey data with the operating schedule in use for public.

Furthermore, on Friday, November 4, 1994, Phase-II of the survey was conducted. This time it took place inside the bus in order to record the bus movement, servicing and operation timing along the route, documenting the stopping and moving steps due to the

transit stops or the traffic control signs and devices, and calculating the actual driving time as well as the actual time lost (delays) occurring on the road during operation

As previously stated, a key purpose of this study was to document the problem of bus delays associated with the existing road network mixed traffic. A detailed analysis for bus operation would indeed highlight the predominant delay issues on that route or any other bus routes merging into the traffic flow on the road network. In addition, the commencement date of this study coincided with major construction on Somerset Street from Bronson to Kent Street, and that was scheduled for a good portion of the fall season. Given the likely abnormal bus delay patterns occurring at this time period, it was not considered prudent to conduct further surveys until such time as the key problems found in the initial survey were fully addressed.

2.2.1 Phase I. (Wednesday, August 10, 1994):

Before the survey started, all of the survey team members were asked to synchronize their watches according to the CBC clock radio on the 07:00 a.m. news. This was to eliminate errors, increase accuracy of the data collected, and assure that the travel time and the actual operating speed between any two observation points were not dependent on the listed bus schedule, but would present the actual travel time recorded on site during the survey day.

The survey conducted on Wednesday, August 10, 1994 was broken into two components, traffic count and bus operation, which are briefly explained in the following subsections. A one-day traffic count and bus #2 operation and schedule adherence survey

was conducted in order to collect as much information as possible on the existing bus #2 schedule and performance associated with the traffic situation on its route. Two video cameras were installed at the corner of each of these two intersections: **Rideau Street & Charlotte Street** and **Montreal Road & St. Laurent Boulevard**. For more than one hour (only during the a.m. peak-hour period between 7:00 and 09:00) the video cameras monitored closely and recorded the movement of the mixed traffic between and through the two intersections and especially focused on the bus operation and its activities at the adjacent bus stop to the intersection while approaching, loading, and unloading passengers. Arrival and departure times were also recorded manually, as well as documented through the video taping.

Furthermore, a traffic count was recorded for each direction through the intersection and was manually extracted from the video tape and summarized in both **Figures: 2.2-A and 2.2-B**. Also, it was summarized in **Tables: 2.1-A and 2.1-B** in order to compare the findings (result) of the RMOC counts in June, 1993 and the survey counts in August, 1994. Both of the RMOC and the survey counts were conducted on a similar week-day, a.m. time period, as well as under the same driving and weather conditions. Also, **Table 2.2** summarizes the study area traffic survey results and the data collected from bus #2 field observation. Each bus was identified by its four digit identification numbers. The bus identification number is written on the panel located below the front wind shield and below the rear window. Observers listed all buses by the arrival time at their location in sequence.

Wed. Aug. 10, 1994
Traffic Survey for Bus #2
East-bound - A.M. Peak-Hour

Road Conditions: Sunny and Dry
 Time of Count: 07:45 to 08:45 A.M.
 Intersection: Montreal Rd and St. Laurent

(666) RMOC Traffic Count (actual peak hour count)
 Peak-hour, Thursday June 24, 1993 (same times and conditions)

Figure 2.2-A: INTERSECTION TRAFFIC COUNT
(St. Laurent & Montreal Road)

(Source: RMOC & Field Count)

Wed. Aug. 10, 1994
Traffic Survey for Bus #2
Eastbound - A.M. Peak-Hour

Road Conditions Sunny and Dry
Time of Count 07:25 to 08:25 A.M.
Intersection Rideau St. and Charlotte

(551) RMO Traffic Count (actual peak hour count)
Peak-Hour, Monday, June 14, 1993 (same times and conditions)

Figure 2.2-B: INTERSECTION TRAFFIC COUNT
(Charlotte & Rideau Street)
(Source: RMO & Field Count)

Wed. Aug. 10, 1994
Traffic Survey for Bus #2
Traffic Count Break-Down
Montreal Rd. & St. Laurent

Table 2.1-A : COMPARISON BETWEEN RMOC & FIELD TRAFFIC COUNTS

East-Bound Traffic								West-Bound Traffic						
RMOC Count				Survey Count				RMOC Count			Survey Count			
Direction	P.Car	HV & Bus	Total	P.Car	HV	Bus	Total	P.Car	HV & Bus	Total	P.Car	HV	Bus	Total
LT	27	N/A	27	33	0	1	34	235	N/A	235	145	10	0	145
TH	367	27	394	392	8	5	405	625	41	666	520	14	8	542
RT	75	N/A	75	101	7	4	112	120	N/A	120	100	N/A	N/A	100

Wed. Aug. 10, 1994
Traffic Survey for Bus #2
Traffic Count Break-Down
Charlotte & Rideau St.

Table 2.1-B : COMPARISON BETWEEN RMOC & FIELD TRAFFIC COUNTS

East-Bound Traffic								West-Bound Traffic						
RMOC Count				Survey Count				RMOC Count			Survey Count			
Direction	P Car	HV & Bus	Total	P Car	HV	Bus	Total	P Car	HV & Bus	Total	P Car	HV	Bus	Total
LT	No left turn		0	No left turn			0	512	N/A	512	333	9	0	342
TH	406	30	436	471	18	14	503	499	52	551	491	16	21	528
RT	27	N/A	27	42	2	0	44	46	N/A	46	37	1	N/A	38

Wed. Aug. 10, 1994
Traffic Survey for Bus # 2
East-Bound - A.M. Peak-Hour

Table 2.2 : BUS #2 SCHEDULE AND FIELD OBSERVATION

Bus stop = 6451				Bus stop = 4987				Bus stop = 2361				Bus stop = 2329				Bus stop = 1806							
Richmond at Forest				Richmond & Churchill				Somerford at Preston(*)				Rideau St. at Charlotte(**)				Montréal Rd. at St. Lawrence							
Bus #	OC-Transpo	Bus #	Arrival	OC-Transpo	Bus #	Arrival	OC-Transpo	Bus #	Arrival	OC-Transpo	Bus #	Arrival	OC-Transpo	Bus #	Arrival	OC-Transpo	Bus #	Arrival	OC-Transpo				
Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule	Time	Schedule				
a 20 minutes				a 20 minutes				a 20 minutes				a 10 minutes				a 10 minutes							
8655	7:27:00		7:25:00	8655	7:39:45		7:30:00	8647	7:33:00		7:35:00	8868	7:09:00		7:09:00	8647	8:07:30		8:10:00				
8645	7:30:00		7:40:00	8645	8:00:30		7:50:00	8748	7:44:00		7:45:00	8605	7:17:00		7:19:00	8748	8:17:20		8:20:00				
8697	8:00:00		8:00:00	8697	8:21:50		8:15:00	8655	7:56:00		7:55:00	8613	7:28:00		7:29:00	8655	8:27:50		8:30:00				
8666	8:30:00		8:25:00	8666	8:45:00		8:30:00	8855	8:04:00		8:05:00	8532	7:33:00		7:39:00	8855	8:37:55		8:40:00				
8728	8:50:00		8:40:00	8728	9:03:50		8:55:00	8620	8:27:00		8:30:00	Missed trip Bus delay(***)								8645	8:44:45		8:50:00

2.2.2 Phase II. (Friday, November 4, 1994):

On the Friday morning during the rush hour period, video taping was conducted in order to document the bus operation and evaluate the services introduced to the public through the OC-Transpo bus service. During the course of this survey, the video camera was installed inside the bus and was aimed outside to record the actual bus traffic movement and the number of stops-stops due to traffic signals and/or loading/unloading passengers. The purpose of this survey was to calculate and breakdown the actual time spent on the route into, time spent at each transit stop, total time serving passengers, time lost due to each traffic control signals, and the actual driving time (while the bus was in motion). The survey started at 06:30 a.m. and finished at 01:15 p.m. on the same day. Data collected during the lunch period (12:00 to 01:00 p.m.) was very similar to the one collected during the rush hours. The bus drivers explained that this route is always busy. On the bus route #2, there are three high schools and the students participate in many activities; therefore, they make steady use of the bus services during the day. However, this bus runs through the downtown area and services many types of customers during the day and evening. It is also noted that this bus route normally experiences delays.

2.3 Summary of Data Analysis:

This section presents in an orderly and concise manner what information was derived from the intersections video taping, traffic count results, bus operation analysis, and the schedule adherence and actual headway in order to assess the existing bus operation and time table.

2.3.1 Analysis of Traffic Counts:

Tables 2.1-A and 2.1-B presents a summary of the key characteristics of each intersection count, including a traffic break-down by vehicle type (passenger car, heavy vehicle, and bus) and by direction (left turn, through traffic, and right turn). Then, the traffic count data were compared with the RMOC data. It is apparent from the summary tables and figures that there is a significant difference in number of vehicles between the two sets of data in most cases. These differences may relate to the changes in the traffic regulatory signs installed at the intersections. Also, traffic was broken down by type of vehicle in order to determine the number of heavy vehicles associated in traffic. Another issue, presented within the summary tables, needs to be noted. The RMOC traffic count considered buses as heavy vehicles, but for this research purposes buses were counted separately. Key data which may be summarized from Tables 2.1-A&B are listed hereafter:

- * There are fewer vehicles in the total East-bound traffic in the RMOC count than the actual survey count at both intersections, while there is a higher vehicular count in the West-bound traffic in the RMOC count than the actual survey count.
- * The RMOC figures show an approximate 50% decrease in the left & right turn movements than the actual count within the East-bound traffic and between 3% to 15% decrease in through traffic.
- * There is a range between 20% to 60% increase in the left & right turn in west-bound vehicles than the actual survey count, and a 4% to 20% increase in through traffic in the west-bound vehicles.

- * Another issue, worth mentioning from the video tape output data results, was that there was an average of 6 to 10 seconds servicing time spent on each bus stop location (loading and unloading passengers).

2.3.2 Analysis of Bus Route #2:

Based on both the survey results and the data collection process, a number of immediate measures may be taken to alleviate the key schedule up-date and the traffic congestion problems on the bus route #2 or any other bus routes within the OC-Transpo network. It should be recognized that the bus delays may be in fact only a symptom of other problems such as heavy traffic during peak-hour periods, number of heavy vehicles, left and right turn lanes, road geometric design, weather conditions, long headway during and/or off peak-hours, un-synchronized traffic control signals, inefficient traffic control signals, and of course, the high number of traffic control devices installed on the road network.

Five observation points were carefully selected on the bus route #2 in order to record and measure the services and accuracy of the bus scheduling system. These observation points were intentionally selected because of their close proximity to an apartment building and/or busy commercial area such as a shopping centre. Total distances between the intersections and observation points were scaled off an accurate Ottawa map, as well as measured by the car odometer from one point to the other. The data collected during the survey were summarized to illustrate the duration spent driving between the selected observation points on the bus route.

Figure 2.3 summarizes the overall results and the characteristics of the bus route #2, specifically, total distance, average travel time, average operating speed, number of traffic control devices, and number of bus stops on the route. Also, the previous Table 2.2 has the actual details for each bus on the route, comparing actual arrival and departure times with OC-Transpo scheduled times. Key results from Figure 2.3 are listed below:

1. Total bus route distance is 25.6 km
2. Average operating speed is 17 km/h
3. Average travel time for the journey is 1.5 hour.
4. Total number of traffic signals on the intersections along the bus route are 92 signals.
5. Total number of bus stops located to service passenger within the bus route are 92 locations.

The average bus operating speed was calculated from the over-all route results. Table 2.2 concluded bus route #2 performance between 7:00 and 9:00 a.m.. For example, Bus #8655 departed bus station #6451 (location: Richmond Road & Forest Street) at 07:27:00 a.m. and arrived at bus station #1896 (location: Montreal Road & St. Laurent Boulevard) at 08:27:50 a.m., a total of 1.0139 hour (60 minutes and 50 seconds). The total distance is 16.3 kilometres (distance was measured by car odometer as well as scaled off a street map).

Wed. Aug. 10, 1994
Traffic survey for Bus #2
East-Bound - A.M. Peak-Hour

STUDY AREA TRAFFIC SURVEY RESULTS

BAYSHORE DR. SHOPPING CENTRE	FOREST ST. LINCOLN HEIGHTS	RICHMOND @ CHURCHILL	SOMERSET @ PRESTON	RIDEAU ST. @ CHARLOTTE	MONTREAL RD. @ ST. LAURENT	BLAIR STATION
•	•	•	•	•	•	•
•<—	—	—	BAYSHORE TO BLAIR STATION	—	—	—>•
•<—	—	—	TOTAL DISTANCE 25.62 Km.	—	—	—>•
•<—	—	—	AVERAGE SPEED 17.25 Km/h.	—	—	—>•
•<—	—	—	TOTAL TRAVEL TIME 01:29:06 HOUR	—	—	—>•
DISTANCE	2.9 Km	3.73 Km	4.26 Km	5.13 Km	2.64 Km	6.96 Km
AVERAGE	00:09:48	00:13:11	00:14:52	00:22:45	00:09:10	00:19:20
BUS TRAVEL TIME (TOTAL OF 01:29:06)						
AVERAGE	17.75 Km/h	16.98 Km/h	17.19 Km/h	13.53 Km/h	17.8 Km/h	21.60 Km/h
BUS SPEED (TOTAL AVG. 17.25 Km/h.)						
No. OF	(6)	(8)	(14)	(36)	(13)	(15)
TRAFFIC CONTROL SIGNALS (TOTAL OF 92)						
No. OF	(12)	(13)	(18)	(20)	(11)	(18)
BUS STOPS (TOTAL OF 92)						

Figure 2.3 : BUS ROUTE #2 PATH CHARACTERISTICS
SUMMARY OF DATA COLLECTION

Many researchers focused on the general traffic pattern and their research concluded that any traffic movement over a certain path depends on the time available to move from one point to another (the total travel time depends on the total trip distance). Consequently, the average flow within the network could be expressed as the form of space mean speed and concentration. The description of traffic patterns and vehicles flow on any road network is primarily measured in terms of volume, speed, concentration, and headway [12,36]. As a general observation, vehicle motion depends on vehicle performance (movement) which is governed by the characteristics of the vehicle and the path, vehicle motion along a path (Newton's laws), and other outside forces involved in vehicle motion. Definitions of some of the vehicle flow measures follow:

Volume is the number of vehicles passing a specified point on a road network at a specified time. Volume is measured in units of vehicles per unit time, and can be expressed as:

$$q = n / t$$

where: q = traffic volume

n = number of vehicles passing a specified point during a specified time interval

t = specified time spent in observation

Speed is the distance covered by a moving vehicle over a specified unit time, and can be expressed as:

$$u = L / t$$

where: u = vehicle speed

L = distance covered by a vehicle during a specified time interval

t = spent time

Concentration is the **Density** of traffic over a specific area or a link of a road at a point in time, and can be expressed as:

$$k = n / L$$

Where: K = concentration of vehicles on a road with L length at a point of time

n = number of vehicles on the road

L = length of the road

or using the general flow relationship:

$$q = k u$$

Headway is defined as the **Time** passing between the time at which the front of a specific vehicle passes an observed point on the road and the time the front of the following vehicle passing through the same observed point, and could be expressed as:

$$h = 1 / q$$

where: h = mean time headway

q = volume of traffic

These variables were calculated and used to identify the different components of the survey results and set up the measures of the traffic flow within the existing road network. **Table 2.3** lists the study area traffic survey results including the vehicle flow measures calculated from the above mentioned variables and by using the actual survey results and data collected from the RMOC [12,37,38].

Table 2.3: FIELD DATA - VEHICLE FLOW MEASURES

STUDY AREA TRAFFIC SURVEY RESULTS

Section of Bus Rout # 2 on Bank Street	Traffic Volume (Veh/h) q	Length/ Distance (Km) L	Speed (Km/h) u	Concentration Density (Veh/Km) k	Mean Headway (Seconds) h(sec)	Mean Headway (Metres) h(m)
Somerset to Lisgar	547	0.20	20	27.40	6.60	36.50
Lisgar to Gloucester	414	0.20	22	18.80	8.70	53.20
Gloucester to Laurier	361	0.10	12	30.10	10.00	33.20
Laurier to Slater	265	0.10	10	26.50	13.60	37.70
Slater to Albert	236	0.10	20	11.80	15.30	84.70

Note: $u = L/t$, $k = q/u$, $h(\text{sec}) = 3600/q$, and $h(\text{m}) = 1000 \text{ m/h}$

Sources of information:

* RMCOC peak-hour traffic count (08:00 to 09:00 a.m.)

* Results of survey on Wednesday, August 10, 1994

2.3.3 Grand Summary for Data Gathering:

1. The bus serviced customers and made complete stops at an average of 81.5% (75 stop out of 92 stop) of the transit stops designated along its route, and spent the total of 00:14:56 minutes loading and unloading passengers. This is equal to 17% of the total trip time.
2. The bus was stopped completely at 48% of the traffic control signs (44 out of 92 traffic stops). Due to the red-interval timing the bus experienced some delays. These delays were equal to 00:17:59 minutes and represented 20.50% of the total trip time.
3. The total trip time (average) was equal to 01:27:50 seconds and the actual driving time was 00:54:56 seconds. The actual time in which the bus was in motion represents 62.50% of the total trip time.

The above mentioned results indicate a significant number of delays experienced due to the traffic control devices. If these delays were prevented, the bus could travel faster and provide better service for its users. The overall average speed was measured along the route and varied between 16.8 and 18.4 Km/h, however, this could be improved to 24 Km/h if the traffic delays were prevented and eliminated from the total trip time. Results are summarized on both **Table 2.4** and **Figure 2.4**. This data represents an average of the total data collection during the rush hour period. This average was taken from four trips on the same day but at different time intervals.

Friday, November 4, 1994
 East-Bound - A.M. Peak-Hour
 System Operation & Evaluation
 Average data collection from four bus trips:

Table 2.4 : BUS ROUTE #2 VIDEO TAPE DATA ANALYSIS

	Trip 1	Trip 2	Trip 3	Trip 4	Average	Total Number On system	Percentage Utilized On route
No. of transit stops utilized:	68	77	79	76	75	92	81.52%
No. of traffic lights observed:	34	45	51	47	44.25	92	48.10%
No. of stop signs on the route:	6	6	6	6	6	6	100.00%
Total time spent on transit stops:	00:12:57	00:15:10	00:16:15	00:15:20	00:14:56	01:27:50	17.00%
Total time spent on traffic delays:	00:15:10	00:18:40	00:19:30	00:18:35	00:17:59	01:27:50	20.40%
Actual / Total driving time:	00:54:53	00:53:55	00:55:44	00:55:10	00:54:56	01:27:50	62.60%
Total trip time:	01:23:00	01:27:45	01:31:29	01:29:05	01:27:50	01:27:50	100.00%
Average bus delays: (compared to OC-Transpo scheduled)	00:02:00	00:02:45	00:08:30	00:03:05	00:06:17		
Average speed: (Km/h)	18.4	17.4	16.7	17.2	17.4		
Average speed / Without traffic delays: (Km/h)	21.8	22.1	21.3	21.7	21.9		

STUDY AREA TRAFFIC SURVEY RESULTS

Figure 2.4: BUS #2 TOTAL TRAVEL TIME

CHAPTER 3

COMPUTER SIMULATION

3.1 Introduction:

After collecting all the relevant data, a search for a computer simulation model was required. For the thesis's purpose, the recommended software package, which is available at the Department of Civil and Environmental Engineering, Carleton University, was the **TRAF-NETSIM** or **NETSIM** for short (this is to be used for any future references). **TRAF-NETSIM** is an abbreviation for **Traffic NETwork SIMulation**. **NETSIM** performs a detailed simulation of traffic flow through a street network. Also, **NETSIM** software package can provide a complete and reliable estimate on various traffic delays, consider public/transit transportation vehicles as a major component in the actual traffic network, and provide a separate analysis for it. The program models each vehicle within the network every second while it is moving through the network. As a result, the program will provide a very detailed analysis for the traffic flow and breakdown estimation for the traffic operation and performance [39,40,41].

The **TRAF-NETSIM** program was developed and released in 1986 under the sponsorship of the Federal Highway Administration (FHA) at the U.S. Department of Transportation, Office of Safety and Traffic Operations, Research and Development. Since 1986, several updates and enhancements have been incorporated into **NETSIM**. The latest available version of **NETSIM**, is the micro-computer Version-IV, released in 1993.

In addition, since the NETSIM software is a Fortran-coded program, the internal art of reasoning in the program is based on the car-flow analogy. This analogy contains an information centre and includes the queue formation/dissipation statistics, algorithms of the lane changes and the associate numerics, driver behaviour, and the vehicle characteristics, generation and trajectories. Furthermore, the NETSIM program analyzes each network according to the data input; thus, it can provide the basis for optimizing the traffic network strategy, and reports the operation performance of vehicles running on that network. At the end of each run of the program (each simulation period), a summary of the statistics analysis is available on vehicle and pedestrian performance measures i.e. speed, volume, density, stops, delays, travel time, queuing, fuel consumption...etc. [39,42,43,44].

3.2 Input Data Requirements:

Most of the information included in this section was carefully selected and summarized from the TRAF-NETSIM User's Manual [42,43]. The NETSIM users are required to input accurate information which describe the actual traffic condition in order to execute the simulation. The salient requirements to be considered in the data entry are as follow:

- * Detailed information on road-way network;
- * detailed information on traffic counts within the proposed study area, broken down by each direction; and number of vehicles entering and exiting each node;

- * traffic model within the network;
- * information on public transit vehicles i.e. bus path, bus route, and mean headway;
- * percentage of heavy vehicles on the road-way network;
- * location, number, and type of each transit stop;
- * characterization of the road-way network;
- * measurements of road-way network;
- * location and number of traffic control devices.

The data input was entered into the computer and created a data base scenario by the completion of a series of information cards included within the NETSIM software program. A description of each card type, (only those used and included during this type of research and for this study purpose) are followed, as per the NETSIM software program design [42,43,45]:

NETSIM Card Options Menu: This is the menu list for the program requirements. This menu includes all the different type of information cards required to be completed to run the simulation.

Identification, Card Type 01: Used for more than one simulation/run identification purposes.

Run Control, Card Type 02: This card is necessary to set- up the NETSIM simulation / program run. The most important entries included within this card are the initialization time and the input/output units used in the data gathering and manipulation. During this specified initialization time, the network will be filled

up with vehicles until it reaches the free flow speed. This speed will be used later in determining traffic delays and average travel speed within the network.

Time Period Specifications, Card Type 03: This card specifies the time period for each specific run, in order to execute the NETSIM run. In this research it was only used for one time period equal to 900 seconds (15 minutes) during the analysis of the a.m. Peak-hour traffic.

Time-Step Control, Card Type 04: This must be filled in order to specify the duration of the simulation period in seconds.

Output Option, Card Type 05: Card type 5 should be used to define the cumulative out-put options desired at the end of each specified program simulation period.

Urban Like Characteristics, Card Type 11: This card is to input and includes all information of the road-way geometric design and the network characteristics such as link length, number and type of lanes; it also must identify the direction of traffic flow and the interconnections of each link through the network.

Turning Movement, Card Type 21: This card is to specify and breakdown the traffic turn movement in percentages from the total traffic for each link within the network.

Sign or Pre-Timed Signal Timing, Card Type 35 & 36: These cards are combined together and to be used to identify the signal timing plan at each traffic light intersection and to specify the type of traffic control device/sign that regulates that intersection.

Entry Link Volumes, Card Type 50: This card specifies the volume of traffic mix with the balance of truck percentages (for this particular entry, number of the percentage of trucks also includes the number of transit vehicles) and the percentage of car pools within each link.

Sub-network Delimiter, Card Type 170: This card is only required to mark the end of the data for each time period.

Bus Station, Card Type 185: Card type 185 lists all the bus stations within the study area and the lanes occupied by the bus during servicing costumers at each station.

Dwell Time, Card Type 186: This card specifies the mean dwell time in seconds, as well as, the percentage of bypass buses on routes servicing each station identified earlier on card type 185.

Bus Path, Card Type 187: This card identifies the bus path for each bus route servicing within the study area.

Bus Route, Card Type 188: This card specifies the bus stations that have been designed for servicing by each bus identified earlier in card 186 & 187.

Bus Flow, Card Type 189: This card lists all of the buses within the study area corresponding to the buses identified earlier in the previous cards and their mean headway in seconds along this route and during the same time period of simulation.

Time Period, Final Card Type 210: This card is required to mark the end of each section of the data in-put (simulation case) and for a specified time period.

Figure 3.1: TRAF-NETSIM SIMULATION PROCEDURES

Furthermore, some of these information cards are marked with an **(R)**, meaning this card is required and has to be filled out for the NETSIM execution. However, some cards are optional, and thus marked with an **(O)**. **Figure 3.1** illustrates the simulation process and the NETSIM input stream.

3.3 Output Data Classification:

TRAF-NETSIM Measures Of Effectiveness:

After the data entry stage has been completed, and the micro-simulation package has successfully executed the sub-network, the TRAF-NETSIM will generate many Measures Of Effectiveness (**MOE**) on each link within the study area. These MOE's are only available through the NETSIM program at the end of a time interval specified on the card type 03. A copy of the program output is provided in **Appendix (A)**. Hereafter, is provided a description of some of the output MOE's provided by the TRAF-NETSIM program and used in the regression analysis (Chapter 5) to develop the delay model [42,43,46]:

Average Number of Vehicles: the average number of vehicles observed during the simulation period.

Vehicle Kilometres (Veh-Km): number of vehicles per kilometre adjusted by NETSIM for each link length.

Vehicle Minutes (Veh-Mins): the total time which vehicles have spent traversing each link.

Mean Travel Speed (Km/h): the total vehicle kilometres of travel divided by the total vehicle minutes.

Total Time (Veh-Min): the total travel time of all vehicles travelled through the link and those who are still present on the link when the run time is executed.

Delay Time (Veh-Min): shows the difference between the total travel time through the link and the moving time actually spent in driving under the mean free flow speed. Furthermore, the delays experienced by the average vehicle during one trip on the link is measured by Seconds/vehicles.

M/T : the ratio between the total moving time (Veh-Min) and the total travel time (Veh-Min) on a link. (Low ratio value indicates that longer delays have been experienced within the total travel time.)

Stop Time (Sec/Veh): the time spent while the vehicle could not be in motion due to traffic congestion or bus stops (dwell time) for transit vehicles.

Average Occupancy: the maximum number of vehicles found in a link at any given time (simulation time). Also, that represents the maximum traffic congestion occurring during the simulation time.

Table 3.1 shows a sample of NETSIM output on bus statistics. This include the number of trips made by transit vehicles on each link, number of passengers utilizing these vehicles, travel time on each link, actual moving time, ratio between moving time over travel time, average bus speed, and number of stops made by transit vehicles at each link.

**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
TRAF SIMULATION MODEL**

Version 4.0, Release date Apr. 1993

Table 3.1 : NETSIM BUS OUTPUTS

LINK	BUS TRIP	PERSON TRIPS	TRAVEL TIME (MINUTES)	MOVING TIME (MINUTES)	DELAY TIME (MINUTES)	M/T	SPEED (KMPH)	NUMBER OF STOPS
(8000 - 1)	2	50						
(1 - 2)	2	50	2.20	1.30	0.90	0.58	28.10	2
(2 - 3)	1	25	1.70	1.10	0.50	0.67	32.60	2
(3 - 4)	1	25	0.90	0.30	0.60	0.29	14.30	2
(4 - 5)	1	25	1.30	0.60	0.70	0.47	22.90	2
(5 - 6)	1	25	0.90	0.40	0.50	0.42	20.50	1
(6 - 7)	1	25	1.00	0.30	0.70	0.32	15.60	1
(7 - 8)	1	25	0.70	0.10	0.60	0.17	8.20	1
(8 - 9)	1	25	0.70	0.10	0.60	0.17	8.20	1
(9 - 10)	1	25	1.10	0.40	0.80	0.32	15.60	1
(10 - 11)	1	25	0.80	0.30	0.50	0.39	18.90	1
(11 - 12)	1	25	0.70	0.20	0.50	0.27	13.10	1
(12 - 13)	1	25	0.70	0.40	0.30	0.52	25.30	0

Sample of TRAF-NETSIM program out-put.
Section [2], from Lincoln Heights Galleria to Richmond R.J. & Churchill Ave.

**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
TRAF SIMULATION MODEL**

Version 4.0, Release date Apr. 1993

Table 3.2 : NETSIM ROUTE OUTPUT

ROUTE	BUS TRIP	TOTAL TRAVEL TIME (BUS-MIN)	MEAN TRAVEL TIME (SEC/BUS)	PERSON TRIPS	PERSON TRAVEL TIME (MINUTES)
2	1	7.70	526.70	25	192.50
5	1	1.10	77.90	25	28.80
11	1	6.00	449.00	25	150.40
14	1	0.60	48.50	25	14.20
18	1	0.80	48.50	25	20.40
19	1	1.10	48.50	25	27.10
20	1	8.10	474.60	25	201.30

These estimates assume an average bus occupancy of 25.0 passenger per bus throughout the network.

Sample of TRAF-NETSIM program output.

Section [6], from Rideau St. & Charlotte to Montreal Rd. & St.Laurent Boulevard

Also, **Table 3.2** presents a sample of the route statistics for each bus on the network. This table includes the number of bus trips throughout the network, total travel time, mean travel time, and number of passengers served in the network area with their travel time spent on the system.

The following is a list of the definitions of each heading:

Bus Trips: only the total number of buses that have completely finished their routes.

Bus Minutes: the total travel time accumulated by all the buses on a link.

Person Minutes: the total travel time (for all passengers) spent on the bus route.

Person Trips: the total number of passengers on the buses which completed their routes. (NETSIM estimates an average occupancy of 25 passengers per bus throughout the route)

Delay Time (Bus-Mins): the difference between the bus travel-time and the bus moving-time.

Mean Travel Time (Sec/Bus): the average travel time for a bus to pass across the entire route.

3.4 Methodology and Data-Entry:

Once all the data is entered into the program and ready to be used, the initial step in data preparation is the data aggregation. The TRAF-NETSIM program has a limited capacity: the maximum size of the area network which can be simulated is 75 nodes (intersection), 150 links (direction of traffic), 1500 vehicles, and not more than 256 buses. The hardware available on campus was a 486 P.C. with 8 M Ram which also has a limited capacity in memory and therefore cannot allow a large simulation and a data analysis to be executed. Thus, it was essential to break the study area (bus route #2) into six sections in order to accommodate the available resources of the software and the hardware. Arbitrarily, it was possible to divide the network area to six sections according to its geographical locations. However, many trials were made to include all of the downtown area in one section (section 4). Finally, in order to achieve the measures of effectiveness for the proposed study area, a total of the six sections will be summed up [35,45].

A list of the six sub-network sections follows:

BUS OPERATION STUDY

BUS ROUTE #2

Section [1]

BAYSHORE SHOPPING CENTRE.

BAYSHORE & WOODRIDGE
 BAYSHORE & RICHMOND
 RICHMOND & BELLFIELD
 RICHMOND & LOVITT
 RICHMOND & GRENON
 RICHMOND & MARIFLLE
 RICHMOND & PINECREST
 RICHMOND & CARLING
 RICHMOND & POULIN
 RICHMOND & FOREST
 RICHMOND & CROYDON
 RICHMOND & ASSALY
LINCOLN HEIGHTS GALLERIA.

Section [2]

LINCOLN HEIGHTS GALLERIA

RICHMOND & EDGORTH (McEWEN)
 RICHMOND & WOODROFFE
 RICHMOND & LOCKHART
 RICHMOND & CLEARY
 RICHMOND & WAVELL
 RICHMOND & WESTMINSTER
 RICHMOND & FRASER
 RICHMOND & BROADVIEW
 RICHMOND & GOLDEN
 RICHMOND & ROOSEVELT
RICHMOND & CHURCHILL.

Section [3]

RICHMOND & CHURCHILL

CHURCHILL & SCOTT
 SCOTT & McRAE
 McRAE & RICHMOND
 RICHMOND & CLIFTON
 RICHMOND & KIRKWOOD
 RICHMOND & ISLAND PARK
 WELLINGTON & PICCADILLY
 WELLINGTON & WESTERN
 WELLINGTON & HAMPTON
 WELLINGTON & GRANGE
 WELLINGTON HARMER
 WELLINGTON & HOLLAND
 WELLINGTON & HAMILTON
 WELLINGTON & PARKDALE
 WELLINGTON & ROSEMOUNT
 WELLINGTON & MELROSE
 WELLINGTON & IRVING
 SOMERSET & BAYSWATER
SOMERSET & PRESTON

Section [4]

SOMERSET & PRESTON
SOMERSET & ROCHESTER
SOMERSET & BOOTH
SOMERSET & BRONSON
SOMERSET & PERCY
SOMERSET & LYON
SOMERSET & KENT
SOMERSET & BANK
BANK & LISGAR
BANK & GLOUCESTER
BANK & LAURIER
BANK & SLATER
BANK & ALBERT
BANK & QUEEN
BANK & WELLINGTON
WELLINGTON & O'CONNER
WELLINGTON & METCALFE
WELLINGTON & ELGIN
RIDEAU & SUSSEX
RIDEAU & WILLIAM
RIDEAU & DALHOUSIE
RIDEAU & CUMBERLAND
RIDEAU & KING EDWARD
RIDEAU & NELSON
RIDEAU & FRIEL
RIDEAU & CHAPEL
RIDEAU & AUGUSTA
RIDEAU & COBOURG
RIDEAU & CHARLOTTE

Section [5]

RIDEAU & CHARLOTTE
RIDEAU & WURTEMBERG
MONTREAL & RIVER
MONTREAL & PALACE
MONTREAL & VANIER PARKWAY
MONTREAL & SAVARD
MONTREAL & CODY
MONTREAL & LACASSE
MONTREAL & LAFONTAINE
MONTREAL & DUCHARME
MONTREAL & CHURCH
MONTREAL & ST. LAURENT

Section [6]

RIDEAU & ST. LAURENT
RIDEAU & CENTRE
MONTREAL & AVIATION PARKWAY
MONTREAL & CODY'S (CARSON'S)
MONTREAL & HOCHÉLOGA
MONTREAL & BATHGATE
MONTREAL & ELMSMERE
MONTREAL & OGILVIE
OGILVIE & JASMINE
OGILVIE & BLAIR
BLAIR STATION

3.5 Network Configuration:

A total of 99 nodes and 519 links have created a computer file for the study area road network. As explained earlier, it was not possible to have the total network analyzed all in one simulation run (one file). A breakdown of the study area was essential to adapt the nature of the program design. Consequently, the author contacted the software

developer for consultation, and their recommendation was to follow the program guideline and capacity. The first attempt was to break the network into three sections. Although the simulation run was completed, the output results were not satisfactory (when compared with the actual field data). The number of vehicles at the peak-hour traffic in some links of the road network exceeded the limits. In such road traffic situations NETSIM considers a spill-back condition on these links. However, in the case of a spill-back situation, traffic on all lanes extends into the upstream intersection. Furthermore, TRAF-NETSIM-MOE's did not match the actual road network characteristics or the field data. For the second attempt, six sections were carefully selected and each created its own data base file. The CBD was contained in Section [4], and was simulated in a separate run. The output results were satisfactory and very similar to the actual traffic conditions in the road network. Each section was simulated separately and a data file was created. All the street intersections were given a number, as well as the entry/exit links. Entry links are the links which carry traffic into the study area, and the exit links carry traffic outside the study area. Both entry and exit links are connecting the upstream nodes with the study area. The upstream nodes are numbered between 8000 and 8999. The internal nodes which link the study area together, are numbered between 1 and 750. **Figure 3.2** explains the different types of nodes and links used by NETSIM software. Also, **Figure 3.3** showed section [I], as an example of a sub-network traffic flow. Each intersection and direction of traffic was given a number to create a coded road network. These numbers were used to identify street directions and to help complete the simulation process.

**Figure 3.2 : TRAF-NETSIM SIMULATION PROGRAM
TYPES OF URBAN NODES AND LINKS**

**Figure 3.3 : TRAF-NETSIM Sub-Network Configuration
Section [1], Bayshore to Lincoln Heights Galleria**

3.6 Analysis and Simulation Results:

After successful simulations of the road network sections, the preprocessor program was used to create a series of NETSIM data files for the bus route #2. Three scenarios were created; each scenario represented all of the network configurations during the a.m. peak period.

The three different scenarios for the road network configuration were as follows:

1. The first road scenario presents the actual street network (i.e. the actual traffic condition and street geometric).
2. The second road scenario presents the network condition while one traffic lane is blocked (i.e. accident, fire, snow removal situation).
3. The third road scenario proceeds with the network under ideal traffic control condition (always green in order to offer the right-of-way (**ROW**) to the bus).

Figure 3.4 illustrates a brief comparison between the three traffic scenarios created and developed by NETSIM simulation program.

Using the simulation results helped in comparing the existing/normal traffic condition with the best case and the worst case traffic scenario. The worst case of bus traffic scenario was introduced in a form of one lane blocked; however, the best case scenario is presented by having the bus moving without any restriction (bus-right-of-way).

Figure 3.4 : COMPARISON OF TRAFFIC CASE SCENARIOS
TRAF-NETSIM Simulation Program Results

The concept of bus-right-of-way means that as a bus approaches the intersection, the detector will send a signal to the traffic light controller device and activate the cycle setting to the green-phase. The time spent during this phase will be calculated to be sufficient for the bus to pass that same intersection towards its destination. This operation will be identified as the "The Public Transit Operation Phase" (**PTO-Phase**). After the bus passes that particular intersection, the regular phase cycle should be continued and serve the other direction.

Using the **TRAF-NETSIM** simulation program has helped build an imaginary street network with a PTO-Phase. The simulation results have shown a great amount of saving on the bus total travel time. **Tables 3.3 and 3.4** summarizes the simulation results for bus route #2 during the three traffic scenarios. Also, Table 3.3 includes a breakdown for the six sub-network sections, as well as the total route results, and contains the average delay times, the average operating speed, and the mean travel time per bus. The total route analysis is the summation of the six sections. The bus average speed was calculated from averaging the bus speeds on each link for each section separately. However, the average speed for all of the bus route was calculated from dividing the total route length by the bus mean travel time. All of the other information provided is an average from the link statistical results at each section.

It is important to know that delays measured by NETSIM output statistics are the difference between the mean travel time and vehicle travel time in the free flow condition.

Table 3.3 :

**ANALYSIS OF TRAFFIC SIMULATION
TRAF-NETSIM Program Output**

BUS ROUTE	LENGTH (KM)	AVG DELAY (MINUTES)				AVG SPEED (KM/PH)				MEAN TRAVEL TIME (MIN BUS)			
		NORMAL	BLOCKED	LANE	GREEN	NORMAL	BLOCKED	LANE	GREEN	NORMAL	BLOCKED	LANE	GREEN
		TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC	TRAFFIC
SECTION 1	2.80	6.80	8.70		5.03	17.40	16.30		21.22	9.40	11.30		8.60
SECTION 2	3.90	6.20	7.30		4.82	18.60	17.90		23.60	11.60	12.10		9.60
SECTION 3	4.30	9.40	11.30		6.90	18.30	16.70		22.22	15.20	17.00		9.20
SECTION 4	5.10	14.40	15.33		8.35	14.69	13.07		22.72	20.83	23.42		13.47
SECTION 5	2.60	5.80	6.60		3.76	16.00	14.80		20.82	8.78	9.50		7.10
SECTION 6	6.90	9.50	11.00		6.40	22.20	21.30		27.08	18.10	19.60		15.10
ALL ROUTE	25.60	52.10	60.23		35.26	18.31	16.53		24.35	83.91	92.92		63.07
BENEFIT		0.00	-8.13		16.84	0.00	-1.78		6.04	0.00	-9.01		20.84

MEASURES OF EFFECTIVENESS
 TRAF-NETSIM SIMULATION MODEL
 BUS STATISTICS OUTPUT RESULTS

Table 3.4 : COMPARISON OF TRAFFIC CASE SCENARIOS

	BAYSHORE SHOPPING CENTER		FOREST SL LINCOLN HEIGHTS		RICHMOND @ CHURCHILL		SOMERSET @ PRESTON		RIDEAU SL @ CHARLOTTE		MONTREAL RD @ St LAURENT		BLAIR STATION	TOTAL BUS ROUTE
	*	1	*	2	*	3	*	4	*	5	*	6	*	
SECTION *														
SUB-NETWORK TRAFFIC SIMULATION														
BASE CASE:														
MEAN TRAVEL TIME		00:09:24		00:11:36		00:15:13		00:20:49		00:08:47		00:18:07		01:23:56
MEAN DELAY TIME		00:06:48		00:06:12		00:09:26		00:14:23		00:05:48		00:09:27		00:52:40
AVERAGE SPEED		17.4 Km		18.6 Km		18.3 Km		14.5 Km		16.0 Km		22.2 Km		18.3 Km
GREEN CASE:														
MEAN TRAVEL TIME		00:05:35		00:09:35		00:12:42		00:14:17		00:07:14		00:15:14		01:07:37
MEAN DELAY TIME		00:05:02		00:04:49		00:06:54		00:08:21		00:03:46		00:06:24		00:35:16
AVERAGE SPEED		21.2 Km		23.6 Km		22.2 Km		22.7 Km		20.8 Km		27.8 Km		24.4 Km
ONE LANE BLOCKED														
MEAN TRAVEL TIME		00:11:19		00:12:03		00:16:59		00:23:25		00:09:28		00:19:33		01:32:47
MEAN DELAY TIME		00:08:42		00:07:15		00:11:20		00:15:20		00:06:35		00:10:57		01:00:09
AVERAGE SPEED		16.3 Km		17.9 Km		16.7 Km		15.1 Km		14.8 Km		21.3 Km		16.5 Km

Summary of TRAF-NETSIM Simulation Program Results

Table 3.4 provides detailed information on bus activity in each section. Under the normal traffic conditions results indicated that the bus route #2 traversed the entire network (bus path/study area) in 01:23:56 seconds, the average bus delays for the total route comprised 00:52:40 seconds, and the average speed calculated from the total bus route was 18.3 Km per hour. Furthermore, in the case of one lane blocked in the network/study area, the bus traversed the same distance in 01:32:47 seconds (10.5% more in travel time), the average bus delays added up 01:00:09 seconds (14.2% more delays), and the average operating speed was decreased to 16.5 Km/h (reduced by 9.8%).

Conversely, the benefits from using the Public Transit Operation Phase (**PTO-Phase**), i.e. "all green case", bus-right-of-way, reflect an improvement on the overall bus performance. The simulation results shows a lot of benefits for bus operation. The expected mean travel time for the network area was 01:07:37 seconds (reduction of travel time by 19.4%) , the average bus delays decreased to 00:35:16 seconds (expected reduction of 33%), and the average operating speed rose to 24.4 Km/h (24% increase).

In order to make a clear comparison between the best and worst case scenario, **Table 3.5** summarizes the percentage of improvement due to the "all green" bus-right-of-way, and the percentage of deterioration due to one-lane blocked for each section as well as for the total bus route. The above mentioned data results have a two fold situation analysis. There is a definite improvement in the public transit operation, and a sharp deterioration level-of-service for the private vehicles.

MEASURES OF EFFECTIVENESS
 TRAF-NETSIM SIMULATION MODEL
 BUS STATISTICS OUTPUT RESULTS

Table 3.5: COMPARISON OF TRAFFIC CASE SCENARIOS
 PERCENTAGE OF IMPROVEMENT AND DETERIORATION

	[1]	[2]	[3]	[4]	[5]	[6]	TOTAL BUS ROUTE
<u>BUS-RIGHT-OF-WAY:</u>							
PERCENTAGE OF IMPROVEMENT ON SUB-NETWORK TRAFFIC:							
TRAVEL TIME:	08.7 %	17.4 %	16.5 %	29.8 %	25.4 %	16.8 %	19.4%
DELAY TIME:	26.0 %	22.3 %	26.9%	42.0 %	43.0 %	32.3 %	33.0%
SPEED:	21.8 %	26.9 %	21.3 %	47.6 %	40.5 %	22.2 %	24.0%
<u>ONE-LANE-BLOCKED:</u>							
PERCENTAGE OF DETERIORATION ON SUB-NETWORK TRAFFIC							
TRAVEL TIME:	20.4 %	03.9 %	11.6 %	12.5 %	07.8 %	08.0 %	10.5%
DELAY TIME:	27.9 %	16.9 %	20.0 %	06.6 %	13.5 %	16.0 %	14.2%
SPEED:	06.3 %	03.2 %	08.7 %	12.2 %	07.5 %	03.9 %	9.8%

TRAF-NETSIM Simulation Program Results

NOTE: TABLE PERCENTAGE WERE EXTRACTED FROM THE BASE CASE SCENARIO TRAFFIC SIMULATION RESULTS

Finally, since the intention of the study is to enhance the bus operating system and attract more users towards the public transportation modes, the author will be focusing only on the benefits of using the, "all-green", bus-right-of-way (PTO-Phase).

Hereafter, **Figure 3.5** illustrates a quick reference for the data results and comparison of sub-network traffic simulation. The bar-graph figure summarizes the simulation output and compares the final results of the three different scenarios.

(A)

(B)

(C)

Figure 3.5 : COMPARISON OF SUB-NETWORK DATA RESULTS
TRAF-NETSIM PROGRAM SIMULATION RESULTS

CHAPTER 4

STUDY AREA TRAFFIC ANALYSIS

4.1 Stopped-Time Delays:

Before defining delay, the author wants to describe the activity involved within a bus trip from one point to another. The total travel time and the average speed between any two transit stop locations along the bus route are affected very much by the total distance and the time which elapses from the instant the bus comes to a stop at the first location to the time it comes to rest at the next. This time includes dwell-time, time spent at the first location serving passengers, acceleration time until the bus reaches its operating speed, travel time at operating speed, and deceleration time until the bus comes to a full stop at the next location. Furthermore, this might include time spent on traffic delays (i.e. cycle length and queue times) due to signalized/non-signalized intersections, and the queue-time [47].

Researchers have described delay as a complex variable that is sensitive to a variety of external, internal, and environmental conditions. For this reason, they have tried to measure delay as a total average of the stopped-time per vehicle within a specific area. In fact, there are more hidden delays than those identifiable ones. For example, at a signalized intersection, there is lost time embedded at each cycle length. This is the time period during the phase changes. Theoretically, the intersection is vacant and has a zero capacity during signal-light switching [47,48]

A study was conducted to identify the transit delays at St. Louis Public Service Company; the results are summarized in **Table 4.1**. The study showed that number of passenger stops formed the largest component of transit delays. It represents about 60% of the total traffic delays and 17.9% of the total trip time. Also, 30 % of the total delays are caused by the traffic signal control, and another 10% delays resulted from stop sign controls and other events. **Figure 4.1** illustrates the total delays breakdown as well as the total trip time breakdown for the St. Louis transit traffic survey. In addition, from previously presented research findings in Figure 2.4, it is worth mentioning that the actual field measurements for bus #2 operations shows that 17.0% of the total trip time was spent at transit stops. Also, 20% of the time was lost as a result of various traffic delays [47].

As was stated earlier, the time increment for the movement of transit vehicles involves vehicle accelerations, cruising, decelerations, dwell time (servicing passengers at each stop), and other delay times encountered during operation. Generally, loading/unloading times and traffic delays form the highest percentage of bus travel time during the peak periods. The primary causes of traffic delays are the traffic signals, bus turning movements, and the general network traffic congestion [47]. In order to reduce the common bus delays at the different intersections, it is essential to minimize bus stopping at each node within the study area. The installation of bus detectors on the street network along the bus route would enhance the bus movement. When the bus passes a street detector, a signal will be sent to the nearest intersection and switch the signal controller to a green phase. Thus, the bus always has the right of way.

Table 4.1: CLASSIFICATION OF TRANSIT DELAYS, St. LOUIS PUBLIC SERVICE Co.

FACTOR	DELAY TIME AS PERCENT OF TOTAL DELAY TIME	DELAY TIME AS PERCENT OF TOTAL TRIP TIME
<u>TRAFFIC DELAYS:</u>		
TRAFFIC SIGNALS	30.70%	9.10%
STOP SIGNS	1.90%	0.60%
OTHER TRAFFIC STOPS	7.20%	2.10%
TOTAL	39.80%	11.80%
<u>PASSENGER STOPS</u>		
TOTAL, ALL DELAYS	100.00%	29.70%

Source: St. Louis Metropolitan area Transportation Survey Report. W.C.
[Gilman & Company, Engineering, 1959] [Reference #47]

TOTAL DELAY TIME

TRANSIT TRAFFIC STUDY St. Louis Metropolitan Area

TOTAL TRIP TIME

Figure 4.1 : BREAKDOWN OF TOTAL DELAY TIME & TOTAL TRIP TIME

Source: St. Louis Metropolitan Area Transportation Survey Report, W C

Although the idea of bus-right-of-way could not be considered as a practical solution for enhancing bus operation, it certainly opens an opportunity for further research and traffic studies. In 1974, Allsop investigated the interaction between traffic assignment and the signal control. His research recommended a repeated assignment/signal control procedure to investigate an interaction. **Figure 4.2** illustrates the interaction between the traffic assignment and the signal control. As shown in the graph, the traffic flow is influenced by the signal control devices, as well as the set-up of the green time phase. Thus, eliminating the signal control procedures would allow the green phase to last longer for the flow direction; and as a result, the traffic flow will directly depend only on the road network assignment [50,51]. Also, his research findings pointed out that the most important element of the bus traffic delays was street merging, where the bus is ready to move and waiting for the chance to join the traffic stream and move to the next transit stop. Although bus #2 does not usually experience this type of problem primarily because most of the stops are located directly on the right lane (unprotected bus stops); however, the majority of the other bus routes, which are using bus stops with special bus bay (protected bus stops), are having difficult times in merging into the traffic stream.

As an example, it may be assumed that a bus driver waiting to join and merge the existing traffic flow measures each time a gap t within the traffic flow on the outside lane of the road. He/She must find an opportunity, an acceptable gap T , which he/she believes to be a sufficient length to allow him/her to make a safe entry and merge into the traffic stream. If the driver accepted his first opportunity at the first gap where $t > T$, the total waiting time is zero. If the driver rejected the first opportunity where $t < T$, and he/she

accepted the second gap, the expected waiting time would be the total of one gap interval. If it is assumed that the driver having a difficult time to accept a suitable gap over a period of time, and this gap does not change with the time, then after a period of time a geometric distribution will be formed and the probability $P(n)$ of any driver having a wait (for the convenience gap) for the n intervals:

$$P(n) = p^n (1-p)$$

Where. $P(n)$ is the probability of having n gaps during waiting time T , n is the number of gaps ($n = 1, 2, 3, \dots$ etc.), and p : is the intensity or service ratio, $P(t < T)$ [12,47].

Figure 4.2 (A) has illustrated the actual relationship between the field delays due to the number of bus #2 stopping within each link. Other delays have been identified due to the random nature of the arrival process for vehicles approaching the intersection, the expected time a vehicle spends (waiting at the intersection for it to clear-out), and the number of vehicles lined up in each lane to cross the intersection. The total queue delays could be identified in such cases as a fundamental part of enhancing the transit services, reducing intersection delays, and reducing the overall travel time. The salient factor within intersection traffic delays, as mentioned before, is the time spent at each intersection waiting for the green light, acceleration, and deceleration. The total queue time includes the queue formation, total time spent in the system, and the time needed for the queue discharge. All of these extra delays are the major factors in the total bus delays [52,53].

**Figure 4.2 : INTERACTION BETWEEN TRAFFIC ASSIGNMENT
AND SIGNAL CONTROL**
(Source. Reference #51)

Figure 4.2 (A): BUS DELAYS vs NUMBER OF TIMES BUS STOPS/LINK

Figure 4.3 illustrates the relationship between the number of vehicles at intersections to the expected delays according to the Webster delay model. In the mean time, **Figure 4.4** shows the actual relationship between number of vehicles and the corresponding delays within the network study area. Also, **Figure 4.5** illustrates the changes of bus travel time due to the vehicle hourly volume per lane. Traffic density is a significant factor in the traffic analysis and contributes more delays when it reaches the congestion situation. In both figures (4.4 & 4.5) the best fit-line is the cubic regression method which obviously gave the highest R^2 .

Although delays should reach their maximum when the volume approaches the saturation flow rate, the actual traffic data show that delay depends on many other factors including bus performance, number of times bus stops, the maximum speed between stations, average dwell time at each station, number of passengers, number of traffic signals, street geometry, and other operating considerations [54].

Cycle time = 60 s
 Effective green time = 30 s
 Saturation volume = 0.5 veh./lane(s)

Figure 4.3 : DELAYS TO VEHICLES AT INTERSECTIONS
 Isolated Signalized Intersection.
 (Source: Introduction to Transportation Engineering and Planning, 1978)

Figure 4.4: BUS DELAYS vs NUMBER OF VEHICLES/HOUR/LANE

Figure 4.5: BUS TRAVEL TIME vs NUMBER OF VEHICLE/HOUR/LANE

4.2 Traffic Priorities and Regulatory Measures:

As was stated earlier, the research goals and objectives are to help transit vehicles to move reasonably freely, faster, and efficiently regardless of other traffic congestion, in order to provide an accurate operating schedule, provide better services, and attract more customers. Providing priorities to transit vehicles is a many fold operation, i.e. improving their performance and reliability, lowering operation costs for services provided, attracting more users/customers, and reducing the number of vehicles within the network area. The end results could be translated to a shorter trip time, increased reliability, reduced costs of transit operation, accurate time tables, and more confidence in the public transit system.

Delays not only cause loss of time but also waste of space. In general, in order to enhance the public transit operation, many priority measures could be considered [50]:

- **Physical Priorities**
- **Operational Priorities**
- **Legal Priorities**

For the purpose of this research the most important category will be the bus operational priority. It is a fact that regulations giving public transit vehicles priority and the right-of-way in urban streets and intersections are less widespread in the industrialized countries [50]. However, in many of the North American cities transit priority is viewed as being an important improvement area by the majority of transit operators which is a

clear sign of transit vehicle inability to function within the existing traffic situation [55]. From the previous research findings concerning bus operation and associated delay presented in Chapter 3, the first worthy attempt is to give the right-of-way to public transportation vehicles at all intersections, where the most common delays so frequently occurred due to the stopping of vehicles at different intersections. The time lost from vehicle slowness and acceleration at each traffic signals is a contributing factor and accumulated in the total traffic delays

In Vancouver, British Columbia, public transit systems have already installed many different " **Queue-Jumpers** " in order to allow transit vehicles to bypass any traffic jam or heavy vehicle concentrations occurring in road network and create a priority system in the traffic flow. Basically, with this technique, the buses bypass the queues of traffic through the application of operational priorities and avoid the delays occurring because of the expected traffic congestion. Also, in the city of Calgary, Alberta, the municipal traffic by-law provides transit vehicles with turning priority at intersections. The by-law states " **Vehicles must not pass the bus on the right at an intersection / or on the left on a one-way street where the bus is signalling to turn left.**" [56]

In the city of Toronto, especially in the metropolitan area, street cars (Trams) have the priority rules and the right of way. Although within the road mixed traffic assignment is expected to give the street cars an automatic right-of-way, it is worth mentioning that these regulations are there and stated clearly in the Railway Act, but they are not enforced and are ignored within the traffic assignment. The regulations controlling this priority to the automatic right of way in Toronto are controlled and administered by the Municipal

Figure 4.7. EXAMPLE VOLUME-DELAY CURVES, VARIOUS ROAD TYPES
 {Source Urban Transportation Planning, 1984 (Hutchinson, 1974)}

Street Railway Act [50]. However, it should be noted that other measures are implemented for enhancing the attractiveness of the transit service to the public, i.e. higher parking charges. For example, a survey conducted by the Toronto Transit Commission in 1982, shown in **Figure 4.6**, illustrates the increasing number of passengers each year due to increasing parking charges, as well as gasoline prices. The gasoline prices are, of course, not influenced by the municipal governments.

In conclusion, and by using Figure 4.6 findings as an example, it is anticipated that people's behaviour, in addition to the surrounding environment is the key role player in choosing the suitable mode of transportation. Also, the following information could be extracted:

- * sudden increase in the ridership in between 1973 - 1975 as a result of higher gas prices due to the Middle-East war in 1973;
- * noticeable decrease in the ridership between 1975 - 1978 due to a fare increase;
- * after 1978, many actions to improve transit service were undertaken to increase its attractiveness as a model of travel such as introduction of the monthly pass program, new transit vehicles in operation, intensive marketing campaign, preferential bus lanes on major arteries, and also the significant factor of gasoline price increases in Canada; and
- * also, the graph details for the period from 1982 to 1985 as the projected number of passengers using the public transit net-work in the Toronto region.

Figure 4.6 : TRANSIT RIDERSHIP IN TORONTO
 (Source: Toronto Transit Commission, 1982)

4.3 Improving Bus Efficiency by Traffic Management:

The Urban Land Institute (ULI) has sponsored research to improve the mobility of traffic and management of congestion. Statistics showed that in 1988, only within Los Angeles and New York City, the total estimated cost for congestion exceeded \$6 billion annually, while eight other locations in the U.S.A. recorded a loss of \$1 billion annually because of the different forms of traffic delay, wasted fuel, and insurance. In 1989, the research objectives identified the problems concerning the relationship between the growth and transportation. Also, during the same year, the Institute of Transportation Engineers (ITE) identified 36 specific actions that could be considered to reduce traffic congestion and improve mobility. Furthermore, in 1990, another survey finding by the ULI & ITE concluded 12 tools for improving mobility and managing congestion. The number one basic tool was the Traffic Signal Improvements. Most of the vehicle delays occur at intersections, while waiting for the green light to come. In the United States, out of the 240,000 signalized intersections there are approximately 148,000 that require immediate upgrading, and another 30,000 have to be re-configured in order to reflect the existing traffic situation [57,58].

The city of Anaheim, California has set up a good example for the traffic management and control system. A \$3 million installation of new traffic equipment will result in substantial savings approximated as 60 times the total spending. Also, the Fuel Efficient Traffic Signal Management Program (FETSIM) in California improved the efficiency of the local signals and resulted in improvement worth 58 times the project cost. The National Studies recommended that the average speed could be improved by

12% to 25% with more sophisticated traffic equipment [58].

Due to the increasing amount of traffic through the major intersections, vehicular delays are rising and creating a major problem. A World Bank Study has revealed that priority measures for public transit vehicles are needed; exclusive bus lanes and segregated right-of-way have been introduced and resulted in remarkable service enhancement and traffic movement without large capital spending, especially in the CBD's area; the next step should be the better control of bus traffic movements, through such means as intersection signalization and traffic regulatory signs [7].

As a part of enhancing the transit services on urban roads in order for transit vehicles to operate at a reasonable speed, the installation of street detectors becomes more effective to provide the public transportation vehicles the right-of-way. This system will have a significant influence upon the public welfare. The National Electrical Manufacturers Association (NEMA) has set-up specifications and standards to cover the design and needs for the actuated controllers and street sensors. Given the expectations and requirements of the market need, traffic sensors and controller manufacturers have found it useful to adhere to follow these standards.

With the help of the new technology, it is possible to achieve the thesis goals and objectives. **Appendix (C)** includes the most up-to-date technologies for the traffic analysis and management. Hereafter, some of the manufacturers and its products:

- Intersection Development Corp. introduces the **Intelligent Transportation Management Systems (ITMS)**, the superior force in traffic control systems and real time transportation management system. The ITMS incorporates the IVHS concept and can provide vehicular counts and incident detections.
- The Peak Traffic - Transyt Corp. presents the **Urban Traffic Control System** and products from local intersection control to real time fully adaptive systems. This system can control up to 1920 intersections and will provide a continuous update of traffic conditions, which will eliminate the cost of traffic surveys and planning operations.
- Econolite Control Products Inc. introduces **The Autoscope™ 2004**; a vehicle detection system, which is a monitor allowing the managers and operators to oversee the traffic situation as well as detect problems before they happen. It has a video image sensor and transmits digital images of traffic parameters i.e. vehicle count, speed,..etc. They also have the latest technology - microprocessor controlled system, radio signal transmission, traffic signal controller, programmable signal activation (to trigger green signal at a distance from 100 to 2400 feet), and vehicle recognition and identification.
- The TIMEMARK INC. can provide traffic counters which can differentiate between two tailgating cars and a 4 axle truck. In addition, they can detect the vehicle speed in a free flow situation.
- SIEMENS AUTOMOTIVE INC. Siemens SCOOT, the **Intelligent Transportation Systems** and Urban Traffic Control System allow the driver to

see more green light than the red. This system can reduce the vehicle delays by 39% and the travel time by 18%.

- Sarasota, can provide the **Traffic Analyzer**, which it can give volume count, speed and length, speed by length, free-flow statistical speed, headway/gap, and axle classification.

4.3.1 Detection Control:

Installation of bus traffic sensors in conjunction with the traffic signal controller along the proposed bus route will reduce the bus delays at the different intersection crossings since the bus will always have the right-of-way. This also will result in a massive reduction in number of buses stopping at traffic signals. The number of traffic signals on a bus route is an important factor determining the total bus delay. In the previous Figure 4.1 and Table 4.1, survey results showed that traffic signals contributes more than 30 percent of the total transit delays. However, **Figure 4.7** presents the volume-delay curves [38]. These curves allow for various types of streets with different vehicular capacity.

Furthermore, for the analysis of the area, **Figure 4.8** illustrates the actual relationship between bus delays and the bus travel time en-route #2. The relationship between the two variables presented in a cubic function. The curve trend explains that bus delays increasing due to longer travel time in a bus path. It is also important to consider other factors contributing to the total bus delay, including number of signals per kilometre, cycle length, and number of lanes.

Figure 4.7 : EXAMPLE VOLUME-DELAY CURVES, VARIOUS ROAD TYPES
 {Source: Urban Transportation Planning, 1984 (Hutchinson, 1974)}

BUS #2 TRAVEL TIME-DELAY CURVE

Figure 4.8: BUS DELAYS vs TRAVEL TIMES

Detectors will be placed far enough from the intersection to allow passage of the arriving traffic towards the intersection direction. The detector location plays a vital role in the intersection traffic operation, where the initial interval has to be long enough to clear the queue of vehicles approaching the intersection. The ideal location and the distance from the detector to an intersection should be calculated and be equal to enough time needed to clear a queue of vehicles with a specific speed (road design speed). A field survey and traffic count should be taken into consideration to set a reasonable estimation for the detector location.

The timing principles for the PTO-Phase is always necessary to set the duration of the green time to allow the bus to cross the intersection to its destination. This process also depends on the transit stop location; some bus stop booths are located immediately before or after the intersection. Therefore, a different set-up from one location to the other, depending on the transit stop location, will be required.

Figure 4.9 demonstrates an example of a possible operation of an actuated PTO-Phase under a significant demand. When a bus is detected by a street sensor, a signal will be sent to the signal controller. Within the main signal program set up, there is a default of a minimum-green-time period calculated for each direction of the intersection. Once the minimum-green-time for the other direction of the intersection had been completed, the signal phase could change to amber and the red-interval clearance will be in place. The PTO-Phase should be in effect and the initial interval of the green-phase would be available to the bus direction.

Figure 4.9 : ACTUATED PHASE DRIVEN BY BUS ARRIVALS

(Source: Traffic Control Devices Handbooks, Federal Highway Administration, 1983.)

If additional bus arrivals still occur, (which it is very possible in most of the down town area), Figure 4.9 illustrates that an extension period will be started from the time of the bus arrival. Also, there is a maximum period for serving this particular direction of the intersection in case of a long line-up of bus arrivals as a result of serving passengers at transit stops (Rideau Centre location is a very good example for this assumption). In addition, for any other reason that bus line ups might occur; i.e. high traffic volume in the other direction, and/or in the event of detector malfunction, had the maximum period been reached, the transition of green-phase would be carried over to the other direction of traffic.

Detection control, especially in the CBD area, is a major benefit to the transit operation. As previously illustrated in the middle part of Figures 4.4 & 4.5, which presents the down town area (section 4 in the simulation analysis); the relationship between the number of vehicles per lane against the observed bus delays and the bus travel times respectively; the bus delays, as well as the bus travel times faces a sharp increase due to the increasing number of vehicles.

4.3.2 Spacing of Transit Stops:

In the urban transportation network the public transit companies are seeking a solution. Transit operators are facing a trade-off between having buses travel as fast as cars and having buses serving customers. The bus operating speed has always been slower than the private vehicle speed. The higher the number of transit stop locations the more people will be serviced and as a consequence longer bus trip time is highly expected. Considering the reduction of the total number of transit stops is a two fold

operation. The main objective is to minimize the service time lost at each transit stop and avoid the delays caused from the bus stopping activity (acceleration and deceleration mechanism). Obviously, that will reflect on the overall operation schedule and service time. The second directly involved, as reaction to the reduction in transit stop locations, is the actual inconvenience for public transit users. Because people are not willing to walk long distances to catch the bus, reduction in bus stop locations will drive some potential users to think of other alternative modes of transportation [49].

In general, it was noted from the actual field measurements for the bus-route #2, that the average distance between the bus stop locations varied from 400 ft. (120 m.) in downtown area (i.e. Bank Street), to sometimes 2000 ft. (600 m.) in urban areas (i.e. St. Laurent Boulevard and Ogilvie Road) considering the type of area (i.e. residential or commercial), population density (i.e. high rise buildings, apartment complexes, condos, townhouses), and number of bus routes serving that location. The total number of bus stops available within our study area (the bus route #2) are 92 locations, and the average serving time was measured between 6 to 15 seconds per location (with an overall average of 10 seconds, depending on the route characteristics and number of people waiting for service). The greater the spacing distances between transit stop locations (or the fewer number of transit stop location), the less time spent serving passengers in different locations, and as a result, the overall passenger travel time will decrease. **Figure 4.10** illustrates the possibilities of delay increases that will occur due to the changes of numbers of stations with respect to the passenger travel time, also indicates the optimum number of transit stations in a bus transit network.

Figure 4.10 : RELATIONSHIP BETWEEN PASSENGER TRAVEL TIME & TRANSIT STATION SPACING ALONG BUS ROUTE.
(Source: Transportation and Traffic Engineering Handbook, 1982)

4.3.3 Automatic Vehicle Location and Control System (AVLC):

The objectives of the automatic vehicle location and control system project is to implement a relatively low cost system to improve service control and passenger information through the real time monitoring of vehicle locations.

The goals of the AVLC are to improve the quality of on-street service, to manage and control service vehicles from centralized areas, and to use the real-time vehicle location information. Those vehicles could be ambulances, fire trucks, police cars, buses...etc, or could be used for private business such as couriers and delivery services which can be redeployed while on assignment. Knowing the exact location of each service unit on duty can have a direct and significant influence upon the business/personal success, decision making, and route choice.

For the purpose of this research, the AVLC project will be mainly focusing on the implementation of a relatively low cost system for public transportation and to improve service control and passenger information through the real time. Since the AVLC system was installed by OC-Transpo as a pilot project, the objectives of the project were stated by the OC-Transpo research team as follow [35]:

1. to improve the accuracy and predictability of existing and future operating schedules;
2. to provide on-time service with 95% accuracy of the published time table at each and every bus stop. (on-time service is defined as not early and no more than 3 minutes late);

3. to provide on-time information where the published service cannot be provided, to inform the public of the status of the service;
4. to provide the actual bus order of arrival. This information will help passengers at bus stops, especially along the busy central area section of the transit-way and at selected transit-way station platforms, to be prepared and to line up; and
5. to establish new technical procedures, whereby AVL data will be collected, analyzed, and assist in forming the requirements of future operating schedules.

4.4 Benefits from Travel Time Savings:

Figure 4.11 illustrates the proposed bus #2 travel time, from the Bayshore Shopping Centre to its final destination at Blair Station. The graph shows the difference in timing between the actual operating speed measured from the field (Figure 2.3) and the desired operating speed predicted by NETSIM program output [Figure 3.5 and Table 3.3 all-green case scenario]. There is a 6 Km/h difference between the two posted speeds (an average speed for the total bus route). Higher speed could be translated to longer distance for the same driving time (improving system efficiency), or less driving time for the same distance (enhancing bus operation & customer satisfaction). In conclusion, a difference of 6 Km/h in the operating schedule will affect the financial, as well as the operating performance of the transit system significantly [47].

The hypothesis of bus-right-of-way (all-Green-Phase) for the bus traffic direction will save the bus #2 a minimum total of 20.84 minutes in each direction (bus trip). This portion of time forms 25% of the current total trip time.

Figure 4.11 :BUS #2 TIME-DISTANCE-SPEED ANALYSIS
Existing Operating Speed vs Desired Speed

The bus can travel with higher speed and/or drive longer distances for the same amount of time. In this case the bus will be able to reach its destination within 01:07:37 seconds instead of 01:23:56 seconds [from Figure 3.5]. In addition, **Figure 4.12** supports the traffic data analysis from the field and summarizes the bus route #2 time-distance diagram. Section 4 which contains the downtown area represents 20% of the total distance (bus route), but it took 25% of the total trip time for a bus to cross this section. On the other hand, section 6, the end of the route, representing more than 27% of the route length and only used 21.4% of the total trip time.

The survey findings explain the differences in driving environment between each section. The intangible benefits of travel time saving (or reduced trip delays) within the transit system is to increase the public transit reliability and safety. In practice, however, most measures of benefits are based on the concept of consumer surplus and monetary values. As mentioned earlier, the underlying basis for assigning a particular value to travel time/travel delays indicates that, if that time was not spent on the road, it could be used for any other activities; i.e. work, production, education, pleasure,...etc. In the case of any work related trips, a reasonable estimate of the value of time for this work/travel time delays can be related to the passenger's wage. For any other trip purposes, the value of the travel time becomes related to this original importance of the activity. Still, different dollar values have been used to represent the value of time, which have been found to be sensitive to trip purpose, a passenger's income level, and the amount of delay time or the saved time from the actual total trip times [38].

(A) BUS ROUTE #2: DISTANCE BREAKDOWN

(B) BUS ROUTE #2: TRAVEL TIME BREAKDOWN

Figure 4.12 : BUS ROUTE #2 TIME - DISTANCE DIAGRAM

From the transit operator's point of view, the value of travel time savings is attributable to facility improvements. Since the overall evaluation of the transit performance is the cost of vehicle's operation, the time savings will result in a reduction of fuel consumption, oil, maintenance, and repair cost. In addition, statistics show that minimizing travel time is a definite potential for reduction in number of accidents. Although determining accident costs sometimes is very crucial, the damage resulting from road blockages, bus delays en-route, as well as passenger delay times, and personal injuries will have a great effect on the network area, as well as the socioeconomic effect on transit users [38].

CHAPTER 5

MODEL DEVELOPMENT AND IMPLEMENTATION

5.1 Introduction:

In Chapters 2 and 3, data collection, data selection, TRAF-NETSIM simulation program input & output and the approaches used to develop transit information have been discussed in detail. Since acquiring data is not enough, the author should determine what conclusions can be drawn from the data. Within this chapter, the computer experimentation will be illustrated in order to develop a delay model. The TRAF-NETSIM, as well as the SPSS statistical software package, were in use through the experimentation stage. The TRAF-NETSIM package was demonstrated previously in detail.

Using the computer for data analysis was essential. Computers simplify many tasks, including data analysis, and the consequences of erroneous data analysis can be severe and far reaching. In order to design a good model, one must analyze the results properly and prepare a cogent description which summarizes what has been found during the research period. A computer program will be in use for analyzing the data, called Statistical Package for Social Science (SPSS). With the help of SPSS many types of statistical analyses and data management tasks can be performed. The SPSS statistical package is a very powerful statistical program which enables the user to identify the necessary variables. The SPSS, Version 6.0 for Windows, is the latest version of SPSS software, which has been widely used by Statistics Canada, researchers and students alike for years [59,60].

5.2 First Road-Network Scenario:

Due to the nature of this research, it was essential to create an actual data base (prototype) presenting the street network study area (bus route #2) in order to focus on the research goals and objectives. After a successful simulation of the actual road network traffic, a wide range of Measures-Of-Effectiveness MOE's were available. Then, the first step in data analysis is describing the data and secondly, testing the hypotheses for the data included for this research. Finally, by looking at the various characteristics together, it was possible to determine the relationship between the different variables in use. At this point the author was able to compute indexes which estimate how strong the relationship is, and build a model which allows the users to predict values of the delay variable based on the values of other variables.

Figure 5.1 illustrates the model development flow chart. Model development involves the simulation stage (data input & output for NETSIM), data preparation and aggregation to the SPSS program (to the order of variables) including data classification, regression analysis, and statistical checks on the developed equation.

5.2.1 Multiple Regression Analysis:

The multiple regression analysis involved a lot of experimentation, trial and error steps. The procedure for developing a model was determined by stipulating the different variables as per the following manner:

Figure 5.1 : MODEL DEVELOPMENT FLOW CHART

- **Identify** the variables
- **Analysis** of available data
- **Formulate** data
- **Choose & Select** good variables
- **Evaluate** results (testing the model)

Identification of the variables was one stage after the NETSIM MOE's classification and organization according to its importance. The program MOE's output data are the results of the simulation to the bus route number 2. A total of 88 observations were extracted and compiled from the output data. Each observation presents information on each internal link along the bus route. Because some of the links did not have a complete set of information, these links were removed before the regression analysis stage. NETSIM output data sheet usually presents the actual link by link traffic condition. In some cases when a link is experiencing high delays (as a result of traffic jam or blocked lane), the bus was left behind in the other link space. However, the NETSIM-Bus-Statistics output results have provided an estimation of all bus delays within each link. As long as the bus remains in one link, the estimated delays were only applied for that particular link. Then, if the next link does not include any buses, there was no delay information provided for that link, and considered a zero bus-delay link. For the accuracy of the data base gatherings during the regression analysis, these links were removed instead of presenting false information.

The Highway Capacity Manual (HCM), provides a list of the important variables to be used i.e. signal timing, pedestrian volume, percent of turning movements, traffic

flow rate (the number of vehicles per hour), density of traffic (the number of vehicles per kilometre per lane at a given time), percent of heavy vehicles, number of vehicle stopping, number of transit buses [26]. After a list of the variables was identified and tested to assure that they are statistically significant, each variable was tested separately against the delay variable. After the regression analysis, other statistical checks were performed; for example, the Multiple R (The Multiple Correlation Coefficient), the R Square (The Multiple Coefficient of Determination), the Adjusted R Square, and the Standard Error were checked. **Figure 5.2** explains the procedures followed during the regression analysis. A list of the important variables was in use and considered during the regression analysis (the variables' units are listed between parentheses):

<i>DELAY:</i>	"The Equation Dependant Variable", and measures the bus delays in minutes (Bus-Min)
<i>LENGTH:</i>	Link length in kilometres (Km)
<i>STATION:</i>	Number of bus stations per link (Station)
<i>BUSTRIP:</i>	Number of buses per link (Bus)
<i>M/T:</i>	Bus efficiency ratio (%), and equal to Moving Time / Total Time .
	MOVING TIME: the idealized travel time under the free flow speed and traffic condition (Veh-Min)
	TOTAL TIME: the actual total travel time, an average of travel times from all vehicles on the link (Veh-Min)

Figure 5.2: PROCEDURES FOR REGRESSION ANALYSIS

<i>BUSTOP:</i>	Number of stops made by buses on the link, i.e. traffic lights, stop signs, and/or bus stations (Stop)
<i>DENSITY:</i>	Total traffic density on each link (including heavy vehicles) and calculated as: Occupancy/# of Lanes/Length (Veh/Lane/Km)
<i>DENS.LT:</i>	Left-turn vehicle density (Veh/Lane/Km)
<i>DENS.TH:</i>	Through vehicle density (Veh/Lane/Km)
<i>DENS.RT:</i>	Right-turn vehicle density (Veh/Lane/Km)
<i>HVDNSTY:</i>	Heavy-vehicle density per link (Veh/lane/Km)
<i>PERSON:</i>	Number of passengers riding the bus (Person)
<i>SIGNPKM:</i>	Number of traffic signals per kilometre (Sign/Km)

By using different combination of variables, more than one equation was developed and listed within this chapter. After compiling those variables, in a stepwise fashion according to individual importance, a new equation was developed. The general delay equation was developed in this form:

$$\begin{aligned}
 \text{DELAY} = & 0.4413 + 0.0227 \text{ DENS.LT} + 0.0023 \text{ DENS.RT} + 0.0118 \text{ DENS.TH} + \\
 & 0.0973 \text{ HVDENSTY} + 0.9734 \text{ LENGTH} - 0.1874 \text{ M/T} + 0.0074 \text{ SIGNPKM} \\
 & + 0.1274 \text{ STATION}
 \end{aligned}
 \tag{5.1}$$

(Multiple R = 0.90028, $R^2 = 0.81051$, Adjusted $R^2 = 0.79132$, Standard Error = 0.14072, F = 42.23723, Signif F = 0.0000, and the Durbin-Watson Test = 1.79031)

Where:

STEP	Mult R	R²	F
1- DENS.TH	0.6242	0.3896	54.898
2- STATION	0.7833	0.6135	67.459
3- LENGTH	0.8086	0.6538	52.871
4- M/T	0.8935	0.7984	82.162
5- DENS.LT	0.8990	0.8082	69.183
6- DENS.RT	0.9000	0.8092	59.123
7- HVDENSTY	0.9001	0.8100	52.937
8- SIGNPKM	0.9003	0.8105	42.237

Analysis:

The R^2 (which is measuring the goodness of fit) is equal to 81%. This positive high value means that 81% of the delays is explained by the variables in the equation, DENS.LT, DENS.RT, DENS.TH, HVDENSTY, LENGTH, M/T, SIGNPKM, and STATION. The F significant for the whole equation is good and could be explained as the probability of rejecting the null hypothesis is zero. The probability that the equation does not explain the variability of the delay (the dependent variable) is equal to zero. From the Correlation matrix, the variables DENS.RT, HVDENSTY, and SIGNPKM were measuring very low values in between the other variables in the equation. Also, the Collinearity Diagnostics between the variables shows that there is a collinearity between the DENS.RT and both of the DENS.TH and DENS.LT. Also, there was a collinearity between the SIGNPKM and the LENGTH & STATION. By using the automatic variable removal feature in the SPSS program (stepwise regression analysis), a new equation was developed.

$$\text{DELAY} = 0.4855 + 0.0287 \text{ DENS.LT} + 0.0168 \text{ DENS.TH} + 0.9654 \text{ LENGTH} - 1.1969 \text{ M/T} + 0.1130 \text{ STATION} \quad (5.2)$$

(Multiple R = 0.89902, $R^2 = 0.80824$, Adjusted $R^2 = 0.79654$, Standard Error = 0.13895, F = 69.12255, Signif F = 0.0000, and the Durbin-Watson Test = 1.79660)

Where:

STEP	Mult R	R^2	F
1- DENS.TH	0.6242	0.3896	54.898
2- STATION	0.7833	0.6135	67.459
3- LENGTH	0.8086	0.6538	52.871
4- M/T	0.8935	0.7984	82.162
5- DENS.LT	0.8990	0.8082	69.123

Analysis:

When adding one variable at the time, three variables were removed from the equation 5.1, **DENS.RT**, **HVDENSTY**, and **SIGNPKM**. The R^2 has remained the same 81%. The correlation between the variables became stronger, and the collinearity has improved significantly. Also, the **M/T** is the ratio between the total moving time (Veh-Min) and the total travel time (Veh-Min) on a link. (Low ratio value indicates that longer delays have been experienced within the total travel time, and the negative coefficient points out that the higher the bus moving time, the fewer delays encountered).

Since all of the above listed variables were very important and could explain the dependant variable (DELAY), the author tried to combine all of these factors in one general model in equation 5.1.

In fact, the relationship between the **DELAY** and any of the independent variables is not a perfect linear relationship. Consequently, another approach has been taken by using the transformation of the independent variables. This method checks the best form which gives the best fit and can explain the relationship between the dependent and the independent variables. This methodology called the "Curve Estimation", within the regression analysis in the SPSS program, allows the user to choose the best curve for the data in use. There are eleven curve estimations in the program in order to select the best curve-fit and this models are listed as follow: *LINEAR, LOGARITHMIC, INVERSE, QUADRATIC, CUBIC, COMPOUND, POWER, S, GROWTH, EXPONENTIAL, AND LOGISTIC MODEL*. In each case, the dependent variable **DELAY** was tested separately against each of the independent variables. **Table 5.1** includes all of the important variables used in the regression analysis and shows the value of the R^2 for each case as an indication for the chosen best curve and fit analysis.

After the transformation of some of the variables, a new equation was developed by the stepwise entry method (adding the necessary variable one at the time):

$$\begin{aligned} \text{DELAY} = & 0.1403 + 7.3533 \times 10^{-07} (\text{DENS.TH})^t + 0.3080 (\text{LENGTH})^t + \\ & 0.1174 (\text{STATION})^2 + 0.08 \text{ T/M} \end{aligned} \quad (5.3)$$

(Multiple R = 0.90626, $R^2 = 0.82131$, Adjusted $R^2 = 0.81270$, Standard Error = 0.13332, F = 95.37080, Signif F = 0.0000, AND THE Durbin-Watson Test = 2.04220)

Table 5.1 : SPSS CURVE-ESTIMATION PROCEDURES

VARIABLE	NON-LINEAR REGRESSION ANALYSIS									
	LINEAR	LOGARITH	INVERSE	QUADRATI	CUBIC	COMPOUND	POWER	S	GROWTH	EXPONENTIAL
HYDENSITY	0.58	0.45	0.09	0.6	0.7	0.49	0.42	0.09	0.49	0.49
BUSTRIIP	0.33	0.31	0.26	0.33	0.33	0.29	0.31	0.29	0.29	0.29
TDENSITY	0.001	0.004	0.006	0.005	0.015	0.009	0.011	0.007	0.009	0.009
LENGTH	0.24	0.15	0.06	0.27	0.29	0.14	0.09	0.03	0.14	0.14
M.T	0.04	0.06	0.09	0.07	0.09	0.14	0.14	0.13	0.14	0.14
PRISINTRIP	0.9	0.9	0.87	0.9	0.9	0.78	0.82	0.85	0.78	0.78
SIGNLPKM	0.18	0.19	0.16	0.2	0.24	0.18	0.18	0.16	0.18	0.18
STATION	0.38			0.42	0.42	0.34			0.34	0.34
VEHCSTOP	0.003	0.009	0.005	0.021	0.021	0.007	0.012	0.003	0.007	0.007
VEHDNSTY	0.002	0.005	0.006	0.006	0.006	0.01	0.012	0.008	0.01	0.01
VEHLANE	0.02	0.006		0.022	0.059	0.018	0.003	0.001	0.018	0.018
DENSITY.LT	0.003			0.007	0.026	0.002			0.002	0.002
DENSITY.RT					0.001	0.002			0.002	0.002
DENSITY.TH	0.003			0.009	0.018	0.01			0.01	0.01

SPSS PROGRAM OUTPUT
NON-LINEAR REGRESSION ANALYSIS

Where:

STEP	Mult R	R ²	F
1- (DENS.TH) ³	0.6656	0.430	68.404
2- (STATION) ²	0.8232	0.6776	89.340
3- T/M	0.8829	0.7796	99.026
4- (LENGTH) ³	0.9063	0.8213	95.371

Analysis:

By transforming the variables: **DENS.TH** to **(DENS.TH)³** (Cubic Model), **STATION** to **(STATION)²** (Quadratic Model), **LENGTH** to **(LENGTH)³** (Cubic Model), and the ratio **M/T** to **T/M** (Inverse Model), the goodness of fit (**R²**) for the equation has slightly improved from 80% to 81% and the Multiple R also changed from 90% to 91%. More variable transformations were made in order to find the best model. Furthermore, the length of the bus path is a very significant variable affecting the bus delays on any bus route. It is a known fact that the longer the path the higher the potential for encountering delays. Thus, this factor will be monitored carefully in order to stay within all of the developed equations.

$$\begin{aligned}
 \text{DELAY} = & 0.1268 + 5.2 \times 10^{-04} (\text{DENS.LT})^3 + 7.2139 \times 10^{-07} (\text{DENS.TH})^3 + \\
 & 9.316 \times 10^{-05} (\text{DENS.RT})^3 + 0.3051 (\text{LENGTH})^3 + 0.081 \text{ T/M} + \\
 & 0.1213 (\text{STATION})^2
 \end{aligned} \tag{5.4}$$

(Multiple R = 0.90852, R² = 0.82541, Adjusted R² = 0.81248, Standard Error = 0.13340, F = 63.82524, Signif F = 0.0000, and the Durbin-Watson Test =1.99596)

Where:

STEP	Mult R	R²	F
1- (DENS.TH)³	0.6656	0.4430	68.404
2- (STATION)²	0.8232	0.6776	89.340
3- T/M	0.8829	0.7796	99.026
4- (LENGTH)³	0.9063	0.8213	95.371
5- (DENS.LT)³	0.9080	0.8220	84.521
6- (DENS.RT)³	0.9085	0.8254	63.825

Analysis:

The statistical analysis for equation 5.4 has changed after adding new variables to equation 5.3. The Multiple R as well as the R² has slightly improved to 91% and 83% consequently. These extra variables were forced into the equation because of their importance and their direct effect on the bus operation in particular and the traffic flow in general. The DENS.RT (right turn vehicle density) is a very important factor to be considered. Generally, buses usually operate on the right lane; therefore, all the bus stations must be located in the right lane. As a result, all the bus exclusive lanes are also selected in the right lanes. Consequently, vehicle's right turn movements could interfere with the bus operation on the express lanes or during servicing time, i.e. bus manoeuvrability to reach the right lane (loading/unloading passengers). Furthermore, the DENS.LT (the vehicle left turn movement), is always a problem for the traffic flow, especially at the intersections which have no left turn lanes. Left turn movements have a direct effect on traffic patterns and are always recommended to be considered by the Highway Capacity Manual (HCM) [26].

$$\begin{aligned}
 \text{DELAY} = & 0.1403 + 0.0046 (\text{HVDNSTY})^3 + 0.3079 (\text{LENGTH})^1 + 0.1174 (\text{STATION})^2 \\
 & + 0.0801 \text{ T/M}
 \end{aligned}
 \tag{5.5}$$

(Multiple R = 0.90628, $R^2 = 0.82134$, Adjusted $R^2 = 0.81273$, Standard Error = 0.13331, F = 95.39315, Signif F = 0.0000, and the Durbin-Watson Test = 2.04224)

Where:

STEP	Mult R	R ²	F
1- (HVDNSTY) ³	0.6653	0.4426	68.297
2- (STATION) ²	0.8228	0.6770	89.078
3- T/M	0.8830	0.7797	99.073
4- (LENGTH) ³	0.9063	0.8213	95.393

Analysis:

During this regression analysis the variable (HVDNSTY)³, the heavy vehicle density, was forced into equation (5.4) and replaced the vehicle density in all directions. The reason to consider the heavy vehicle effect on traffic is a very significant and vital factor in the road network traffic. Heavy vehicles are intended to be in the right lane most of the time. They usually operate at slow speed and are difficult to manoeuvre. This equation will be best used in those areas with heavy truck volumes, i.e. designated truck routes in urban areas by the municipalities. Also, in this equation the - M/T was inverted to become + T/M. Since the ratio between the Moving Time to the Travel Time is a good representation of traffic delays, more than one trial is necessary to include this important variable in all equations. Although the statistical strength for the above equation remains almost the same as equation (5.4), the collinearity diagnostics show a lot better results between the variables in use.

$$DELAY = 0.1403 + 5.772 \times 10^{-07} (DENSITY)^3 + 0.3079 (LENGTH)^3 + 0.1174 (STATION)^2 + 0.08 T/M \quad (5.6)$$

(Multiple R = 0.90629, R² = 0.82137, Adjusted R² = 0.81276, Standard Error = 0.1333, F = 95.41081, Signif F = 0.0000, and the Durbin-Watson Test = 2.04186)

Where:

STEP	Mult R	R ²	F
1- (DENSITY) ³	0.6655	0.4429	68.363
2- (STATION) ²	0.8235	0.6782	89.577
3- T/M	0.8830	0.7797	99.082
4- (LENGTH) ³	0.9063	0.8214	95.411

Analysis:

Equation (5.6) is similar to equation (5.5), there is no increase in the value of the R² or the Multiple R. The only reason to include the variables (DENSITY)³ instead of the variable (HVDNSTY)³, is because the total traffic density variable could be used for all of the CBD area. It is also a very important variable to describe the traffic delays in general terms.

$$DELAY = 0.2845 + 2.343 \times 10^{-04} (BUSTOP)^3 + 0.5823 (LENGTH)^3 + 6.709 \times 10^{-07} (DENSITY)^3 + 0.0733 T/M \quad (5.7)$$

(Multiple R = 0.8353, R² = 0.6978, Adjusted R² = 0.68319, Standard Error = 0.17339, F = 47.90352, Signif F = 0.0000, and the Durbin-Watson Test = 1.77739)

Where:

STEP	Mult R	R²	F
1- (DENSITY)³	0.6655	0.4429	68.363
2- (LENGTH)³	0.7634	0.5827	59.352
3- T/M	0.8343	0.6961	64.141
4- (BUSTOP)³	0.8353	0.6978	47.904

Analysis:

More than one attempt was made to include the variable **SIGNPKM**, number of traffic signals per kilometre, but with no success. This variable is highly correlated with the other variables in use. It was not possible to force this variable into the equation. Alternatively, another variable was developed in order to serve the same purpose. **(BUSTOP)³**, the number of stops made by the bus for all purposes including the bus station location. The variable **(STATION)³**, number of bus stops on the link, was removed in order not to repeat the information in other variables. Although the **BUSTOP** was successfully included into the equation, the statistical information shows a high value for the Significant T (Sig T = 0.5042). Also, the overall result shows a sharp decrease in the R², multiple R, and the Adjusted R².

5.3 Second Road-Network Scenario:**Case of One Lane Blocked:**

As was mentioned in Chapter 1, there are always unusual delays and uncertainties experienced in bus scheduling due to the prevailing traffic conditions (rush-hour congestion), the harsh weather conditions (especially during winter time), the reoccurring

mechanical problems (bus break down, then it is out of service), or non-recurring incidents (accidents, fire), as well as the different geometric design of the urban roads which cause a detour for some routes. All of these factors, most probably, will cause at least one lane blocked within the road network.

When incidents occur, the level of service will be disrupted and the capacity will be reduced. It is very important to consider the actual effect of an incident on the traffic delays in general and the bus delays for this research in particular. A study has been conducted and showed that an incident resulting in blocking one lane in a three-lane road facility, could reduce the road capacity by 50 %. Furthermore, it should be mentioned that most of the accidents that occur go un-reported. In addition, a study of accident occurrence in Illinois, revealed that approximately 71% of the total automobile and 80% of the total truck involvements have gone un-reported [47,48].

As a result, the author has attempted to estimate the delays associated with the closing of one traffic lane. The methodology used to estimate these delays was to create a case scenario within the TRAF-NETSIM program. One lane was blocked in each section, and a new set of data file was developed, summarized, and analyzed similarly to those employed earlier under normal traffic condition.

The choice for the road lane-blocking was selected according to the most recent accident data available (RMOC, 1993 accident statistics; Appendix D). Those streets and/or intersections which recorded the highest number of accidents have been selected and used in the simulator to present a blocked road or intersection. Also, more than one equation has been developed and listed underneath. After forcing in and/or deleting a

new variable(s) in a stepwise fashion, according to its importance, a new model was developed.

$$\begin{aligned} \text{DELAY} = & 0.2460 + 1.2126 \times 10^{-06} (\text{DENSITY})^4 + 0.3189 (\text{LENGTH})^4 + \\ & 0.1416 (\text{STATION})^2 + 0.0707 \text{ T/M} \end{aligned} \quad (5.8)$$

(Multiple R = 0.87637, $R^2 = 0.76802$, Adjusted $R^2 = 0.75684$, Standard Error = 0.23454, F = 68.69729, Signif F = 0.0000, and the Durbin-Watson Test = 1.75021)

Where:

STEP	Mult R	R^2	F
1- (DENSITY) ³	0.7569	0.5729	115.3534
2- (STATION) ²	0.8449	0.7139	106.0559
3- T/M	0.8654	0.7490	83.55100
4- (LENGTH) ³	0.8764	0.7680	68.69729

Analysis:

Comparing equation (5.8) with equation (5.6), the total expected delays from the model designed for the one lane blocked case are higher (i.e. approximately 4% more delay due to blocking a lane within one link only) than delays estimated from the normal case delay model. The effect of one lane blocking should definitely increase the total delays in the road network system. Due to the new case (lane blocked data-base) and new variable values, the Multiple R and the R^2 values have decreased to 88% & 77% respectively.

$$\begin{aligned}
 \text{DELAY} = & 0.4255 + 1.4305 \times 10^{-06} (\text{DENSITY})^3 + 0.6527 (\text{LENGTH})^4 + \\
 & 1.0311 \times 10^{-04} (\text{BUSTOP})^3 + 0.0623 \text{ T/M}
 \end{aligned}
 \tag{5.9}$$

(Multiple R = 0.83295, $R^2 = 0.69380$, Adjusted $R^2 = 0.67904$, Standard Error = 0.26946, F = 47.01592, Signif F = 0.0000, and the Durbin-Watson Test = 1.74032)

Analysis:

Modification was made for equation (5.8) in order to include the other possibilities of bus stopping. As mentioned earlier, it is difficult to include the number of traffic signal devices as a variable within the regression analysis. In the above equation (5.9) the **BUSTOP** variable includes all the stops made by the bus during the service period on a link including stops due to traffic signals. Also, the total expected delays will be approximately 11% higher than the normal case model (compared with equation 5.7). Furthermore, it is worth mentioning that the Multiple R and the R^2 values have remained constant in both model regression analysis 83% and 69% respectively.

$$\begin{aligned}
 \text{DELAY} = & 0.4283 + .0116 (\text{HVDNSTY})^3 + 0.6510 (\text{LENGTH})^4 + \\
 & 1.0398 \times 10^{-04} (\text{BUSTOP})^3 + 0.0618 \text{ T/M}
 \end{aligned}
 \tag{5.10}$$

(Multiple R = 0.83337, $R^2 = 0.69450$, Adjusted $R^2 = 0.67978$, Standard Error = 0.26915, F = 47.17213, Signif F = 0.0000, and the Durbin-Watson Test = 1.74406)

Analysis:

Once again, another attempt was made to include the effect of the heavy vehicles upon the bus delays. Some of the city streets are designated as truck routes; thus, where the buses are located on these streets could be affected. Although the R^2 value is not as strong as in the other equations, it is still within the acceptable range.

In conclusion, many attempts were made in order to include all of the variables in one model. However, it was not possible to do so due to many statistical reasons. Ten models were developed based on regression analysis of the simulated data. Each included a different combination of variables, and different types of regression analyses were performed (linear/non-linear) in order to estimate bus delays under different traffic conditions. In addition, TRAF-NETSIM estimates assume an average bus occupancy of 25 passenger per bus throughout the entire network. Due to data and computer program limitations, the loading/unloading and occupancy variables could not be included in the equations. Although, some of the variables, PERSON (number of passengers riding the bus at each location) are relevant for the study of bus delays, it was not possible for them to be included within the models. Testing the developed delay models by using the road characteristics and the prevailing traffic conditions will identify the best model applicable to bus route #2. However, the other delay models would help investigate the different bus delays in other routes under different traffic conditions experienced.

CHAPTER 6

MODEL VALIDATION, USAGE, AND SIGNIFICANCE

6.1 General:

An important step at this time is to define the model output. The developed delay model is measuring the bus delays in minutes per link (or other specified distance in kilometres at the developed equation). This model should define delays the same as the simulation program in use. TRAF-NETSIM has defined delays as total delays per bus and the delay is equal to the difference between the two values: the Total Travel Time and the Free Flow Travel Time for each link [42,45]. Due to the non-availability of funds, as well as human resources, which is necessary for confirming the research validity and testing of the developed delay models, only a visual observation of bus arrival times were recorded from the field in order to fulfil the requirement and test the model.

However, to assure the accuracy of the model in the general road network, new bus routes with different bus paths were considered to test the reliability of the model. Due to the importance of the city CBD and the alleviated bus scheduling, Slater Street was selected for testing the model. Slater Street services a high volume of traffic in addition to containing an exclusive bus lane (part of the East-West Transit-way for the Ottawa-Carleton Transit Commission). Furthermore, bus route number 95 is considered the most important and busiest route within the downtown Ottawa region, as well many vital and busy routes traverse Slater Street. The rest of the information required for the substitution of the model parameters have been collected from the RMOC i.e., vehicle

count, turn movement count, percentage of heavy vehicles, signal timing, number of lanes, and link length. Any other important information will be measured from the field while the data are recorded i.e., arrival and departure times, dwelling times, and mean headway.

6.2 Model Testing:

A first attempt was made to test the validity of the developed model within the proposed study area. A section from the bus path (route #2) was carefully selected according to its strategic location. Section 4 presents the CBD traffic condition for the city of Ottawa. Since it is the busiest area within the bus route (starting from Somerset and Preston Street to Rideau and Charlotte), a model testing was carried out to investigate its validity. More than one good reason was behind the selection of that area: it is in the downtown core, and always busy with traffic; it contains other busy bus routes, and road construction was taking place on Somerset Street during the video taping and data gathering. The Somerset road condition created a golden chance to test the developed delay models both for the normal traffic and for a lane blocked scenarios. A total of fifteen nodes (Intersections) and fourteen links (Street) were used. Equation 5.1 was applied and the results were impressive.

Table 6.1 summarizes the estimated delays from the different developed models compared with the estimated delays for TRAF-NETSIM program as well as the actual field delays recorded from the video tape. The model results were very close to those estimated by the NETSIM program.

Since NETSIM program output bus delays were rounded to the nearest one decimal point of a minute, the measurement of the field delays, as well as the delay models, will be in minutes to show a sensitive degree of accuracy (approximated delays were used to the nearest two decimal point of the minute).

Figure 6.1 graphically illustrates a comparison of field delays and the average estimated delays from the different delay models. The following delay results are a summary from Table 6.2. These delays are estimated from an average of the different delay models output and compared with the NETSIM output as well as the actual field delays (Bus.Min):

Table 6.1 : SUMMARY OF ESTIMATED BUS DELAYS

<u>Link</u>	<u>NETSIM-Delays</u>	<u>Model-Delays</u>	<u>Field-Delays</u>
Preston to Rochester	0.6	0.60	0.65
Rochester to Booth	0.4	0.56	0.30
Booth to Bronson	0.5	0.45	0.55
<i>Bronson to Percy</i>	<i>0.5</i>	<i>(0.52) 0.63</i>	<i>0.52</i>
<i>Percy to Lyon</i>	<i>0.3</i>	<i>(0.40) 0.54</i>	<i>0.40</i>
<i>Lyon to Kent</i>	<i>0.3</i>	<i>(0.40) 0.56</i>	<i>0.40</i>
Kent to Bank	0.8	0.60	0.30
Bank to Lisgar	0.9	0.70	0.75
Lisgar to Gloucester	0.6	0.60	0.55
Gloucester to Laurier	0.5	0.56	0.10
Laurier to Slater	0.6	0.61	0.63
Slater to Albert	0.8	0.86	0.10
Albert to Queen	0.7	0.75	0.55
Queen to Wellington	0.5	0.50	0.58

(Italics present the case of one-lane-blocked streets, and values between parenthesis presenting an average delay from the normal traffic condition delay models.)

Figure 6.1: COMPARISON OF ESTIMATED DELAYS WITH FIELD OBSERVATION

In addition, Table 6.1 concluded that the NETSIM delays estimations are very similar to the average delay estimations from the developed delay models. The difference between the delay model values and the NETSIM output results vary from 0.00 to 0.20 minutes or 12 seconds. These could be translated as the percentage of the differences fluctuating between 0.00% and 22.20% from the total travel time within a specified link. In addition, the difference between the model delays and the actual field results vary from 0.00 to 0.76 minutes or 45 seconds. Only in two cases were the values very inconsistent, but the average variance was 0.21 minutes or 12 seconds. Many factors influence the final delay estimation and contribute to the dissimilarity values between the estimated and the actual delays i.e. date of traffic count, road construction, percentage of turn movements...etc. The vehicular count, turn movements and the percentage of heavy vehicles data used during the study were collected in 1992/1993. Many road capacities have changed since 1993, as well as the annual increase in private automobile ownership. In order to have an accurate model with higher accuracy results, data should be updated to the same time frame used in the model testing.

Also, Table 6.2 includes a comparison of the different delay model results. As it is noted, the output results from the different delay models are identical in the first two decimal points of the minute and very close in the fifth digits approximation. Although the linear delay models have estimated delays fairly accurately (presented by equations 5.1 & 5.2), the non-linear delay models have provided more accuracy in the final results (presented by equations 5.3 to 5.7).

Table 6.2: ESTIMATED DELAYS BY THE DIFFERENT DELAY MODELS

INTERSECTION	VEHICLE DENSITY (Vehicles per Hour or of Lane-Mile)				LENGTH (Km)	M/T (Ratio)	No. of		ESTIMATED		ESTIMATED DELAYS FROM EQUATION NUMBER:									
	DENSITY 1	DENSITY 2	DENSITY 3	DENSITY 4			SIGNAL (per Km)	STATION (per Lane)	ACTUAL FIELD DELAY (SEC)	DELAY BY NETRMA	5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	5.10
SOMERSET / PRESTON	0.1	3.032	0.733	0.435	0.201	0.28	4.975	1	0.05	0.6	0.561046	0.511119	0.545835	0.540004	0.548466	0.545613	0.551286	0.64283	0.653373	0.65536
SOMERSET / ROCKMASTER	2.17	5.511	1.555	0.333	0.101	0.26	9.9	1	0.3	0.4	0.582346	0.539418	0.565729	0.565827	0.560086	0.565842	0.567827	0.660659	0.666334	0.667186
SOMERSET / BOOTH	1.54	4.509	1.96	0.179	0.503	0.54	1.988	1	0.55	0.5	0.542096	0.557534	0.445035	0.436639	0.445153	0.44516	0.464646	0.558815	0.624482	0.625766
SOMERSET / BRONSON	0	4.183	0.915	0.327	0.201	0.31	4.975	1	0.52	0.6	0.516687	0.491655	0.518223	0.512089	0.5186	0.518041	0.528007	0.616462	0.631984	0.633454
SOMERSET / PENT	0	4.084	1.51	0.302	0.302	0.59	3.311	1	0.4	0.3	0.268007	0.252543	0.401749	0.394208	0.40199	0.401716	0.425143	0.516508	0.546422	0.551409
SOMERSET / STON	1.86	5.08	0	0.36	0.201	0.45	4.975	1	0.4	0.3	0.407783	0.363013	0.437891	0.434183	0.43837	0.437884	0.452809	0.547825	0.569466	0.571718
SOMERSET / BENT	0.86	3.89	0.97	0.29	0.201	0.23	4.975	1	0.3	0.8	0.82425	0.607136	0.60768	0.60331	0.608374	0.607733	0.608284	0.697699	0.701816	0.702899
SOMERSET / TO.BANK	0.36	3.9	0	0.66	0.171	0.19	5.848	1	0.75	0.9	0.672077	0.612461	0.680215	0.676132	0.6819	0.678859	0.673462	0.761462	0.756708	0.760245
BANK / LONGAR	0.8	2.9	0	0.57	0.171	0.24	5.848	1	0.55	0.6	0.601833	0.547877	0.592483	0.587508	0.59365	0.592216	0.580086	0.683917	0.688346	0.691302
BANK / CLONKLESTER	0	2.7	1.02	1.1	0.101	0.2	9.9	0	0.1	0.5	0.517121	0.38692	0.540546	0.532345	0.547021	0.540175	0.651626	0.588969	0.737638	0.753357
BANK / LAITER	0	3.7	0.07	1	0.11	0.18	9.09	0	0.63	0.6	0.543585	0.438322	0.585089	0.577372	0.590086	0.584659	0.69252	0.638359	0.772422	0.784055
BANK / SLATER	0	1.8	0	0.55	0.101	0.13	9.9	1	0.1	0.8	0.661112	0.570576	0.873256	0.871686	0.874586	0.872883	0.849152	0.931839	0.905247	0.908371
BANK / ALBERT	0	2.04	1.36	1.5	0.101	0.16	9.9	1	0.55	0.7	0.72368	0.538685	0.757891	0.755045	0.773688	0.757481	0.743508	0.828683	0.915594	0.954388
BANK / QUEEN	1.8	0.43	1.3	0.85	0.201	0.33	4.975	1	0.58	0.5	0.541113	0.456343	0.502531	0.499342	0.50561	0.502375	0.511627	0.604578	0.618586	0.628074
BANK / WELLINGTON																				

- Note:
- Equation 5.1 and 5.2 presenting estimated delays from a linear regression analysis for the normal traffic condition
 - Equation 5.3 to 5.7 presenting estimated delays from a non-linear regression analysis for the normal traffic condition
 - Equation 5.8 to 5.10 presenting estimated delays from a non-linear regression analysis for the case of one lane blocked
 - There was road construction on Somerset Street from Bronson Ave to Kent Street

Table 6.2 showed that in the existing traffic condition model 5.6 would give the best delay results; and during one-lane-blocked model 5.8 will have the closest estimation for bus delays within the network area. Both models included the following variables: DENSITY for total traffic, LENGTH for each given link, number of bus STATION located at each link, and T/M the bus efficiency ratio.

Finally, equations 5.8, 5.9, and 5.10 were designed for the case of one lane blockage; thus, the output results were usually higher than the other developed models. Once again it was a golden opportunity to test the model for the case of one lane blocked on the road network during the research period. The model delays for one lane blocked were slightly higher than the actual field delays, the interpretation and dissertation of that matter may be influenced by: people (driver) behaviour, choosing the route with the least amount of delays i.e. faster speed and less traffic volume. Due to the major road construction on that area, a noticeable reduction in the actual traffic volume is expected. In fact, most people will shift from this route to use other faster and easier driving alternatives. The traffic count used in this study presents the average normal traffic volume in the area. Of course, higher delays are expected due to this theory.

Further testing has been carried out in order to assure the model accuracy as well as to generalize the use of the developed models in wider areas. Three locations have been chosen, Slater and Lyon Streets, Slater and bank Streets, Slater and O'Connor Streets, and the various bus arrival times have been recorded manually. Table D-1, Appendix D, contains the data collected from the field on Thursday, June 22, 1995. At the first two locations, times were recorded in minutes and seconds; however, the third

location observer could not record bus arrivals in seconds. Due to the high volume of traffic, including buses (more than 200 bus/hour), it was very difficult to maintain a high level of accuracy within the three observation stations. For the fairness of the research, all data collected were arranged within Table D-1 according to the bus arrival times. For a period of 33 minutes, 95 buses were observed.

Table 6.3 shows the estimated delays from the different developed delay models. Because some equations are more sensitive to some variables than the others, the linear model showed higher delays than the non-linear models. However, the average bus delay between the intersections of Slater and Lyon and Slater & Bank Streets is 0.668 minutes (40 seconds), and from Slater & Bank to Slater and O'Connor Streets is 0.466 minutes (28 seconds).

MODEL TESTING
THURSDAY, JUNE 22, 1995
BUS EXCLUSIVE LANE, SLATER STREET

Table 6.3 : ESTIMATED DELAYS ON SLATER STREET BY THE DIFFERENT DELAY MODELS

INTERSECTION	VEHICLE DENSITY (Vehicles per Hour/Lane/Km.)			LENGTH (Km)	M/T (Ratio)	No. of SIGNAL (per Km.)	No. of BUS STATION (per Lane)	ESTIMATED DELAYS FROM EQUATION NUMBER:										
	DENSITY 1	DENSITY 2	DENSITY 3					5.1	5.2	5.3	5.4	5.5	5.6	5.7	5.8	5.9	5.10	
SLATER / LYON	4.3	6.81	1.77	2.21	0.41	0.32	5	1	1.012808	0.839102	0.52755	0.562912	0.57717	0.520083	0.553358	0.633156	0.663029	0.78808
SLATER / BANK	0.175	5.59	0.95	1.42	0.2	0.47	5	1	0.453012	0.327805	0.430422	0.423143	0.443646	0.430472	0.445702	0.541272	0.564047	0.588238
SLATER / O'CONNOR																		

Note:

- Equation 5.1 and 5.2 presenting estimated delays from a linear regression analysis for the normal traffic condition
- Equation 5.3 to 5.7 presenting estimated delays from a non-linear regression analysis for the normal traffic condition
- Equation 5.8 to 5.10 presenting estimated delays from a non-linear regression analysis for the case of one lane blocked

6.3 Model Usage and Application:

The developed model can be widely used to upgrade the bus scheduling system. This could be for the long term plan as well as the short term. The long term schedule planning is the printed schedule at the bus stop location. The short term schedule update will be through the technology of the AVL system and the 560 system. Providing the computer system with the information and substitute for the variable on the equation will result on having an accurate estimation for the bus arrivals at the different locations. This system will create a new era of planning and will result in a complete revolution in the public transportation system.

Table 6.4 provides an illustrative example of a computer calculation including an estimation for bus arrivals at Slater and Bank Streets and Slater and O'Connor Streets. Calculations were based on the bus free flow speed, the distance between each two locations, and the estimated delays from the developed delay models. Since time is a function of distance over operating speed, a bus travel time could be estimated between any two locations.

$$\text{Total Bus Travel Time} = (\text{Distance} / \text{Free Flow Speed}) + \text{Expected Delays}$$

Distance was measured from the field, the bus free flow speed was considered as 25 mph or 40 km/h as per the TRAF-NETSIM User Reference Guide recommendation [42,43], and the expected delays were estimated by an average of the developed delay models (Table 6.3).

Table 6.4 : MODEL TESTING
THURSDAY, JUNE 22, 1995
BUS EXCLUSIVE LANE, SLATER STREET

BUS NUMBER	ROUTE NUMBER	BUS ARRIVAL TIME				
		SLATER @ BANK ST.			SLATER @ O'CONNOR	
		FIELD	MODEL	DIFFERENCE	FIELD	MODEL
8769	86	08:29:20	08:29:01	00:00:19	08:30	08:29:49
8860	95	08:30:10	08:30:00	00:00:10	08:30	08:30:48
8799	85	08:30:29	08:30:01	00:00:28	08:30	08:30:49
7432	44	08:30:54	08:30:30	00:00:24	08:31	08:31:18
5714	41	08:31:05	08:30:33	00:00:32	08:31	08:31:21
7746	97	08:33:02	08:32:33	00:00:29	08:33	08:33:21
7440	69	08:33:22	08:32:53	00:00:29	08:33	08:33:41
5702	72	08:33:25	08:32:54	00:00:31	08:33	08:33:42
7451	50	08:35:01	08:34:23	00:00:38	08:35	08:35:11
9206	75	08:35:02	08:34:36	00:00:26	08:35	08:35:24
8642	95	08:35:05	08:34:40	00:00:25	08:36	08:35:28
7642	65	08:35:28	08:35:13	00:00:15	08:36	08:36:01
9136	13	08:35:57	08:35:18	00:00:39	08:36	08:36:06
7534	78	08:36:07	08:35:28	00:00:39	08:36	08:36:16
7455	60	08:36:08	08:35:33	00:00:35	08:36	08:36:21
7521	64	08:36:09	08:35:35	00:00:34	08:37	08:36:23
8621	85	08:36:20	08:36:03	00:00:17	08:37	08:36:51
9111	70	08:37:15	08:36:46	00:00:29	08:38	08:37:34
8941	96	08:37:22	08:36:50	00:00:32	08:38	08:37:38
9306	67	08:37:33	08:37:31	00:00:02	08:38	08:38:19
7705	76	08:38:15	08:37:58	00:00:17	08:38	08:38:46
8865	95	08:38:19	08:38:00	00:00:19	08:38	08:38:48
5746	86	08:38:22	08:38:02	00:00:20	08:38	08:38:50
7706	63	08:38:50	08:38:23	00:00:27	08:39	08:39:11
7747	61	08:38:52	08:38:28	00:00:24	08:39	08:39:16
9129	97	08:38:53	08:38:33	00:00:20	08:39	08:39:21
8001	73	08:40:00	08:39:36	00:00:24	08:40	08:40:24
7433	8	08:40:04	08:39:38	00:00:26	08:40	08:40:26
9135	3	08:40:06	08:39:43	00:00:23	08:41	08:40:31
8742	95	08:40:09	08:39:48	00:00:21	08:41	08:40:36
8732	95	08:42:00	08:41:45	00:00:15	08:42	08:42:33
7414	62	08:42:02	08:41:46	00:00:16	08:42	08:42:34
7416	59	08:42:08	08:41:47	00:00:21	08:42	08:42:35
9110	46	08:43:09	08:43:28	(00:00:19)	08:43	08:44:16
9114	60	08:43:11	08:43:29	(00:00:18)	08:44	08:44:17
8524	86	08:44:12	08:43:34	00:00:38	08:44	08:44:22
7825	66	08:44:15	08:43:48	00:00:27	08:44	08:44:36
9131	76	08:44:19	08:43:49	00:00:30	08:45	08:44:37
7520	41	08:45:01	08:44:48	00:00:13	08:45	08:45:36
9119	44	08:45:04	08:44:53	00:00:11	08:45	08:45:41

Table 6.4: Continued

BUS NUMBER	ROUTE NUMBER	BUS ARRIVAL TIME				
		SLATER @ BANK ST			SLATER @ O'CONNOR	
		FIELD	MODEL	DIFFERENCE	FIELD	MODEL
7764	97	08:45:49	08:45:18	00:00:31	08:46	08:46:06
8730	95	08:45:57	08:45:23	00:00:34	08:46	08:46:11
7754	57	08:46:48	08:46:29	00:00:19	08:47	08:47:17
7459	69	08:47:01	08:46:31	00:00:30	08:47	08:47:19
7412	50	08:47:09	08:46:35	00:00:34	08:47	08:47:23
7855	13	08:47:12	08:47:18	(00:00:06)	08:48	08:48:06
7419	73	08:47:16	08:47:21	(00:00:05)	08:49	08:48:09
9102	8	08:47:50	08:47:23	00:00:27	08:49	08:48:11
8849	95	08:49:06	08:49:01	00:00:05	08:49	08:49:49
7844	65	08:50:01	08:49:28	00:00:33	08:50	08:50:16
9226	75	08:50:03	08:49:35	00:00:28	08:50	08:50:23
8634	85	08:50:04	08:49:36	00:00:28	08:50	08:50:24
9258	78	08:50:42	08:50:18	00:00:24	08:51	08:51:06
5710	55	08:50:45	08:50:28	00:00:17	08:51	08:51:16
5767	63	08:51:49	08:51:31	00:00:18	08:52	08:52:19
9124	96	08:51:56	08:51:32	00:00:24	08:52	08:52:20
8761	95	08:52:01	08:51:36	00:00:25	08:52	08:52:24
7701	62	08:52:47	08:52:28	00:00:19	08:53	08:53:16
7428	46	08:52:58	08:52:29	00:00:29	08:53	08:53:17
5724	61	08:53:56	08:53:29	00:00:27	08:54	08:54:17
9147	41	08:53:58	08:53:33	00:00:25	08:54	08:54:21
9234	70	08:54:53	08:54:28	00:00:25	08:55	08:55:16
5768	78	08:54:59	08:54:45	00:00:14	08:56	08:55:33
8921	3	08:56:02	08:55:32	00:00:30	08:56	08:56:20
5716	50	08:56:04	08:55:33	00:00:31	08:56	08:56:21
9220	57	08:56:05	08:55:38	00:00:27	08:57	08:56:26
9101	59	08:56:42	08:56:28	00:00:14	08:57	08:57:16
8628	95	08:57:00	08:56:30	00:00:30	08:57	08:57:18
9009	97	08:57:04	08:56:34	00:00:30	08:57	08:57:22
9311	67	08:57:34	08:57:38	(00:00:04)	08:58	08:58:26

Average Difference:

00:00:23

Adding the total bus travel time to the existing time at any point within the bus path, an estimated bus arrival time will be available to the bus users. This could be achieved through updating the 560 telephone system and/or on-street monitoring system.

Also, Table 6.4 showed that the model results are similar to the actual field observations. The difference varies from 2 to 39 seconds. In fact, the model was consistently measuring fewer delays which gives an earlier bus arrival than the actual data. This is a definite indication that the traffic volume has increased since 1993 (RMOC traffic volume and survey data used for this research were backdated to 1993). The author could not compare the difference of model results and the actual bus arrival data at the intersection Slater and O'Connor Streets due to the different level of accuracy for the data collected. However, model results appear to be very reasonable and within the expected figures.

The developed models could also help the authorities (transit agencies) to have a more concise idea about the transit services modifications, as well as to encourage people to change their mode of travel from private automobile to the public mass transit system. The system will also result in a significant reduction in the vehicle total kilometre travel and improvement in the flow of traffic with the use of information and communication technology, like variable sign messages within the Intelligent Vehicle Highway System (IVHS) and the Automatic Vehicle Location & Control System (AVLC). As a result, a reduction in traffic jams, especially during the rush hour period, is a possibility. In fact, this system will create another new phenomena in travel patterns to spread the peak period more uniformly.

The model can help engineers, planners, as well as decision makers to choose appropriate truck routes. Equation 5.5, as well as 5.10, can explain the influence of heavy vehicles on the bus transit system operation. Some bus routes are merging with a massive numbers of trucks, especially for delivery purposes in the CBD, and many delays are caused because of the lack of space.

In this case, the developed model can give a good idea of how much improvement could be achieved with the reduction of number and/type of heavy vehicles in the road network system. Using the same methodology, it can be very easy to estimate the effect of the number of traffic lights installed on any bus route, as well as a determination analysis for the effect on the number of bus stops for the different reasons and the distance between the transit stops that could be achieved.

Finally, the developed delay models, as well as the whole research technique, could benefit other public service agencies, i.e. Fire Departments, Ambulances, Police Departments, and also many other private organizations, such as the courier & delivery companies. Using the developed delay models will assist in anticipating vehicle arrival times at any location. Living in a more consciously oriented society inundated with sophisticated technology, people's sensitivity towards value of time is growing faster exponentially. From the customer services point of view, arriving a few minutes late could drastically change one's perception, image, as well as attitudes towards, a company's service and its reputation.

CHAPTER 7

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Research Summary:

Public Transportation Systems play a major role in the efficient functioning of any nation's economy. Enhancing the bus system will have a significant impact on public welfare. Also, improving the bus service will have an impact on private car ownership; the benefits would affect the economy as well as the environment. A remarkable decrease in vehicle fuel consumption, as well as air pollution (especially in the metropolitan areas in North America), will be the positive consequence. The urban public transit developments are more likely to expand for many various reasons, i.e. improving environmental quality, energy conservation, forming a balanced urban transportation system, available and accessible for most users without cars, and providing the most competitive and alternative mode of travel to the private vehicle in case of energy crises and/or environmental disruption [61].

Actual traffic data on bus route #2, from Bayshore Shopping Centre (Ottawa-West) to Blair Station (Ottawa-East), were received from the Regional Municipality of Ottawa-Carleton and the City of Ottawa. Also, field studies were carried out on bus operation and traffic flow. This network information was compiled and entered into a simulation package to obtain an estimation of bus delays associated with the existing traffic conditions. In order to develop the data base for this research, the simulation approach was used since it was not possible to collect sufficient data on bus delays, operations, and

traffic flow from the field in order to develop regression models. The TRAF-NETSIM program, the most reliable and calibrated micro-simulation model, was used for this purpose. This package uses a comparison between the total travel time (total time spent on the system) and the free flow travel time (travel time under "**free flow**" condition) to calculate the delays. The multiple regression analysis was executed to develop the best fit for the variable. The model was developed by using a well known Statistical Package for Social Science "**SPSS**". A step-wise variable entry method and/or a partial regression analysis were performed to accept or drop a given variable to develop an equation. An attempt was made to accommodate all of the aforementioned variables, listed earlier in Chapter 5, provided they met the stipulated statistical level of significance.

The developed delay models have shown impressive results for determining bus delays that will be reflected in the accurate estimation of the bus arrivals at any particular location. Furthermore, since the intention of the OC-Transpo Planning and Operation Department (or at any other Public Transit Operator Companies) is to reduce the bus travel time while serving the required ridership rate (increase the ridership to the maximum), there were two sets of models developed for the following different conditions:

- ▶ normal traffic condition (existing traffic situation)
- ▶ case of one lane blocked (i.e. accident occurrence, snow storm)
- ▶ bus-right-of-way (a new signal phase by creating a special green phase (**PTO-Phase**) for transit buses only)

Also, the analyses of bus operation and traffic flow have been carried out through a series of intersection video taping. Survey results and recommendations are listed in previous chapters.

Rapid development of transportation technology can result in changes to traffic operation and also data can be obtained for model development. Traditionally, the performance of any transportation facility is measured by "Level Of Services" (LOS) standards. The existing LOS standards for all intersections are in terms of stopped delay in seconds per vehicle. The main objective of this research was to improve the LOS for transit buses. **Appendix (C)** includes some of the new technologies available in the market for the transportation and traffic analysis.

7.2 Conclusions:

The analysis of field data and examination of the developed delay models suggested the following conclusions:

1. The total delay for any bus in operation can be estimated in Bus.Min. Also, it could be in Bus.Sec depending on the level of accuracy required for the model user and the units in use during the model development.
2. Although the delay function (the delay against its explanatory variables) can be expressed as a linear relationship, it is more accurate to describe the function in a non-linear format. This observation is made on the basis of the regression analysis and the SPSS program output.
3. Link length, number of bus stations, and the T/M ratio (travel time / moving time)

proved to be the most significant independent variables influencing the actual bus delay estimation (they were significant in all equations at 0.00 level of significance). Field observations show that the longer the route length, the more chances for delays; the more bus stations on the bus path, the more customer service time required and the ratio between the total travel time and the moving time represents the bus inefficiency ratio. The higher the ratio the greater the delays encountered on the road.

4. The vehicle density variable had a strong effect on the bus delays; the best description for the delay caused by the vehicle density was the cubic curve relationship.
5. The left turn vehicle density also had an effect on bus delays; this is logical because the left turn vehicles slow down the general traffic movement and thus contribute to more delays for buses. This variable was highly significant in some equations and less in others, depending on their combinations.
6. The vehicular hourly volume, speed, as well as the number of lanes are all related to the vehicle density variable.
7. The heavy vehicle density was considered for inclusion in regression analysis. Considering the other variables included in the equation, this variable was not statistically significant enough to be present in all equations.
8. The number of traffic signals per kilometre is definitely a good variable that may cause extra delays for traffic flow in general. During the multiple regression analysis (non-linear regression), the **SIGNPKM** (number of signals per kilometre)

showed a negative relation to delay. However, this is illogical. The simple correlation of this variable with delay was tested and found to be positive. For information only, the signal/km was left in the first model and was deleted in the following developed models.

9. The videotaping technique was a very useful tool to conduct the bus operation survey. Furthermore, its results are used to verify the developed delay model by regression-based models.
10. The bus survey has provided detailed information on the bus operation, as well as the actual traffic pattern on the study area network.
11. Data obtained from the video tape have resulted in the following breakdown of bus activities [summary of Figure 2.4]:

time spent on bus stops	17.00%
time spent on traffic delays	20.40%
<u>total driving time</u>	<u>62.60%</u>
Total Trip Time	100.00%

12. Bus #2 operation-survey results showed that on the average, 15 minutes were spent on transit stops. An average bus has stopped on 81.50% of the bus stations located en-route.
13. An average bus made a complete stop at 48% of the traffic control signs, and as a result, a bus has experienced the sum of 18 minutes of delays due to traffic signalization. This delays presents 20.50% of the total bus trip time.
14. The average bus traversed the 25.6 kilometre trip in 01:27:50 seconds with an

average speed of 17 km/h.

15. Data outcome from the computer simulation showed the results of the "bus-right-of-way scenario" which will improve (shorten) the total travel time by 19.4%, decrease bus delays by 33%, and will also improve the average operating speed by 24%.
16. In case of accident occurrence or the event of "one-lane blocked", the bus travel time will be affected with 10.5% increase, the total bus delays also will increase by 14.2%, and the average operating speed will decrease by 9.8%.
17. Traffic priorities and regulatory measures will help transit vehicles to operate efficiently, freely, and faster regardless of the road traffic conditions.
18. Providing priorities to transit vehicles will result in lowering operation cost, attracting more customers, improving bus performance, and schedule adherence.

Also, the study methodology, developed models, and results have enabled the author to point out other conclusions:

Public and Customer's Level:

The development of the delay models has resulted in the identification of many parameters pertaining to the users of public transportation system, such as:

1. The delay models will improve reliability in obtaining information about the bus delays and bus arrivals at the different locations.
2. Low cost operation will benefit many of the social layers represented in the

- public, (low operation cost intended to reflect on the final cost per passenger).
3. **Consumer sensitivity for advanced trip planning and higher confidence in the transit system will be achieved.**
 4. **The system will improve comfort, security, frequency, reliability, and the public information services where it's possible.**

Operators and Manager's level:

The delay models will help managers increase productivity in the following areas:

1. **Expansion of the transit system.**
2. **Increasing the ridership as a result of enhancing the services.**
3. **Improving planning, implementation and level of services.**
4. **Development of a higher quality transit services to compete with, and increase its attractiveness in comparison to the private vehicle mode. (increasing their market share)**
5. **Better control of the bus fleet and decision making based on facts and real time monitoring system.**
6. **Shorter trip time and fewer delays resulting in improvements in the door-to-door trips and minimize waiting and transfer times.**
7. **Use of the new technology and advanced telecommunication, i.e. the Automatic Vehicle Location and Control System (AVLC), Intelligent Highway Vehicle System (IVHS), computerized bus detection & control system (PTO system), and many other new transit software programs.**

8. Development of the bus-stop information system by using the AVL system.

Social and Environmental Level:

This research has resulted in highlighting many social and environmental concerns:

1. Creation of an environment where the transit system can play the dominant role.
2. Could influence the private-vehicle-ownership rate, which could result in a significant reduction in emission released into the environment.
3. Fewer cars means less pollution and major decrease in toxic gases, i.e. Hydro-Carbons (HC), Carbon-Monoxide (CO), Carbon-Dioxide (CO₂), Nitrogen-Oxide (NO_x), Sulphur-Dioxide (SO₂), and many other small, unidentified, and particular matters [62].
4. A healthy environment by improving the air quality and reducing the noise level [63].

7.3 Recommendations:

Application of the Findings of This Research: Based on the above conclusions, the author strongly recommends the following:

1. Using the same research methodology, its important to consider the effect of opposite traffic direction and its effect on bus operation.
2. Considering number of passengers on board as a variable in the developed delay models.

3. Analysis of a bus route using the exclusive-bus-lanes.
4. Using of up-to-date traffic counts in order to have an accurate model results.
5. Using bus detectors to eliminate bus delays at the intersection crossing.
6. Installation of the on-street traffic monitoring equipment in bus pathways for producing reliable data and control of bus movements.
7. Enhancing transit system operations in order to reduce the number of private vehicle trips, especially during the peak hour period.
8. Investing more money in advanced technology, i.e. AVLC, IVHS, and PTO systems, to control vehicle operation on the road, which will reduce emissions.
9. Simulating the study area in one file (one run), as well as considering traffic comparison with other bus routes within the region.

Recommendations for Further Studies:

There is a definite need for further study on the subject of this thesis. Such a study could potentially supplement and refine the results of this analysis. Since TRAF-NETSIM soft were has a limited capability for transit analysis, more reliable delay estimation software packages for the transit vehicles would enhance the results provided in this thesis. These deserve serious consideration. In urban areas where the largest portion of bus delays is caused by traffic signalization, the idea of bus-right-of-way, PTO-Phase, to the bus system must be seriously considered in order to make the public transit system the most favourable option to the public. It would be useful to have the same type of research for the express buses with the exclusive right-of-way.

The first attempt for such a study, is to revise regression analyses using an up-to-date traffic count. As indicated in Chapter 2, there was a significant difference in the traffic volumes counted by the RMOC and the survey counts at some of the intersections. The dissimilarity in results cannot be ignored.

Further investigation needs to be conducted through an inclusion of more variables in the developed delay models, and an improved data base in order to investigate the relevance of the number of signals/km variable . More field data should be collected for checking the accuracy of the developed delay models under different traffic conditions. Thus, more simulation work is required to estimate delays during the off-peak periods since this research mainly focused on the a.m. peak hour. Also, it is worth investigating the effects produced by different bus stops whether protected (bus bay) or un-protected, on the system level overall delays.

Development of a computer software program which can use the developed delay models in updating the 560-system is crucial. The impact of using accurate estimation for bus arrivals would definitely have a positive impact in attracting more customers to transit services.

Finally, the number of people travelling on the buses (bus occupancy) should have an effect on bus delays. Also, it is useful to use the data from the automatic passenger counter installed in most of the OC-Transpo buses and be included in the regression analysis.

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TRAF-NETSIM NETWORK SIMULATION DATA

49 6 5 825 1 0 8007 48008 4 25 22 10 0111 11
50 7 6 825 2 00 8009 58026 5 25 22 10 0111 11
05EQ 4 1 2 3 4 5 6 7 8

1 CARD FILE LIST (CONT.)
05EQ 4 1 2 3 4 5 6 7 8

51 8 7 330 160 2 1 00 8010 68011 6 25 22 10 0111 11
52 9 8 990 01 8012 78027 7 25 22 10 0111 11
53 10 9 500 00 8011 88014 8 25 22 10 0111 11
54 11 10 850 001 8015 98016 9 25 22 10 0111 11
55 12 11 640 00 8017 108018 10 25 22 10 0111 11
56 13 121200 00 8019 118020 11 25 22 10 0111 11
57 8000 1 3 391 43 8001 1 53 180 21
58 8002 1 7 7 1 2 13 295 21
59 8003 2 125 564 8004 2 277 73 41 21
60 2 3 540 8005 3 17 10 30 21
61 3 4 467 21
62 8006 4 60 15 44 8025 4 17 10 76 21
63 4 5 8 580 7 8007 5 17 4 76 21
64 8008 5 17 4 76 5 6 8 580 21
65 8009 6 60 13 44 8018 11 17 7 77 21
66 6 7 25 612 114 8010 7 66 126 580 21
67 8011 7 6 357 96 7 8 9 618 10 21
68 8012 8 60 13 44 8027 8 17 10 76 21
69 8 9 0 435 751 8013 9 0 697 4 21
70 8014 9 1931059 0 9 10 104 540 5 21
71 8015 10 2 11 7 8016 10 84 0 49 21
72 10 11 12 521 25 8017 11 20 29 26 21
73 11 12 20 612 73 8019 12 33 35 53 21
74 12 13 9 618 10 8020 12 20 99 18 21
75 8021 13 21 6 62 8022 13 142 14 19 21
76 8023 13 34 345 21 21
77 2 1 64 299 3 3 2 315 92 21
78 4 3 21 262 26 5 4 24 265 22 21
79 6 5 21 262 28 7 6 158 12 21
80 8 7 95 125 7 9 8 34 345 12 21
81 10 9 63 435 751 11 10 104 540 14 21
82 12 11 43 395 7 13 12 43 395 21
83 1 08000 280018002 28 17 6 35
84 2 0 180048003 3 34 17 22 35
85 3 48005 2 35
86 4 0 3 580068025 39 21 35
87 5 0 6 480078008 39 21 35
88 6 78009 5 35
89 7 9380108011 6 8 70 50 35
90 8 080128027 7 9 39 21 35
91 9 3880138014 8 10 45 50 25 35
92 10 5080158016 9 11 28 32 35
93 11 0 10 1280178018 32 18 35
94 12 52 13 1180198020 24 46 35
95 13 48023 1280218022 40 30 35
96 1 1122 2211 2221 36
97 2 2211 4142 1122 36
98 3 5 36
99 4 1122 2211 36
100 5 1122 2244 36
05EQ 4 1 2 3 4 5 6 7 8

1 CARD FILE LIST (CONT.)
05EQ 4 1 2 3 4 5 6 7 8

101 6 5 36
102 7 2211 1122 36
103 8 2211 1122 36
104 9 2211 1122 4422 36
105 10 2211 1122 36
106 11 1122 2211 36
107 12 2211 1122 36
108 13 1122 2211 36
109 8000 1 437 13 8001 1 233 23 8002 1 14 0 50
110 8003 2 689 3 8004 2 391 7 50
111 8005 3 35 2 50
112 8006 4 117 4 8025 4 97 3 50
113 8007 5 117 4 8008 5 112 2 50
114 8009 6 115 4 50
115 8010 7 459 5 8011 7 772 6 50
116 8012 8 115 3 8027 8 99 2 50
117 8013 91252 6 8014 9 702 5 50
118 8015 10 133 5 8016 10 52 4 50
119 8017 11 135 3 8018 11 122 2 50
120 8019 12 137 5 8020 12 121 2 50
121 8021 13 175 8 8022 13 89 8 8023 13 637 5 50
122 0 50
123 1 1 1 2 300 4 1 2 1 2 3 200 1 1 3 0 3 4 650 1 1 170
124 4 0 3 4 250 1 1 5 0 4 5 550 1 1 6 0 4 5 180 1 1 185
125 7 0 5 6 200 1 1 8 1 6 7 200 1 1 9 1 7 8 100 1 1 185
126 10 1 8 9 100 1 11 1 9 10 100 1 112 1 10 11 120 1 1 185
127 13 1 11 12 250 1 1 185
128 1 10 0 2 10 10 3 10 10 4 10 10 5 10 10 6 10 10 186
129 7 10 10 8 10 10 9 10 10 10 10 10 11 10 10 12 10 10 186
130 13 10 10 186
131 188017 11 12 138023 187
132 208017 11 12 138023 187
133 228000 1 28003 187
134 228000 1 2 3 4 5 68026 187
135 238000 1 28003 187
136 28000 1 2 3 4 5 6 7 9 10 11 12 138023 187
137 248003 2 3 4 5 68026 187
138 2 1 2 3 4 5 6 7 8 910111213 188
139 18 13 188
140 20 13 188
141 21 1 188
142 23 1 188
143 24 2 3 4 5 188
144 24 900 18 999 20 600 21 900 22 900 23 900 2 600 188
145 1 0 0 189
05EQ 4 1 2 3 4 5 6 7 8 210

TRAP SIMULATION MODEL

DEVELOPED FOR

U. S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
INTELLIGENT VEHICLE HIGHWAY SYSTEM RESEARCH DIVISION

START OF CASE 1

OC-Transpo...Route#2 - Section (1) Bus Operation Study

DATE = 5/ 24/ 94
USER = Ali Abdelfattah
AGENCY = Carleton University
RUN CONTROL DATA

VALUE RUN PARAMETERS AND OPTIONS

1 RUN IDENTIFICATION NUMBER
0 NEXT CASE CODE = (0,1) IF ANOTHER CASE (DOES NOT, DOES) FOLLOW
1 RUN TYPE CODE = (1, 2, 3) TO RUN (SIMULATION, ASSIGNMENT, BOTH)
(-1,-2,-3) TO CHECK (SIMULATION, ASSIGNMENT, BOTH) ONLY

NETSIM ENVIRONMENTAL OPTIONS

0 FUEL/EMISSION RATE TABLES ARE NOT PRINTED
0 SIMULATION: PERFORMED ENVIRONMENTAL MEASURES CALCULATED
RATE TABLES: EMBEDDED TRAJECTORY FILE NOT WRITTEN

0 INPUT UNITS CODE = (0,1) IF INPUT IS IN (ENGLISH, METRIC) UNITS
2 OUTPUT UNITS CODE = (0,1,2,3) IF OUTPUT IS IN (SAME AS INPUT, ENGLISH, METRIC, BOTH) UNITS
730 CLOCK TIME AT START OF SIMULATION (HHMM)
0 SIGNAL TRANSITION CODE = (0,1,2,3) IF (NO IMMEDIATE, 2-CYCLE, 3-CYCLE) TRANSITION WAS REQUESTED
7581 RANDOM NUMBER SEED
7781 RANDOM NUMBER SEED TO GENERATE TRAFFIC STREAM FOR NETSIM OR LEVEL I SIMULATION

900 DURATION (SEC) OF TIME PERIOD NO 1
60 LENGTH OF A TIME INTERVAL, SECONDS
30 MAXIMUM INITIALIZATION TIME, NUMBER OF TIME INTERVALS
0 NUMBER OF TIME INTERVALS BETWEEN SUCCESSIVE STANDARD OUTPUTS
0 TIME INTERMEDIATE OUTPUT WILL BEGIN AT INTERVALS OF 0 SECS FOR 0 SECS. FOR MICROSCOPIC MODELS
0 NETSIM MOVEMENT-SPECIFIC OUTPUT CODE = (0,1) IF NOT, IF REQUESTED FOR NETSIM SUBNETWORK
0 NETSIM GRAPHICS OUTPUT CODE = (0,1) IF GRAPHICS OUTPUT (IS NOT, IS) REQUESTED

TIME PERIOD 1 - NETSIM DATA

NETSIM LINKS

-LANE'S- -CHANNEL-

LINK	LENGTH FT / M	F U L	P K T	G R D	L I N K	C U R	DESTINATION NODE LEFT THRU RIGHT	OPP NODE	LOST TIME SEC	Q DIS HDWY SEC	FREE SPEED MPH/KMPH	RTOR CODE	PED CODE	LANE ALIGN -MENT	STREET NAME
1000	11	0	0	2	0	0	0000000	8002 2 8001	0	2 2 5	2 2	10/ 48	0 3	1-1	
1001	11	0	0	3	0	0	4410000	8000 0 2	0	2 2 5	2 2	10/ 48	0 3	1-1	
1002	11	0	0	2	0	0	4100000	2 0 8000	0	0 2 5	2 2	10/ 48	0 3	1-1	
1	21	730/ 223	5	0	0	0	4441100	3 0 8003	0	2 2 5	2 2	10/ 48	0 3	1-1	
1003	21	0	0	4	0	0	0011000	1 3 0	0	1 2 5	2 2	10/ 48	0 3	1-1	
1004	21	0	0	4	0	0	4011000	8003 1 3	0	0 2 5	2 2	10/ 48	0 3	1-1	
2	31	495/ 151	2	0	0	0	0000000	0 4 8024	0	4 2 5	2 2	10/ 48	0 3	1-1	
1005	31	0	0	1	0	0	0000000	2 8024 4	0	0 2 5	2 2	10/ 48	0 2	1-1	
1006	121	0	0	1	0	0	0000000	13 8019 11	0	8019 2 5	2 2	10/ 48	0 2	1-1	
3	41	1120/ 341	1	0	0	0	0000000	0 5 0	0	5 2 5	2 2	10/ 48	0 3	1-1	
1006	41	0	0	1	0	0	0000000	3 8025 5	0	8025 2 5	2 2	10/ 48	0 2	1-1	
1007	41	0	0	1	0	0	0000000	5 8006 3	0	8006 2 5	2 2	10/ 48	0 2	1-1	
4	51	990/ 302	1	0	0	0	0000000	8008 6 8007	0	6 2 5	2 2	10/ 48	0 3	1-1	
1007	51	0	0	1	0	0	0000000	4 8008 6	0	8008 2 5	2 2	10/ 48	0 2	1-1	
1008	51	0	0	1	0	0	0000000	6 8007 4	0	8007 2 5	2 2	10/ 48	0 2	1-1	
5	61	825/ 251	1	0	0	0	0000000	8026 7 0	0	7 2 5	2 2	10/ 48	0 3	1-1	
1009	61	0	0	1	0	0	0000000	5 8026 7	0	0 2 5	2 2	10/ 48	0 2	1-1	
1010	111	7/ 0	1	0	0	0	0000000	12 8017 10	0	8017 2 5	2 2	10/ 48	0 2	1-1	
6	71	825/ 251	2	1	0	0	0000000	8011 8 8010	0	8 2 5	2 2	10/ 48	0 3	1-1	
1010	71	0	0	1	0	0	0000000	6 8011 8	0	8011 2 5	2 2	10/ 48	0 2	1-1	
1011	71	0	0	1	0	0	0000000	8 8010 6	0	8010 2 5	2 2	10/ 48	0 2	1-1	
7	81	330/ 101	2	0	0	0	0000000	8027 9 8012	0	9 2 5	2 2	10/ 48	0 3	1-1	
1012	81	0	0	1	0	0	0000000	7 8027 9	0	8027 2 5	2 2	10/ 48	0 2	1-1	
1027	81	0	0	1	0	0	0000000	9 8012 7	0	8012 2 5	2 2	10/ 48	0 2	1-1	
8	91	990/ 302	2	0	0	0	0100000	8014 10 8013	0	10 2 5	2 2	10/ 48	0 3	1-1	
1013	91	0	0	1	0	0	0000000	8 8014 10	0	8014 2 5	2 2	10/ 48	0 2	1-1	
1014	91	0	0	1	0	0	0000000	10 8013 8	0	8013 2 5	2 2	10/ 48	0 2	1-1	
9	101	500/ 152	3	0	0	0	4000000	8016 11 8015	0	11 2 5	2 2	10/ 48	0 3	1-1	
1015	101	0	0	2	0	0	0100000	9 8016 11	0	8016 2 5	2 2	10/ 48	0 2	1-1	
1016	101	0	0	2	0	0	0000000	11 8015 9	0	8015 2 5	2 2	10/ 48	0 2	1-1	
10	111	850/ 259	7	0	0	0	0000000	8018 12 8017	0	12 2 5	2 2	10/ 48	0 3	1-1	
1017	111	0	0	1	0	0	0000000	10 8018 12	0	8018 2 5	2 2	10/ 48	0 2	1-1	
11	121	000/ 201	2	1	0	0	0000000	8020 13 8019	0	13 2 5	2 2	10/ 48	0 3	1-1	
1019	121	0	0	1	0	0	0000000	11 8020 13	0	8020 2 5	2 2	10/ 48	0 2	1-1	
12	131	1200/ 366	2	0	0	0	0000000	8022 8023 8021	0	8023 2 5	2 2	10/ 48	0 3	1-1	
1021	131	0	0	1	0	0	0000000	12 8022 8023	0	8022 2 5	2 2	10/ 48	0 2	1-1	
1022	131	0	0	1	0	0	0000000	8023 8021 12	0	8021 2 5	2 2	10/ 48	0 2	1-1	
1023	131	0	0	2	0	0	0000000	8021 12 8022	0	12 2 5	2 2	10/ 48	0 2	1-1	
2	1	730/ 223	4	0	0	0	4400000	8001 8000 8002	0	8000 2 5	2 2	10/ 48	0 3	1-1	
3	21	495/ 151	4	0	0	0	4000000	8004 8003 1	0	8003 2 5	2 2	10/ 48	0 3	1-1	
4	31	1120/ 341	1	0	0	0	0000000	8005 2 8024	0	2 2 5	2 2	10/ 48	0 3	1-1	
5	41	990/ 302	2	0	0	0	4000000	8006 3 8025	0	3 2 5	2 2	10/ 48	0 3	1-1	
6	51	825/ 251	1	0	0	0	0000000	8007 4 8026	0	4 2 5	2 2	10/ 48	0 3	1-1	
7	61	825/ 251	2	0	0	0	0000000	8009 5 8026	0	5 2 5	2 2	10/ 48	0 3	1-1	
8	71	330/ 101	2	1	0	0	0000000	8010 6 8011	0	6 2 5	2 2	10/ 48	0 3	1-1	

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NETS IN LINKS (CONT.)

		-LANES-		-CHANNEL-		MAIN LINE COUNT													
LINK	LENGTH FT / M	F U		C U		DESTINATION LEFT THRU RIGHT	MODE DIAG	OPP MODE	LOST TIME SEC	Q DIS HWMY SEC	FREE SPEED MPH-KMPH	PTOR CODE	PED CODE	LANE ALIGN -MENT	STREET NAME				
		L	R	L	R														
						214567													
(9. 8)	990/ 302	2	0	0	1*	01000000	8012	7 8027	0	7 2 5	2 2	30 48	0 3	1-1					
(10. 9)	500/ 152	2	0	0	1*	00000000	8013	8 8014	0	8 2 5	2 2	30 48	0 3	1-1					
(11. 10)	850/ 259	3	0	0	1*	00100000	8015	9 8016	0	9 2 5	2 2	30 48	0 3	1-1					
(12. 11)	660/ 201	2	0	0	1*	00000000	8017	10 8018	0	10 2 5	2 2	30 48	0 3	1-1					
(13. 12)	1200/ 366	2	0	0	1*	00000000	8019	11 8020	0	11 2 5	2 2	30 48	0 3	1-1					

* INDICATES DEFAULT VALUES WERE SPECIFIED

LINK TYPE	LANE CHANNELIZATION CODES	RTOR CODES	PEDESTRIAN CODES
IDENTIFIES THE DISTRIBUTION USED FOR QUEUE DISCHARGE AND START-UP LOST TIME CHARACTERISTICS	0 UNRESTRICTED 1 LEFT TURNS ONLY 2 BUSES ONLY 3 CLOSED 4 RIGHT TURNS ONLY 5 CAR - POOLS 6 CAR - POOLS + BUSES	0 RTOR PERMITTED 1 RTOR PROHIBITED	0 NO PEDESTRIANS 1 LIGHT 2 MODERATE 3 HEAVY

TOTAL LINKS 50 (ALLOWED 500)
TOTAL NON-ENTRY NODES 13 (ALLOWED 250)

NETSIM TURNING MOVEMENT DATA

LINK	TURN MOVEMENT PERCENTAGES				TURN MOVEMENT POSSIBLE				PACKET LENGTH (IN FEET/METERS)			
	LEFT		THROUGH RIGHT DIAGONAL		LEFT		THROUGH RIGHT DIAGONAL		LEFT		RIGHT	
(8000. 1)	1	89	10	0	YES	YES	YES	NO	9	0	0/	0
(8001. 1)	23	0	77	0	YES	NO	YES	NO	0/	0	0/	0
(8002. 2)	50	0	50	0	YES	NO	YES	NO	0/	0	0/	0
(1. 2)	4	0	96	0	YES	NO	YES	NO	0	0	0/	0
(8003. 2)	18	82	0	0	YES	YES	NO	NO	0/	0	0/	0
(8004. 2)	71	19	10	0	YES	YES	YES	NO	0	0	0/	0
(2. 3)	0	100	0	0	NO	YES	YES	NO	0/	0	0/	0
(8005. 3)	30	18	52	0	YES	YES	YES	NO	0/	0	0/	0
(8020. 12)	15	72	13	0	YES	YES	YES	NO	0/	0	0/	0
(3. 4)	0	100	0	0	NO	YES	NO	NO	0/	0	0/	0
(8006. 4)	50	13	37	0	YES	YES	YES	NO	0/	0	0/	0
(8025. 4)	17	10	73	0	YES	YES	YES	NO	0/	0	0/	0
(4. 5)	1	98	1	0	YES	YES	YES	NO	0/	0	160/	49
(8007. 5)	18	4	78	0	YES	YES	YES	NO	0/	0	0/	0
(8008. 5)	18	4	78	0	YES	YES	YES	NO	0/	0	0/	0
(5. 6)	1	99	0	0	YES	YES	NO	NO	0/	0	0/	0
(8009. 6)	51	11	38	0	YES	YES	YES	NO	0/	0	0/	0
(8018. 11)	17	7	76	0	YES	YES	YES	NO	0/	0	0/	0
(6. 7)	3	82	15	0	YES	YES	YES	NO	160/	49	0/	0
(8010. 7)	9	16	75	0	YES	YES	YES	NO	0/	0	0/	0
(8011. 7)	1	78	21	0	YES	YES	YES	NO	0/	0	0/	0
(7. 8)	1	97	2	0	YES	YES	YES	NO	0	0	0/	0
(8012. 8)	51	11	38	0	YES	YES	YES	NO	0	0	0/	0
(8027. 8)	17	10	73	0	YES	YES	YES	NO	0/	0	0/	0
(8. 9)	0	17	63	0	YES	YES	YES	NO	0/	0	0/	0
(8013. 9)	0	99	1	0	YES	YES	YES	NO	0/	0	0/	0
(8014. 9)	15	85	0	0	YES	YES	YES	NO	0/	0	0/	0
(9. 10)	16	83	1	0	YES	YES	YES	NO	0/	0	0/	0
(8015. 10)	10	55	35	0	YES	YES	YES	NO	0/	0	0/	0
(8016. 10)	63	0	37	0	YES	YES	YES	NO	0/	0	0/	0
(10. 11)	2	94	4	0	YES	YES	YES	NO	0/	0	0/	0
(8017. 11)	27	38	35	0	YES	YES	YES	NO	0	0	0/	0
(11. 12)	3	87	10	0	YES	YES	YES	NO	160/	49	0/	0
(8019. 12)	27	29	44	0	YES	YES	YES	NO	0/	0	0/	0
(12. 13)	1	97	2	0	YES	YES	YES	NO	0/	0	0/	0
(8021. 13)	24	7	69	0	YES	YES	YES	NO	0/	0	0/	0
(8022. 13)	81	8	11	0	YES	YES	YES	NO	0/	0	0/	0
(8023. 13)	9	86	5	0	YES	YES	YES	NO	0/	0	0/	0
(2. 1)	17	82	1	0	YES	YES	YES	NO	0/	0	0/	0
(3. 2)	0	77	23	0	YES	YES	YES	NO	0/	0	0/	0
(4. 3)	7	85	8	0	YES	YES	YES	NO	0/	0	0/	0
(5. 4)	8	85	7	0	YES	YES	YES	NO	0/	0	0/	0
(6. 5)	7	84	9	0	YES	YES	YES	NO	0/	0	0/	0
(7. 6)	0	93	7	0	YES	YES	YES	NO	0/	0	0/	0
(8. 7)	42	55	3	0	YES	YES	YES	NO	160/	49	0/	0

NETSIM TURNING MOVEMENT DATA (CONT)

LINK	TURN MOVEMENT PERCENTAGES				TURN MOVEMENT POSSIBLE				POCKET LENGTH (IN FEET/METERS)			
	LEFT		RIGHT		LEFT		RIGHT		LEFT		RIGHT	
(9. 8)	9	88	3	0	YES	YES	YES	NO	0/	0	0/	0
(10. 9)	5	15	60	0	YES	YES	YES	NO	0/	0	0/	0
(11. 10)	16	82	2	0	YES	YES	YES	NO	0/	0	0/	0
(12. 11)	10	88	2	0	YES	YES	YES	NO	0/	0	0/	0
(13. 12)	10	88	2	0	YES	YES	YES	NO	0/	0	0/	0

SPECIFIED FIXED-TIME SIGNAL CONTROL AND SIGN CONTROL CODE.

INTERVAL NUMBER	OFFSET (SEC)	0 SEC DURATION (PCT)	0 SEC (8000)	1 (1)	2 (1)	1 (1)	APPROACHES (8001)	1	40 (1)	1	CYCLE LENGTH	51 SEC
1	28	54	1		1		2		2			
2	17	33	2		2		4		4			
3	6	11	2		2		2		1			

INTERVAL NUMBER	DURATION (SEC)	(PCT)	(1)	(2)	(8004, 2)	(8003, 2)	(3, 2)
1	34	46	2	2	1	1	
2	17	23	4	1	4	2	
3	22	30	1	1	2	2	
NODE 3 IS UNDER SIGN CONTROL							
INTERVAL NUMBER	DURATION (SEC)	(PCT)	(4)	(3)	(8005, 3)	(2, 3)	
1	0	100	0	5	0		
NODE 4							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(3)	(4)	(5, 4)	(8006, 4)	(8025, 4)
1	39	65	1	1	2	2	
2	21	35	2	2	1	1	
NODE 5							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(4)	(5)	(4, 5)	(8007, 5)	(8008, 5)
1	39	65	1	1	2	2	
2	21	35	2	2	4	4	
NODE 6 IS UNDER SIGN CONTROL							
INTERVAL NUMBER	DURATION (SEC)	(PCT)	(6)	(6)	(8009, 6)	(5, 6)	
1	0	100	0	5	0		
NODE 7							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(7)	(7)	(8011, 7)	(6, 7)	(8, 7)
1	70	54	2	2	1	1	
2	50	41	1	1	2	2	
NODE 8							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(8)	(8)	(8027, 8)	(7, 8)	(9, 8)
1	39	65	2	2	1	1	
2	21	35	1	1	2	2	
NODE 9							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(9)	(9)	(8014, 9)	(8, 9)	(10, 9)
1	45	37	2	2	1	1	
2	50	41	1	1	2	2	
3	25	30	4	4	2	2	
NODE 10							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(10)	(10)	(8016, 10)	(9, 10)	(11, 10)
1	28	46	2	2	1	1	
2	32	53	1	1	2	2	
NODE 11							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(10)	(11)	(12, 11)	(8017, 11)	(8018, 11)
1	32	54	1	1	2	2	
2	18	36	2	2	1	1	
NODE 12							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(11)	(12)	(11, 12)	(8019, 12)	(8020, 12)
1	24	34	2	2	1	1	
2	44	55	1	1	2	2	
NODE 13							
INTERVAL NUMBER	OFFSET (SEC)	DURATION (PCT)	(11)	(13)	(12, 13)	(8021, 13)	(8022, 13)
1	40	57	1	1	2	2	
2	10	42	2	2	1	1	

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

TRAFFIC CONTROL TABLE - SIGNS AND FIXED TIME SIGNALS

CONTROL CODE: 00 = PROTECTED
 N000 = NOT PERMITTED
 AMBR = AMBER
 PERM = PERMITTED NOT PROTECTED
 PROT = PROTECTED
 STOP = STOP SIGN
 YLD = YIELD SIGN

NODE 1 FIXED TIME (MTP L) OFFSET = 0 SECONDS CYCLE LENGTH = 51 SECONDS

INTERVAL DURATION	(8000, 1)	(2, 1)	(8001, 1)	(8002, 1)	
	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG

1	28	PERM GO GO	PERM GO GO	NOGO	NOGO	NOGO	NOGO
2	17	NOGO NOGO NOGO	NOGO NOGO NOGO	PROT GO	GO	PROT GO	GO
3	6	NOGO NOGO NOGO	NOGO NOGO NOGO	NOGO	NOGO	PROT GO	GO

NODE 2 FIXED TIME CONTROL OFFSET = 0 SECONDS CYCLE LENGTH = 73 SECONDS

INTERVAL DURATION		APPROACHES			
		(1, 2)	(8004, 2)	(8003, 2)	(3, 2)
1	34	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	17	NOGO NOGO NOGO	NOGO NOGO NOGO	PERM GO	PERM GO GO
3	22	PROT NOGO	PROT GO GO	NOGO NOGO	NOGO NOGO NOGO

NODE 3 SIGN CONTROL

INTERVAL DURATION		APPROACHES			
		(4, 3)	(8005, 3)	(2, 3)	
1	0	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
		YLD YLD YLD	STOP STOP STOP	YLD YLD	

NODE 4 FIXED TIME CONTROL OFFSET = 0 SECONDS CYCLE LENGTH = 60 SECONDS

INTERVAL DURATION		APPROACHES			
		(3, 4)	(5, 4)	(8006, 4)	(8025, 4)
1	39	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	21	GO NOGO	PERM GO GO	PERM GO GO	PERM GO GO

NODE 5 FIXED TIME CONTROL OFFSET = 0 SECONDS CYCLE LENGTH = 60 SECONDS

INTERVAL DURATION		APPROACHES			
		(6, 5)	(4, 5)	(8007, 5)	(8008, 5)
1	39	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	21	PERM GO GO	PERM GO GO	NOGO NOGO NOGO	NOGO NOGO NOGO

NODE 6 SIGN CONTROL

INTERVAL DURATION		APPROACHES			
		(7, 6)	(8009, 6)	(5, 6)	
1	0	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
		YLD YLD YLD	STOP STOP STOP	YLD YLD	

NODE 7 FIXED TIME CONTROL OFFSET = 93 SECONDS CYCLE LENGTH = 120 SECONDS

INTERVAL DURATION		APPROACHES			
		(8010, 7)	(8011, 7)	(6, 7)	(8, 7)
1	70	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	50	NOGO NOGO NOGO	NOGO NOGO NOGO	PERM GO GO	PERM GO GO

NODE 8 FIXED TIME CONTROL OFFSET = 0 SECONDS CYCLE LENGTH = 60 SECONDS

INTERVAL DURATION		APPROACHES			
		(8012, 8)	(8027, 8)	(7, 8)	(9, 8)
1	39	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	21	NOGO NOGO NOGO	NOGO NOGO NOGO	PERM GO GO	PERM GO GO

NODE 9 FIXED TIME CONTROL OFFSET = 38 SECONDS CYCLE LENGTH = 120 SECONDS

INTERVAL DURATION		APPROACHES			
		(8013, 9)	(8014, 9)	(8, 9)	(10, 9)
1	45	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	50	NOGO NOGO NOGO	NOGO NOGO NOGO	PERM GO GO	PERM GO GO

NODE 10 FIXED TIME CONTROL OFFSET = 50 SECONDS CYCLE LENGTH = 60 SECONDS

INTERVAL DURATION		APPROACHES			
		(8015, 10)	(8016, 10)	(9, 10)	(11, 10)
1	28	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	32	NOGO NOGO NOGO	NOGO NOGO NOGO	PERM GO GO	PERM GO GO

NODE 11 FIXED TIME CONTROL OFFSET = 0 SECONDS CYCLE LENGTH = 50 SECONDS

INTERVAL DURATION		APPROACHES			
		(10, 11)	(12, 11)	(8017, 11)	(8018, 11)
1	32	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG	LEFT THRU RITE DIAG
2	18	PERM GO GO	PERM GO GO	NOGO NOGO NOGO	NOGO NOGO NOGO

NODE 12 FIXED TIME CONTROL OFFSET = 52 SECONDS CYCLE LENGTH = 70 SECONDS

INTERVAL DURATION		(13, 12)		(11, 12)		APPROACHES (8019, 12)		(8020, 12)									
		LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG
1	24	NOGO	NOGO	NOGO		NOGO	NOGO	NOGO		PERM	GO	GO		PERM	GO	GO	
2	46	PERM	GO	GO		PERM	GO	GO		NOGO	NOGO	NOGO		NOGO	NOGO	NOGO	

NODE 13 FIXED TIME CONTROL OFFSET = 4 SECONDS CYCLE LENGTH = 70 SECONDS

INTERVAL DURATION		(8023, 13)		(12, 13)		APPROACHES (8021, 13)		(8022, 13)									
		LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG	LEFT	THRU	RITE	DIAG
1	40	PERM	GO	GO		PERM	GO	GO		NOGO	NOGO	NOGO		NOGO	NOGO	NOGO	
2	30	NOGO	NOGO	NOGO		NOGO	NOGO	NOGO		PERM	GO	GO		PERM	GO	GO	

ENTRY LINK VOLUMES

LINK	FLOW RATE (VEH/HOUR)	TRUCKS (PERCENT)	CAR POOLS (PERCENT)
(8000, 11)	417	13	0
(8001, 11)	233	23	0
(8002, 11)	14	0	0
(8003, 21)	649	3	0
(8004, 21)	391	7	0
(8005, 31)	35	2	0
(8006, 41)	117	4	0
(8025, 41)	97	3	0
(8007, 51)	117	4	0
(8008, 51)	112	2	0
(8009, 61)	115	4	0
(8010, 71)	459	5	0
(8011, 71)	772	6	0
(8012, 81)	115	3	0
(8027, 81)	77	2	0
(8013, 91)	1252	5	0
(8014, 91)	702	5	0
(8015, 101)	133	5	0
(8016, 101)	52	4	0
(8017, 111)	135	3	0
(8018, 111)	122	2	0
(8019, 121)	117	5	0
(8020, 121)	121	2	0
(8021, 131)	175	8	0
(8022, 131)	89	8	0
(8023, 131)	637	5	0

VEHICLE TYPE SPECIFICATIONS

VEHICLE TYPE	LENGTH FEET/METERS	MAXIMUM ACCELERATION (MPH/SEC) / (KMPH/SEC)	MAXIMUM SPEED (MPH) / (KMPH)	Q DSCNG HDWY FACTOR (PCT)	AVG. OCCUP	FLEET AUTO	COMPONENT TRUCK	PERCENTAGES CARPOOL	BUS
0 1**	17.0 / 5.2	5.5 / 8.8	75.0 / 120.7	100	1.3	100	0	0	0
0 2**	34.0 / 10.4	3.0 / 4.8	60.0 / 96.6	120	1.2	0	100	0	0
0 3**	17.0 / 5.2	5.5 / 8.8	75.0 / 120.7	100	3.5	0	0	100	0
0 4**	47.0 / 14.3	2.0 / 3.3	50.0 / 80.5	120	25.0	0	0	0	100

** INDICATES THAT ALL PARAMETERS FOR VEHICLE TYPE ASSUME DEFAULT VALUES

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, 2)	430	131	4	10	100
2	1	(2, 3)	295	50	1	10	90
3	0	(3, 4)	470	143	1	10	90
4	0	(3, 4)	870	245	1	10	90
5	0	(4, 5)	440	134	1	10	90
6	0	(4, 5)	810	247	1	10	90
7	0	(5, 6)	625	191	1	10	90
8	1	(6, 7)	625	191	1	10	90
9	1	(7, 8)	230	70	1	10	90
10	1	(8, 9)	890	271	1	10	90
11	1	(9, 10)	400	122	1	10	90
12	1	(10, 11)	730	223	1	10	90
13	1	(11, 12)	410	125	1	10	90

THE TYPE CODE IDENTIFIES THE APPLICABLE STATISTICAL DISTRIBUTION OF DWELL TIME

BUS ROUTE PATHS

ROUTE	SEQUENCE OF NODES DEFINING PATH
0 18	8017 11 12 13 8023
0 20	8017 11 12 13 8023
0 21	8000 1 2 8003
0 22	8000 1 2 3 4 5 6 8026
0 23	8000 1 2 8003
0 2	8000 1 2 3 4 5 6 7 8 9 10 11 12 13 8023
0 24	8003 2 3 4 5 6 8026

BUS STATIONS BY ROUTE

ROUTE	SEQUENCE OF STATIONS SERVICED BY ROUTE
0 2	1 2 3 4 5 6 7 8 9 10 11 12 13
0 18	13
0 20	13
0 21	1
0 23	1
0 24	2 3 4 5

BUS VOLUMES

ROUTE	VOLUME (VEH/HR)	MEAN HEADWAY (SEC)
0 24	4	900
0 18	4	959
0 20	5	600
0 21	4	900
0 22	4	900
0 23	4	900

0
12 6 600
INITIALIZATION STATISTICS

TIME INTERVAL NUMBER	SUBNETWORK TYPE	PRIOR CONTENT (VEHICLES)	CURRENT CONTENT (VEHICLES)	PERCENT DIFFERENCE
1	NETSIM	0	104	10000
2	NETSIM	104	160	53
3	NETSIM	160	202	26
4	NETSIM	202	212	14
5	NETSIM	212	275	18
6	NETSIM	275	308	12
7	NETSIM	308	332	7

EQUILIBRIUM ATTAINED

ALL EXISTING SUBNETWORKS REACHED EQUILIBRIUM

0 SPILLBACK ON NETSIM LINK (7. 8) STARTS 657 SECONDS INTO SIMULATION
0 SPILLBACK ON NETSIM LINK (7. 8) ENDS 673 SECONDS INTO SIMULATION AFTER A DURATION OF 16 SECONDS
1 CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0:15: 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEHICLE KM TRIPS	VEHICLE MINUTES MOVE DELAY TOTAL TIME TIME TIME	RATIO MOVE/ TOTAL	MINUTES TOTAL TIME	KM DELAY TIME	SECONDS / VEHICLE TOTAL DELAY QUEUE TIME TIME TIME	STOP TIME	AVERAGE VALUES STOPS VOLUME SPEED (%) VPH KMPH
(8000. 1)	83							332
(8001. 1)	55							220
(8002. 1)	4							16
(1. 2)	25.14 113	31.2 21.0 52.3	0.60	2.08	0.84	27.8 11.2 5.3	4.7	87 452 28.9
(8003. 2)	86							344
(8004. 2)	86							344
(2. 3)	11.47 76	14.3 7.0 21.3	0.67	1.85	0.61	16.8 5.5 2.3	2.4	39 304 12.4
(8005. 3)	7							28
(8020. 12)	24							96
(3. 4)	27.65 81	34.4 15.2 49.5	0.69	1.79	0.55	36.7 11.2 4.0	4.0	28 324 33.5
(8006. 4)	26							104
(8025. 4)	21							84
(4. 5)	26.86 89	33.4 21.3 54.7	0.61	2.04	0.79	36.9 14.4 7.7	7.2	48 356 29.5
(8007. 5)	0							0
(8008. 5)	0							0
(5. 6)	23.13 92	28.8 10.9 39.7	0.72	1.71	0.47	25.9 7.1 0.5	0.7	10 368 35.0
(8009. 6)	24							96
(8018. 11)	29							116
(6. 7)	25.15 100	31.3 38.9 70.2	0.45	2.79	1.55	42.1 23.4 15.2	13.9	60 400 21.5
(8010. 7)	63							252
(8011. 7)	55							220
(7. 8)	9.66 96	12.0 222.4 234.4	0.05	24.28	13.04	146.5 139.0 128.9	118.9	86 384 2.5
(8012. 8)	22							88
(8027. 8)	18							72
(8. 9)	28.06 93	34.9 507.6 542.5	0.06	19.33	18.09	350.0 327.5 221.4	187.3	100 372 3.1
(8013. 9)	329							1316
(8014. 9)	149							596
(9. 10)	8.23 54	10.2 9.9 20.1	0.51	2.44	1.20	22.3 11.0 6.7	6.3	50 216 24.6
(8015. 10)	25							100
(8016. 10)	12							48
(10. 11)	14.25 55	17.7 8.1 25.8	0.69	1.81	0.57	28.1 8.8 4.7	4.3	34 220 33.2
(8017. 11)	32							128
(11. 12)	14.28 71	17.8 11.3 29.1	0.61	2.04	0.79	24.6 9.6 4.9	4.5	43 284 29.5
(8019. 12)	26							104
(12. 13)	28.53 78	35.5 18.9 54.4	0.65	1.91	0.66	41.8 14.6 8.8	8.2	47 312 31.5
(8021. 13)	35							140
(8022. 13)	20							80
(8023. 13)	95							380
(2. 1)	13.35 60	16.6 10.7 27.3	0.61	2.05	0.80	27.3 10.7 6.8	6.0	46 240 29.3
(3. 2)	10.56 70	13.1 17.9 31.0	0.42	2.93	1.69	26.6 15.3 9.2	8.6	57 280 20.5
(4. 3)	26.63 78	33.1 13.2 46.3	0.71	1.74	0.50	35.6 10.2 2.3	1.8	11 312 34.5
(5. 4)	17.80 59	22.1 18.1 40.2	0.55	2.26	1.02	40.9 18.4 11.9	11.2	64 236 26.6
(6. 5)	16.34 65	20.3 14.9 35.2	0.58	2.15	0.91	32.5 13.7 6.5	5.6	46 260 27.9
(7. 6)	13.83 55	17.2 5.8 23.0	0.75	1.66	0.42	25.1 6.3 1.0	0.7	16 220 36.1
(8. 7)	6.04 60	7.5 18.7 26.2	0.29	4.34	3.10	26.2 18.7 14.6	13.7	63 240 13.8

* AVERAGE QUEUE AND STOP TIME ARE COMPUTED AS TOTAL QUEUE TIME OR TOTAL STOP TIME DIVIDED BY
TOTAL NUMBER OF VEHICLES DISCHARGED FROM LINK PLUS NUMBER OF VEHICLES CURRENTLY ON THE LINK.

1

CUMULATIVE NETSIM STATISTICS AT TIME 7:45: 0

ELAPSED TIME IS 0:15: 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEHICLE KM TRIPS	VEHICLE MINUTES MOVE DELAY TOTAL TIME TIME TIME	RATIO MOVE/ TOTAL	MINUTES TOTAL TIME	KM DELAY TIME	SECONDS / VEHICLE TOTAL DELAY QUEUE TIME TIME TIME	STOP TIME	AVERAGE VALUES STOPS VOLUME SPEED (%) VPH KMPH
(9. 8)	10.86 36	13.5 6.3 19.8	0.68	1.82	0.58	32.9 10.4 6.6	6.4	27 144 33.0
(10. 9)	13.87 91	17.2 39.4 56.6	0.30	4.08	2.84	37.3 26.0 19.6	17.5	76 364 14.7
(11. 10)	25.65 99	31.9 28.1 60.0	0.53	2.34	1.10	36.4 17.0 11.6	11.0	63 396 25.6
(12. 11)	16.70 83	20.8 10.2 31.0	0.67	1.85	0.61	22.4 7.4 4.0	3.7	42 332 32.4
(13. 12)	30.72 84	38.2 9.6 47.8	0.80	1.56	0.31	34.1 6.9 4.3	4.0	29 336 38.6
OSUBNETWORK=	444.76 1285	9.21 18.09 27.30	0.34	3.64	2.44	1.27 0.84 0.68	0.60	73.9 16.3
--- VEHICLE - HOURS ---								PER TRIP
--- MINUTES / VEHICLE-TRIP ---								

1

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0:15: 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEH-MINS * QUEUE STOP TIME TIME		AVERAGE OCCUPANCY (VEHICLE)	-- CONGESTION -- STORAGE PHASE (%) FAILURE		----- QUEUE LENGTH (VEHICLE) ----- AVERAGE QUEUE BY LANE ** 1 2 3 4 5 6 7							MAXIMUM QUEUE BY LANE 1 2 3 4 5 6 7						
						1	2	3	4	5	6	7	1	2	3	4	5	6	7
(1. 2)	10.4	9.1	4.1	2.5	0	0	0	0	0	0	0	0	4	2	1	1	1	0	0
(2. 3)	3.0	3.1	1.8	4.1	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
(3. 4)	5.8	5.8	3.8	7.8	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0
(4. 5)	12.1	11.3	4.3	6.4	0	1	0	0	0	0	0	0	9	0	0	0	0	0	0

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( 5. 6) 0.8 1.0 3.0 8.1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
( 6. 7) 26.6 24.3 5.2 6.4 0 1 1 0 0 0 0 0 5 4 0 0 0 0 0
( 7. 8) 268.6 247.8 20.7 70.0 9 9 10 0 0 0 0 0 17 17 0 0 0 0 0
( 8. 9) 487.1 412.1 40.8 45.3 8 17 0 0 0 0 0 0 49 0 0 0 0 0 0
( 9. 10) 6.0 5.7 1.7 2.5 0 0 0 0 0 0 0 0 1 2 2 0 0 0 0
( 10. 11) 4.5 4.2 2.2 2.8 0 0 0 0 0 0 0 0 1 2 0 0 0 0 0
( 11. 12) 6.1 5.6 2.4 3.6 0 0 0 0 0 0 0 0 3 2 0 0 0 0 1
( 12. 13) 11.8 10.9 3.8 3.6 0 0 0 0 0 0 0 0 2 4 0 0 0 0 0
( 13. 1) 6.8 6.0 2.3 1.7 0 0 0 0 0 0 0 0 0 0 1 3 0 0 0
( 1. 2) 10.8 10.2 2.5 2.8 0 0 0 0 0 0 0 0 1 2 2 3 0 0 0
( 4. 3) 3.1 2.4 3.6 7.0 0 0 0 0 0 0 0 0 5 0 0 0 0 0 0
( 5. 4) 11.4 11.0 3.1 3.4 0 0 1 0 0 0 0 0 1 5 0 0 0 0 0
( 6. 5) 7.2 6.3 2.7 7.1 0 0 0 0 0 0 0 0 1 0 0 0 0 0 0
( 7. 6) 1.0 0.7 2.0 2.6 0 0 0 0 0 0 0 0 1 1 0 0 0 0 0
( 8. 7) 14.6 13.7 2.1 5.7 0 0 0 0 0 0 0 0 3 1 0 0 0 0 3

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CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEH-MINS *		AVERAGE OCCUPANCY (VEHICLE)	-- CONGESTION --		AVERAGE QUEUE BY LANE **							MAXIMUM QUEUE BY LANE						
	QUEUE TIME	STOP TIME		STORAGE (%)	PHASE FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7
(9. 8)	4.1	4.0	1.7	1.9	1	0	0	0	0	0	0	0	2	2	0	0	0	0	0
(10. 9)	10.1	28.3	4.3	9.5	1	1	1	0	0	0	0	0	5	4	0	0	0	0	0
(11. 10)	20.5	19.4	4.6	4.0	0	1	1	0	0	0	0	0	3	3	2	0	0	0	0
(12. 11)	5.7	5.2	2.5	4.2	0	0	0	0	0	0	0	0	4	2	0	0	0	0	0
(13. 12)	6.2	5.8	3.5	3.3	0	0	0	0	0	0	0	0	3	2	0	0	0	0	0
OSUBNETWORK=	964.5	853.6	128.6	7.2	19	0	0	0	0	0	0	0	3	2	0	0	0	0	0

* THESE VALUES INCLUDE THE TIME FOR VEHICLES CURRENTLY ON THE LINK
 ** AVERAGE QUEUE CALCULATED BASED ON TIME SINCE BEGINNING OF SIMULATION

NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(R000. 1)				
(R001. 1)				
(R002. 1)				
(1. 2)	42.7	192.1	35.8	88.9
(R003. 2)				
(R004. 2)				
(2. 3)	25.6	169.6	15.6	47.4
(R005. 3)				
(R020. 12)				
(3. 4)	52.0	152.4	28.5	93.2
(R006. 4)				
(R025. 4)				
(4. 5)	49.1	162.8	39.0	100.0
(R007. 5)				
(R008. 5)				
(5. 6)	41.9	166.7	19.8	71.9
(R009. 6)				
(R018. 11)				
(6. 7)	38.5	153.3	59.1	107.6
(R010. 7)				
(R011. 7)				
(7. 8)	14.9	148.2	343.4	361.9
(R012. 8)				
(R027. 8)				
(8. 9)	36.4	120.7	659.8	704.0
(R013. 9)				
(R014. 9)				
(9. 10)	10.7	70.0	12.8	26.0
(R015. 10)				
(R016. 10)				
(10. 11)	18.4	71.2	10.5	33.4
(R017. 11)				
(11. 12)	23.3	115.7	18.4	47.4
(R019. 12)				
(12. 13)	45.6	124.8	30.3	87.0
(R021. 13)				
(R022. 13)				
(R023. 13)				
(2. 1)	17.2	77.4	13.9	35.3
(3. 2)	13.7	90.5	23.1	40.1
(4. 3)	34.4	100.9	17.1	59.9
(5. 4)	23.0	76.3	24.4	52.0
(6. 5)	21.1	84.1	19.2	45.5
(7. 6)	17.9	71.3	7.5	29.8

NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(8. 7)	7.8	77.9	24.3	34.0
(9. 8)	14.1	46.7	8.1	25.6
(10. 9)	18.0	118.0	51.1	73.4
(11. 10)	33.2	124.2	36.4	77.7
(12. 11)	21.6	107.4	11.2	40.0
(13. 12)	39.8	108.7	12.4	61.8

*** NOTE *** TIME PERIOD 1 SPECIFIC NETSIM STATISTICS ARE THE SAME AS CUMULATIVE OUTPUT AT THE END OF TIME PERIOD 1

NETSIM BUS STATISTICS

LINK	BUS TRIPS	PERSON TRIPS	TRAVEL TIME (MINUTES)	MOVING TIME (MINUTES)	DELAY TIME (MINUTES)	M T	SPEED (KMPH)	NUMBER OF STOPS
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(8000, 1)	2	50							
(1, 2)	2	50	1.3	0.6	0.7	0.44	21.1	2	
(8003, 2)	1	25							
(2, 3)	1	75	1.4	0.6	0.9	0.19	18.9	1	
(3, 4)	2	50	2.7	0.8	1.9	0.11	15.2	5	
(4, 5)	2	50	2.1	0.8	1.3	0.16	17.4	1	
(5, 6)	2	50	1.3	0.6	0.7	0.49	21.5	1	
(6, 7)	1	25	1.2	0.1	0.9	0.27	12.9	1	
(7, 8)	1	25	2.7	0.1	2.5	0.05	2.3	1	
(8017, 11)	1	25							
(11, 12)	1	25	0.6	0.3	0.4	0.19	19.1	1	
(12, 13)	1	25	0.8	0.5	0.4	0.54	25.1	0	

NETSIM BUS-STATION STATISTICS

STATION NUMBER	TIME CAPACITY EXCEEDED (MINUTES)	TIME EMPTY (MINUTES)	TOTAL DWELL TIME (BUS-MIN)	BUSES SERVICED
1	0.0	14.8	0.3	2
2	0.0	14.6	0.4	3
3	0.0	14.5	0.6	3
4	0.0	14.8	0.2	2
5	0.0	14.6	0.4	2
6	0.0	14.8	0.2	1
7	0.0	14.8	0.3	1
8	0.0	14.8	0.1	1
9	0.0	14.9	0.1	1
13	0.0	14.9	0.1	1

CUMULATIVE VALUES OF FUEL CONSUMPTION AND OF EMISSIONS

LINK	FUEL CONSUMPTION			VEHICLE EMISSION RATES (G/GAL)			KM HOUR	
VEHICLE TYPE-	AUTO	LITERS TRUCK	BUS	AUTO	M.P.L. TRUCK	BUS	HC	CO
(8000, 1)								
(8001, 1)								
(8002, 1)								
(1, 2)	3.9	2.5	0.3	5.0	1.8	1.7	0.041	0.660
(8003, 2)								
(8004, 2)								
(2, 3)	1.6	0.2	0.2	6.1	2.2	1.9	0.027	0.405
(8005, 3)								
(8020, 12)								
(3, 4)	5.3	0.5	0.6	4.8	2.0	1.5	0.036	0.611
(8006, 4)								
(8025, 4)								
(4, 5)	4.8	0.4	0.4	5.5	2.3	1.5	0.036	0.542
(8007, 5)								
(8008, 5)								
(5, 6)	3.4	0.3	0.2	6.2	2.5	2.2	0.032	0.475
(8009, 6)								
(8018, 11)								
(6, 7)	6.3	0.5	0.2	3.9	1.9	1.5	0.058	1.005
(8010, 7)								
(8011, 7)								
(7, 8)	11.2	0.5	0.1	0.9	0.6	0.8	0.273	4.112
(8012, 8)								
(8027, 8)								
(8, 9)	22.5	1.0	0.1	1.3	0.7	1.3	0.169	2.341
(8013, 9)								
(8014, 9)								
(9, 10)	2.1	0.2	0.0	3.6	1.5	0.0	0.030	0.511
(8015, 10)								
(8016, 10)								
(10, 11)	2.5	0.4	0.0	5.2	1.9	0.0	0.022	0.364
(8017, 11)								
(11, 12)	2.7	0.3	0.1	5.0	2.4	1.4	0.031	0.518
(8019, 12)								
(12, 13)	4.0	0.5	0.1	6.1	2.2	2.7	0.025	0.392
(8021, 13)								
(8022, 13)								
(8023, 13)								
(2, 1)	2.6	0.7	0.0	4.1	1.7	0.0	0.026	0.442
(3, 2)	2.7	0.5	0.0	3.5	1.5	0.0	0.040	0.619
(4, 3)	4.1	0.6	0.0	6.0	2.6	0.0	0.027	0.428
(5, 4)	2.9	0.5	0.0	5.7	2.2	0.0	0.022	0.336
(6, 5)	3.4	0.6	0.0	4.3	1.7	0.0	0.031	0.542
(7, 6)	2.5	0.2	0.0	5.3	2.4	0.0	0.023	0.346
(8, 7)	1.6	0.0	0.0	3.3	5.7	0.0	0.034	0.596

CUMULATIVE VALUES OF FUEL CONSUMPTION AND OF EMISSIONS

LINK	FUEL CONSUMPTION			VEHICLE EMISSION RATES (G/GAL)			KM HOUR	
VEHICLE TYPE-	AUTO	LITERS TRUCK	BUS	AUTO	M.P.L. TRUCK	BUS	HC	CO
(9, 4)	1.9	0.1	0.0	5.3	3.2	0.0	0.014	0.237
(10, 9)	4.0	0.3	0.0	3.4	1.5	0.0	0.061	1.016
(11, 10)	4.9	0.6	0.0	5.0	2.1	0.0	0.043	0.714
(12, 11)	2.6	0.5	0.0	6.0	2.2	0.0	0.030	0.478
(13, 12)	4.2	0.7	0.0	6.7	2.5	0.0	0.026	0.412
SUBNETWORK-	107.9	12.6	2.5	3.8	1.9	1.6	0.043	0.675

EMISSION STATISTICS FOR TRUCKS AND BUSES ARE NOT AVAILABLE

THE MAXIMUM NUMBER OF VEHICLES ON THE NETWORK WAS 846 VEHICLES
THIS MAXIMUM OCCURED AT 896 SECONDS

CUMULATIVE NETWORK-WIDE BUS STATISTICS AT TIME 7.45.0

ELAPSED TIME IS 0.15.0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

ROUTE STATISTICS

ROUTE	BUS TRIPS	TOTAL TRAVEL TIME (BUS-MIN)	MEAN TRAVEL TIME (SEC-BUS)	PERSON TRIPS	PERSON TRAVEL TIME (MINUTES)
2	0	9 8	564 2	0	245 0
18	1	1 5	97 2	25	16 7
20	0	0 0	97 2	0	0 0
21	0	0 0	38 2	0	0 0
22	0	0 0	248 5	0	0 0
23	0	0 0	38 2	0	0 0
24	1	2 8	210 5	25	57 5

THESE ESTIMATES ASSUME AN AVERAGE BUS OCCUPANCY OF 25 0 PASSENGERS PER BUS THROUGHOUT THE NETWORK

TOTAL CPU TIME FOR THIS RUN = 42 46 SECONDS
 LAST CASE PROCESSED

SCENARIO (II): ONE LANE-BLOCKED

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0.15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

[illegible]

* AVERAGE QUEUE AND STOP TIME ARE COMPUTED AS TOTAL QUEUE TIME OR TOTAL STOP TIME DIVIDED BY TOTAL NUMBER OF VEHICLES DISCHARGED FROM LINK PLUS NUMBER OF VEHICLES CURRENTLY ON THE LINK.

1

CUMULATIVE NETSIM STATISTICS AT TIME 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS), TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEHICLE		VEHICLE MINUTES			RATIO MOVE/ TOTAL	MINUTES / KM		SECONDS / VEHICLE			-- AVERAGE VALUES --				
	KM	TRIPS	MOVE TIME	DELAY TIME	TOTAL TIME		TOTAL TIME	DELAY TIME	TOTAL TIME	DELAY TIME	QUEUE TIME	STOP TIME	STOPS (%)	VOLUME VPH	SPEED KM/PH	
(9, 8)	9.66	32	12.0	4.2	16.1	0.74	1.67	0.43	30.3	7.8	3.1	3.1	18	128	35.9	
(10, 9)	15.39	101	19.1	83.0	102.1	0.19	6.64	5.39	60.7	49.3	37.3	33.2	86	404	9.0	
(11, 10)	28.24	109	35.1	29.6	64.7	0.54	2.29	1.05	35.6	16.3	10.6	9.9	65	436	26.2	
(12, 11)	17.90	89	22.3	10.3	32.6	0.68	1.82	0.58	22.0	7.0	3.5	3.2	18	356	33.0	
(13, 12)	34.02	93	42.3	12.0	54.3	0.78	1.60	0.35	35.0	7.7	4.6	4.3	29	372	37.6	
OSUBNETWORK=	294.89	1124	6.11	11.75	17.85	0.34	3.63	2.39	0.95	0.63	0.68	0.64	60.2		16.5	
			-- VEHICLE - HOURS --						--- MINUTES			VEHICLE-TRIP ---			PER TRIP	

1

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS) TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

[illegible]

(7, 6) 564 5 562.8 0 0 0 0 19 19 0 0 0 0 0 33 32 0 0 0 0 0
 (8, 7) 12 0 11.2 1.9 5 0 0 0 0 0 0 0 0 0 3 2 0 0 0 0 3
 1 CUMULATIVE NETSIM STATISTICS AT TIME 7:45: 0

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEH-MINS *		AVERAGE OCCUPANCY (VEHICLE)	CONGESTION --		O U B U E					L E N G T H		MAXIMUM QUEUE BY LANE						
	QUEUE TIME	STOP TIME		STORAGE (%)	PHASE FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7
(9, 8)	1 7	1 7	1 5	1 6	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
(10, 9)	65 0	57 5	7 3	16 0	2	4	1	0	0	0	0	0	14	5	0	0	0	0	0
(11, 10)	20 1	18 9	4 6	4 0	0	1	1	0	0	0	0	0	2	1	3	0	0	0	0
(12, 11)	5 3	4 8	2 7	4 4	0	0	0	0	0	0	0	0	3	3	0	0	0	0	0
(13, 12)	7 1	6 7	4 0	3 7	0	0	0	0	0	0	0	0	2	2	0	0	0	0	0
OSUBNETW-RK=	2046 9	1983 8	104 4	7 2	24	0	0	0	0	0	0	0	2	2	0	0	0	0	0

* THESE VALUES INCLUDE THE TIME FOR VEHICLES CURRENTLY ON THE LINK
 ** AVERAGE QUEUE CALCULATED BASED ON TIME SINCE BEGINNING OF SIMULATION

1 NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(8000, 1)				
(8001, 1)				
(8002, 1)				
(1, 2)	30 3	136 4	26 9	64 7
(8003, 2)				
(8004, 2)				
(2, 3)	21 6	141 4	8 0	34 4
(8005, 3)				
(8020, 12)				
(3, 4)	32 9	96 4	22 2	63 1
(8006, 4)				
(8025, 4)				
(4, 5)	6 6	22 0	6 0	14 3
(8007, 5)				
(8008, 5)				
(5, 6)	0 0	0 0	0 0	0 0
(8009, 6)				
(8018, 11)				
(6, 7)	0 0	0 0	0 0	0 0
(8010, 7)				
(8011, 7)				
(7, 8)	7 7	76 5	9 7	19 2
(8012, 8)				
(8027, 8)				
(8, 9)	37 9	125 7	551 9	599 0
(8013, 9)				
(8014, 9)				
(9, 10)	11 3	74 1	18 7	32 7
(8015, 10)				
(8016, 10)				
(10, 11)	28 7	110 7	19 3	55 0
(8017, 11)				
(11, 12)	29 4	146 0	23 6	60 1
(8019, 12)				
(12, 13)	56 3	153 9	37 7	107 7
(8021, 13)				
(8022, 13)				
(8023, 13)				
(2, 1)	14 9	67 1	11 8	30 3
(3, 2)	4 1	27 1	9 6	14 6
(4, 3)	10 6	31 1	3 4	16 6
(5, 4)	0 0	0 0	0 0	0 0
(6, 5)	0 0	0 0	0 0	0 0
(7, 6)	0 0	0 0	0 0	0 0

1 NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(8, 7)	6 8	67 5	20 4	28 8
(9, 8)	12 5	41 5	5 4	20 9
(10, 9)	19 9	130 7	107 4	132 2
(11, 10)	36 6	141 1	38 3	83 8
(12, 11)	23 2	115 2	13 4	42 2
(13, 12)	44 1	120 5	15 6	70 3

1 *** NOTE *** TIME PERIOD 1 SPECIFIC NETSIM STATISTICS ARE THE SAME AS CUMULATIVE OUTPUT AT THE END OF TIME PERIOD 1

1 NETSIM BUS STATISTICS

LINK	BUS TRIPS	PERSON TRIPS	TRAVEL TIME (MINUTES)	MOVING TIME (MINUTES)	DELAY TIME (MINUTES)	M T	SPEED (KMPH)	NUMBER OF STOPS
(8000, 1)	2	25						
(1, 2)	1	25	0 6	0 3	0 4	0 4	20 5	1
(8003, 2)	1	25						
(2, 3)	2	50	1 0	0 4	0 6	0 6	19 7	2
(3, 4)	1	25	1 0	0 4	0 6	0 4	19 5	4
(4, 5)	1	25	0 9	0 3	0 5	0 3	18 3	1
(80, 12)	1	25						
(11, 12)	2	50	1 5	0 5	1 0	0 11	15 9	2
(12, 13)	2	50	2 0	0 9	1 1	0 4	22 3	0

NETSIM BUS-STATION STATISTICS

STATION NUMBER	TIME CAPACITY EXCEEDED (MINUTES)	TIME EMPTY (MINUTES)	TOTAL DWELL TIME (BUS-MIN)	BUSES SERVICED
1	0 0	14 8	0 2	1
2	0 0	14 8	0 3	2
3	0 0	14 7	0 4	2
4	0 0	14 8	0 3	2
5	0 0	14 8	0 2	1
12	0 0	14 8	0 2	1
13	0 0	14 9	0 2	2

THE MAXIMUM NUMBER OF VEHICLES ON THE NETWORK WAS 1149 VEHICLES
THIS MAXIMUM OCCURED AT 899 SECONDS.

1

CUMULATIVE NETWORK-WIDE BUS STATISTICS AT TIME 7:45. 0

ELAPSED TIME IS 0 15 0 (900 SECONDS) TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

ROUTE STATISTICS

ROUTE	BUS TRIPS	TOTAL TRAVEL TIME (BUS-MIN)	MEAN TRAVEL TIME (SEC/BUS)	PERSON TRIPS	PERSON TRAVEL TIME (MINUTES)
2	1	3 3	286 8	25	82 5
18	1	2 1	103 1	25	52 9
20	0	0 0	105 1	0	0 0
21	0	0 0	38 8	0	0 0
22	0	0 0	131 2	0	0 0
23	0	0 0	38 8	0	0 0
24	0	1 4	92 6	0	40 0

THESE ESTIMATES ASSUME AN AVERAGE BUS OCCUPANCY OF 25 0 PASSENGERS PER BUS THROUGHOUT THE NETWORK

TOTAL CPU TIME FOR THIS RUN = 559 30 SECONDS
OLAST CASE PROCESSED

SCENARIO (III): ALL-GREEN

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEHICLE KM	TRIPS	VEHICLE MOVE TIME	MINUTES DELAY TIME	MINUTES TOTAL TIME	RATIO MOVE/ TOTAL	MINUTES TOTAL TIME	KM DELAY TIME	SECONDS TOTAL TIME	SECONDS DELAY TIME	VEHICLE QUEUE TIME	STOP TIME	AVERAGE VALUES (%)	VOLUME VPH	SPEED KMPH
(R000, 1)		94												176	
(R001, 1)		51												204	
(R002, 1)		2												8	
(1, 2)	27 59	124	34.3	24 9	59 4	0 58	2 14	0 90	28 6	12 0	5 8	5 2	94	496	28 0
(R003, 2)		49												196	
(R004, 2)		92												168	
(2, 3)	5 58	17	6 9	1 1	8 0	0 87	1 44	0 19	13 0	1 8	0 3	0 4	5	148	41 8
(R005, 3)		8												32	
(R020, 12)		28												112	
(3, 4)	13 66	40	17.0	3 3	20 3	0 84	1 48	0 24	30 4	4 9	0 3	1 6	5	160	40 4
(R006, 4)		26												104	
(R025, 4)		16												64	
(4, 5)	15 39	53	19 9	3 3	23 2	0 86	1 45	0 21	26 3	3 4	0 3	0 9	3	212	41 4
(R007, 5)		28												112	
(R008, 5)		25												100	
(5, 6)	19 87	79	24 7	4 4	29 1	0 85	1 46	0 22	22 1	3 3	0 3	0 2	2	316	41 0
(R009, 6)		25												100	
(R018, 11)		28												112	
(6, 7)	22 63	90	28.1	6 3	34 4	0 82	1 52	0 28	22 9	4 2	0 7	0 7	11	360	39 5
(R010, 7)		44												176	
(R011, 7)		41												164	
(7, 8)	9 76	97	12.1	3 9	16 0	0 76	1 64	0 40	9 9	2 4	0 3	0 2	1	388	36 6
(R012, 8)		27												108	
(R027, 8)		23												92	
(8, 9)	33 19	110	41 3	14 1	55 4	0 75	1 67	0 42	30 2	7 7	2 1	1 7	27	440	36 0
(R013, 9)		307												1228	
(R014, 9)		54												216	
(9, 10)	8 08	53	10 0	2 1	12 1	0 83	1 50	0 26	13 7	2 1	0 4	0 6	9	212	40 1
(R015, 10)		22												88	
(R016, 10)		12												48	
(10, 11)	16 32	63	20.3	2 0	22 3	0 91	1 37	0 11	21 2	1 4	0 2	0 2	1	252	43 9
(R017, 11)		24												96	
(11, 12)	14 28	71	17.8	4 0	21 7	0 82	1 52	0 28	18 4	3 4	0 9	1 1	9	284	39 5
(R019, 12)		28												112	
(12, 13)	27 07	74	33 6	3 7	37 3	0 90	1 38	0 14	30 3	3 0	0 2	0 0	1	296	43 5
(R021, 13)		26												104	
(R022, 13)		20												80	
(R023, 13)		122												488	
(2, 1)	14 46	65	18.0	2 9	20 9	0 86	1 44	0 20	19 3	2 7	0 3	0 0	1	260	41 6
(3, 2)	11 77	78	14.6	28 4	43 1	0 34	3 66	2 42	33 1	21 9	8 7	18.2	79	312	16 4
(4, 3)	32 43	95	40.3	6 9	47 2	0 85	1 46	0 21	29 3	4 4	0 6	0 2	5	380	41.2
(5, 4)	26 25	87	32.6	6 9	39 5	0 83	1 50	0 26	27 2	4 7	0 7	0 3	6	348	39 9
(6, 5)	16 85	67	20.9	2 9	23 9	0 88	1 42	0 17	21 4	2 6	0 3	0 1	1	268	42.3
(7, 6)	13 58	54	16.9	2 4	19 2	0 88	1 42	0 17	21 4	2 6	0 4	0 1	5	216	42 4
(8, 7)	6 14	61	7.6	3 8	11.4	0 67	1 86	0 51	11 2	3 7	1 3	0 7	11	244	32 3

* AVERAGE QUEUE AND STOP TIME ARE COMPUTED AS TOTAL QUEUE TIME OR TOTAL STOP TIME DIVIDED BY
TOTAL NUMBER OF VEHICLES DISCHARGED FROM LINK PLUS NUMBER OF VEHICLES CURRENTLY IN THE LINK

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEHICLE KM	TRIPS	VEHICLE MOVE TIME	MINUTES DELAY TIME	MINUTES TOTAL TIME	RATIO MOVE/ TOTAL	MINUTES TOTAL TIME	KM DELAY TIME	SECONDS TOTAL TIME	SECONDS DELAY TIME	VEHICLE QUEUE TIME	STOP TIME	AVERAGE VALUES (%)	VOLUME VPH	SPEED KMPH
(9, 8)	12 37	41	15 4	1 5	16 9	0 91	1 37	0 11	24 8	2 3	0 6	0 6	12	164	43 9
(10, 9)	17 22	113	21.4	8 4	29 8	0 72	1 73	0 44	15 8	4 5	1 3	1.1	24	452	34 7
(11, 10)	30 83	119	38.3	4 8	43 1	0 89	1 40	0 15	21 7	2 4	0 4	0 1	5	476	43 0
(12, 11)	22 73	113	28.3	2 8	31 1	0 91	1 37	0 11	16 5	1 5	0 2	0 1	1	452	43 9
(13, 12)	43 53	119	54.1	2 7	56 8	0 95	1 31	0 06	28 6	1 4	0 1	0 1	2	476	46 0
OS/NETWORK	462 17	1219	9.57	2 46	12 03	0 80	1 56	0 32	0 59	0 12	0 04	0.04	25 4		38 4
-- VEHICLE - HOURS --													PER TRIP		
--- MINUTES / VEHICLE-TRIP ---															

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEN-MINS *		AVERAGE OCCUPANCY (VEHICLE)	CONGESTION		AVERAGE QUEUE BY LANE **							QUEUE LENGTH (VEHICLE)								
	QUEUE TIME	STOP TIME		STORAGE (%)	PHASE FAILURE	AVERAGE QUEUE BY LANE **							MAXIMUM QUEUE BY LANE								
						1	2	3	4	5	6	7	1	2	3	4	5	6	7		
1	2)	12 5	11.2	4 4	2 7	0	1	0	0	0	0	0	0	4	2	1	0	0	0	0	0
2	3)	0 2	0 3	0 8	2 0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	4)	0 2	1 1	1 8	3 8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	5)	0 3	0 8	2 1	4 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6)	0 5	0 3	2 4	6 5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	7)	1 2	1.2	2 7	3 4	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1
7	8)	0 4	0 3	1 5	4 9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	9)	3 9	3 3	3 9	4 4	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0
9	10)	0 4	0 5	1 1	1 7	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
10	11)	0 2	0 2	1 9	2 4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	12)	1 0	1.3	2 0	3 1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1
12	13)	0 3	0 0	3 0	2 9	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
2	1)	1 4	0 1	1 8	1 3	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
3	2)	25 0	24.2	3 5	3 8	1	0	0	0	1	0	0	0	2	2	3	3	0	0	0	0
4	3)	0 9	0 4	1 7	7 2	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
5	4)	1 0	0 5	3 0	3 3	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0	0
6	5)	0 3	0 1	2 2	5 8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
7	6)	0 3	0 1	1 6	2 2	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
8	7)	1 3	0 8	1 1	3 0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0

CUMULATIVE NETSIM STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS). TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

LINK	VEH-MINS *		AVERAGE OCCUPANCY (VEHICLE)	CONGESTION		QUEUE					LENGTH (VEHICLE)		MAXIMUM QUEUE BY LANE						
	QUEUE TIME	STOP TIME		STORAGE (%)	PHASE FAILURE	1	2	3	4	5	6	7	1	2	3	4	5	6	7
(9, 8)	0 4	0 4	1 5	1 7	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
(10, 9)	2 4	2 2	2 4	5 3	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
(11, 10)	0 8	0 3	3 5	3 0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0
(12, 11)	0 3	0 1	2 6	4 3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
(13, 12)	0 3	0 1	4 2	3 8	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
OSUBNETWOPK=	54 5	49 8	58 7	3 3	1														

* THESE VALUES INCLUDE THE TIME FOR VEHICLES CURRENTLY ON THE LINK
 ** AVERAGE QUEUE CALCULATED BASED ON TIME SINCE BEGINNING OF SIMULATION

1 NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(R000, 1)				
(R001, 1)				
(R002, 1)				
(1, 2)	51.1	229 8	46 1	109 6
(R003, 2)				
(R004, 2)				
(2, 3)	14 4	95 4	1 8	20 7
(R005, 3)				
(R020, 12)				
(3, 4)	33 9	99 3	4 1	50 3
(R006, 4)				
(R025, 4)				
(4, 5)	35 1	116 2		50 9
(R007, 5)				
(R008, 5)				
(5, 6)	37 7	149 8	8 3	55 1
(R009, 6)				
(R018, 11)				
(6, 7)	41 2	164 0	11 4	62 7
(R010, 7)				
(R011, 7)				
(7, 8)	15 0	149 3	5 4	24 6
(R012, 8)				
(R027, 8)				
(8, 9)	50 1	166 1	11 3	83 6
(R013, 9)				
(R014, 9)				
(9, 10)	14 1	92 3	3 6	21 1
(R015, 10)				
(R016, 10)				
(10, 11)	27 3	105 3	3 4	37 3
(R017, 11)				
(11, 12)	32 8	163 1	4 1	49 9
(R019, 12)				
(12, 13)	61 1	167 0	8 3	84 3
(R021, 13)				
(R022, 13)				
(R023, 13)				
(2, 1)	18 6	83 8	1 1	26 9
(3, 2)	15 2	100 7	1 1	55 6
(4, 3)	42 0	122 9	4 4	61 1
(5, 4)	34 0	112 6	4 4	51 1
(6, 5)	21 8	86 8	1 8	10 9
(7, 6)	17 6	70 0	1 1	24 9

1 NETSIM PERSON MEASURES OF EFFECTIVENESS

LINK	PERSON KM	PERSON TRIPS	DELAY PERSON-MIN	TRAVEL TIME PERSON-MIN
(8, 7)	7 9	79 0	3 3	14 7
(9, 8)	16 0	57 0	2 0	21 9
(10, 9)	22 3	146 4	10 9	38 6
(11, 10)	40 0	154 2	6 1	55 8
(12, 11)	29 5	146 4	3 1	40 3
(13, 12)	56 4	154 1	1 1	73 6

1 *** NOTE *** TIME PERIOD 1 SPECIFIC NETSIM STATISTICS ARE THE SAME AS CUMULATIVE OUTPUT AT THE END OF TIME PERIOD 1

1 NETSIM BUS STATISTICS

LINK	BUS TRIPS	PERSON TRIPS	TRAVEL TIME (MINUTES)	MOVING TIME (MINUTES)	DELAY TIME (MINUTES)	M T	SPEED (KMPH)	NUMBER OF STOPS
(R000, 1)	3	75						
(1, 2)	3	75	2 0	0 8	1 1	0 41	19.7	3
(2, 3)	2	50	0 8	0 4	0 1	0 45	21 7	2
(3, 4)	2	50	2 6	0 8	1 1	0 33	15.9	4
(4, 5)	2	50	2 2	0 8	1 1	0 34	16 5	4
(5, 6)	2	50	1 2	0 6	0 1	0 51	24 8	2
(6, 7)	2	50	1 3	0 6	0 1	0 48	23 2	2
(7, 8)	1	25	0 5	0 1	0 1	0 26	12 5	2
(8, 9)	1	25	0 7	0 4	0 1	0 52	25 3	1
(9, 10)	1	25	0 6	0 2	0 4	0 31	15 2	1
(10, 11)	1	25	0 7	0 3	0 4	0 46	22.2	1
(R017, 11)	2	50						
(11, 12)	3	75	2 5	0 8	1 1	0 10	14 7	3
(12, 13)	3	75	1 5	1 4		0 89	42.9	0

NETSIM BUS-STATION STATISTICS

STATION NUMBER	TIME CAPACITY EXCEEDED (MINUTES)	TIME EMPTY (MINUTES)	TOTAL DWEIL TIME (BUS-MIN)	BUSES SERVICED
1	0 0	14 6	0 4	1
2	0 0	14 9	0 2	1
3	0 0	14 6	0 5	1
4	0 0	14 5	0 5	1
5	0 0	14 8	0 2	1
6	0 0	14 5	0 5	1
7	0 0	14 8	0 2	1
8	0 0	14 8	0 3	1
9	0 0	14 8	0 3	1
10	0 0	14 9	0 1	1
11	0 0	14 8	0 2	1
12	0 0	14 8	0 2	1
13	0 2	14 5	0 5	1

CUMULATIVE NETWORK-WIDE BUS STATISTICS AT TIME 7 45 0

ELAPSED TIME IS 0 15 0 (900 SECONDS) TIME PERIOD 1 ELAPSED TIME IS 900 SECONDS

ROUTE STATISTICS

ROUTE	BUS TRIPS	TOTAL TRAVEL TIME (BUS-MIN)	MEAN TRAVEL TIME (SEC. BUS)	PERSON TRIPS	PERSON TRAVEL TIME (MINUTES)
2	1	13 4	514 6	25	174 2
18	1	1 1	80 3	25	31 7
20	1	1 4	80 3	25	31 7
21	0	0 0	40 9	0	0 0
22	0	0 0	245 8	0	0 0
23	1	0 8	40 9	25	31 7
24	0	0 0	205 1	0	0 0

THESE ESTIMATES ASSUME AN AVERAGE BUS OCCUPANCY OF 25 0 PASSENGERS PER BUS THROUGHOUT THE NETWORK

TOTAL CPU TIME FOR THIS RUN = 44 05 SECONDS
LAST CASE PROCESSED

SPSS MODEL REGRESSION ANALYSIS

EQUATION 5.1

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Dev	Label
DELAY	.599	.308	
STATION	1.034	.490	
DENS.LT	.638	1.107	
DENS.RT	.984	1.512	
DENS.TH	8.380	10.290	
M.T	.366	.146	
SIGNALKM	4.248	2.068	
LENGTH	.286	.220	
HVDENSTY	.358	.559	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	STATION	DENS.LT	DENS.RT	DENS.TH	M.T	SIGNALKM	LENGTH
DELAY	1.000	.453	-.021	.045	.624	-.297	-.250	.306
	.	.000	.422	.337	.000	.002	.010	.002
STATION	.453	1.000	-.217	-.090	-.032	.135	-.522	.567
	.000	.	.021	.201	.384	.105	.000	.000
DENS.LT	-.021	-.217	1.000	-.029	-.087	.039	.177	-.021
	.422	.021	.	.394	.209	.361	.050	.423
DENS.RT	.045	-.090	-.029	1.000	.073	-.113	.231	-.105
	.337	.201	.394	.	.249	.147	.015	.164
DENS.TH	.624	-.032	-.087	.073	1.000	-.373	-.099	-.194
	.000	.384	.209	.249	.	.000	.179	.035
M.T	-.297	.135	.039	-.113	-.373	1.000	-.253	.657
	.002	.105	.361	.147	.000	.	.009	.000
SIGNALKM	-.250	-.522	.177	.231	-.099	-.253	1.000	-.407
	.010	.000	.050	.015	.179	.009	.	.000
LENGTH	.306	.67	-.021	-.105	-.194	.657	-.407	1.000
	.002	.000	.423	.164	.035	.000	.000	.
HVDENSTY	.599	-.054	.020	.136	.966	-.329	-.180	-.184
	.000	.308	.428	.103	.000	.001	.047	.043

HVDENSTY

DELAY	.599
	.000
STATION	-.054
	.308
DENS.LT	.020
	.428
DENS.RT	.136
	.103
DENS.TH	.966
	.000

M.T -.329
 .001

SIGNALKM -.180
 .047

LENGTH -.184
 .043

HVDENSTY 1.000
 .

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 11

Block Number 1. Method: Enter

STATION DENS.LT DENS.RT DENS.TH M.T SIGNALKM LENGTH HVDENSTY

Variable(s) Entered on Step Number

- 1.. HVDENSTY
- 2.. DENS.LT
- 3.. DENS.RT
- 4.. LENGTH
- 5.. SIGNALKM
- 6.. STATION
- 7.. M.T
- 8.. DENS.TH

Multiple R .90028
R Square .81051
Adjusted R Square .79132
Standard Error .14072

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	8	6.69142	.83643
Residual	79	1.56444	.01980

F = 42.23723 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)

Below Diagonal: Covariance Above: Correlation

	HVDENSTY	DENS.LT	DENS.RT	LENGTH	SIGNALKM	STATION
HVDENSTY	.02318	-.54886	-.48826	.11524	.60666	.22443
DENS.LT	-.00142	2.885E-04	.31163	-.15976	-.39174	.03192
DENS.RT	-8.805E-04	6.269E-05	1.403E-04	-.06554	-.44822	-.12921
LENGTH	.00212	-3.273E-04	-9.364E-05	.01455	.06846	-.54713
SIGNALKM	.00108	-7.761E-05	-6.192E-05	9.632E-05	1.360E-04	.44459
STATION	.00160	2.538E-05	-7.163E-05	-.00309	2.427E-04	.00219
M.T	-.00187	1.999E-04	9.897E-05	-.01329	2.230E-04	.00296
DENS.TH	-.00120	7.467E-05	4.405E-05	-1.260E-04	-5.189E-05	-7.180E-05

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Var-Covar Matrix of Regression Coefficients (B)

Below Diagonal: Covariance Above: Correlation

M.T DENS.TH

HVDENSTY	-.07611	-.97887
DENS.LT	.07312	.54746
DENS.RT	.05191	.46315
LENGTH	-.68423	-.13012
SIGNALKM	.11877	-.55414
STATION	.39295	-.19103
M.T	.02591	.14699
DENS.TH	1.900E-04	6.447E-05

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce	Intrvl B	Beta
STATION	.127376	.046808	.034206	.220545	.202654
DENS.LT	.022693	.016986	-.011117	.056502	.081559
DENS.RT	.002266	.011844	-.021309	.025841	.011123
DENS.TH	.011844	.008029	-.004138	.027826	.395639
M.T	-1.187422	.160955	-1.507795	-.867049	-.563921
SIGNALKM	.007435	.011663	-.015779	.030650	.049925
LENGTH	.973357	.120635	.733239	1.213474	.694056
HVDENSTY	.097333	.152271	-.205715	.400381	.176538
(Constant)	.441333	.101293	.239713	.642952	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
STATION	.432507	2.312	2.721	.0080
DENS.LT	.643605	1.554	1.336	.1854
DENS.RT	.709474	1.409	.191	.8488
DENS.TH	.033342	29.992	1.475	.1442
M.T	.410521	2.436	-7.377	.0000
SIGNALKM	.391122	2.557	.638	.5256
LENGTH	.324177	3.085	8.069	.0000
HVDENSTY	.031455	31.791	.639	.5245
(Constant)			4.357	.0000

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Constant	Proportions	STATION	DENS.LT	DENS.RT	DENS.TH	M.T
1	5.67130	1.000	.00064	.00199	.00451	.00588	.00033	.00145	
2	1.27601	2.108	.00017	.00134	.01028	.00216	.00543	.00292	
3	.77090	2.712	.00006	.00838	.48001	.00547	.00008	.00117	
4	.71631	2.814	.00000	.00145	.04457	.54377	.00066	.00059	
5	.33608	4.108	.00486	.00269	.09687	.19050	.00032	.00006	
6	.12995	6.606	.00202	.37278	.03907	.00020	.00022	.10699	
7	.07453	8.723	.02829	.00431	.00001	.00372	.00772	.25483	
8	.01534	19.229	.82973	.45597	.04826	.00770	.08257	.63026	
9	.00959	24.321	.13422	.15108	.27641	.24060	.90269	.00172	

	SIGNALKM	LENGTH	HVDENSTY
1	.00174	.00254	.00030
2	.00079	.00805	.00734
3	.00277	.01390	.00004
4	.00400	.00735	.00069
5	.10598	.07478	.00145
6	.00414	.08662	.00164
7	.20049	.50855	.00366
8	.13412	.29698	.03878
9	.54597	.00122	.94610

End Block Number 1 All requested variables entered.

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.2

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Dev	Label
DELAY	.599	.308	
DENS.LT	.638	1.107	
DENS.TH	8.380	10.290	
LENGTH	.286	.220	
M.T	.366	.146	
STATION	1.034	.490	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	DENS.LT	DENS.TH	LENGTH	M.T	STATION
DELAY	1.000	-.021	.624	.306	-.297	.453
	.	.422	.000	.002	.002	.000
DENS.LT	-.021	1.000	-.087	-.021	.039	-.217
	.422	.	.209	.423	.361	.021
DENS.TH	.624	-.087	1.000	-.194	-.373	-.032
	.000	.209	.	.035	.000	.384
LENGTH	.306	-.021	-.194	1.000	.657	.567
	.002	.423	.035	.	.000	.000
M.T	-.297	.039	-.373	.657	1.000	.135
	.002	.361	.000	.000	.	.105
STATION	.453	-.217	-.032	.567	.135	1.000
	.000	.021	.384	.000	.105	.

3 OF / DE 3

PM-1 3½"x4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce Intrvl B	Beta
DENS.LT	.028657	.013953	9.01275E-04	.056413
DENS.TH	.016775	.001571	.013649	.019901
LENGTH	.965440	.118312	.730080	1.200801
M.T	-1.196888	.154662	-1.504561	-.889215
STATION	.112971	.041209	.030993	.194949
(Constant)	.485496	.067659	.350902	.620090

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
DENS.LT	.929954	1.075	2.054	.0432
DENS.TH	.848826	1.178	10.676	.0000
LENGTH	.328584	3.043	8.160	.0000
M.T	.433465	2.307	-7.739	.0000
STATION	.544039	1.838	2.741	.0075
(Constant)			7.176	.0000

Collinearity Diagnostics

Number	Eigenval	Cond	Variance	Proportions				
		Index	Constant	DENS.LT	DENS.TH	LENGTH	M.T	STATION
1	4.24357	1.000	.00248	.01195	.01194	.00539	.00295	.00482
2	.77239	2.344	.00011	.73158	.09884	.00058	.00002	.00412
3	.67002	2.517	.00007	.09307	.50837	.02854	.00494	.00370
4	.16499	5.071	.09763	.06034	.17358	.37756	.02759	.00106
5	.12551	5.815	.00007	.05382	.06760	.02532	.15642	.48412
6	.02351	13.434	.89964	.04923	.13967	.56241	.80809	.50218

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
100	0:.....:	:	:	:	1.30	.7124	.5876

1 Outliers found.

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	-.0876	2.2634	.5987	.2769	88

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.3

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Devia	Label
DELAY	.599	.308	
DENS.TH3	10749.132	92426.361	
LENGTH3	.087	.252	
STATION2	1.307	1.118	
TT.MT	3.381	2.312	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	DENS.TH3	LENGTH3	STATION2	TT.MT
DELAY	1.000	.666	.347	.463	.649
	.	.000	.000	.000	.000
DENS.TH3	.666	1.000	-.039	-.031	.780
	.000	.	.359	.387	.000
LENGTH3	.347	-.039	1.000	.555	-.221
	.000	.359	.	.000	.019
STATION2	.463	-.031	.555	1.000	-.159
	.000	.387	.000	.	.069
TT.MT	.649	.780	-.221	-.159	1.000
	.000	.000	.019	.069	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 1

Block Number 1. Method: Enter DENS.TH3 LENGTH3 STATION2 TT.MT

Variable(s) Entered on Step Number

1..	TT.MT
2..	STATION2
3..	LENGTH3
4..	DENS.TH3

Multiple R	.90626
R Square	.82131
Adjusted R Square	.81270
Standard Error	.13332

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	6.78059	1.69515
Residual	83	1.47527	.01777

F = 95.37060 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
 Below Diagonal: Covariance Above: Correlation

	TT.MT	STATION2	LENGTH3	DENS.TH3
TT.MT	1.078E-04	.05904	.22764	-.79161
STATION2	9.441E-06	2.371E-04	-.52535	-.03981
LENGTH3	1.654E-04	-5.659E-04	.00489	-.16456
DENS.TH3	-2.082E-09	-1.553E-10	-2.916E-09	6.416E-14

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce Intrvl B	Beta
DENS.TH3	7.35333E-07	2.5330E-07	2.31527E-07 1.23914E-06	.220627
LENGTH3	.308017	.069959	.168871 .447163	.252255
STATION2	.117368	.015397	.086744 .147991	.425906
TT.MT	.079988	.010385	.059333 .100643	.600341
(Constant)	.140274	.042125	.056490 .224059	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
DENS.TH3	.372740	2.683	2.903	.0047
LENGTH3	.655863	1.525	4.403	.0000
STATION2	.689683	1.450	7.623	.0000
TT.MT	.354397	2.822	7.702	.0000
(Constant)			3.330	.0013

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Proportions Constant	DENS.TH3	LENGTH3	STATION2	TT.MT
1	2.75557	1.000	.01242	.00618	.02225	.02895	.01110
2	1.24732	1.486	.00011	.14534	.12966	.02083	.01258
3	.73584	1.935	.02716	.16651	.36080	.00017	.00574
4	.20639	3.654	.04475	.06237	.46648	.86793	.05472
5	.05488	7.086	.91556	.61960	.02081	.08213	.91586

End Block Number 1 All requested variables entered.

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	.2484	2.4958	.5987	.2792	88
*RESID	-.2894	.4426	.0000	.1302	88
*ZPRED	-1.2545	6.7955	.0000	1.0000	88
*ZRESID	-2.1709	3.3201	.0000	.9767	88

Total Cases = 88

Durbin-Watson Test = 2.04220

Scatterplot

Dependent Variable: DELAY

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.4

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Devia	Label
DELAY	.599	.308	
DENS.LT3	7.108	37.410	
DENS.RT3	16.576	63.755	
LENGTH3	.087	.252	
TT.MT	3.381	2.312	
STATION2	1.307	1.118	
DENS.TH3	10749.132	92426.361	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	DENS.LT3	DENS.RT3	LENGTH3	TT.MT	STATION2	DENS.TH3
DELAY	1.000	-.059	-.011	.347	.649	.463	.666
	.	.294	.459	.000	.000	.000	.000
DENS.LT3	-.059	1.000	-.033	-.046	-.056	-.162	-.019
	.294	.	.381	.334	.302	.066	.429
DENS.RT3	-.011	-.033	1.000	-.053	.041	-.083	-.015
	.459	.381	.	.313	.354	.221	.446
LENGTH3	.347	-.046	-.053	1.000	-.221	.555	-.039
	.000	.334	.313	.	.019	.000	.359
TT.MT	.649	-.056	.041	-.221	1.000	-.159	.780
	.000	.302	.354	.019	.	.069	.000
STATION2	.463	-.162	-.083	.555	-.159	1.000	-.031
	.000	.066	.221	.000	.069	.	.387
DENS.TH3	.666	-.019	-.015	-.039	.780	-.031	1.000
	.000	.429	.446	.359	.000	.387	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 13

Block Number 1. Method: Enter

DENS.LT3 DENS.RT3 LENGTH3 TT.MT STATION2 DENS.TH3

Variable(s) Entered on Step Number

1.. DENS.TH3
 2.. DENS.RT3
 3.. DENS.LT3
 4.. LENGTH3
 5.. STATION2
 6.. TT.MT

Multiple R .90852
 R Square .82541
 Adjusted R Square .81248
 Standard Error .13340

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	6	6.81449	1.13575
Residual	81	1.44137	.01779

F = 63.82524 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
Below Diagonal: Covariance Above: Correlation

	DENS.TH3	DENS.RT3	DENS.LT3	LENGTH3	STATION2	TT.MT
DENS.TH3	6.472E-14	.06114	-.05820	-.16258	-.04519	-.79315
DENS.RT3	3.513E-12	5.100E-08	.04105	-.00805	.06704	-.06272
DENS.LT3	-5.776E-12	3.616E-09	1.522E-07	-.02972	.17197	.09200
LENGTH3	-2.896E-09	-1.273E-07	-8.120E-07	.00490	-.52184	.22378
STATION2	-1.801E-10	2.372E-07	1.051E-06	-5.726E-04	2.455E-04	.06951
TT.MT	-2.110E-09	-1.481E-07	3.754E-07	1.639E-04	1.139E-05	1.094E-04

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confidence Interval B	Beta
DENS.LT3	5.20014E-04	3.9013E-04	-2.56213E-04 .001296	.063151
DENS.RT3	9.31603E-05	2.2583E-04	-3.56179E-04 5.42499E-04	.019281
LENGTH3	.305071	.070032	.165730 .444412	.249842
TT.MT	.081021	.010458	.060213 .101830	.608096
STATION2	.121296	.015668	.090122 .152469	.440160
DENS.TH3	7.21389E-07	2.5439E-07	2.15226E-07 1.22755E-06	.216443
(Constant)	.126813	.043263	.040733 .212893	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
DENS.LT3	.960252	1.041	1.333	.1863
DENS.RT3	.986636	1.014	.413	.6811
LENGTH3	.655253	1.526	4.356	.0000
TT.MT	.349828	2.859	7.747	.0000
STATION2	.666802	1.500	7.742	.0000
DENS.TH3	.369970	2.703	2.836	.0058
(Constant)			2.931	.0044

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Proportions	DENS.LT3	DENS.RT3	LENGTH3	TT.MT	STATION2
1	2.84319	1.000	.01125	.00368	.01129	.01922	.01036	.02527
2	1.25148	1.507	.00010	.00437	.00616	.14204	.01164	.02291
3	1.01941	1.670	.00184	.58915	.12071	.03154	.00019	.00368
4	.97751	1.705	.00007	.24994	.63576	.01475	.00002	.00037
5	.65786	2.079	.02434	.08611	.20534	.33138	.00754	.00585
6	.19717	3.797	.04579	.03751	.02072	.44380	.06701	.84248
7	.05338	7.298	.91660	.02925	.00001	.01728	.90324	.09945

DENS.TH3

1	.00533
2	.13031
3	.04692
4	.01367
5	.11840

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.5

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Dev	Label
DELAY	.599	.308	
HVDNSTY3	1.660	14.768	
LENGTH3	.087	.252	
STATION2	1.307	1.118	
TT.MT	3.381	2.312	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	HVDNSTY3	LENGTH3	STATION2	TT.MT
DELAY	1.000	.665 .000	.347 .000	.463 .000	.649 .000
HVDNSTY3	.665 .000	1.000	-.038 .362	-.031 .388	.779 .000
LENGTH3	.347 .000	-.038 .362	1.000	.555 .000	-.221 .019
STATION2	.463 .000	-.031 .388	.555 .000	1.000	-.159 .069
TT.MT	.649 .000	.779 .000	-.221 .019	-.159 .069	1.000

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 18

Block Number 1. Method: Enter HVDNSTY3 LENGTH3 STATION2 TT.MT

Variable(s) Entered on Step Number

1..	TT.MT
2..	STATION2
3..	LENGTH3
4..	HVDNSTY3

Multiple R	.90628
R Square	.82134
Adjusted R Square	.81273
Standard Error	.13331

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	6.78088	1.69522
Residual	83	1.47498	.01777

F = 95.39315 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
 Below Diagonal: Covariance Above: Correlation

	TT.MT	STATION2	LENGTH3	HVDNSTY3
TT.MT	1.073E-04	.05874	.22815	-.79049
STATION2	9.369E-06	2.370E-04	-.52535	-.03941
LENGTH3	1.653E-04	-5.658E-04	.00489	-.16516
HVDNSTY3	-1.295E-05	-9.593E-07	-1.827E-05	2.501E-06

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnc	Intrvl B	Beta
HVDNSTY3	.004595	.001581	.001450	.007741	.220309
LENGTH3	.307860	.069959	.168714	.447007	.252126
STATION2	.117384	.015395	.086764	.148004	.425966
TT.MT	.080055	.010359	.059451	.100660	.600845
(Constant)	.140313	.042113	.056553	.224074	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
HVDNSTY3	.374524	2.670	2.906	.0047
LENGTH3	.655730	1.525	4.401	.0000
STATION2	.689705	1.450	7.625	.0000
TT.MT	.356071	2.808	7.728	.0000
(Constant)			3.332	.0013

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Constant	Proportions HVDNSTY3	LENGTH3	STATION2	TT.MT
1	2.75319	1.000	.01245	.00605	.02235	.02904	.01116
2	1.24703	1.486	.00011	.14709	.12842	.02063	.01269
3	.73823	1.931	.02691	.16633	.36098	.00013	.00583
4	.20650	3.651	.04433	.06244	.46739	.86780	.05506
5	.05504	7.072	.91620	.61808	.02086	.08240	.91527

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
81	O:.....:	:O			1.30	.8574	.4426
	.	..*	.				

1 Outliers found.

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.6

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Deviat	Label
DELAY	.599	.308	
LENGTH3	.087	.252	
STATION2	1.307	1.118	
TT.MT	3.381	2.312	
DENSITY3	14077.972	118065.467	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	LENGTH3	STATION2	TT.MT	DENSITY3
DELAY	1.000	.347	.463	.649	.665
	.	.000	.000	.000	.000
LENGTH3	.347	1.000	.555	-.221	-.040
	.000	.	.000	.019	.357
STATION2	.463	.555	1.000	-.159	-.032
	.000	.000	.	.069	.383
TT.MT	.649	-.221	-.159	1.000	.780
	.000	.019	.069	.	.000
DENSITY3	.665	-.040	-.032	.780	1.000
	.000	.357	.383	.000	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 22

Block Number 1. Method: Enter LENGTH3 STATION2 TT.MT DENSITY3

Variable(s) Entered on Step Number

1..	DENSITY3
2..	STATION2
3..	LENGTH3
4..	TT.MT

Multiple R	.90629
R Square	.82137
Adjusted R Square	.81276
Standard Error	.13330

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	6.78110	1.69528
Residual	83	1.47476	.01777

F = 95.41081 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
 Below Diagonal: Covariance Above: Correlation

	DENSITY3	STATION2	LENGTH3	TT.MT
DENSITY3	3.939E-14	-.03839	-.16485	-.79209
STATION2	-1.173E-10	2.369E-04	-.52558	.05791
LENGTH3	-2.289E-09	-5.659E-04	.00489	.22784
TT.MT	-1.634E-09	9.265E-06	1.657E-04	1.080E-04

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce Intrvl B		Beta
LENGTH3	.307900	.069950	.168772	.447029	.252159
STATION2	.117428	.015393	.086812	.148045	.426126
TT.MT	.079908	.010394	.059235	.100581	.599741
DENSITY3	5.77242E-07	1.9847E-07	1.82487E-07	9.71996E-07	.221238
(Constant)	.140253	.042084	.056550	.223956	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
LENGTH3	.655799	1.525	4.402	.0000
STATION2	.689760	1.450	7.629	.0000
TT.MT	.353663	2.828	7.688	.0000
DENSITY3	.371942	2.689	2.908	.0047
(Constant)			3.333	.0013

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Constant	Proportions			
				LENGTH3	STATION2	TT.MT	DENSITY3
1	2.75723	1.000	.01242	.02217	.02888	.01108	.00627
2	1.24762	1.487	.00012	.13043	.02099	.01251	.14428
3	.73412	1.938	.02736	.36083	.00020	.00568	.16679
4	.20615	3.657	.04534	.46560	.86878	.05445	.06262
5	.05487	7.089	.91477	.02097	.08114	.91628	.62005

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
81	0:.....:	:	:	:	1.30	.8579	.4421

1 Outliers found.

Normal P-P Plot of Regression Standardized Resi

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.7

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Deviat	Label
DELAY	.599	.308	
BUSTOP3	27.705	54.665	
LENGTH3	.087	.252	
TT.MT	3.381	2.312	
DENSITY3	14077.972	118065.467	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	BUSTOP3	LENGTH3	TT.MT	DENSITY3
DELAY	1.000	.100	.347	.649	.665
	.	.178	.000	.000	.000
BUSTOP3	.100	1.000	.051	.083	-.047
	.178	.	.319	.220	.332
LENGTH3	.347	.051	1.000	-.221	-.040
	.000	.319	.	.019	.357
TT.MT	.649	.083	-.221	1.000	.780
	.000	.220	.019	.	.000
DENSITY3	.665	-.047	-.040	.780	1.000
	.000	.332	.357	.000	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 26

Block Number 1. Method: Enter BUSTOP3 LENGTH3 TT.MT DENSITY3

Variable(s) Entered on Step Number

1.. DENSITY3
 2.. LENGTH3
 3.. BUSTOP3
 4.. TT.MT

Multiple R .83532
 R Square .69776
 Adjusted R Square .68319
 Standard Error .17339

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	5.76059	1.44015
Residual	83	2.49527	.03006

F = 47.90352 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
 Below Diagonal: Covariance Above: Correlation

	DENSITY3	LENGTH3	BUSTOP3	TT.MT
DENSITY3	6.935E-14	-.23492	.20087	-.80078
LENGTH3	-4.821E-09	.00607	-.11514	.31991
BUSTOP3	1.847E-11	-3.134E-06	1.220E-07	-.21791
TT.MT	-2.916E-09	3.448E-04	-1.052E-06	1.913E-04

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce Intrvl B	Beta
BUSTOP3	2.34265E-04	3.4924E-04	-4.60355E-04 9.28884E-04	.041571
LENGTH3	.582343	.077927	.427350 .737336	.476918
TT.MT	.073295	.013829	.045789 .100801	.550107
DENSITY3	6.70850E-07	2.6334E-07	1.47071E-07 1.19463E-06	.257114
(Constant)	.284478	.048941	.187137 .381819	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
BUSTOP3	.948115	1.055	.671	.5042
LENGTH3	.894075	1.118	7.473	.0000
TT.MT	.338004	2.959	5.300	.0000
DENSITY3	.357462	2.797	2.547	.0127
(Constant)			5.813	.0000

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Constant	Proportions BUSTOP3	LENGTH3	TT.MT	DENSITY3
1	2.39038	1.000	.01965	.05174	.02201	.01610	.01186
2	1.15332	1.440	.00308	.07779	.17714	.00601	.16354
3	.83046	1.697	.00154	.21881	.61397	.00069	.04494
4	.56883	2.050	.06878	.62589	.04164	.01010	.10484
5	.05702	6.475	.90696	.02578	.14523	.96710	.67482

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
81	O:.....:	:.....:O			1.30	.6482	.6518

1 Outliers found.

Normal P-P Plot of Regression Standardize

Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

Regression Standardized Residual

EQUATION 5.8

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Deviat	Label
DELAY	.750	.476	
DENSITY3	14077.972	118065.467	
LENGTH3	.087	.252	
STATION2	1.307	1.118	
TT.MT	3.874	3.514	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	DENSITY3	LENGTH3	STATION2	TT.MT
DELAY	1.000	.757	.260	.351	.726
	.	.000	.007	.000	.000
DENSITY3	.757	1.000	-.040	-.032	.906
	.000	.	.357	.383	.000
LENGTH3	.260	-.040	1.000	.555	-.157
	.007	.357	.	.000	.072
STATION2	.351	-.032	.555	1.000	-.126
	.000	.383	.000	.	.120
TT.MT	.726	.906	-.157	-.126	1.000
	.000	.000	.072	.120	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 1

Block Number 1. Method: Enter DENSITY3 LENGTH3 STATION2 TT.MT

Variable(s) Entered on Step Number

1..	TT.MT
2..	STATION2
3..	LENGTH3
4..	DENSITY3

Multiple R	.87637
R Square	.76802
Adjusted R Square	.75684
Standard Error	.23454

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	15.11583	3.77896
Residual	83	4.56573	.05501

F = 68.69729 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)
 Below Diagonal: Covariance Above: Correlation

	TT.MT	STATION2	LENGTH3	DENSITY3
TT.MT	3.146E-04	.08950	.19614	-.91256
STATION2	4.310E-05	7.370E-04	-.52375	-.07667
LENGTH3	4.252E-04	-.00174	.01494	-.16844
DENSITY3	-8.437E-09	-1.085E-09	-1.073E-08	2.717E-13

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce Intrvl B		Beta
DENSITY3	1.21260E-06	5.2124E-07	1.75877E-07	2.24932E-06	.301002
LENGTH3	.318872	.122216	.075789	.561954	.169134
STATION2	.141621	.027148	.087625	.195617	.332847
TT.MT	.070701	.017738	.035420	.105981	.522328
(Constant)	.246020	.078188	.090508	.401532	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
DENSITY3	.166954	5.990	2.326	.0224
LENGTH3	.665097	1.504	2.609	.0108
STATION2	.686537	1.457	5.217	.0000
TT.MT	.162746	6.145	3.986	.0001
(Constant)			3.147	.0023

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Proportions				
			Constant	DENSITY3	LENGTH3	STATION2	TT.MT
1	2.71294	1.000	.01080	.00438	.02282	.02820	.00731
2	1.35616	1.414	.00091	.05614	.10781	.02452	.00883
3	.69699	1.973	.03490	.05453	.43616	.00200	.00154
4	.19701	3.711	.07626	.03673	.41274	.88779	.02421
5	.03691	8.573	.87713	.84821	.02046	.05750	.95812

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
84	0:.....:	:	0	*	2.70	1.2941	1.4059

1 Outliers found.

Normal P-P Plot of Regression Standardized Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.9

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

	Mean	Std Deviat	Label
DELAY	.750	.476	
DENSITY3	14077.972	118065.467	
LENGTH3	.087	.252	
TT.MT	3.874	3.514	
BUSTOP3	61.227	197.915	

N of Cases = 88

Correlation, 1-tailed Sig:

	DELAY	DENSITY3	LENGTH3	TT.MT	BUSTOP3
DELAY	1.000	.757	.260	.726	.020
	.	.000	.007	.000	.425
DENSITY3	.757	1.000	-.040	.906	-.031
	.000	.	.357	.000	.386
LENGTH3	.260	-.040	1.000	-.157	-.001
	.007	.357	.	.072	.498
TT.MT	.726	.906	-.157	1.000	-.024
	.000	.000	.072	.	.412
BUSTOP3	.020	-.031	-.001	-.024	1.000
	.425	.386	.498	.412	.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Descriptive Statistics are printed on Page 5

Block Number 1. Method: Enter DENSITY3 LENGTH3 TT.MT BUSTOP3

Variable(s) Entered on Step Number

1..	BUSTOP3
2..	LENGTH3
3..	DENSITY3
4..	TT.MT

Multiple R	.83295
R Square	.69380
Adjusted R Square	.67904
Standard Error	.26946

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	13.65505	3.41376
Residual	83	6.02652	.07261

F = 47.01592 Signif F = .0000

Var-Covar Matrix of Regression Coefficients (B)

Below Diagonal: Covariance Above: Correlation

	BUSTOP3	LENGTH3	DENSITY3	TT.MT
BUSTOP3	2.133E-08	-.00118	.02246	-.01048
LENGTH3	-2.067E-08	.01431	-.24556	.28641
DENSITY3	1.959E-12	-1.754E-08	3.567E-13	-.91198
TT.MT	-3.107E-08	6.954E-04	-1.106E-08	4.120E-04

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

----- Variables in the Equation -----

Variable	B	SE B	95% Confdnce	Intrvl B	Beta
DENSITY3	1.43054E-06	5.9723E-07	2.42672E-07	2.61841E-06	.355102
LENGTH3	.652695	.119613	.414789	.890601	.346199
TT.MT	.062269	.020299	.021896	.102642	.460036
BUSTOP3	1.03108E-04	1.4605E-04	-1.87375E-04	3.93591E-04	.042904
(Constant)	.425448	.080454	.265427	.585469	

----- Variables in the Equation -----

Variable	Tolerance	VIF	T	Sig T
DENSITY3	.167856	5.957	2.395	.0189
LENGTH3	.916512	1.091	5.457	.0000
TT.MT	.164042	6.096	3.068	.0029
BUSTOP3	.998900	1.001	.706	.4822
(Constant)			5.288	.0000

Collinearity Diagnostics

Number	Eigenval	Cond Index	Variance Proportions				
			Constant	DENSITY3	LENGTH3	TT.MT	BUSTOP3
1	2.22952	1.000	.01729	.01257	.02129	.01330	.02753
2	1.19668	1.365	.00913	.05336	.19130	.00331	.14839
3	.90434	1.570	.00011	.00054	.40170	.00000	.55646
4	.63074	1.880	.06791	.06242	.27736	.00319	.26721
5	.03873	7.588	.90556	.87111	.10835	.98020	.00041

End Block Number 1 All requested variables entered.

***** MULTIPLE REGRESSION *****

Equation Number 1 Dependent Variable.. DELAY

Casewise Plot of Standardized Residual

Outliers = 3. *: Selected M: Missing

Case #	-6.	-3.	3.	6.	DELAY	*PRED	*RESID
84	O:.....	:.....	:O	*	2.70	1.0946	1.6054

1 Outliers found.

Normal P-P Plot of Regression Standardized Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

EQUATION 5.10

* * * * MULTIPLE REGRESSION * * * *

Listwise Deletion of Missing Data

Equation Number 1 Dependent Variable.. DELAY

Block Number 1. Method: Enter LENGTH3 TT.MT BUSTOP3 HVDNSTY3

Variable(s) Entered on Step Number

1.. HVDNSTY3
 2.. BUSTOP3
 3.. LENGTH3
 4.. TT.MT

Multiple R .83337
 R Square .69450
 Adjusted R Square .67978
 Standard Error .26915

Analysis of Variance

	DF	Sum of Squares	Mean Square
Regression	4	13.66891	3.41723
Residual	83	6.01266	.07244

F = 47.17213 Signif F = .0000

----- Variables in the Equation -----

Variable	B	SE B	Beta	T	Sig T
LENGTH3	.650959	.119534	.345279	5.446	.0000
TT.MT	.061796	.020179	.456541	3.062	.0030
BUSTOP3	1.03981E-04	1.4589E-04	.043268	.713	.4780
HVDNSTY3	.011570	.004746	.359229	2.438	.0169
(Constant)	.428307	.080450		5.324	.0000

End Block Number 1 All requested variables entered.

* * * * MULTIPLE REGRESSION * * * *

Equation Number 1 Dependent Variable.. DELAY

Residuals Statistics:

	Min	Max	Mean	Std Dev	N
*PRED	.5318	4.0922	.7497	.3964	88
*RESID	-.5725	1.6060	.0000	.2629	88
*ZPRED	-.5497	8.4326	.0000	1.0000	88
*ZRESID	-2.1271	5.9669	.0000	.9767	88

Total Cases = 88

Hi-Res Chart # 4:Histogram of *zresid

Hi-Res Chart # 6:Normal p-p plot of *zresid

Hi-Res Chart # 5:Scatterplot of *zpred with delay

Normal P-P Plot of Regression Standardized Dependent Variable: DELAY

Scatterplot

Dependent Variable: DELAY

Histogram

Dependent Variable: DELAY

APPENDIX

TRAFFIC ANALYSIS EQUIPMENTS & MANAGEMENT TECHNOLOGY

Sarasota

Sarasota Automation, Inc. offers the following equipments:

- ▶ Traffic Analyzer
- ▶ Speed, Occupancy & headway system
- ▶ Speed Warning & Queue Detection System
- ▶ Priority Vehicle Detector
 - * Bus priority
 - * emergency Vehicle Preemption
 - * Selection Access Control
- ▶ Vehicle Identification System - Multicoder

Applications:

Sarasota Traffic Analyzer:

Sarasota traffic analyzer is a microprocessor based, capable of collecting vehicle data in many different modes:

- * Volume Count
- * Speed and Length
- * Speed by Length
- * Free-Flow statistical Speed
- * Headway / Gap
- * Axle Classification to FHWA Schedule (F) as 13 types

Figure C-1, illustrate the Sarasota-VC system diagram for the traffic data collection procedures.

Source.

Sarasota Automation Inc. Traffic Engineering Fact Sheet.
1500 North Washington Boulevard, Sarasota, Florida 3436, USA.

Figure C-1: SARASOTA TRAFFIC ANALYZER SYSTEM

Source

Sarasota Automation Inc. Traffic Engineering Fact Sheet.
1500 North Washington Boulevard, Sarasota, Florida 3436, USA

Speed Warning & Queue Detection System:

The Sarasota Speed Warning and Queue Detection System finds application wherever failure to observe mandatory speed restrictions causes exceptional traffic hazard or where traffic queues are invisible to oncoming vehicles.

The sarasota speed warning and queue detection system will provide a warning of over-speed, under-speed or queue situations.

- * For over-speed application, the system provides an output when a vehicle exceeds a preset speed.
- * In under-speed and Queue Detection Mode, the system responds to vehicles failing to reach the preset speed, and to vehicles present over either of two loops for more than 4 seconds (or 8 seconds link selectable).

Figure C-2, illustrates the schematic diagram for on-street lay-out and equipments installation.

Source: Sarasota Automation Inc. Traffic Engineering Fact Sheet.
1500 North Washington Boulevard, sarasota, Florida 3436, USA

Speed Warning & Queue Detection System

Figure C-2: ON-STREET EQUIPMENTS INSTALLATION & LAY-OUT

Source.

Sarasota Automation Inc. Traffic Engineering Fact Sheet.
1500 North Washington Boulevard, sarasota, Florida 3436, USA

EMTRAC

TRAFFIC CONTROL SYSTEM

The EMTRAC Traffic Pre-Emption System allow the following:

- ▶ Control of traffic signals from an equipped vehicle (to clear intersection, allow safe passage, and improve response time)
- ▶ Programmable sign activation distance (to trigger green signal at a distance from 100 to 2400 feet)
- ▶ Vehicle identification numbers (for recognition of special/system vehicles)

Application:

The EMTRAC Traffic Control System allows city agencies and transit operators (public transit, emergency, and/or law enforcement vehicles) to command green signals in the vehicle travel direction and temporarily interrupt the current traffic signal sequencing at a given intersection. This enables the modification process of traffic flow at that particular intersection to accommodate vehicles linked to the EMTRAC system.

The most important benefit of using the EMTRAC control system to give transit vehicles the right-of-way, thus avoiding conflict and delays with general traffic. Once the bus has cleared the intersection, the receiver no longer detect a signal so it allows controller operation to return to the normal sitting.

Source:

ECONOLITE Canada, Inc. EMTRAC; The Intelligent Traffic Control System
1650 Midland Ave. Scarborough, Ontario M1P 3C2

8524	86	08:42:16	08:44:12	08:44
7825	66	08:42:30	08:44:15	08:44
9131	76	08:42:31	08:44:19	08:45
7520	41	08:43:30	08:45:01	08:45
9119	44	08:43:35	08:45:04	08:45
7764	97	08:44:00	08:45:49	08:46
8730	95	08:44:05	08:45:57	08:46
7754	57	08:45:11	08:46:48	08:47
7459	69	08:45:13	08:47:01	08:47
7412	50	08:45:17	08:47:09	08:47
7855	13	08:46:00	08:47:12	08:48
7419	73	08:46:03	08:47:16	08:49
9102	8	08:46:05	08:47:50	08:49
7558	56		08:49:02	08:49
8849	95	08:47:43	08:49:06	08:49
8408	64	08:47:45	08:49:10	
7844	65	08:48:10	08:50:01	08:50
3226	75	08:48:17	08:50:03	08:50
8634	85	08:48:18	08:50:04	08:50
9258	78	08:49:00	08:50:42	08:51
5710	55	08:49:10	08:50:45	08:51
5767	63	08:50:13	08:51:49	08:52
9124	96	08:50:14	08:51:56	08:52
8761	95	08:50:18	08:52:01	08:52
7701	62	08:51:10	08:52:47	08:53
7428	46	08:51:11	08:52:58	08:53
5724	61	08:52:11	08:53:56	08:54
9147	41	08:52:15	08:53:58	08:54
9234	70	08:53:10	08:54:53	08:55
5768	78	08:53:27	08:54:59	08:56
8921	3	08:54:14	08:56:02	08:56
5716	50	08:54:15	08:56:04	08:56
9220	57	08:54:20	08:56:05	08:57
9101	59	08:55:10	08:56:42	08:57
8628	95	08:55:12	08:57:00	08:57
9009	97	08:55:16	08:57:04	08:57
9311	67	08:56:20	08:57:34	08:58
8548	72	08:56:22		08:58
5703	44	08:56:25		08:58
5725	73	08:56:26		08:58
9202	51		08:59:40	
8846	95	08:58:12	08:59:59	
5712	63	08:59:10	09:01:02	
8512	86	08:59:47	09:01:06	
7744	97	08:59:49	09:01:10	
7721	65	08:59:51	09:01:15	
5747	60	09:00:28	09:01:52	
7646	86	09:00:29		
8614	85	09:00:30

Figure C-4:

ACTIVATING GREEN SIGNAL FROM PROGRAMMABLE DISTANCE

Source:

ECONOLITE Canada, Inc. EMTRAC; The Intelligent Traffic Control System.
1650 Midland Ave. Scarborough, Ontario M1P 3C2

APPENDIX D

MISCELLANEOUS DATA COLLECTION

BUS ROUTE #2
ACCIDENT DATA FOR 1993

The following is a list of the streets and intersections which have experienced more than 5 accident during the year 1993. If a bus was involved in the collision, the number of stars will indicate the number of accidents which occurred and which bus was involved.

<u>INTERSECTION</u>	<u>FROM BAYSHORE SHOPPING CANTER</u>			<u>No. OCCURRED</u>
Section [1]:				
BAYSHORE & WOODRIDGE	7			W
BAYSHORE & WOODRIDGE (S)	30	*		W
CARLING & RICHMOND	17			W
POULIN & RICHMOND	6			W
RICHMOND & CROYDON	11			
RICHMOND FROM ASSALY TO CROYDON	7	*		W
Section [2]:				
RICHMOND & WOODROFFE	8			
RICHMOND FROM CHURCHILL TO ROOSEVELT	9	*		
RICHMOND & CHURCHILL	9	*		
Section [3]:				
RICHMOND & ISLAND PARK	10	*		W
WELLINGTON & HOLLAND	18	*		
WELLINGTON & PARKDALE	8			W
SOMERSET & BAYSWATER	7			W
SOMERSET & PRESTON	6			

Section [4]: (CBD Area)

* Indicates the number of accidents involving a bus
W Indicates the weather effect on some of the accidents occurred (i.e. snow storm)

SOMERSET & BOOTH	10		
SOMERSET & BRONSON	26	***	W
SOMERSET & LYON	6		
SOMERSET & BANK	12	***	W
BANK & GLOUCESTER	7	**	
BANK & LAURIER	7	*	
BANK & SLATER	6		
BANK & WELLINGTON	12	**	
WELLINGTON & O'CONNER	10	*	W
WELLINGTON & ELGIN (E)	10	*	
RIDEAU & MACKENZIE	22	*	W
RIDEAU & SUSSEX	24	****	
RIDEAU & KING EDWARD	26	*	W
Section [5]:			
RIDEAU & CHARLOTTE	13		
MONTREAL & RIVER	13		
MONTREAL & VANIER PERKWAY	22	*	
MONTREAL & St.LAURENT	20		
Section [6]:			
MONTREAL Rd. FROM CHURCH TO St.LAURENT	12	**	W
MONTREAL FROM AVIATION PKWY TO CARSON'S	10		

FINAL DESTINATION AT BLAIR STATION

This list only includes some of the highest accident rate, which occurred along the bus path and within the study area during the year 1993. Information and statistics were collected from the Regional Municipality of Ottawa-Carleton.

-
- * Indicates the number of accidents involving a bus
W Indicates the weather effect on some of the accidents occurred (i.e. snow storm)

Table D-1 : BUS MONITORING & FIELD OBSERVATION
THURSDAY, JUNE 22, 1995
BUS EXCLUSIVE LANE, SLATER STREET

BUS NUMBER	ROUTE NUMBER	BUS ARRIVALS		
		SLATER/LYON	SLATER/BANK 2	SLATER/O'CONNOR
8421	3		08:27:10	08:27
8505	95		08:27:15	08:27
9144	8		08:27:40	08:28
7762	59		08:28:03	08:29
7711	55		08:29:04	08:29
7542	66		08:29:10	08:29
7628	46		08:29:14	08:30
8769	86	08:27:43	08:29:20	08:30
5707	50		08:29:34	08:30
8860	95	08:28:42	08:30:10	08:30
8799	85	08:28:43	08:30:29	08:30
7432	44	08:29:12	08:30:54	08:31
5714	41	08:29:15	08:31:05	08:31
7746	97	08:31:15	08:33:02	08:33
7440	69	08:31:35	08:33:22	08:33
5702	72	08:31:36	08:33:25	08:33
7451	50	08:33:05	08:35:01	08:35
9206	75	08:33:18	08:35:02	08:35
8642	95	08:33:22	08:35:05	08:36
7642	65	08:33:55	08:35:28	08:36
9136	13	08:34:00	08:35:57	08:36
7534	78	08:34:10	08:36:07	08:36
7455	60	08:34:15	08:36:08	08:36
7521	64	08:34:17	08:36:09	08:37
8621	85	08:34:45	08:36:20	08:37
9111	70	08:35:28	08:37:15	08:38
8941	96	08:35:32	08:37:22	08:38
9306	67	08:36:13	08:37:33	08:38
7705	76	08:36:40	08:38:15	08:38
8865	95	08:36:42	08:38:19	08:38
5746	86	08:36:44	08:38:22	08:38
7706	63	08:37:05	08:38:50	08:39
7747	61	08:37:10	08:38:52	08:39
9129	97	08:37:15	08:38:53	08:39
	50		08:39:45	08:39
8001	73	08:38:18	08:40:00	08:40
7433	8	08:38:20	08:40:04	08:40
9135	3	08:38:25	08:40:06	08:41
8742	95	08:38:30	08:40:09	08:41
8732	95	08:40:27	08:42:00	08:42
7414	62	08:40:28	08:42:02	08:42
7416	59	08:40:29	08:42:08	08:42
8791	51		08:43:04	08:43
9110	46	08:42:10	08:43:09	08:43
9114	60	08:42:11	08:43:11	08:44

8524	86	08:42:16	08:44:12	08:44
7825	66	08:42:30	08:44:15	08:44
9131	76	08:42:31	08:44:19	08:45
7520	41	08:43:30	08:45:01	08:45
9119	44	08:43:35	08:45:04	08:45
7764	97	08:44:00	08:45:49	08:46
8730	95	08:44:05	08:45:57	08:46
7754	57	08:45:11	08:46:48	08:47
7459	69	08:45:13	08:47:01	08:47
7412	50	08:45:17	08:47:09	08:47
7855	13	08:46:00	08:47:12	08:48
7419	73	08:46:03	08:47:16	08:49
9102	8	08:46:05	08:47:50	08:49
7558	56		08:49:02	08:49
8849	95	08:47:43	08:49:06	08:49
8408	64	08:47:45	08:49:10	
7844	65	08:48:10	08:50:01	08:50
9226	75	08:48:17	08:50:03	08:50
8634	85	08:48:18	08:50:04	08:50
9258	78	08:49:00	08:50:42	08:51
5710	55	08:49:10	08:50:45	08:51
5767	63	08:50:13	08:51:49	08:52
9124	96	08:50:14	08:51:56	08:52
8761	95	08:50:18	08:52:01	08:52
7701	62	08:51:10	08:52:47	08:53
7428	46	08:51:11	08:52:58	08:53
5724	61	08:52:11	08:53:56	08:54
9147	41	08:52:15	08:53:58	08:54
9234	70	08:53:10	08:54:53	08:55
5768	78	08:53:27	08:54:59	08:56
8921	3	08:54:14	08:56:02	08:56
5716	50	08:54:15	08:56:04	08:56
9220	57	08:54:20	08:56:05	08:57
9101	59	08:55:10	08:56:42	08:57
8628	95	08:55:12	08:57:00	08:57
9009	97	08:55:16	08:57:04	08:57
9311	67	08:56:20	08:57:34	08:58
8548	72	08:56:22		08:58
5703	44	08:56:25		08:58
5725	73	08:56:26		08:58
9202	51		08:59:40	
8846	95	08:58:12	08:59:59	
5712	63	08:59:10	09:01:02	
8512	86	08:59:47	09:01:06	
7744	97	08:59:49	09:01:10	
7721	65	08:59:51	09:01:15	
5747	60	09:00:28	09:01:52	
7646	86	09:00:29		
8614	85	09:00:30		

END

1 0 0 6 9 6

FIN