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DEVELOPMENT OF URBAN TRAFFIC MODELS USING A BAYESIAN REGRESSION APPROACH

By

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B.Sc. (Civil Engineering) 1991

University of Ottawa

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

MASTER OF ENGINEERING

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The undersigned hereby recommend to the Faculty of Graduate Studies and Research
acceptance of the thesis entitled,

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submitted by

Luc A. Fréchette, B.Sc. (Civil Engineering)

in partial fulfilment of the requirements for the degree of

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August 1996

ABSTRACT

In this thesis, a Bayesian regression approach is used to develop equations for predicting travel time on central area streets using contributory variables that are intuitive, and for which data are readily available in most transportation agencies. Bayesian regression is a specialized adaptation of Bayes' Theorem involving the development of multivariate regression models which explicitly consider two disparate sources of information: 1) 'a priori' (what is known prior to an experiment), and 2) experimental data (information derived from an experiment). Traffic simulation output from NETSIM was utilized as the source of 'a priori' information whereas the experimental data were obtained from video recordings of traffic operations on various downtown streets. A logical and systematic approach for building the predictive models was followed. The statistical results of the models were assessed and interpreted from a Bayesian perspective in relation to the various model iterations attempted. The final models are believed to provide reasonable predictions of actual travel times that drivers would experience during peak traffic periods in medium to large central business districts.

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GLOSSARY OF TERMS AND ACRONYMS

GLOSSARY OF ACRONYMS

ART SPD	Average Arterial Travel Speed
ATIS	Advanced Traveller Information Systems
b_i	regression coefficients
BRAP	Bayesian Regression Analysis Package
BSTAT	Bayesian Statistical Analysis Program
C-SHRP	Canadian Strategic Highway Research Program
CBD	Central Business District
ESAL	Equivalent Standard Axle Load
E_T	Passenger Car Equivalent
EXCEL	spreadsheet based computer software by Microsoft Corporation
FHWA	Federal Highway Administration
FORTTRAN	computer programming language
HCM	Highway Capacity Manual
HV	Percentage of Heavy Vehicles
k_{total}	Average traffic density over an arterial (vehicles per kilometer)
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
LOS	Level Of Service, according to the Highway Capacity Manual
MOE	Measure of Effectiveness
NETSIM	Microscopic Traffic Simulation Program for Street Networks
N_u	Degrees of Freedom
OC Transpo	Ottawa-Carleton Regional Transit Authority
pdf	Probability Density Function
q_{lt}	Average Flow of "left" Turning Vehicles along the arterial (vehicles per minute)
q_{rt}	Average Flow of "right" Turning Vehicles along the arterial (vehicles per minute)
q_{thr}	Average Flow of through moving vehicles along the arterial (vehicles per minute)
q_{total}	Average total flow of vehicles along the arterial (vehicles per minute)
q_{bus}	Number of Transit Buses per hour
R^2	Coefficient of Multiple Determination
RMOC	Regional Municipality of Ottawa-Carleton

Se	Standard Error
Se ²	Variance of the residuals (regression standard error, squared)
Sigpkm	Number of Traffic Signals Per Kilometer
STOP	Percentage of Vehicles Stopped at least once on a given segment, and average for the entire arterial
TAC	Transportation Association of Canada
TravTime	dependent variable for thesis; defined as the mean travel time (seconds/vehicle) to traverse 1km of the given arterial
TRB	Transportation Research Board
XLBAYES	Bayesian Linear Regression Program (Microsoft Excel Add-in)

GLOSSARY OF TERMS

a priori	Refers to information that is known prior to an experiment, in the context of Bayes' Theorem
approach delay	amount of time needed by a vehicle to stop at an intersection taking into account the acceleration and deceleration time
arterial	type of street that experiences interrupted flow
average running speed	driver's desired speed with both the environment (block spacing, street geometry, land use, pedestrian activity, parking, etc..) and the traffic (other vehicles) considered
average running time	travel time based on the "average running speed"
average travel speed	actual speed of drivers taking into account the effect of traffic signals and all other stops
Bayes' Theorem	statistical theorem on inverse probability attributed to the manuscript, "An Essay Towards Solving a Problem in the Doctrine of Chances", by Thomas Bayes
Bayesian regression	specialized adaptation of Bayes' Theorem involving the development of multivariate regression models using two disparate sources of information: 'a priori' information, and experimental data
coefficient of multiple determination	R^2 , percentage of the total variation of the dependent variable that can be explained by the independent variables (i.e. by the regression equation)
correlation	a measure of the relationship between two variables; varies between -1 and +1; zero indicates that x_1 and x_2 are totally independent

correlation matrix	matrix of correlation coefficients; e.g. correlation of 0 means that the two variables are completely independent of each other, while 1 indicates perfect correlation
covariance	a measure of how two random variables vary together; positive covariance means that if x_1 increases, x_2 will increase, and vice versa; zero covariance means that x_1 and x_2 are totally independent; covariance of $+\infty$ or $-\infty$ indicates that x_1 and x_2 are perfectly related
curvi-linear relationship	refers to model forms that are linear in the coefficients (hence can be analyzed using “linear” regression) but that have non-linear relationships between the independent variables and the dependent variable
Data (model)	the classical regression model, based on the experimental data
data-based prior	Bayesian “prior” derived from samples of past data
degrees of freedom	in classical regression, it defines the number of knowns (usually the # of observations) minus the number of constraints (usually the number of terms) in the predictive equation; usually denoted as N_u or v
free flow speed	speed most drivers would choose on the arterial if they had green indications and were alone in their direction of movement
inference space	indicates the model limits; i.e. the variable ranges where the model is applicable
judgement-based prior	Bayesian “prior” derived through subjective or theoretical information
model-based prior	Bayesian “prior” derived from existing models or simulation programs
Posterior (model)	the Bayesian regression model, based on the prior information source and the experimental data
Prior (model)	regression model describing a state of information before any experimental data is collected; i.e. model based solely on the ‘a priori’ information
prior	term coined to represent the Bayesian regression parameters derived from the ‘a priori’ information source; “the prior” is used as input to perform Bayesian regression analysis
probability density function	pdf; normalized probability distribution of the regression coefficients; area under the curve is equal to one; x-axis represents the value of the coefficient while the spread of the curve indicates the standard deviation of the coefficient mean
residual variance	Se^2 , represents the dispersion in the data set

standard deviation	square root of the variance; in regression analysis, this term is often called the “standard error, Se ”, and refers to the total variability of the dependent variable observations
standard error	Se ; explained as the standard deviation of the variability in the y observations unexplained by the regression
equation	
stopped delay	the amount of time at an intersection when a vehicle is completely stopped
t-statistic	measure of the statistical significance of a regression coefficient based on the “student t-distribution”
total intersection approach delay	
	total of the “approach delays” at all intersections within the defined arterial
variance	fundamental measure of dispersion in a data set
variance/covariance matrix	describes the uncertainty (variances) and the intercorrelation (covariances) of the computed regression coefficients

CHAPTER 1

INTRODUCTION

1.1. Background / Problem Definition

Transportation engineers and planners are well acquainted with urban traffic congestion. This problem is not new to the public either. "Until only a few years ago, traffic congestion was almost the exclusive 'privilege' of the large metropolitan cities, but now has become a major concern in all areas of North America. In many of these areas, public opinion surveys indicate that traffic congestion has superseded crime, housing, and pollution as the number-one concern. The worsening traffic congestion problem brings with it diminished air quality, wasted fuel, and dampened economic growth" (ITE 1986). According to the U.S. Federal Highway Administration, congestion is expected to continue increasing at a significant rate not just in major urban centers but also in medium and small urban areas (Jacks 1989).

With predicted increases in future congestion in central business districts (CBD), there is now more than ever a genuine need for effective techniques for analyzing urban arterials and downtown street networks¹ in order to obtain estimates of travel times, speeds, and delays under various levels of traffic volumes. These techniques will provide the traffic engineer with a better understanding of the factors that influence the performance of the street and

¹ According to the 1994 Highway Capacity Manual (HCM 1994), "*urban and suburban arterials* are signalized streets that primarily serve through traffic; secondarily, they provide access to abutting properties". "*Downtown streets* are usually signalized facilities that often resemble arterials. They not only move through traffic but also provide access to local business for passenger cars, transit buses, and trucks. Turning movements at downtown intersections are often greater than 20 percent of total traffic because downtown flow involves a substantial amount of circulatory traffic. Typical of downtown streets are numerous pedestrian conflicts and lane obstructions caused by stopping or standing taxicabs, buses, trucks, and parking vehicles that cause turbulence in the traffic flow" (TRB 1994).

relate these to congestion, which is the first step towards finding solutions to the surface street congestion problem.

As noted by McShane and Roess, the key performance measures of roads relate to the consumption of time in travel (McShane and Roess 1990);

- How long the trip took (*travel time*)
- Where the delay occurred, and how long it existed (*delay*)
- What speed the vehicles were able to achieve (*speed*)

Travel time can be defined as, “the total time for a vehicle to complete a designated trip, over a section of road or from a specified origin to a specified destination”. Travel time values, and models used to predict travel times, have many uses including (McShane and Roess 1990):

- prediction of problem locations (i.e. congestion) on facilities, by virtue of high travel times and delay
- input into transportation planning models, microassignment models, and route-diversion models
- generation of contour maps and other depictions of traffic congestion in an area or region
- input to economic analysis of transportation alternatives
- evaluation of route improvements
- measurement of arterial level of service, as described in the 1994 Highway Capacity Manual

With the recent advent of Intelligent Transportation Systems (ITS)², there is a new usefulness for travel time models, as input into Advanced Traveller

² *Intelligent Transportation Systems (ITS), also called Intelligent Vehicle-Highway Systems (IVHS), refer to transportation systems that involve integrated applications of advanced surveillance, communications, display, computer, and control process technologies, as used both in the vehicle and on the highway. (Johnson et al. 1991)*

Information Systems (ATIS)³. It has been shown that the actual benefits realized from traveller information systems depend heavily on the quality of the traffic information provided to drivers (Bonsall and May 1989). In most existing traveller information systems and demonstration projects, the guidance passed to drivers is either based on current traffic information (Smart Corridor, Travtek, AMTICS, and RACS) or on simple predictions of future traffic conditions (LISB and AUTOGUIDE) (Kaysi et al. 1993). According to a study for the TravelGuide system developed by the Ministry of Transportation of Ontario, a key element of route guidance systems centres around the means to generate reliable real-time traffic information, and that this challenge is made more acute in systems where the vehicles are not able to act as probes to automatically provide the system operator with information on road travel times (Heti 1991). Additionally, there is the requirement to predict travel time for changing traffic conditions. As the preceding references indicate, there is currently a necessity in ATIS for accurate travel time models that can be updated continuously with real-time traffic data. The author believes that this need will exist at least until such a time when the increasingly sophisticated systems based on road beacons and vehicle probes are more proven.

1.2 Rationale for Developing New Urban Traffic Models

It has been stated that there is a need for effective techniques for analyzing and quantifying the traffic characteristics on surface street networks, especially in the nineties with the increasing occurrence of traffic congestion in urban areas. There are some existing tools for this purpose. Perhaps the most widely used model for interrupted flow conditions is the one presented in the 1994 Highway

³ *Advanced Traveller Information Systems (ATIS) can reduce traffic delays due to congestion by providing real-time information to drivers with respect to current traffic and road conditions and by suggesting alternative routes to their destinations. The source of the traffic information can be roadside beacons, video cameras, or on-board electronic devices, and transmitted to the driver via radio, computer terminals at home or work, changeable message signs, or onboard navigation systems.*

Capacity Manual (TRB 1994). The HCM 1994 concept involves estimating the arterial level-of-service based on the *average travel speed* for the segment, section, or entire arterial under consideration. With this method, the average arterial travel speed, ART SPD, is computed from;

$$\text{ART SPD} = \frac{3600 (\text{Length})}{(\text{running time per km})(\text{length}) + (\text{total of intersection approach delay})}$$

where:

- length = arterial or segment length (kilometers)
- running time per km = total time on the arterial or segment due to the environment and traffic (i.e. effects of the signals are removed)
- total intersection approach delay = total of the approach delay at all intersections within the defined arterial or section

The calculated speed is then looked up in Table 11-1 of the HCM 1994 to obtain the level-of-service for the arterial.

It has been stated that the value in the HCM 1994 procedure is not in the predictive equation but in the methodological approach and the level-of-service definitions. Hence, if specific values for *average travel speed* can be obtained from field data or from validated models, then the HCM framework can be used to determine the level of service of the arterial without reference to running-time and intersection-delay estimates (McShane and Roess 1990).

Two other traffic models noteworthy of mention include NETSIM (NETwork SIMulation) and TRANSYT (TRAffic Network StudY Tool). Both programs will simulate traffic operations on a street network and produce a wealth of measures of effectiveness (MOE), such as travel times, delay times, average speeds, queue lengths, and many other congestion-based measures. The fundamental difference between the two packages is the unit of simulation; TRANSYT

simulates platoons (groups) of vehicles (*macroscopic simulation*), whereas NETSIM simulates individual vehicles (*microscopic simulation*).

A fundamental problem with both programs is that they require a considerable amount of detailed inputs; for example, NETSIM requires information on the characteristics of each roadway link, the traffic control system, traffic demand and composition, and bus operations. Another difficulty involves the excessive computing time required to set up and execute a traffic simulation. Needless to say, in this day and age of financial constraints most practitioners do not have the time or resources to use such sophisticated traffic models as NETSIM and TRANSYT. Moreover, "traffic engineers now recognize that the applications, features, theory, terminology and many of the output measures of effectiveness (MOE) vary substantially between different simulation and optimization models" (Sabra and Stockfisch 1995).

From the preceding discussion, there definitely seems to be a need for the development of new models aimed at estimating the expected travel time on different types of downtown streets. These models should be simple, reliable, and be composed of a limited number of variables for which data are readily available in most transportation agencies such as *traffic flow*, *arterial length*, and *average signal spacing*. As discussed earlier in this Chapter, these travel time models will have many uses such as; the quantification of the traffic and environmental characteristics that contribute to congestion; input into planning studies; input into economic analyses of transportation alternatives; and as the algorithm component of Advanced Traveller Information Systems (ATIS).

1.3 Research Objectives and Framework

The main purpose of this thesis research is to *investigate the practicality of using a Bayesian regression methodology towards the development of travel time models for multi-link streets in a Central Business District (CBD)*.

The specific objectives of this thesis involve:

1. developing arterial traffic models for one-way and two-way downtown streets;
2. qualifying and quantifying the influence of various roadway, traffic and signalization characteristics on the duration of trips in a Central Business District (CBD);
3. developing a field data collection procedure using videotape technology, and assessing its viability;
4. evaluating the various capabilities of the TRAF-NETSIM software, and in particular its usefulness in providing input data for the development of regression models of traffic flow;

The overall research methodology that was followed to complete this thesis is depicted in Figure 1.1.

The first step of the research framework involved defining the problem and stating the purpose and objectives of the thesis. Next the general research approach was developed in the form of the research flowchart in Figure 1.1. Once a decision was made to apply a *Bayesian approach* to the development of travel time models, the third step involved defining the type and form of the model equations. At this point a decision needed to be made as to which types of streets to study. It was decided that since the purpose of the thesis is to illustrate the development of traffic models for improved prediction of time and delay, based on the Bayesian regression technique, models for every type and configuration of street in a CBD were not necessary. Rather, four common street types prevalent in most medium to large-size city centres were selected from a survey of the Ottawa CBD, and modelled during peak traffic periods. They include;

1. *Two-way Street with two lanes in one direction, parking permitted*
2. *Two-way Street with one lane in one direction, parking prohibited*
3. *One-way Street with three lanes, parking prohibited*
4. *One-way Street with three mixed traffic lanes and one transit bus lane, parking prohibited*

FIGURE 1.1: Research Framework Flowchart

A literature review was then conducted to identify the contributory variables believed to have the greatest influence on travel time, for inclusion in the predictive equations. The mathematical form of the equations (i.e. the relationship between travel time and each of the independent variables) was also determined based on the literature.

The fourth task in the research framework involved evaluating the methods for performing the Bayesian regression analysis. The XLBAYES computer program was identified as the most suitable tool for this purpose. The next major task dealt with assembling the input data for Bayesian regression. The first source of information was obtained by videorecording the traffic flows during peak periods in the Ottawa CBD, on the four street types under study. The data from the video cassettes were then extracted into spreadsheet form. Secondly, the output from the TRAF-NETSIM traffic simulation program was used as the source of 'A Priori' information. This was accomplished by simulating actual traffic conditions in the Ottawa CBD and processing the NETSIM output (Measures of Effectiveness, MOE) into prior modelling variables.

The final step in the research involved performing the Bayesian regression analysis and evaluating the quality of the resultant models (i.e. goodness of fit). Based on results of the models for the four street configurations under study, a decision was made whether to modify any aspect of the equation (i.e. re-iterate) in order to improve its predictive capability.

The research, data collection, traffic simulations, modelling, and report writing in the context of this thesis were conducted from January 1995 to July 1996. The field data used in the development of travel time models were obtained by videotaping various streets in the Ottawa downtown core for a total of 45 peak period hours during the month of June 1995. The NETSIM traffic simulations were conducted in the summer and fall of 1995. The Bayesian regression

analyses (multiple iterations) were performed from March to July of 1996. The writing of the thesis report took place throughout the January 1995 to July 1996 timeframe with the bulk of it completed from May to July 1996.

1.5 Thesis Outline

This thesis report is divided according to 7 chapters and four appendices.

Chapter 1 provides an introduction to the thesis research including a statement of the problem, the thesis objectives, and the research framework. **Chapter 2** introduces the reader to Bayesian analysis methods with particular emphasis on Bayesian regression and the XLBAYES computer program. **Chapter 3** contains an overview of the process that was followed to develop travel time models using a Bayesian solution.

In Chapters 4 and 5, the two disparate sources of input for Bayesian regression analysis are presented. **Chapter 4** describes a method in which the Bayesian 'a priori' information related to the modelling system is provided via the NETSIM traffic simulation program. Specifically, a three-stage process for using NETSIM is explained, including retrieval and input of actual Ottawa traffic characteristics, execution of the program, and the conversion of the output MOE into the Bayesian prior parameters. In **Chapter 5**, a cost-effective procedure is explained for obtaining field observations using video technology, and for extracting the desired data from the videocassette.

Chapter 6 leads the reader through the steps to prepare input data for XLBAYES, and provides a detailed discussion of the modelling results for the four common urban street configurations. Multiple iterations for each of the four models are described including a statistical evaluation of the model results and an overall interpretation from a Bayesian perspective.

Chapter 7 provides the author's conclusions from the research as well as recommendations for future research work. In order to position the Bayesian regression technique in proper perspective, **Appendix A** contains a short discussion on Bayes' Theorem as the foundation for all Bayesian statistical analysis methods. In **Appendix B**, the derivation of the Bayesian regression equations used within the XLBAYES computer program is given. **Appendix C** contains the field data tables assembled from video observations of the Ottawa CBD, while **Appendix D** contains the statistical output from the Bayesian regression program.

CHAPTER 2

BAYESIAN REGRESSION MODELLING

2.1 Overview and Practicality of a Bayesian Solution to the Problem

Bayesian statistical analysis includes all approaches which rely on a statistical inference based on *Bayes' theorem*.⁴

In general terms, Bayesian analysis provides a mechanism for incorporating *new information* in the form of empirical observations with *prior information* about random variables. The link between the prior information (in the form of a prior probability distribution) and the empirical data is provided by *likelihoods* which are also probabilities. The result is a *posterior* distribution that reflects both the empirical data and the prior information. This posterior distribution is simply a conditional probability distribution, where the conditioning is provided by the empirical data. It can be calculated by way of Bayes' Theorem (Zellner 1971) which is summarized in Appendix A.

To conceptually illustrate the Bayesian methodology, we can examine Figure 2.1.

⁴ Thomas Bayes was a Presbyterian minister and mathematician who lived in England in the 1700s (born circa 1702 and died April 17, 1761). Bayes' theorem is attributed to Bayes' manuscript ("An Essay Towards Solving a Problem in the Doctrine of Chances" - Bayes 1763) on inverse probability in which he proposed a method for making probability inferences about the parameters of a binomial distribution conditional on some observations from that distribution. The theorem has since been generalized to be applicable beyond the binomial distribution, to any sampling distribution (Press 1989, pp. 15-16)

Combine prior knowledge and experience with data.

FIGURE 2.1: Conceptual Illustration of Bayesian Statistical Analysis
 (Source: C-SHRP, *Training Sessions in Bayesian Methods and Software*,
 Transportation Association of Canada, 1994)

As illustrated in Figure 2.1, both subjective and objective information are utilized to reduce the uncertainty in the model coefficients to be derived.

A Bayesian statistical approach has been extensively employed, in one form or another, in various disciplines;

- economics & production (Klinge-Loy 1985; Cyert et al. 1986; Boyer et al. 1984)
- medicine (Sims 1991; Levitt et al. 1993; Vegas et al. 1991)
- image analysis (Hanson 1993; Qian et al. 1993)
- investing (Jammernegg 1988; Dongcheol 1989)
- technological system testing (Ida et al. 1993; Chang et al. 1993)
- human behavior (Anderson 1988; Endahl 1983)
- water quality analysis (Walley et al. 1992)
- transportation planning (Gregurich 1993; Johnson 1969; Khan 1969, 1971; Manheim 1966) and pavement engineering (Hutchinson 1965; Smith et al. 1979; C-SHRP 1994)

As noted, Bayesian statistical decision theory has been employed in different **transportation engineering and planning applications**. Gregurich relied on a Bayesian approach to estimate the regression coefficients of a multinomial logit model (Gregurich 1993); Johnson used Bayesian decision theory to evaluate the cost-benefits of collecting additional information (Johnson 1969); Bayesian decision theory was also utilized by Khan in a regional transport system plan selection problem and in the economic evaluation of transportation alternatives (Khan 1969, 1971); and Manheim applied statistical decision theory in the context of planning and design (Manheim 1966). In discussing the topic of uncertainty in transportation systems analysis, Manheim suggests that “ transportation systems should provide a mechanism to account for new information and changes in previous assumptions or estimates” (Manheim 1979). The preceding statement is basically the essence of the Bayesian statistical decision process whereby *experimental data are used to update the state of information known prior to the experiment*.

Bayesian methods are especially useful in the following two situations;

- 1) there is a limited amount of data, i.e: small sample size (**thin database**) and/or;
- 2) only near term data in the life of the system to be modelled are available (**premature database**).

For example, in the case of the **thin database**, let us assume that we are trying to estimate the proportion of defectives (dependent variable) generated by a production process but that only a few observations are available and collecting more data is too costly. This situation is typical of most modelling projects as it is becoming increasingly difficult to justify the expenditures on large-scale data collection activities. In this example, suppose that certain technicians have previous experience with similar processes. The technicians' experience is a valuable source of information which can be combined with the experimental

observations available using a Bayesian approach to yield a posterior distribution for the dependent variable.

In the situation of the **premature database**, let's suppose that a new type of structure was built five years ago and we need to predict its performance twenty years into the future in order to budget for ongoing maintenance and rehabilitation. In this scenario, the difficulty is with forecasting future performance with only the initial 5 years of performance data available. Using a classical regression analysis, there is no way of knowing how the predicted curve should plot beyond 5 years. However, experienced structural engineers could realistically supplement the field observations to cover the period where data are not yet available.

This research project, aimed at modeling traffic flow in an urban CBD, presented a "thin database" problem. Most traffic data collection is done manually, either because the scale of the study does not warrant the installation of automated detection devices, or because the information sought cannot be easily observed in any other way (McShane and Roess 1990, p.72). This thesis research involved collection of various field data using videotape technology, including intersection turning volumes, stopped vehicle counts, bus and truck counts, to support the model building exercise. However it was believed that the field observations would be insufficient to model the complex relationships of vehicular motion on signalized central area roadways. Hence at the outset of the project, it was decided to employ a Bayesian modeling approach to improve the predictive power of the models.

2.2 Bayesian Regression

In its simplest sense, Bayesian regression is a specialized adaptation of *Bayes' Theorem* involving the development of multivariate regression models which explicitly consider two disparate sources of information;

- **A Priori Information** - information that is known prior to an experiment
- **Experimental Data** - information that is derived from the experiment

In the latter half of this century, different mathematicians (Press 1989; Pilz 1991; Raiffa and Schlaiffer 1961; Zellner 1971) have applied Bayes' Theorem to regression analysis. As shown by Zellner (Zellner 1971) and later by C-SHRP (C-SHRP 1996), the manner in which the two separate sources of information are balanced and combined using Bayes' Theorem is explained by way of the matrix expressions outlined in this Section. For each equation defined, a corresponding Microsoft Excel formula (made up of Excel functions) is included as a footnote to enable the reader to reproduce the Bayesian regression within a regular spreadsheet.

posterior regression coefficients, b_{post}

The Bayesian posterior regression coefficients are calculated using a weighted average of the prior regression coefficients (b_{prior}) and the regression coefficients from the data (b_{data});

$$b_{\text{post}} = \frac{(A_{\text{prior}}) b_{\text{prior}} + (A_{\text{data}}) b_{\text{data}}}{A_{\text{prior}} + A_{\text{data}}} \quad (\text{Eqn. 2.1}^5)$$

where;

b_{prior}	=	vector of coefficient means derived from the prior information (explained in Section 2.2.1)
b_{data}	=	vector of coefficients derived from the experimental data using classical regression analysis (see below)
A_{prior}	=	prior precision matrix (see below)
A_{data}	=	precision matrix from the data (see below)
M_{post}	=	posterior precision matrix = $A_{\text{prior}} + A_{\text{data}}$

⁵ Excel formula equivalent to equation 2.1 is:

$b_{\text{post}} = \text{mmult}(\text{minverse}(M_{\text{post}}), \text{mmult}(A_{\text{prior}}, b_{\text{prior}}) + \text{mmult}(A_{\text{data}}, b_{\text{data}}))$

vector of data coefficients, b_{data}

The data coefficients are calculated in the same way as with classical regression by evaluating the following matrix formula:

$$b_{data} = (X_{data}^t X_{data})^{-1} X_{data}^t Y_{data} \quad (\text{Eqn. 2.2}^6)$$

where; X_{data} = matrix of independent variable observations
 X_{data}^t = transpose of the matrix of independent variable observations
 Y_{data} = vector of dependent variable observations

precision matrix for the data, A_{data}

This precision matrix provides the weight (or influence) of the vector of data coefficients in the calculation of the posterior coefficients.

$$A_{data} = (X_{data}^t X_{data}) \quad (\text{Eqn. 2.3}^7)$$

where X_{data} and X_{data}^t were defined in Equation 2.2.

prior precision matrix, A_{prior}

The prior precision matrix is where the weighting of the prior information takes place. It can be calculated using two methods depending on the type of prior information used, an N-Prior or a G-Prior (see Section 2.2.1).

⁶ Excel formula equivalent to equation 2.2 is:

$b_{data} = \text{mmult}(\text{mmult}(\text{minverse}(A_{data}), \text{transpose}(X_{data})), Y_{data})$

⁷ Excel formula equivalent to equation 2.3 is:

$A_{data} = \text{mmult}(\text{transpose}(X_{data}), X_{data})$

N-Prior: (typically used with subjective prior information)

$$A_{\text{prior}} = \left[\frac{\text{Var/Covar}_{\text{prior}} * (v_{\text{prior}} - 2)}{v_{\text{prior}} (Se_{\text{prior}})^2} \right]^{-1} \quad (\text{Eqn. 2.4a}^8)$$

where; $\text{Var/Covar}_{\text{prior}}$ = variance/covariance matrix of the prior information

$$= \begin{bmatrix} S_{b1}^2 & \text{Cov}(b_1, b_2) & \dots & \text{Cov}(b_1, b_k) \\ \text{Cov}(b_2, b_1) & S_{b2}^2 & \dots & \text{Cov}(b_2, b_k) \\ \vdots & \vdots & \ddots & \vdots \\ \text{Cov}(b_k, b_1) & \dots & \dots & S_{bk}^2 \end{bmatrix}$$

The diagonal terms of Var/Covar contain estimates of the variance of each prior regression coefficient; off-diagonal elements are estimates of the covariance between pairs of regression coefficients. The Var/Covar matrix must be derived from the 'a priori' information

G-Prior (typically used with non-subjective prior information, as is the case in this thesis):

$$A_{\text{prior}} = g (X_{\text{prior}}^t X_{\text{prior}}) \quad (\text{Eqn. 2.4b}^9)$$

where; g = g-prior factor is a positive real number specified by the user to increase or decrease the influence of the prior in the calculation of the posterior; a typical value for g is 1 which gives equal weight to both the prior information and the data; a g -value above 1 means that the prior information will have more influence on the posterior results than the data, and vice versa

X_{prior} = independent variable data set derived from the prior information source (in this thesis, it is the output from the NETSIM traffic simulation)

⁸ Excel formula equivalent to equation 2.4a is:

$$A_{\text{prior}} = \text{minverse}(\text{var/covar}_{\text{prior}} * (v_{\text{prior}} - 2) / (v_{\text{prior}} * Se_{\text{prior}}^2))$$

⁹ Excel formula equivalent to equation 2.4b is:

$$A_{\text{prior}} = \text{mmult}(\text{transpose}(X_{\text{prior}}), X_{\text{prior}}) * g$$

posterior standard error, S_{post}

The standard error of the Bayesian posterior model is calculated as follows;

$$S_{\text{post}}^2 = \frac{V_{\text{data}} S_{\text{data}}^2 + V_{\text{prior}} S_{\text{prior}}^2 + (b_{\text{prior}} - b_{\text{post}})' A_{\text{prior}} (b_{\text{prior}} - b_{\text{post}}) + (b_{\text{data}} - b_{\text{post}})' A_{\text{data}} (b_{\text{data}} - b_{\text{post}})}{V_{\text{post}}} \quad (\text{Eqn. 2.5}^{10})$$

where;

$$S_{\text{data}}^2 = \begin{aligned} &\text{standard error of the data model (analogous to classical} \\ &\text{regression)} \\ &= \frac{(Y_{\text{data}} - X_{\text{data}} * b_{\text{data}})' (Y_{\text{data}} - X_{\text{data}} * b_{\text{data}})}{V_{\text{data}}} \end{aligned} \quad (\text{Eqn. 2.6})$$

$$\begin{aligned} S_{\text{prior}}^2 &= \text{standard error of the prior model (must be derived from} \\ &\text{the prior information - see Section 2.2.1)} \\ V_{\text{data}} &= \text{degrees of freedom of the data (equals the number of} \\ &\text{observations minus the number of terms in the functional} \\ &\text{form plus one if a constant is used)} \\ V_{\text{prior}} &= \text{degrees of freedom of the prior information (must be} \\ &\text{derived from the prior information -see Section 2.2.1)} \end{aligned}$$

posterior degrees of freedom

The degrees of freedom of the Bayesian posterior model are calculated by adding the degrees of freedom of both the data and the prior, and adding the number of terms in the equation.

$$V_{\text{post}} = V_{\text{prior}} + V_{\text{data}} - k \quad (\text{Eqn. 2.7})$$

A condensed version of the derivation of the Bayesian regression equations is provided in Appendix B. It is important to note that the assumptions and limitations of classical regression analysis also apply to Bayesian regression.

¹⁰ *Excel formula equivalent to equation 2.5 is:*

$$V_{\text{post}} S_{\text{post}}^2 = V_{\text{data}} * S_{\text{data}}^2 + V_{\text{prior}} * S_{\text{prior}}^2 + \text{mmult}(\text{mmult}(\text{transpose}(b_{\text{prior}} - b_{\text{post}}), A_{\text{prior}}), (b_{\text{prior}} - b_{\text{post}})) + (\text{mmult}(\text{mmult}(\text{transpose}(b_{\text{data}} - b_{\text{post}}), A_{\text{data}}), (b_{\text{data}} - b_{\text{post}})))$$

2.2.1 Bayesian Regression Inputs

As noted in the preceding Section, Bayesian regression is a technique which applies Bayes' Theorem towards regression analysis using two input sources: 1) 'a priori' information, and 2) experimental data.

1) 'A Priori' Information

'A priori' information can be simply defined as " anything that is known before an experiment, an event, or a measurement, above and beyond the data" (Canadian Strategic Highway Research Program, 1994). For example, the speed of light is $300,000 \text{ km/sec} \pm 8,050 \text{ km/sec}$, price elasticity of supply is positive, and travel speed decreases with increasing vehicular density.

The prior information may be contained in samples of past data (data-based prior), existing models or simulation programs (model-based prior), or it may be obtained through subjective or theoretical considerations (judgment-based prior). According to the matrix formulas outlined in Section 2.2, the statistics that describe the prior information are:

- *prior regression coefficients vector* (b_{prior})
- *prior precision matrix* (A_{prior})
 - *variance/covariance matrix of prior coefficients* ($\text{var/cov}_{\text{prior}}$)
 - *degrees of freedom in the prior information source* (v_{prior})
 - *variance of the residuals, based on the prior model* (Se^2_{prior})

The preceding parameters have been coined " the prior" , and must be obtained from the " a priori" information source, be it expert judgement, an old database, or an existing model. In a research project for the Transportation Association of Canada, Nesbitt et al operationalized six different methods of deriving " the prior" from various prior information sources (Nesbitt 1994). One subjective method involves structuring a series of systematic questions that represent real world situations. An example of one question is as follows;

- For a pavement with the following attributes
 - current age: 7 years
 - pavement thickness: 150mm
 - average traffic loading: 300,000 Equivalent Standard Axle Loads per year (ESAL/yr)
 - environment type: wet/freeze
- What will be the service life of the pavement ?

Each question should represent a different real world situation and the questions must span the full range of possible situations. In this example, all questions would be asked to various experts and their answers would provide for a database of a priori information, from which the prior parameters can be derived. This method is called the “Market Questionnaire” method since it has been successfully used in designing new products and predicting their performance in the market. “When designing the market questionnaire method, it is important that the questions collectively contain the full range of variability; i.e. the questions must not be co-linear” (Nesbitt 1994).

Another method known as a “Data-Derived Prior” makes use of an old database as a source of prior information (Nesbitt 1994). An example of such a database may involve a data collection exercise conducted 5 years ago with less stringent quality control. Consequently it would be inappropriate to combine this old database to newer ones as the errors inherent in these databases would be different. For this case, classical regression can be performed on the old database to produce the necessary “prior” parameters.

In this research thesis, a “model-based prior” will be employed in the form of the TRAF-NETSIM traffic simulation program. In essence, classical regression will be performed on selected outputs of NETSIM to produce the following “prior” parameters: b_{prior} , V_{prior} , Se^2_{prior} . Using the G-Prior option (refer to Section 2.2), the X_{prior} data set (NETSIM output) and a g-value are first specified to obtain the

$\text{var/cov}_{\text{prior}}$. Whatever the source of the 'A Priori' information, Bayesian Regression provides a mathematically sound technique of combining the prior information with the experimental data.

2) Experimental Data

The definition of the experimental data in Bayesian regression is exactly the same as that used in classical regression. To perform the Bayesian regression according to the Section 2.2 formulas, the actual observations for the dependent (y) and independent (x_i) variables need to be specified.

An overview of the inputs required to perform a Bayesian regression analysis is illustrated in Figure 2.2.

FIGURE 2.2: Schematic Illustration of Bayesian Regression Inputs

The computed posterior regression coefficients obtained after performing the Bayesian regression will usually lie between the data and prior distributions with the uncertainty of the predictions balanced between the two extremes (data & prior), as illustrated in Figure 2.3.

FIGURE 2.3: Typical Bayesian Regression Model Distributions

(Source: C-SHRP, Transportation Association of Canada, *Training Sessions in Bayesian Methods and Software*, 1994)

In the preceding Figure, the "classical regression solution" is based solely on the sample data whereas the "Bayesian solution" reflects a combination of both the data and the prior estimates. The x-axis value represents the value of the model coefficient while the spread of the curve indicates the standard deviation (i.e. uncertainty) in the information source.

2.3 Bayesian Analysis Research Framework

A typical research approach to the Bayesian methodology is presented in simplified form in Figure 2.4 (Smith et al. 1979).

FIGURE 2.4: Typical Bayesian Analysis Research Methodology

(Source: Smith et al., NCHRP Report 213, TRB, 1979)

Figure 2.4 illustrates a Bayesian modelling approach used to develop flexible pavement distress models as part of the National Cooperative Highway Research Program (Smith et al. 1979). In this project, the past experience of highway engineers was extracted into statistical format and then combined to field performance data using Bayes' Theorem.

The general methodology followed to conduct Bayesian regression in this thesis is summarized in Figure 2.5. This Figure is similar to Figure 2.4 except for the source of 'a priori' information (computer simulation of the system instead of expert judgement) and the intended uses of the modelling results. In the project

depicted in Figure 2.4, the Bayesian regression results were used to design field data acquisition systems based on the variables shown to be statistically significant with respect to the dependent variable. The results may also influence the future opinion or beliefs of the engineers involved in providing their expert judgement for the project. As stated in Chapter 1, the models developed as part of this thesis can be used to provide travel time estimates for use in various transportation applications such as ATIS, level-of-service determination, planning, and the economic analysis of transportation alternatives.

FIGURE 2.5: Bayesian Regression Analysis Framework - Thesis

2.4 XLBAYES Computer Program

The tool used to perform the Bayesian regression analysis using the concepts and equations explained in Appendix B is a software program called XLBAYES, Version 1.11 (Linear Addition) (Vemax Management Inc. 1994). This computer program, which works interactively within Microsoft EXCEL, Version 5.0, was developed under the Canadian Strategic Highway Research Program (C-SHRP)¹¹ as part of a pavement performance modeling project.

Early in its mandate, C-SHRP recognized the advantages of using a Bayesian modeling approach to support the development of preliminary performance models when not much data was available (i.e. “premature” database problem). However, although Bayesian regression theory existed in the published literature (Press 1989; Pilz 1991; Raiffa and Schlaiffer 1961; Zellner 1971), a straightforward computer program to manipulate the complex statistical equations was lacking. A literature review resulted in the discovery of one existing program called, “The Bayesian Regression Analysis Package (BRAP)”, version 2.0. (Zellner et al., University of Chicago 1987).

BRAP provides a unified software for Bayesian analysis of the multiple regression model. The BRAP User’s Manual provides among other things, a summary of the basic formulae used in BRAP routines and step-by-step instructions for using BRAP commands (Zellner et al., University of Chicago 1987). A major problem with the BRAP program is its lack of user-friendliness. The user must learn a series of BRAP-specific commands (to be used within a text editor for the preparation of input data files), and have a working knowledge of FORTRAN.

¹¹ C-SHRP is a special research division of the Transportation Association of Canada which is located in Ottawa, Canada.

For these reasons, C-SHRP decided that a more practical Bayesian regression program was needed to satisfy its sponsors. The BSTAT program was thus developed in 1992, employing the BRAP code (with permission from the University of Chicago) and a user-friendly interface (Microsoft EXCEL). The current edition of BSTAT is version 2.1 which was finalized in August 1994 (Vemax Management Inc. and Decision Focus Inc. 1994). A difficulty encountered with BSTAT is its slow processing time because it performs all calculations outside of EXCEL using BRAP's FORTRAN code (first converting all input data from EXCEL's spreadsheet format to a text format) and then converts and copies the statistical results back into EXCEL.

The XLBAYES program was subsequently produced to optimize and accelerate the *linear* regression feature of BSTAT. XLBAYES works as an add-in module to Microsoft EXCEL, version 5.0 (Vemax Management Inc. 1994). As such anyone familiar with EXCEL should have little difficulty using XLBAYES. The Bayesian regression concepts and equations used within BRAP and BSTAT (and outlined in Section 2.2) are incorporated into XLBAYES using the *Microsoft Visual Basic computer programming language*. The use of Visual Basic provides for the development of sophisticated programs within a Windows-based environment.

XLBAYES has the capability of performing a Bayesian regression or a classical regression analysis. The program works via a system of pull-down menus, and prompts the user to define the spreadsheet ranges containing the appropriate data sources; 1) the a priori information, and 2) the experimental data. Once the input information are selected, the user clicks on the "Analyze" button and the program automatically performs the Bayesian regression analysis and exports all statistical analysis results to a new file. Separate statistical modeling results for the experimental data, the prior information, and for the combination thereof (i.e. Bayesian posterior), are produced including;

- **regression coefficients and associated statistics**; t-statistic, p-value, standard deviation
- **variance/covariance matrices**; diagonal terms indicate the variances between regression coefficients while the other terms indicate the covariances between coefficients
- **correlation matrices**; indicates the degree of correlation between each independent variable (from -1 to 1; 0= no correlation)
- **precision matrices**; where the weighing of the prior versus the data is made with respect to the calculation of the posterior model coefficients
- **degrees of freedom**; defines the number of knowns minus the number of constraints
- **residual variance**; represents the dispersion in the data set (i.e. standard error of the model, Se, squared)

Normal probability distribution curves are also generated for each model coefficient. A comprehensive discussion and evaluation of the Bayesian regression output, based on the travel time models for the four street types under study, is included in Chapter 6.

CHAPTER 3

DEVELOPMENT OF TRAVEL TIME MODELS

3.1 Definition and Functional Form of Models

As mentioned in Section 1.3, the goal of this project involves investigating the practicality of using a Bayesian regression technique to develop arterial traffic models for downtown streets. Four downtown street configurations were selected as being representative of streets often found in typical medium to large-size central business districts. They are:

1. Two-way street, two lanes in one direction, parking permitted at all times;
2. Two-way street, one lane in one direction, parking prohibited at all times;
3. One-way street, three lanes, parking prohibited during peak periods;
4. One-way street, three mixed traffic lanes, one dedicated bus lane, parking prohibited during peak periods.

The principal objective of this thesis is to develop models capable of predicting, with a reasonable degree of accuracy, *the expected time for a driver to traverse a given length of the arterial during peak traffic flow periods*. This is then the *dependent* variable for the four models.

SELECTION OF INDEPENDENT VARIABLES

The 1994 HCM (TRB 1994) methodology for analyzing arterials is based on the *average through-vehicle travel speed* for the arterial under consideration. The equation given below was introduced in Chapter 1;

$$\text{ART SPD} = \frac{3600 \times \text{Length}}{(\text{running time per km}) \times (\text{length}) + (\text{total intersection approach delay})} \quad (\text{Eqn 3.1})$$

where;	ART SPD =	arterial or segment average travel speed (kph); i.e. the actual speed with the additional effects of signals and all other stops added
	Length =	arterial or segment length (km)
	Running Time=	total of running time per km on all segments (i.e. from one signal to the next signal) in the arterial
	Intersection Total Delay =	summation of total delays for through movements at all signalized intersections within the defined arterial; <i>total delay</i> can be assumed to be 1.3 times the <i>stopped delay</i> (McShane and Roess 1990)

As shown in Equation 3.1, the average travel speed over the arterial is strongly influenced by the delay occurring at signalized intersections. In actual fact, the arterial signal spacing is probably the most significant variable affecting the average speed and travel time. It has been shown that “even *great* intersection performance may not be good enough to obtain *good* arterial performance if there are too many signals per mile.” (McShane and Roess 1990). Hence, it is clear that a variable that accounts for signal spacing is a prerequisite to any arterial traffic model.

According to HCM 1994, the operation of vehicles on arterial streets is influenced by three main factors:

1. the arterial environment,
2. the interaction among vehicles, and
3. the effect of traffic signals.

The *arterial environment* affects a driver's notion of safe speed. The environment restricts a driver's desired speed, that is, the maximum speed at which a driver would like to travel under an ideal set of environmental conditions. The *interaction among vehicles* restricts vehicle speeds due to the friction between

vehicles in the traffic stream as caused by the differences in desired speeds or vehicles that are stopped downstream. *Traffic signals* force vehicles to stop and remain stopped for a period of time. The delays and speed changes caused by traffic signal operation significantly reduce the quality of traffic flow on arterial streets.

From a review of the published literature related to traffic flow on urban arterials, the following list of factors are believed to influence arterial travel times. These influential factors were assessed for possible inclusion in the predictive equations, in one form or another.

INFLUENTIAL FACTORS	EXPLANATION
1. Arterial Environment Number of lanes and width	<ul style="list-style-type: none"> • an increase in the number of lanes allow more vehicles to go from point A to point B • the width of the lanes will affect the driver's notion of safe speed
Pedestrian conflict	<ul style="list-style-type: none"> • pedestrians are a source of conflict as they significantly affect right and left turning vehicles that must cross the pedestrian flow
Driveway Access points	<ul style="list-style-type: none"> • access locations to small side streets, commercial developments, and houses provide for "sources" and "sinks" in the traffic stream; the manoeuvres to and from these driveways conflict with the through traffic
Loading Zones	<ul style="list-style-type: none"> • trucks loading or unloading near moving traffic lanes can interfere and even block traffic
Bus stops	<ul style="list-style-type: none"> • bus stop blockage occurs at "unprotected" bus stops while buses serve passengers (if the bus stop is "protected", the number of buses that can be stored in the bus bay must be known)
Parking manoeuvres	<ul style="list-style-type: none"> • parking adjacent to traffic streams interferes with adjacent passing-by traffic
Geometry of turning pockets	<ul style="list-style-type: none"> • related to the number of vehicles that can be stored in the turning pockets, away from moving lanes
Speed limit	<ul style="list-style-type: none"> • the posted speed limit on urban arterials has a direct impact on actual travel speed and travel time
Mid-block pedestrian crosswalks	<ul style="list-style-type: none"> • existence of pedestrian crosswalks at which vehicles must regularly stop
Grade of roadway	<ul style="list-style-type: none"> • the traffic flow pattern will be different whether the

	arterial is on level terrain, on an upgrade or on a downgrade (particularly with respect to heavy vehicles)
Pavement condition	<ul style="list-style-type: none"> • whether the pavement is rough or smooth, wet or dry, icy or dry; affects a driver's conception of safe speed
Visibility	<ul style="list-style-type: none"> • drivers tend to decrease their speed after daylight hours, and also when visibility is poor due to conditions such as rain and fog
Weather conditions	<ul style="list-style-type: none"> • current weather conditions (e.g. rain, snow, strong winds) will also affect the driver's notion of safe speed
2. Interaction Among Vehicles	
Average travel speed	<ul style="list-style-type: none"> • the average speed of all vehicles over the arterial, considering the effect of the environment, traffic, signals, and all other stops; the average travel speed is really another way of presenting travel time, and could then be the dependent variable
Running Time	<ul style="list-style-type: none"> • total travel time between the stops at intersections
Traffic density	<ul style="list-style-type: none"> • as the traffic density increases, all vehicles must slow down as a result of friction between vehicles
Traffic flow	<ul style="list-style-type: none"> • traffic flow is defined as the volume of vehicles passing a given point over time
Turning movements	<ul style="list-style-type: none"> • vehicles turning left or right at an intersection will influence the speed of upstream traffic, particularly when turning pockets are not present; turning movements also have a significant impact on vehicles travelling in the opposite direction
Proportion of heavy vehicles	<ul style="list-style-type: none"> • heavy vehicles consume more space and are generally slower than passenger cars especially on slopes
Local transit buses	<ul style="list-style-type: none"> • transit buses consume more space than automobiles and often block traffic when serving passengers
3. Traffic Signals	
Average stopped delay per vehicle	<ul style="list-style-type: none"> • duration of the average stop per vehicle is a measure of the effect of traffic signals on the quality of traffic flow; it depends mainly on the proportion of red time, traffic volume, and the quality of traffic progression
Intersection Total Delay	<ul style="list-style-type: none"> • summation of total delays for through movements on all signalized intersections
Percentage of stopped vehicles	<ul style="list-style-type: none"> • percent of vehicles stopped at least once on each segment; provides an indirect measure of "stopped delay"
Number of traffic signals per kilometre	<ul style="list-style-type: none"> • spacing between signalized intersections has a significant influence on the arterial performance, in relation to the number of stops at red lights
Green ratio (g/C)	<ul style="list-style-type: none"> • green time over the cycle length; influences the time for vehicles to discharge through the intersection
Traffic signal progression	<ul style="list-style-type: none"> • indicates the proportion of vehicles arriving on the green

The following criteria were used in deciding on the contributory variables to include in the predictive models:

1. variables most often found in the literature (indicates variables believed to have the greatest influence on traffic delay or travel time);
2. variables must be simple, predictable and intuitive to the prospective user of the models, and;
3. variables should be relatively common so that data are either readily available or easily obtained.

Based on these criteria, seven contributory factors were selected as prime candidates for inclusion in the *first iteration* of the travel time models;

1. Average flow of “through” moving vehicles;
2. Average flow of “left” turning vehicles;
3. Average flow of “right” turning vehicles;
4. Number of signalized intersections per kilometre;
5. Percentage of “stopped” vehicles on each link;
6. Proportion of heavy vehicles;
7. Flow of transit buses;

The detailed definition for the preceding variables is provided later in this Section.

Under an idealistic scenario, many other previously described variables would have been included in the equation to help predict travel time. However due to the statistical limitations of regression analysis to discern small variable effects given a moderate sample size, seven independent variables are considered to be reasonable. An assumption made is that *the “Percentage of Stopped Vehicles” variable will, by its very nature, take into account many of the factors that force vehicles to come to a complete stop* such as traffic signals, conflict with pedestrians, traffic opposing turn movements, bus stop blockage, truck

loading, parking manoeuvres, overflow of vehicles from turning pockets, and others.

Although “traffic density” is a proven indicator of delay and travel time, volume or “traffic flow” was selected for the models in this thesis because it is believed that traffic flow is generally a more intuitive variable to traffic engineers. Furthermore, data on traffic flow are usually more readily available.

It is important for the reader to note that the final selection of the independent variables is based on the goodness of fit of the models, and is described in Chapter 6. The valid ranges (inference space) for the preceding seven independent variables and the applicability of the models themselves are discussed in Section 3.1.1.

SELECTION OF MODEL FUNCTIONAL FORM

The next step in defining the predictive models involved determining the most appropriate relationship between each of the preceding independent variables and the dependent variable, and also the relationship amongst the independent variables themselves; in other words, establishing the *functional form* of the predictive equations. Helali and Khan developed predictive models for “delay” in which a curvi-linear equation¹² was derived from classical regression on NETSIM-generated data and later substantiated with field data. These equations were of the following form (Helali and Khan 1993):

$$\text{DELAY} = a + b(\text{OCCUP}) + c(\text{STOP} \times \text{SIGPKM}) + d(\text{NLAN}) + e(\text{LT}) + f(\text{HV})^2 + g(\text{NBUS})^2$$

(Eqn. 3.2)

¹² Linear models are such that the partial derivative of each independent variable (or term) does not contain any other independent variable; therefore the solution to the regression equation is deterministic. Within the general class of linear models, equations can be characterized as “simple additive” or “curvi-linear”. Curvi-linear refers to models that contain at least one transform and results in the dependent variable (y) not being a straight line relation with every independent variable (x’s).

where;	DELAY:	total delay in vehicle-minutes;
	OCCUP:	average number of vehicles at an instant in time;
	STOP:	percent of vehicles stopped at least once on each link;
	SIGPKM:	average number of signals per kilometre;
	NLAN:	number of moving lanes;
	LT:	percent of left turns averaged for the street;
	HV:	percent of heavy vehicles;
	NBUS:	number of buses per hour.

Subsequent work by Choudhry and Khan (unpublished paper) resulted in similar equations for traffic delay;

$$\text{DELAY} = a + b(\text{DENS}_{\text{thr}})^3 + c(\text{STOP} \times \text{SIGPKM})^3 + d(\text{DENS}_{\text{rt}})^2 + e(\text{DENS}_{\text{autoht}})^2 + f(\text{DENS}_{\text{hv}} + \text{DENS}_{\text{bus}})^2 \quad (\text{Eqn. 3.3})$$

where;	DELAY:	average stopped delay in seconds/vehicle;
	DENS _{thr} :	average density of "through moving" automobiles per km per lane at a given time during peak traffic hour;
	STOP:	percent of vehicles stopped at least once on each link;
	SIGPKM:	average number of signals per kilometre;
	DENS _{rt} :	average density of "right turning" automobiles per km per right lane at a given time during peak traffic hour;
	DENS _{lt} :	average density of "left turning" automobiles per km per left lane at a given time during peak traffic hour;
	DENS _{hv} :	heavy vehicle density per km at a given time during peak traffic hour;
	DENS _{bus} :	transit bus density per km per lane at a given time during peak traffic hour.

Eventhough the preceding two equations have curvi-linear functional forms, they are nonetheless linear in the coefficients and hence can be analyzed using standard linear regression.

Since “delay” and “travel time” are both in the time domain (i.e. same units of measurement), a similar curvi-linear mathematical form was selected for each of the four street configurations under study, as shown in Equations 3.4 to 3.7¹³. The functional form of Equations 3.4 to 3.8 was used for the first iteration of the models; subsequent iterations and the final equations are described in Chapter 6.

Model #1: Two-way street, two lanes in one direction, parking permitted

$$\begin{aligned} \text{TravTime} = & b_0 + b_1 (q_{thr})^3 + b_2(q_{rt}) + b_3(q_{lt}) + b_4(\text{Stop} \times \text{Sigpkm})^3 \\ & + b_5(HV)^2 + b_6(q_{bus})^2 \end{aligned} \quad (\text{Eqn. 3.4})$$

Model #2: Two-way street, one lane in one direction, parking prohibited

$$\begin{aligned} \text{TravTime} = & b_0 + b_1 (q_{thr})^3 + b_2(q_{rt}) + b_3(\text{Stop} \times \text{Sigpkm})^3 \\ & + b_4(HV)^2 + b_5(q_{bus})^3 \end{aligned} \quad (\text{Eqn. 3.5})$$

Model #3: One-way street, three lanes, parking prohibited

$$\begin{aligned} \text{TravTime} = & b_0 + b_1 (q_{thr})^3 + b_2(q_{rt}) + b_3(q_{lt}) + b_4(\text{Stop} \times \text{Sigpkm})^3 \\ & + b_5(HV)^2 + b_6(q_{bus})^2 \end{aligned} \quad (\text{Eqn. 3.6})$$

Model #4: One-way street, three mixed lanes & one transit bus lane, parking prohibited

$$\begin{aligned} \text{TravTime} = & b_0 + b_1 (q_{thr})^3 + b_2(q_{rt} \times q_{bus}) + b_3(q_{lt}) + b_4(\text{Stop} \times \text{Sigpkm})^3 \\ & + b_5(HV)^2 \end{aligned} \quad (\text{Eqn. 3.7})$$

¹³ For certain applications such as Advanced Traveller Information Systems (ATIS), the level of detail in Equations 3.4 to 3.7 may be too great. In defining the functional form, the intent is to include as many influential variables as feasibly possible, for the first iteration, to ensure the greatest potential for accurate predictions.

Each variable is defined as follows;

Average Travel Time Per Kilometer, TravTime (seconds/vehicle-km)

It is the mean travel time for each vehicle (seconds/vehicle) to traverse 1 km of the given urban arterial, during peak traffic periods. *It is the actual time of travel taking into account all lost time due to the environment, other vehicles, and traffic signals.*

Average Flow of Through Moving Vehicles Along the Street, q_{thr} (vehicles per minute)

For each intersection along the urban arterial under study, the flow of vehicles travelling through the intersection is obtained during peak traffic periods and then averaged for the entire street. The definition of “vehicles” in this context includes automobiles and heavy vehicles (not transit buses since they are accounted for in the q_{bus} variable).

As more vehicles enter the arterial, the flow increases resulting in more friction between the vehicles, which produces a corresponding decrease in travel speed and increase in travel time. However when the flow reaches capacity, the addition of another vehicle will produce a decrease in traffic flow but a continued increase in travel time. Hence as explained in Section 3.1.1, the models are only valid when the street is operating at a level-of-service of E or better, that is, when the arterial is at or undercapacity as defined by HCM 1994.

Average Flow of “Left” Turning Vehicles Along the Street, q_{lt} (vehicles per minute)

For each intersection along the urban arterial under study, the flow of vehicles turning left at the intersection is obtained during peak traffic periods and then averaged for the entire street. The definition of “vehicles” in this context includes automobiles and heavy vehicles (not transit buses since they are accounted for in the q_{bus} variable).

In the absence of a left turning lane or pocket, the left turning vehicles have a significant impact on the speed of the downstream vehicles that desire to drive through. This situation is aggravated if the signal timing plans do not favour left turns (i.e. no protected LT phase) and also when there is considerable opposing right turning vehicles, and numerous pedestrians. In the case when a left turning pocket exists but can accommodate 'x' number of vehicles; the 'x+1' vehicle will affect downstream traffic.

Average Flow of "Right" Turning Vehicles Along the Street, q_r (vehicles per minute)

For each intersection along the urban arterial under study, the flow of vehicles turning right at the intersection is obtained during peak traffic periods and then averaged for the entire street. The definition of "vehicles" in this context includes automobiles and heavy vehicles (not transit buses since they are accounted for in the q_{bus} variable).

In the absence of a right turning lane or pocket, the right turning vehicles have a significant impact on the speed of the downstream vehicles that desire to drive through. This situation is aggravated when there is considerable opposing left turning vehicle volume, and numerous pedestrians. In the case when a right turning pocket exists but can accommodate 'x' number of vehicles; the 'x+1' vehicle will affect downstream vehicles.

Average Proportion of Heavy Vehicles, HV (percentage)

Heavy vehicles are defined as vehicles having more than four tires touching the pavement. For each segment of the urban arterial under study, the number of heavy vehicles in the traffic stream (all turning movements) was obtained during peak traffic periods and a percentage calculated. This percentage was then averaged for the entire street.

Whenever vehicles other than passenger cars (including small trucks and vans) exist in the traffic stream, the number of vehicles that can be served is affected.

Heavy vehicles adversely impact traffic in two ways (TRB 1994):

- they are larger than passenger cars and therefore occupy more roadway space than passenger cars;
- they have poorer operating capabilities than passenger cars, particularly with respect to acceleration, deceleration, and the ability to maintain speed on upgrades

Average Transit Bus Flow, q_{bus} (buses per hour)

For each segment of the urban arterial under study, the number of transit buses per hour was observed during peak traffic periods, and then averaged for the entire street.

Local transit buses influence traffic patterns since they occupy more space than automobiles, and more importantly they often block traffic during stops to discharge or pick-up passengers.

Percentage of "Stopped" Vehicles, Stop (percent)

Percentage of vehicles coming to a complete stop at least once on each segment and averaged for the entire street, during peak traffic periods. This variable is strongly related to "stopped delay".

On an urban arterial, vehicles are forced to stop due to red traffic lights and also for various other reasons such as; pedestrian conflicts; intersection turns; vehicles entering and exiting driveways; parking manoeuvres; bus blockage; and truck loading. *This "Stop" variable is a real-world value that can be measured in the field or obtained as output from traffic simulation programs. Consequently, it implicitly considers all factors that cause a vehicle to stop.*

Average Number of Signalized Intersections Per Kilometre, Sig_{pkm} (# of signals per km)

A self-explanatory variable, Sig_{pkm} , can also be converted to signal spacing. Along with the percentage of stopped vehicles, this variable is expected to have the most significant influence on the average travel time.

In Equation 3.7, a cluster term was developed using “bus flow” and “right turning flow” because having a dedicated transit bus lane, buses are only expected to influence vehicles in the three mixed traffic lanes when they conflict with a right-turning vehicle. Equation 3.5 (for a two-way street with one lane in each direction) does not include the q_{rt} variable because the two arterial segments selected for field observations had prohibited left turns. This is not uncommon at intersections of two-lane streets (one lane in each direction) where left turn pockets are not always feasible.

The following two variables are also defined since they may be inserted into one or more of the equations 3.4 to 3.7 during the subsequent model iterations described in Chapter 6;

Average Total Flow, q_{total} (vehicles per minute)

For each intersection along the urban arterial under study, the total flow of vehicles at each intersection is obtained during peak traffic periods and then averaged for the entire street. The definition of “vehicles” in this context includes automobiles and heavy vehicles (not transit buses since they are accounted for in the q_{bus} variable).

Total Flow equals the sum of “through flow (q_{thr})”, “left turning flow (q_{lt})” and “right turning flow (q_{rt})”.

Average Total Traffic Density, k_{total} (vehicles per kilometer)

For the urban arterial under study, k_{total} is defined as the total number of vehicles over a 1 kilometer distance at an instant in time. The definition of “vehicles” in this context includes automobiles and heavy vehicles (not transit buses since they are accounted for in the q_{bus} variable).

Total Density equals the total flow divided by the average travel speed on the given arterial.

3.1.1 Suggested Applicability of Prediction Models

Whenever prediction models of any kind are developed, it is important to define the proper *inference space* of each independent variable, and of the model. This will indicate the variable ranges where the model is applicable.

Model Inference Space

A difficult decision was made regarding the selection of “traffic flow” over “traffic density”. From a theoretical perspective, density has a clear relationship with travel time: as the density of vehicles increases, average vehicle speed will decrease resulting in a corresponding increase in travel time. On the other hand, an increase in traffic flow does not always produce higher travel times that strongly correlate with traffic volume. According to the author, depending on the general arterial traffic conditions, the relationship between traffic flow, density, speed, and travel time will vary as outlined below:

1) traffic condition scenario: *primarily free-flow conditions (at or near LOS A)*

increase in traffic flow + corresponding increase in density	impact:	-travel speed at or near posted speed limit for the ave. driver -travel times that are for near free flow
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2) traffic condition scenario: *typical weekday peak traffic on urban arterials (from LOS B to LOS E)*

increase in traffic flow + increase in traffic density	impact:	-dropping average speed from LOS B to LOS E -higher travel times
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3) traffic condition scenario: *highly unstable traffic operations, high congestion (LOS F)*

increase in traffic density	corresponds to:	-decreased traffic flow -decrease in travel speed -increasing travel times
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For example under the first traffic condition scenario (corresponding to near free-flow conditions), travel speeds are not constrained by traffic. Since the models are developed for peak-hour periods, this scenario is not applicable.

Under the second scenario (which represents usual traffic conditions), an *increase* in traffic flow corresponds to rising traffic density which in turn results in *increased* travel times.

The third scenario, corresponding to a high congestion level, suggests that further increase in density will drastically reduce travel speed (and produce significant increases in the average travel time), generating a *decrease* in traffic flow -- ultimately resulting in gridlock.

In the travel time models developed in this study, traffic flow and density are defined as having a *positive* correlation with travel time. That is, as traffic flow and density increase so does travel time. The traffic models are only applicable under typical weekday peak traffic conditions on urban arterials, at levels-of-service of approximately B to E. This corresponds to the second scenario described above.

The level-of-service of any arterial can be obtained from Table 11-1 in HCM 1994 using the *average travel speed*. Consequently, the models should only be employed when the average travel speed is LOWER than the travel speed at LOS B and GREATER than the speed that corresponds with the onset of LOS F.

Variable Inference Space

The appropriate inference space for each independent variable is outlined below:

Q_{thr} , Q_{rt} , Q_{lt} :	-flow values corresponding to LOS B, C, D, E (see above explanation)
Stop:	-0 to 100% (however, values near 100 may indicate a level-of-service greater than E at which point the model inference space governs)
Sigpkm:	-1 to 20 (i.e. at least one signal is required to have interrupted flow conditions; 20 signals per km, or signal spacing=50m, is taken as the hypothetical upper reasonable limit)
HV:	-0 to 30% (i.e. 30% heavy vehicles is taken as the hypothetical upper reasonable limit on downtown streets; typical range is from 2 to 10%)

Q_{bus}

-0 to 300 buses per hr (i.e. 300 buses per hour, or five buses every minute, is used as a reasonable upper range limit - if a transit bus lane exists, as is the case in Ottawa, bus flow will be near the upper echelons of this range)

3.2 Application of Bayesian Regression to Traffic Modelling

Chapter 2 provided an overview of Bayesian regression analysis. Numerous references from different disciplines were highlighted in which a Bayesian solution to a problem was employed. It was noted that Bayesian methods are especially useful in cases where limited experimental data are available. Section 2.2 provided a discussion on Bayesian regression (i.e. Bayesian analysis of a multiple regression model) with emphasis on the two sources of information needed: 'a priori' information, and experimental data. Techniques for developing the 'a priori' parameters required for Bayesian regression were also discussed. Finally, the Bayesian regression computer program, XLBAYES, used in this project was described.

This Section will summarize the procedures followed to assemble the Bayesian prior information and the experimental data. Chapters 4 and 5, respectively, will describe in greater detail these data gathering procedures.

3.2.1 'A Priori' Information

In Section 2.2, 'A Priori' information was defined as anything that is known prior to an experiment taking place. It was also explained that no matter what the scope of the problem is, there is usually some form of reliable prior information known regarding the problem, before any experimental data is collected.

In this project, a *model-based* prior was selected as being most appropriate. Although a subjective or *judgement-based* prior is most typically used with Bayesian analysis methods, it is not feasible for traffic modelling due to the many complex factors that influence travel time during rush hour traffic; in other words, it would have been extremely difficult for local traffic engineers to provide reasonably accurate estimates of the model parameters, as was suggested in the case of the Market Questionnaire example in Section 2.2.1.

The TRAF-NETSIM traffic simulation program was selected to provide the model-based prior information. Computer simulation programs such as NETSIM have many advantages. They enable the user to model the performance of an urban street network under controlled conditions and examine a wide variety of different situations and conditions that would otherwise require a tremendous amount of field data at high costs. Being microscopic in nature, NETSIM provides a wealth of output information on a *link-specific basis* and aggregated over the *entire network*. The output MOE include;

- travel times
- total and stopped delays
- speeds
- timing data
- queue lengths
- vehicle occupancies
- fuel consumption
- pollution emissions
- etc...

Since NETSIM simulates actual, real world field conditions, the output MOE can logically be used as reliable *prior information* on the traffic patterns in downtown Ottawa. This prior information will then be combined with experimental field data

by way of the Bayesian methodology to derive improved predictive models of travel time.

Some people may ask why develop travel time models that use a simulation program as a source of input for model development when this program is already available to provide travel time estimates. The answer to this question rests with one of the objectives of this project, which is to develop efficient models with moderate data requirements, capable of providing reasonable predictions of travel time. NETSIM, as with other simulation programs, requires numerous input data, is very time-consuming to set up and run, and demands considerable computing power. As such, NETSIM is better suited to a detailed analysis of an urban street network.

The methodology followed to simulate the Ottawa CBD traffic and convert the NETSIM MOE into Bayesian 'a priori' information is described in Chapter 4.

3.2.2 Field Observations

The second source of information required for Bayesian modelling is experimental data. These data were obtained through a traffic study conducted on four downtown streets in the Ottawa central business district. The videotape was selected as the data collection technique since it provides a continuous, real time, permanent record of traffic movements on roads.

The first step involved conducting a survey of the Ottawa urban street network in order to locate; 1) streets corresponding to the four street configurations being modelled, and 2) suitable high rise buildings providing an unobstructed view of the street activity. Once this was accomplished, multiple video cameras were set up at two locations and on six separate weekdays in order to film various streets during morning and afternoon peak period traffic conditions. All filming was

performed between Tuesday and Thursday. In total, 45 hours of traffic activity was captured.

The data required for modelling were extracted from the videotapes by way of manual observation of the video. This task proved to be very time-consuming since each time period needed to be viewed 4 times in order to extract all necessary modelling variables. Various means were defined during this exercise to facilitate future video data collection and data reduction tasks.

More detailed information on the field data collection exercise using video technology is provided in Chapter 5.

CHAPTER 4

PREPARATION OF THE PRIOR INFORMATION

A conceptual flowchart of the procedure followed to derive 'a priori' information for use in the Bayesian regression analysis is illustrated in Figure 4.1.

4.1 Traffic Simulation using TRAF-NETSIM Program

The TRAF-NETSIM program Version 5.0 (March 1995) (Federal Highway Administration 1995) was used in this research to simulate traffic flow in the Ottawa Central Business District. NETSIM produced various traffic Measures of Effectiveness (MOE) which were used as prior information in the Bayesian regression analysis.

NETSIM is a fixed-step, microscopic network simulation model that applies interval-based simulation to describe traffic operations. This means that every vehicle is a distinct object which is moved every second, and that every variable control device (traffic signals) and event are updated every second. Furthermore, each vehicle is identified by category (auto, car pool, truck, bus), and its kinematic properties (speed, acceleration) are determined, as well as its status (queued, free flowing). Turn movements are assigned stochastically, as are its free flow speed, queue discharge headways and other behavioural attributes. In addition, a "driver behavioural characteristic" (passive, aggressive) is assigned to each vehicle. Consequently, each vehicle's behaviour may be simulated in a manner reflecting real world processes (Federal Highway Administration 1995).

The microscopic nature of NETSIM ensures a real world simulation. Each vehicle is assigned an individual target speed, ranging from 75 to 127% of the

FIGURE 4.1: Flowchart - The Use of NETSIM to Generate 'A Priori' Information

link travel speed (Sadgeh et al. 1988). The total delay time of a vehicle is then affected by not only the traffic signals, but also by friction among individual vehicles in the traffic stream.

Vehicles are initially emitted onto the network via “entry links” surrounding the area to be studied. The vehicles then move through the street system according to car following logic, response to traffic control devices and response to other demands. For example, buses must service passengers at bus stops and hence their movements differ from those of private vehicles. Pedestrian traffic is also simulated as it can contribute to traffic delay at intersections. Each time a vehicle is moved, the program recalculates a series of statistics; its position (both lateral and longitudinal) on the link and relative to other vehicles, its position in queue, its cumulative travel time and distance, its cumulative delay and number of stops incurred to date, and its projected turning movement at the next intersection. Once the vehicle has traversed the network, it is discharged at an “exit” link located at the periphery of the network.

While continuously maintaining a statistical record of each vehicle, NETSIM also monitors the performance of specific links within the network, each second.

These link-specific Measures of Effectiveness (MOE) include;

- mean travel time, delay time, stopped time, and time in queue, per vehicle
- mean speed
- percentage of vehicles stopping at least once
- vehicle-kms, person-kms, vehicle-trips, person-trips
- total travel time, delay time and moving time (vehicle minutes and person minutes)
- bus travel (in bus-trips and passenger-trips)
- bus travel time, delay time, and moving time
- turning movements
- fuel consumed, fuel economy

- CO, HC, and Nox emissions

In the early 1980's, the Federal Highway Administration (FHWA) developed an integrated set of simulation models, known as TRAF, in an effort to represent the entire traffic environment. NETSIM was integrated within the TRAF environment to provide the urban traffic simulation component. The program was thus renamed TRAF-NETSIM.

To obtain more detailed information on the TRAF-NETSIM simulation program, there are many references available, of which;

1. TRAF User Reference Guide, FHWA, U.S. Department of Transportation, Office of Safety and Traffic Operations R&D, ITS Research Division, March 1995.
2. Wong, S.Y., TRAF-NETSIM: How It Works, What It Does, ITE Journal, April, 1990.
3. Rath, A.K., and Santiago, A.J., The New NETSIM: TRAF-NETSIM Version 2.00 Simulation Program, Paper Presented at the Transportation Research Board's 68th Annual Meeting in Washington, D.C., January 1989.

4.2 Experiment Design and Setup: Ottawa CBD

An important consideration when using Bayesian regression analysis is that the *definition and attributes of both the prior information and the field data must be identical*. Consequently, it was essential to design the NETSIM traffic simulation experiment so as to reflect as much as possible the actual field conditions in the Ottawa urban street network.

A general map of the Ottawa central area is provided in Figure 4.2. The main section of the Ottawa CBD, from Wellington Street in the North to Laurier Street in the South and from Lyon Street in the West to Metcalfe Street in the East, was selected as the study network. Necessarily, this network comprises the four streets in which field observations were made: Queen, Bank, Lyon, and Albert.

FIGURE 4.2: Map of Ottawa Central Business District
(Source: MapArt Corporation)

This street system was then sketched according to a “node-link” configuration, as shown in Figure 4.3, for ease of data input. In Figure 4.3, the nodes represent intersections and the links represent sections of the streets between two nodes. Due to the nature of NETSIM which only works with uni-directional links, a two-way street is represented by two uni-directional links. The nodes in the form of an ellipse (numbered above 8000) represent “entry/exit” nodes while the circular shapes are “internal” nodes. The rectangular nodes between entry/exit and internal nodes represent “buffer” nodes, and they allow collection of statistics on the traffic approaching and exiting the network.

FIGURE 4.3: Ottawa CBD Street Network for NETSIM Traffic Simulation

4.2.1 NETSIM Input Variables

Before the actual simulation of downtown Ottawa was conducted, the traffic flow on a trial street network was simulated based on various fictitious input data. This allowed a better understanding of the input data required, the various intricacies of the computer program, and the different Measures of Effectiveness (output data) of the traffic simulation.

Three sources of information were used to obtain the necessary input data.

i) Field Survey

For the entire street network illustrated in Figure 4.3, the physical layout of the street network and the regulatory characteristics during peak periods were recorded manually, on site. This required sketching each of the streets and noting any physical factors which may affect traffic patterns. The following information, required by NETSIM, was recorded for each street;

Physical Characteristics

- **Block lengths;** i.e. the link length from stop bar to stop bar
- **Number of moving lanes;** i.e. the lanes used for vehicle movement only (parking lanes excluded)
- **Lane channelization;** i.e. the use of each lane (e.g. all movements permitted, left turn only, right turn only, through traffic only, buses only, etc..)
- **Length of left and right turning pockets;** i.e. distance extending upstream from stop line
- **Lane alignment;** i.e. the alignment of lanes in one link with those of the receiving link
- **Existence of loading zones and taxi stands;** i.e. can result in the reduction in the number of moving lanes

- **Bus stop characteristics;** i.e. distance to downstream stop bar; protected or unprotected, maximum number of buses that can be contained at one time; bus routes servicing each bus stop

Regulatory Characteristics

- **Existence of parking;** i.e. whether parking actually occurs or not during peak periods - will affect the "Number of moving lanes" (*eventhough some streets in downtown Ottawa prohibit parking during peak periods, numerous vehicles continue to park which results in the reduction of the number of actual moving lanes*)
- **Intersection control;** i.e. permitted left turns, permitted right turn on red (RTOR)

ii) Regional Municipality of Ottawa-Carleton

The second source of information for NETSIM input was the Regional Municipality of Ottawa-Carleton (RMOC). This organization provided real world information on the following peak period traffic characteristics in the Ottawa CBD.

- **Traffic volumes;** i.e. using vehicle counts conducted in 1994, the "entry link volumes" were obtained at the intersections located on the periphery of the study network
- **Percentage of heavy vehicles & car pools;** i.e. the volume of heavy vehicles obtained at the entry links divided by the total number of vehicles; percentage of car-pools was not available from RMOC so it was assumed to be 5%
- **Turning movement volumes;** i.e. volumes of vehicles turning right, left, and going through each intersection - based on vehicle counts conducted over an extended period in 1994

- **Pedestrian volumes;** i.e. number of pedestrians crossing each intersection every half hour - actual value was classified according to *light (100-250 ped/hr)*, *moderate (250-500 ped/hr)*, and *heavy pedestrian flow (above 500 ped/hr)*
- **Signal timing plan characteristics;** i.e. includes signal type for each interval (e.g. green, green left turn arrow, amber, red, etc.); duration of each signal interval; and cycle length

Figure 4.4 illustrates a sample RMO figure in which vehicle volumes and turning percentages were extracted for the intersection of Bank and Wellington. Figures 4.5 and 4.6 show the peak period pedestrian and heavy vehicle volumes, respectively. The Heavy Vehicle Count Summary Sheet includes both trucks and all buses. In order to separate the trucks and transit buses, it was assumed that on all streets *without a dedicated transit bus lane* the ratio of transit buses to trucks was 50:50. Alternatively, on the streets *with a dedicated bus lane* (i.e. Albert and Slater), the bus to truck ratio was assumed to be 80:20. These ratios were confirmed by the field data collected with video. The reader should be aware that although Figure 4.4 represents traffic counts conducted on only one day in 1994, traffic counts on other days and other years were also examined to ensure the selected volumes were representative of usual traffic patterns at each intersection.

REGIONAL MUNICIPALITY OF OTTAWA-CARLETON - TRANSPORTATION DEPARTMENT
Vehicle Flow Diagram

Intersection: BANK and WELLINGTON

Date: 24/8/94 Day: WED Time of Count Start: 700

Road Conditions: DRY

A.M. PEAK HOUR
800-900

P.M. PEAK HOUR
1545-1645

FIGURE 4.4: Sample RMO Traffic Count Summary - Bank & Wellington
(Source: Regional Municipality of Ottawa-Carleton-Transportation Department)

PEDESTRIAN VOLUME COUNT SUMMARY SHEET
INTERSECTION: BANK AND WELLINGTON **DATE: 24 AUG 94**

	CROSSING WELLINGT E/B APPR.	CROSSING WELLINGT W/B APPR.	STREET TOTAL	CROSSING BANK N/B APPR.	CROSSING BANK S/B APPR.	STREET TOTAL	GRAND TOTAL
700 - 800	147	124	271	33	54	87	358
800 - 900	261	257	518	39	111	150	668
900 - 1000	203	213	416	101	282	383	799
1130 - 1230	332	284	616	241	268	509	1125
1230 - 1330	378	375	753	304	238	542	1295
1500 - 1600	311	183	494	107	115	222	716
1600 - 1700	480	329	809	157	194	351	1160
1700 - 1800	314	256	570	123	122	245	815
8 HR TOT	2426	2021	4447	1105	1384	2489	6936

PEAK PERIOD SUMMARIES

PEAK PERIOD (7:00-9:00)							
700 - 715	25	5	30	2	11	13	43
715 - 730	34	16	50	7	13	20	70
730 - 745	34	41	75	11	13	24	99
745 - 800	54	62	116	13	17	30	146
800 - 815	58	82	140	22	15	37	177
815 - 830	42	52	94	4	22	26	120
830 - 845	67	71	138	4	19	23	161
845 - 900	94	52	146	9	55	64	210
TOTALS	408	381	789	72	165	237	1026

FIGURE 4.5: Sample RMOc Pedestrian Volumes - Bank & Wellington
 (Source: Regional Municipality of Ottawa-Carleton-Transportation Department)

HEAVY VEHICLE COUNT SUMMARY SHEET
INTERSECTION: BANK AND WELLINGTON **DATE: 24 AUG 94**

	EASTBOUND APPR. ON WELLINGT	WESTBOUND APPR. ON WELLINGT	STREET TOTAL	NORTHEBOUND APPR. ON BANK	SOUTHEBOUND APPR. ON BANK	STREET TOTAL	GRAND TOTAL
700 - 800	89	66	155	23	2	25	180
800 - 900	77	70	147	25	11	36	183
900 - 1000	44	57	101	28	33	61	162
1130 - 1230	48	49	97	22	10	32	129
1230 - 1330	31	46	77	34	12	46	123
1500 - 1600	38	116	154	23	17	40	194
1600 - 1700	31	128	159	29	8	37	196
1700 - 1800	25	121	146	30	7	37	183
8 HR TOT	383	653	1036	214	100	314	1350

FIGURE 4.6: Sample RMOc Heavy Vehicle Traffic Volumes - Bank & Wellington
 (Source: Regional Municipality of Ottawa-Carleton-Transportation Department)

With regards to the traffic signal timing plans at each intersection, it was necessary to meet with a traffic control engineer from RMOC to obtain an explanation of their timing plan summaries, an example of which is given in Figure 4.7 for the intersection of Bank and Wellington.

		Phase	Signal Type	Interval Duration (sec)		Direction Signal										
Timing Plan 1		IVL	A	F	4	A	0000	0000	1	N	000-	1000	0000	EW	W	
		IVL	A	V	3+32	A	0000	0000	1	N	000-	1000	0000	EW	W	
		IVL	A	F	13	A	0000	0000	1	N	000-	1000	0000	EW	D	
		IVL	A	F	3	A	0000	0000	1	N	0000	0200	0000	EW	A	
		IVL	A	F	3	A	0000	0000	1	N	0000	0000	0000	EW	R	
		IVL	B	F	4	A	0000	0000	1	N	0000	0030	0000	NB	W	
		IVL	B	V	3+7	A	0000	0000	1	N	0000	0030	0000	NB	W	
		IVL	B	F	16	A	0000	0000	1	N	0000	0030	0000	NB	D	
		IVL	B	F	3	A	0000	0000	1	N	0000	0200	0000	NB	A	
		IVL	B	F	3	A	0000	0000	1	N	0000	0000	0000	NB	R	
		IVL	C	F	3	A	0000	0000	1	N	0000	0030	0000	EW	L	
		IVL	C	V	2+6	A	0000	0000	1	N	0000	0030	0000	EW	L	
		IVL	C	F	3	A	0000	0000	1	N	0000	0200	0000	EW	A	
		IVL	C	F	2	A	0000	0000	1	N	0000	0000	0000	EW	R	
		SIG	2	N	1000		0000	EW	W							
		IVL	A	F	4	A	0000	0000	1	N	000-	1000	0000	EW	W	
		IVL	A	V	3	A	0000	0000	1	N	000-	1000	0000	EW	W	
		IVL	A	F	13	A	0000	0000	1	N	000-	1000	0000	EW	D	
		IVL	A	F	3	A	0000	0000	1	N	0000	0200	0000	EW	A	
		IVL	A	F	3	A	0000	0000	1	N	0000	0000	0000	EW	R	
		IVL	B	F	4	A	0000	0000	1	N	0000	0030	0000	NB	W	
		IVL	B	V	3	A	0000	0000	1	N	0000	0030	0000	NB	W	
		IVL	B	F	16	A	0000	0000	1	N	0000	0030	0000	NB	D	
		IVL	B	F	3	A	0000	0000	1	N	0000	0200	0000	NB	A	
		IVL	B	F	3	A	0000	0000	1	N	0000	0000	0000	NB	R	
		TIM	1	1	110	60	0100	0100								
		PHS	58													
		PHS	36													
		PHS	16													
Timing Plan 2		TIM	2	1	80	45	0100	0100								
		PHS	39													
		PHS	31													
		PHS	10													
Timing Plan 3		TIM	3	1	90	55	0100	0100								
		PHS	44													
		PHS	31													
		PHS	15													

FIGURE 4.7: Sample RMOC Signal Timing Plans - Bank & Wellington
(Source: Regional Municipality of Ottawa-Carleton-Transportation Department)

Without going into too much detail, signal timing plan #1 has a 110 second cycle length and three phases: phase A (58 sec), phase B (36 sec), and phase C (16 sec). The following summarizes the signal intervals within each phase;

<u>Phase</u>	<u>Interval #</u>	<u>Duration (sec)</u>	<u>Direction</u>	<u>Signal</u>
A	1	39	EW	Walk
	2	13	EW	Flashing Don't Walk
	3	3	EW	Amber
	4	3	EW	All Red
B	5	14	NB	Walk
	6	16	NB	Flashing Don't Walk
	7	3	NB	Amber
	8	3	NB	All Red
C	9	11	EW	Left Turn
	10	3	EW	Amber
	11	2	EW	All Red

Figure 4.7 identifies 3 different timing plans. According to the RMOC, timing plan #1 was employed during the morning peak, and timing plan #3 during the afternoon peak period in June of 1995 when the field data were collected. Eight pre-defined algorithms enable RMOC to quickly change timing plans for the different traffic requirements during a 24 hour day.

iii) OC Transpo

The third information source for input into NETSIM was the Ottawa-Carleton Transit Commission (OC Transpo). They provided detailed information on the transit buses operating in the Ottawa CBD during the morning peak traffic period. This information included;

- **Bus stops;** i.e. the location of each bus stop; mean dwell time at each bus stop; and the percentage of buses that do not stop due to lack of demand

- **Bus routes;** i.e. bus route numbers servicing each bus stop; the path each bus takes through the network; and the headway (flow rate) for each bus route

The bus stop locations were obtained from a transit bus map of the Ottawa CBD. All of the bus route information was extracted from public bus route flyers. The mean dwell time and the percent of buses not stopping was estimated from an OC Transpo computer program called, "Automatic Passenger Counting System, Revenue Utilization", for a few indicative bus stops.

It is important to note that Version 5.0 of the TRAF-NETSIM program is limited to 25 bus routes for the entire network. Although the maximum 25 routes was input into NETSIM, numerous routes on the OC Transpo Transitway (i.e. Albert and Slater Streets) could not be entered; in reality, over 70 bus routes serve downtown Ottawa during peak periods. Consequently during the NETSIM simulation, the influence of buses on the traffic flow (i.e. blocking lanes, friction) on Albert and Slater will be less than real world conditions. One would then expect the "travel time" MOE on Albert and Slater to be slightly lower than what would be measured in the field.

The data entry procedure for NETSIM was very time-consuming. This can be explained by NETSIM's data structure where the input stream consists of a sequence of "cards". Each card type contains specific data items related to a given classification of information. Figure 4.8 illustrates the layout of the NETSIM input stream.

FIGURE 4.8: NETSIM Card Format for Data Entry

(Source: TRAF User Reference Guide)

4.3 Execution of Traffic Simulations

In Section 4.1, the simulation technique used by the NETSIM program was explained. In Section 4.2, the design and preparation of the simulation experiment on the Ottawa CBD was described which included an account of how all of the required NETSIM input variables were obtained. This Section will deal with the actual execution of the traffic simulations, highlighting the output variables to be used in the Bayesian regression.

The TRAF system describes the changing conditions that prevail over a roadway network. These changing conditions are either *endogenous* (internal to the system) or *exogenous* (specified as external stimuli as input by the user). For example, exogenous data include changes in traffic volumes, turning movement percentages, lane channelizations, etc. If these time-dependent data items change in the course of a simulation run, the user must partition the simulation time into a series of *time periods*, whereby each set of exogenous input data remains constant for one time period. In this research, only one time period was needed (i.e. all exogenous data remained constant) since only a 15 minute period was simulated during the morning peak period (7:30 - 7:45). All of the input data (i.e. traffic volumes, turning percentages, signal timing plans, etc.) were obtained for the morning peak period, as described in the previous Section.

TRAF-NETSIM allows the user to enter random numbers which will control all random traffic-related processes during the simulation. These random numbers are used to generate random events from distributions for various activities. For example, there is a probability distribution for a driver to stop at a yellow light. If the same random numbers are entered in successive runs, NETSIM will generate vehicles at identical times with identical driver characteristics and with identical paths through the network. The user can enter different random numbers to generate an entirely new pattern of traffic, which may reflect differences that might be observed between the traffic stream on a Tuesday morning to that on a Wednesday afternoon. A series of runs with different random numbers would illustrate the variance in the traffic performance MOE which are due to variations in traffic patterns (Federal Highway Administration 1995, pp. 4-8)

In this research six simulation runs were executed, each with different random numbers to ensure that the output statistics (i.e. Measures of Effectiveness) represent six different traffic conditions in the network.

Figures 4.9, 4.10, and 4.11 illustrate sample outputs generated by NETSIM.

Figure 4.9 contains cumulative link-specific MOE after *15 minutes of simulation*.

The MOE used for modelling purposes from Figure 4.9 include;

- Mean total travel time per vehicle (seconds/vehicle)
- Percentage of vehicle stops

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	VEHICLE DELAY TIME	VEHICLE QUEUE TIME	STOP TIME	-- AVERAGE VALUES --		
													STOPS (#)	VOLUME YPH	SPEED KMPH
(52, 53)	25.51	133	31.7	25.7	57.4	0.55	2.25	1.01	25.9	11.6	7.1	7.0	32	532	26.7
(53, 54)	24.14	134	30.0	22.2	52.2	0.58	2.16	0.92	23.4	3.9	6.3	5.7	47	536	27.8
(54, 55)	18.29	100	22.7	6.7	29.4	0.77	1.61	0.37	17.7	4.0	1.5	1.4	16	400	37.3
(55, 156)	12.64	127	15.7	2.4	18.1	0.87	1.43	0.19	8.5	1.1	0.1	0.0	0	508	42.0
(8056, 156)		175												700	
(156, 55)	17.40	174	21.6	40.6	62.2	0.35	3.58	2.33	21.5	14.0	10.5	10.0	60	696	16.8
(55, 54)	27.98	153	34.8	36.2	70.9	0.49	2.54	1.29	27.8	14.2	9.3	8.8	71	612	23.7
(54, 53)	21.64	121	26.9	56.9	83.8	0.32	3.87	2.63	41.5	28.2	27.6	26.7	78	484	15.5
(53, 52)	16.90	88	21.0	327.7	348.7	0.06	20.63	19.39	237.7	223.4	217.8	212.1	98	352	2.9
(52, 51)	14.55	77	18.1	14.2	32.3	0.56	2.22	0.97	25.1	11.0	7.1	6.9	12	308	27.1
(51, 150)	7.38	74	9.2	1.6	10.8	0.85	1.47	0.22	8.8	1.3	0.1	0.0	0	296	40.9
(1, 11)	8.09	102	10.1	8.9	19.0	0.53	2.35	1.10	11.2	5.3	3.4	3.3	14	408	25.6
(11, 21)	8.05	102	10.0	29.6	39.6	0.25	4.91	3.67	23.3	17.4	13.2	13.2	72	408	12.2
(21, 31)	10.58	134	13.1	25.0	38.1	0.34	3.60	2.36	17.1	11.2	6.6	6.8	41	536	16.6
(31, 41)	10.97	139	13.6	38.1	51.7	0.26	4.71	3.47	22.3	16.4	11.3	10.7	87	556	12.7
(41, 51)	13.37	133	16.6	10.3	26.9	0.62	2.01	0.77	12.1	4.6	1.5	1.4	15	532	29.8
(51, 161)	12.97	130	16.1	1.8	17.9	0.90	1.38	0.14	8.3	0.8	0.0	0.0	0	520	43.5
(8062, 162)		250												1000	
(162, 52)	23.99	240	29.8	507.0	536.8	0.06	22.37	21.13	134.2	126.7	98.2	89.3	97	960	2.7
(52, 42)	24.76	244	30.8	212.7	243.5	0.13	9.84	8.59	59.9	52.3	36.1	29.4	90	976	6.1
(42, 32)	8.29	105	10.3	31.0	41.3	0.25	4.99	3.74	23.6	17.7	13.4	12.8	74	420	12.0

FIGURE 4.9: NETSIM Cumulative Output Statistics
(Source: TRAF-NETSIM, Version 5.0)

Figure 4.10 contains cumulative link and turn-movement specific MOE after 15 minutes of simulation. The statistics used for modelling include;

- Vehicle-trips; i.e. total number of vehicles implicated in the three turning movements (not including transit buses)

NETSIM MOVEMENT SPECIFIC STATISTICS - TABLE I (CONT.)

LINK	VEHICLE-KM			VEHICLE-TRIPS			SPEED (KMPH)			STOPS (PCT)		
	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT	LEFT	THRU	RIGHT
(52, 53)	0.00	23.78	3.26	0	124	17	0.0	31.6	19.6	0.0	23.4	94.1
(53, 54)	0.00	17.65	10.09	0	98	56	0.0	26.1	19.6	0.0	48.0	83.9
(54, 55)	1.83	18.84	0.00	10	103	0	28.1	33.1	0.0	90.0	21.4	0.0
(55, 156)	0.00	13.55	0.00	0	136	0	0.0	41.5	0.0	0.0	0.0	0.0
(8056, 156)				0	175	0						
(156, 55)	0.00	12.40	5.10	0	124	51	0.0	19.3	12.4	0.0	47.6	94.1
(55, 54)	9.88	17.74	0.00	54	97	0	20.3	23.7	0.0	77.8	59.8	0.0
(54, 53)	0.00	21.69	0.36	0	121	2	0.0	18.3	23.9	0.0	70.2	100.0
(53, 52)	0.00	10.75	6.72	0	56	35	0.0	8.6	3.7	0.0	98.2	97.1
(52, 51)	2.83	13.42	0.00	15	71	0	23.4	28.2	0.0	73.3	38.0	0.0
(51, 150)	0.00	7.98	0.00	0	80	0	0.0	40.2	0.0	0.0	0.0	0.0
(1, 11)	0.00	7.53	0.00	0	95	0	0.0	32.0	0.0	0.0	6.3	0.0
(11, 21)	1.26	5.21	0.79	16	66	10	11.0	12.4	11.6	93.8	65.2	100.0
(21, 31)	0.00	7.97	1.26	0	101	16	0.0	15.1	17.8	0.0	49.5	56.3
(31, 41)	1.58	7.97	0.00	20	101	0	7.7	13.7	0.0	100.0	86.1	0.0
(41, 51)	1.20	9.44	1.00	12	94	10	18.1	31.8	21.4	75.0	11.7	50.0
(51, 161)	0.00	11.95	0.00	0	120	0	0.0	42.7	0.0	0.0	0.0	0.0
(8062, 162)				0	213	0						
(162, 52)	3.00	16.50	2.60	30	165	26	4.7	2.5	2.5	96.7	85.5	88.5
(52, 42)	0.00	3.75	17.02	0	37	168	0.0	13.5	5.1	0.0	62.2	97.6
(42, 32)	1.34	4.82	0.00	17	61	0	12.7	15.1	0.0	76.5	55.7	0.0
(32, 22)	1.08	5.23	2.08	14	68	27	14.9	28.9	20.8	71.4	14.7	59.3
(22, 12)	0.00	8.13	0.00	0	103	0	0.0	25.3	0.0	0.0	24.3	0.0
(12, 2)	2.59	0.97	4.78	32	12	59	4.5	8.5	15.6	96.9	58.3	86.4
(2, 102)	0.00	3.07	0.00	0	31	0	0.0	41.0	0.0	0.0	0.0	0.0

FIGURE 4.10: NETSIM Movement Specific Output Statistics
(Source: TRAF-NETSIM, Version 5.0)

Figure 4.11 illustrates cumulative link-specific bus MOE from which “bus trips” was used for modelling.

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, 100)	3	75						
(100, 1)	3	75	0.7	0.4	0.3	0.53	25.7	0
(8006, 106)	2	50						
(106, 5)	2	50	0.8	0.2	0.6	0.30	14.4	0
(5, 4)	2	50	4.3	0.5	3.8	0.11	5.3	0
(4, 3)	2	50	0.5	0.4	0.1	0.78	37.6	0
(8026, 126)	1	25						
(126, 25)	1	25	0.4	0.1	0.2	0.34	16.4	0
(25, 24)	1	25	0.7	0.2	0.5	0.31	15.2	1
(24, 23)	1	25	1.0	0.2	0.8	0.23	11.0	1
(23, 22)	1	25	0.8	0.2	0.6	0.29	14.2	1
(22, 21)	1	25	1.1	0.2	0.9	0.19	9.4	1
(8036, 136)	7	175						
(136, 35)	7	175	1.1	0.9	0.2	0.78	37.6	0
(35, 34)	7	175	1.6	1.5	0.1	0.97	46.7	0
(34, 33)	7	175	7.4	1.6	5.9	0.21	10.2	7
(33, 32)	7	175	4.9	1.7	3.3	0.34	16.4	0
(32, 31)	7	175	7.9	1.6	6.3	0.20	9.9	7
(31, 130)	8	200	1.4	1.0	0.4	0.71	34.3	0
(8040, 140)	8	200						
(140, 41)	8	200	3.5	1.0	2.5	0.28	13.6	0
(41, 42)	12	275	10.9	2.6	8.2	0.24	11.7	11
(42, 43)	12	300	6.1	2.9	3.2	0.47	22.9	0
(43, 44)	12	300	11.6	2.7	8.9	0.23	11.3	12
(44, 45)	12	300	4.6	2.6	2.0	0.57	27.7	0
(45, 146)	12	300	1.9	1.5	0.4	0.79	38.2	0
(1, 11)	3	75	0.9	0.3	0.5	0.35	17.2	0

FIGURE 4.11: NETSIM Bus Output Statistics
(Source: TRAF-NETSIM, Version 5.0)

Another time-consuming aspect of NETSIM is the correction of programming errors. Over 30 iterations of the first simulation were executed, with each run resulting in various “warning messages” and “fatal error messages”. The TRAF diagnostic logic does not *dynamically link* the different symptoms of an error. Consequently, the many *related* input mistakes in different cards (e.g. sign control approaches-card 35, and control codes for signs-card 36) must all be fixed individually.

4.4. Processing NETSIM MOE for Bayesian Regression

The MOE for each street type (see Figure 4.3) matching the four street configurations under study were extracted for modelling purposes. The streets used include;

1. *Two-way street, two lanes in one direction, parking permitted:*

Queen St. (node 8020 to 126, and node 8026 to 120)

2. *Two-way street, one lane in one direction, parking prohibited*

Bank St. (node 8003 to 163, and node 8063 to 103)

3. *One-way street, three lanes, parking prohibited*

Lyon St. (node 1 to 161)

Kent St. (node 8062 to 102)

Metcalfe St. (node 8065 to 105)

4. *One-way street, three mixed lanes, one dedicated transit bus lane*

Albert St. (node 8036 to 130)

Slater St. (node 8040 to 146)

To use these MOE for modelling, it was necessary to convert them into the modelling variable units previously defined in Section 3.1. The following conversions were made;

<u>NETSIM MOE</u>	<u>Conversion</u>	<u>Modelling variable</u>
Mean total travel time (sec/vehicle) (sec/veh.km)	-->divided by the link length	-->Travtime
Percentage of vehicle stops	-->no conversion	-->Stop (%)
Left Vehicle-trips	-->divide by 15	--> q_{lt} (veh/min)
Through Vehicle-trips	-->divide by 15	--> q_{thr} (veh/min)
Right Vehicle -trips	-->divide by 15	--> q_{rt} (veh/min)
Bus trips	-->multiply by 4	--> q_{bus} (veh/hr)

Tables 4.1 to 4.4 illustrate, for each street type under study, the NETSIM MOE along with the converted variables used for Bayesian regression.

NETSIM Traffic Simulation Data - Bayesian Prior																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
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33-43	79	0	42	0	2	4	30	18	21.95	0.00	21.95	1202.1	512.0	16.0	21.2	227.8
43-53	107	0	56	9	1	4	49	18	52.03	0.60	81.37	1793.4	64.0	16.0	92.5	168.2
163-53	100	0	57	26	0	5	59	29.3	54.87	1.73	169.42	19729.2	0.0	25.0	161.5	293.0
53-43	107	0	53	4	0	5	73	30.9	44.11	0.27	54.87	6118.2	0.0	25.0	305.9	288.8
33-23	79	0	11	43	0	5	100	23.4	0.39	2.87	46.66	5613.3	0.0	25.0	786.3	296.2
23-13	79	0	19	0	0	5	15	10.5	2.03	0.00	2.03	22.1	0.0	25.0	2.7	132.9
Simulation #5																
Bank	3-13	79	0	55	0	2	49	18.4	49.30	0.00	49.30	2883.6	512.0	16.0	92.5	232.9
	13-23	79	0	51	5	2	23	13.6	39.30	0.33	52.03	1229.1	512.0	16.0	9.6	172.2
	23-33	79	0	50	28	2	89	24	37.04	1.87	140.61	18251.9	512.0	16.0	554.3	303.8
	33-43	79	0	46	0	2	30	18.2	28.84	0.00	28.84	1632.6	512.0	16.0	21.2	230.4
	43-53	107	0	46	7	0	56	18.6	28.84	0.47	44.11	1072.7	0.0	16.0	138.1	173.8
	163-53	100	0	47	21	0	60	22.9	30.76	1.40	93.17	5179.7	0.0	25.0	169.8	229.0
	53-43	107	0	55	0	0	90	33.2	49.30	0.00	49.30	6817.5	0.0	25.0	573.2	310.3
	33-23	79	0	6	51	0	100	20.8	0.06	3.40	54.87	4636.7	0.0	25.0	786.3	263.3
	23-13	79	0	18	0	0	27	11.3	1.73	0.00	1.73	23.4	0.0	25.0	15.5	143.0

NETSIM Traffic Simulation Data - Bayesian Prior																											
Table 4.3: Conversion of NETSIM MOE for Modeling - Model #3 (1-way, 3 lanes, parking prohibited)																											
Street	Network Link	Length (m)	NETSIM Output Statistics - 15 minute simulation					Modelling Variables										Travel Time (sec/veh.km)									
			Vehicle-Trips			Trucks		Total Time (sec/veh)	Q _{obs 1}	Q _h	Q _h	Q _{obs 2}	K _{obs 3}	Q _{obs 4}	HV 2	HV 2	(Stop X Signkm) ¹										
Left	Thru	Right	Trips	(%)	(%)																						
Simulation #1																											
Lyon	1-11	81	0	94	0	3	17	115	246.1	0.0	0.0	246.1	3260.6	144.0	9.0	22.8	142.0										
	11-21	79	11	70	12	3	70	219	101.6	0.8	0.7	238.3	23505.7	144.0	9.0	1588.9	277.2										
	21-31	79	0	122	11	4	3	45	538.0	0.7	0.0	697.1	34482.1	256.0	9.0	422.1	220.3										
	31-41	79	20	130	0	3	3	80	651.0	0.0	1.3	1000.0	111293.4	144.0	9.0	237.6	288.6										
	41-51	101	18	112	5	0	3	20	418.3	0.3	1.2	729.0	7032.0	0.0	9.0	37.1	127.7										
Kent	52-42	102	0	74	162	2	2	87	120.1	10.8	0.0	3894.6	4559183.9	64.0	4.0	3050.5	632.4										
	42-32	79	36	89	0	0	2	72	208.9	0.0	2.4	578.7	57861.4	0.0	4.0	1729.0	278.5										
	32-22	79	23	78	54	0	2	43	140.6	3.6	1.5	1103.4	17903.2	0.0	4.0	388.3	151.9										
	22-12	79	0	110	0	0	2	25	394.4	0.0	0.0	394.4	4664.9	0.0	4.0	72.4	136.7										
	165-55	100	20	135	21	0	2	72	728.0	1.4	1.3	1615.3	165931.7	0.0	4.0	1729.0	281.0										
Metcalfe	55-45	111	0	161	31	0	2	28	1236.5	2.1	0.0	2097.2	34266.3	0.0	4.0	113.0	152.3										
	45-35	79	43	125	0	0	2	92	578.7	0.0	2.9	1404.9	469783.2	0.0	4.0	3607.2	416.5										
	35-25	79	29	72	28	0	2	27	110.6	1.9	1.9	638.1	12821.2	0.0	4.0	81.2	163.3										
	25-15	79	0	88	0	0	2	45	201.9	0.0	0.0	201.9	20744.3	0.0	4.0	422.1	281.0										
	1-11	81	0	88	0	3	3	15	201.9	0.0	0.0	201.9	2808.0	144.0	9.0	15.6	140.7										
Lyon	11-21	79	15	66	7	3	3	60	85.2	0.5	1.0	201.9	9817.0	144.0	9.0	1000.6	219.0										
	21-31	79	0	103	18	4	3	42	323.8	1.2	0.0	524.9	21345.7	256.0	9.0	343.2	206.3										
	31-41	79	14	118	0	3	3	84	488.8	0.0	0.9	681.5	72888.8	144.0	9.0	2745.6	284.8										
	41-51	101	12	113	11	0	3	21	427.5	0.7	0.8	745.3	7189.4	0.0	9.0	42.9	127.7										
	52-42	102	0	53	167	2	2	84	44.1	11.1	0.0	3155.0	4102898.5	64.0	4.0	3847.6	654.9										
Kent	42-32	79	20	88	0	0	2	68	201.9	0.0	1.3	373.2	41540.0	0.0	4.0	1458.6	288.6										
	32-22	79	29	78	34	0	2	41	140.6	2.3	1.8	630.6	15601.3	0.0	4.0	319.3	159.5										
	22-12	79	0	115	0	0	2	25	450.6	0.0	0.0	450.6	5632.0	0.0	4.0	72.4	139.2										
	165-55	100	16	126	33	0	2	67	592.7	2.2	1.1	1588.0	96632.4	0.0	4.0	1393.3	236.0										
	55-45	111	0	150	29	0	2	34	1000.0	1.9	0.0	1699.4	21768.6	0.0	4.0	182.1	152.3										
Metcalfe	45-35	79	44	132	0	0	2	93	681.5	0.0	2.9	1615.3	956265.3	0.0	4.0	3726.1	503.6										
	35-25	79	25	80	32	0	2	25	151.7	2.1	1.7	761.9	8522.1	0.0	4.0	72.4	139.2										
	25-15	79	0	104	0	0	2	24	333.3	0.0	0.0	333.3	5273.9	0.0	4.0	64.0	150.6										
	Simulation #3																										
	Lyon	1-11	81	0	106	0	3	3	8	352.9	0.0	0.0	352.9	2805.8	144.0	9.0	2.4	119.8									
11-21		79	21	77	9	3	3	67	135.3	0.6	1.4	363.0	26512.2	144.0	9.0	1393.3	257.0										
21-31		79	0	117	18	4	3	41	474.6	1.2	0.0	729.0	41951.3	256.0	9.0	319.3	231.6										
31-41		79	28	107	0	3	3	88	363.0	0.0	1.9	729.0	90222.6	144.0	9.0	3156.9	307.6										
41-51		101	15	99	6	0	3	25	287.5	0.4	1.0	512.0	6313.0	0.0	9.0	72.4	136.6										
Kent	52-42	102	0	56	151	2	2	90	52.0	10.1	0.0	2628.1	4817574.6	64.0	4.0	3377.0	734.3										
	42-32	79	17	80	0	0	2	71	151.7	0.0	1.1	2701.9	29701.9	0.0	4.0	1658.0	287.3										
	32-22	79	23	67	49	0	2	33	89.1	3.3	1.5	795.7	13904.4	0.0	4.0	168.5	155.7										
	22-12	79	0	88	0	0	2	21	278.9	0.0	0.0	278.9	3031.4	0.0	4.0	42.9	132.9										
	165-55	100	26	118	28	0	2	68	488.8	1.9	1.7	1507.7	121271.0	0.0	4.0	1458.6	259.0										
Metcalfe	55-45	111	0	145	30	0	2	31	903.3	2.0	0.0	1588.0	25488.6	0.0	4.0	138.0	151.4										
	45-35	79	39	118	0	0	2	92	488.8	0.0	2.6	1146.6	412078.4	0.0	4.0	3607.2	426.6										
	35-25	79	30	57	35	0	2	35	54.9	2.3	2.0	538.0	11885.7	0.0	4.0	198.6	168.4										
	25-15	79	0	77	0	0	2	24	135.3	0.0	0.0	135.3	1690.6	0.0	4.0	64.0	139.2										

Simulation #4		1-11	11-21	21-31	31-41	41-51	51-61	61-71	71-81	81-91	91-101	101-111	111-121	121-131	131-141	141-151	151-161	161-171	171-181	181-191	191-201	201-211	211-221	221-231	231-241	241-251	251-261	261-271	271-281	281-291	291-301	301-311	311-321	321-331	331-341	341-351	351-361	361-371	371-381	381-391	391-401	401-411	411-421	421-431	431-441	441-451	451-461	461-471	471-481	481-491	491-501	501-511	511-521	521-531	531-541	541-551	551-561	561-571	571-581	581-591	591-601	601-611	611-621	621-631	631-641	641-651	651-661	661-671	671-681	681-691	691-701	701-711	711-721	721-731	731-741	741-751	751-761	761-771	771-781	781-791	791-801	801-811	811-821	821-831	831-841	841-851	851-861	861-871	871-881	881-891	891-901	901-911	911-921	921-931	931-941	941-951	951-961	961-971	971-981	981-991	991-1001	1001-1011	1011-1021	1021-1031	1031-1041	1041-1051	1051-1061	1061-1071	1071-1081	1081-1091	1091-1101	1101-1111	1111-1121	1121-1131	1131-1141	1141-1151	1151-1161	1161-1171	1171-1181	1181-1191	1191-1201	1201-1211	1211-1221	1221-1231	1231-1241	1241-1251	1251-1261	1261-1271	1271-1281	1281-1291	1291-1301	1301-1311	1311-1321	1321-1331	1331-1341	1341-1351	1351-1361	1361-1371	1371-1381	1381-1391	1391-1401	1401-1411	1411-1421	1421-1431	1431-1441	1441-1451	1451-1461	1461-1471	1471-1481	1481-1491	1491-1501	1501-1511	1511-1521	1521-1531	1531-1541	1541-1551	1551-1561	1561-1571	1571-1581	1581-1591	1591-1601	1601-1611	1611-1621	1621-1631	1631-1641	1641-1651	1651-1661	1661-1671	1671-1681	1681-1691	1691-1701	1701-1711	1711-1721	1721-1731	1731-1741	1741-1751	1751-1761	1761-1771	1771-1781	1781-1791	1791-1801	1801-1811	1811-1821	1821-1831	1831-1841	1841-1851	1851-1861	1861-1871	1871-1881	1881-1891	1891-1901	1901-1911	1911-1921	1921-1931	1931-1941	1941-1951	1951-1961	1961-1971	1971-1981	1981-1991	1991-2001	2001-2011	2011-2021	2021-2031	2031-2041	2041-2051	2051-2061	2061-2071	2071-2081	2081-2091	2091-2101	2101-2111	2111-2121	2121-2131	2131-2141	2141-2151	2151-2161	2161-2171	2171-2181	2181-2191	2191-2201	2201-2211	2211-2221	2221-2231	2231-2241	2241-2251	2251-2261	2261-2271	2271-2281	2281-2291	2291-2301	2301-2311	2311-2321	2321-2331	2331-2341	2341-2351	2351-2361	2361-2371	2371-2381	2381-2391	2391-2401	2401-2411	2411-2421	2421-2431	2431-2441	2441-2451	2451-2461	2461-2471	2471-2481	2481-2491	2491-2501	2501-2511	2511-2521	2521-2531	2531-2541	2541-2551	2551-2561	2561-2571	2571-2581	2581-2591	2591-2601	2601-2611	2611-2621	2621-2631	2631-2641	2641-2651	2651-2661	2661-2671	2671-2681	2681-2691	2691-2701	2701-2711	2711-2721	2721-2731	2731-2741	2741-2751	2751-2761	2761-2771	2771-2781	2781-2791	2791-2801	2801-2811	2811-2821	2821-2831	2831-2841	2841-2851	2851-2861	2861-2871	2871-2881	2881-2891	2891-2901	2901-2911	2911-2921	2921-2931	2931-2941	2941-2951	2951-2961	2961-2971	2971-2981	2981-2991	2991-3001	3001-3011	3011-3021	3021-3031	3031-3041	3041-3051	3051-3061	3061-3071	3071-3081	3081-3091	3091-3101	3101-3111	3111-3121	3121-3131	3131-3141	3141-3151	3151-3161	3161-3171	3171-3181	3181-3191	3191-3201	3201-3211	3211-3221	3221-3231	3231-3241	3241-3251	3251-3261	3261-3271	3271-3281	3281-3291	3291-3301	3301-3311	3311-3321	3321-3331	3331-3341	3341-3351	3351-3361	3361-3371	3371-3381	3381-3391	3391-3401	3401-3411	3411-3421	3421-3431	3431-3441	3441-3451	3451-3461	3461-3471	3471-3481	3481-3491	3491-3501	3501-3511	3511-3521	3521-3531	3531-3541	3541-3551	3551-3561	3561-3571	3571-3581	3581-3591	3591-3601	3601-3611	3611-3621	3621-3631	3631-3641	3641-3651	3651-3661	3661-3671	3671-3681	3681-3691	3691-3701	3701-3711	3711-3721	3721-3731	3731-3741	3741-3751	3751-3761	3761-3771	3771-3781	3781-3791	3791-3801	3801-3811	3811-3821	3821-3831	3831-3841	3841-3851	3851-3861	3861-3871	3871-3881	3881-3891	3891-3901	3901-3911	3911-3921	3921-3931	3931-3941	3941-3951	3951-3961	3961-3971	3971-3981	3981-3991	3991-4001	4001-4011	4011-4021	4021-4031	4031-4041	4041-4051	4051-4061	4061-4071	4071-4081	4081-4091	4091-4101	4101-4111	4111-4121	4121-4131	4131-4141	4141-4151	4151-4161	4161-4171	4171-4181	4181-4191	4191-4201	4201-4211	4211-4221	4221-4231	4231-4241	4241-4251	4251-4261	4261-4271	4271-4281	4281-4291	4291-4301	4301-4311	4311-4321	4321-4331	4331-4341	4341-4351	4351-4361	4361-4371	4371-4381	4381-4391	4391-4401	4401-4411	4411-4421	4421-4431	4431-4441	4441-4451	4451-4461	4461-4471	4471-4481	4481-4491	4491-4501	4501-4511	4511-4521	4521-4531	4531-4541	4541-4551	4551-4561	4561-4571	4571-4581	4581-4591	4591-4601	4601-4611	4611-4621	4621-4631	4631-4641	4641-4651	4651-4661	4661-4671	4671-4681	4681-4691	4691-4701	4701-4711	4711-4721	4721-4731	4731-4741	4741-4751	4751-4761	4761-4771	4771-4781	4781-4791	4791-4801	4801-4811	4811-4821	4821-4831	4831-4841	4841-4851	4851-4861	4861-4871	4871-4881	4881-4891	4891-4901	4901-4911	4911-4921	4921-4931	4931-4941	4941-4951	4951-4961	4961-4971	4971-4981	4981-4991	4991-5001	5001-5011	5011-5021	5021-5031	5031-5041	5041-5051	5051-5061	5061-5071	5071-5081	5081-5091	5091-5101	5101-5111	5111-5121	5121-5131	5131-5141	5141-5151	5151-5161	5161-5171	5171-5181	5181-5191	5191-5201	5201-5211	5211-5221	5221-5231	5231-5241	5241-5251	5251-5261	5261-5271	5271-5281	5281-5291	5291-5301	5301-5311	5311-5321	5321-5331	5331-5341	5341-5351	5351-5361	5361-5371	5371-5381	5381-5391	5391-5401	5401-5411	5411-5421	5421-5431	5431-5441	5441-5451	5451-5461	5461-5471	5471-5481	5481-5491	5491-5501	5501-5511	5511-5521	5521-5531	5531-5541	5541-5551	5551-5561	5561-5571	5571-5581	5581-5591	5591-5601	5601-5611	5611-5621	5621-5631	5631-5641	5641-5651	5651-5661	5661-5671	5671-5681	5681-5691	5691-5701	5701-5711	5711-5721	5721-5731	5731-5741	5741-5751	5751-5761	5761-5771	5771-5781	5781-5791	5791-5801	5801-5811	5811-5821	5821-5831	5831-5841	5841-5851	5851-5861	5861-5871	5871-5881	5881-5891	5891-5901	5901-5911	5911-5921	5921-5931	5931-5941	5941-5951	5951-5961	5961-5971	5971-5981	5981-5991	5991-6001	6001-6011	6011-6021	6021-6031	6031-6041	6041-6051	6051-6061	6061-6071	6071-6081	6081-6091	6091-6101	6101-6111	6111-6121	6121-6131	6131-6141	6141-6151	6151-6161	6161-6171	6171-6181	6181-6191	6191-6201	6201-6211	6211-6221	6221-6231	6231-6241	6241-6251	6251-6261	6261-6271	6271-6281	6281-6291	6291-6301	6301-6311	6311-6321	6321-6331	6331-6341	6341-6351	6351-6361	6361-6371	6371-6381	6381-6391	6391-6401	6401-6411	6411-6421	6421-6431	6431-6441	6441-6451	6451-6461	6461-6471	6471-6481	6481-6491	6491-6501	6501-6511	6511-6521	6521-6531	6531-6541	6541-6551	6551-6561	6561-6571	6571-6581	6581-6591	6591-6601	6601-6611	6611-6621	6621-6631	6631-6641	6641-6651	6651-6661	6661-6671	6671-6681	6681-6691	6691-6701	6701-6711	6711-6721	6721-6731	6731-6741	6741-6751	6751-6761	6761-6771	6771-6781	6781-6791	6791-6801	6801-6811	6811-6821	6821-6831	6831-6841	6841-6851	6851-6861	6861-6871	6871-6881	6881-6891	6891-6901	6901-6911	6911-6921	6921-6931	6931-6941	6941-6951	6951-6961	6961-6971	6971-6981	6981-6991	6991-7001	7001-7011	7011-7021	7021-7031	7031-7041	7041-7051	7051-7061	7061-7071	7071-7081	7081-7091	7091-7101	7101-7111	7111-7121	7121-7131	7131-7141	7141-7151	7151-7161	7161-7171	7171-7181	7181-7191	7191-7201	7201-7211	7211-7221	7221-7231	7231-7241	7241-7251	7251-7261	7261-7271	7271-7281	7281-7291	7291-7301	7301-7311	7311-7321	7321-7331	7331-7341	7341-7351	7351-7361	7361-7371	7371-7381	7381-7391	7391-7401	7401-7411	7411-7421	7421-7431	7431-7441	7441-7451	7451-7461	7461-7471	7471-7481	7481-7491	7491-7501	7501-7511	7511-7521	7521-7531	7531-7541	7541-7551	7551-7561	7561-7571	7571-7581	7581-7591	7591-7601	7601-7611	7611-7621	7621-7631	7631-7641	7641-7651	7651-7661	7661-7671	7671-7681	7681-7691	7691-7701	7701-7711	7711-7721	7721-7731	7731-7741	7741-7751	7751-7761	7761-7771	7771-7781	7781-7791	7791-7801	7801-7811	7811-7821	7821-7831	7831-7841	7841-7851	7851-7861	7861-7871	7871-7881	7881-7891	7891-7901	7901-7911	7911-7921	7921-7931	7931-7941	7941-7951	7951-7961	7961-7971	7971-7981	7981-7991	7991-8001	8001-8011	8011-8021	8021-8031	8031-8041	8041-8051	8051-8061	8061-8071	8071-8081	8081-8091	8091-8101	8101-8111	8111-8121	8121-8131	8131-8141	8141-8151	8151-8161	8161-8171	8171-8181	8181-8191	8191-8201	8201-8211	8211-8221	8221-8231	8231-8241	8241-8251	8251-8261	8261-8271	8271-8281	8281-8291	8291-8301	8301-8311	8311-8321	8321-8331	8331-8341	8341-8351	8351-8361	8361-8371	8371-8381	8381-8391	8391-8401	8401-8411	8411-8421	8421-8431	8431-8441	8441-8451	8451-8461	8461-8471	8471-8481	8481-8491	8491-8501	8501-8511	8511-8521	8521-8531	8531-8541	8541-8551	8551-8561	8561-8571	8571-8581	8581-8591	8591-8601	8601-8611	8611-8621	8621-8631	8631-8641	8641-8651	8651-8661	8661-8671	8671-8681	8681-8691	8691-8701	8701-8711	8711-8721	8721-8731	8731-8741	8741-8751	8751-8761	8761-8771	8771-8781	8781-8791	8791-8801	8801-8811	8811-8821	8821-8831	8831-8841	8841-8851	8851-8861	8861-8871	8871-8881	8881-8891	8891-8901	8901-8911	8911-8921	8921-8931	8931-89
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NETSIM Traffic Simulation Data - Bayesian Prior																	
Table 4.4: Conversion of NETSIM MOE for Modeling - Model #4 (1-way, 3 mixed lanes & 1 transit lane)																	
Street	Network	Length (m)	NETSIM Output Statistics -15 minute simulation								Modeling Variables						
			Vehicle-Trips		Bus		Trucks		Stops		Total Time		Q _{tr} ³	(Q _{tr} X Q _{bus})	Q _{tr}	Q _{total} ³	K _{total} ³
Left	Thru	Right	Trips	(%)	Trips	(%)	Trips	(%)	(sec/veh)								
Simulation #1																	
Albert	35-34	178	70	183	0	9	4	46	43.1	1815.8	0.0	4.7	4798.3	315359.4	16.0	58.7	242.1
	34-33	181	0	204	0	7	4	22	21.0	2515.5	0.0	0.0	2515.5	18188.0	16.0	6.4	116.0
	33-32	194	0	166	58	7	4	43	31.5	1355.3	108.3	0.0	3330.2	65999.9	16.0	48.0	182.4
	32-31	187	28	169	0	7	4	84	36.3	1430.2	0.0	1.9	2265.3	76712.5	16.0	357.6	194.1
Slater	41-42	192	52	178	0	11	4	91	60.9	1671.0	0.0	3.5	3605.0	532603.7	16.0	454.7	317.2
	42-43	194	1	318	21	13	4	31	24.9	9528.1	72.8	0.1	11645.6	113999.3	16.0	18.0	128.4
	43-44	181	0	310	11	13	4	93	37.6	8827.0	38.1	0.0	9800.3	406738.6	16.0	485.3	207.7
	44-45	177	16	367	0	13	4	28	34.0	14646.2	0.0	1.1	16646.5	546242.8	16.0	13.2	192.1
Simulation #2																	
Albert	35-34	178	86	169	0	8	4	57	43	1430.2	0.0	5.7	4913.0	327413.6	16.0	111.7	243.3
	34-33	181	4	196	0	9	4	28	22.3	2231.0	0.0	0.3	2370.4	20523.0	16.0	13.2	123.2
	33-32	194	0	172	51	7	4	39	28.5	1507.7	95.2	0.0	3285.8	48229.9	16.0	35.8	146.9
	32-31	187	31	161	0	7	4	89	44.8	1236.5	0.0	2.1	2097.2	133501.3	16.0	425.3	239.6
Slater	41-42	192	50	191	0	12	4	94	63.8	2064.6	0.0	3.3	4147.4	704501.5	16.0	501.1	332.3
	42-43	194	4	327	24	14	4	23	32.2	10360.2	89.6	0.3	13256.0	280620.9	16.0	7.3	166.0
	43-44	181	0	318	14	13	4	96	37	9528.1	48.5	0.0	10842.8	428801.4	16.0	533.8	204.4
	44-45	177	22	351	0	13	4	32	24.4	12812.9	0.0	1.5	15376.3	186487.0	16.0	19.8	137.9
Simulation #3																	
Albert	35-34	178	60	192	0	8	4	54	57.5	2097.2	0.0	4.0	4741.6	739976.0	16.0	95.0	323.0
	34-33	181	2	223	0	9	4	24	21.5	3285.8	0.0	0.1	3375.0	26187.8	16.0	8.3	118.8
	33-32	194	0	187	59	9	4	39	26.4	1937.5	141.6	0.0	4410.9	51461.7	16.0	35.8	136.1
	32-31	187	24	175	0	7	4	85	35.5	1588.0	0.0	1.6	2335.0	73959.2	16.0	370.5	189.8
Slater	41-42	192	47	213	0	12	4	93	93.6	2863.3	0.0	3.1	5207.7	2793292.2	16.0	485.3	487.5
	42-43	194	4	334	26	14	4	36	39.6	11039.9	97.1	0.3	14289.9	562674.2	16.0	28.1	204.1
	43-44	181	0	315	16	13	4	96	37	9261.0	55.5	0.0	10745.1	424938.3	16.0	533.8	204.4
	44-45	177	14	367	0	13	4	27	31.1	14646.2	0.0	0.9	16387.1	411536.9	16.0	11.9	175.7
Simulation #4																	
Albert	35-34	178	55	185	0	7	2	45	48.2	1876.0	0.0	3.7	4096.0	376519.4	4.0	55.0	270.8
	34-33	181	2	198	0	7	2	20	19.7	2300.0	0.0	0.1	2370.4	14149.0	4.0	4.8	108.8
	33-32	194	0	171	48	7	2	32	23.9	1481.5	89.6	0.0	3112.1	26939.7	4.0	19.8	123.2
	32-31	187	23	172	0	7	2	90	35.7	1507.7	0.0	1.5	2197.0	70771.1	4.0	439.8	190.9
Slater	41-42	192	45	214	0	11	2	89	46.1	2903.8	0.0	3.0	5147.8	329891.3	4.0	425.3	240.1

42-43	194	2	357	24	12	2	23	28.9	13481.3	76.8	0.1	16646.5	254775.2	4.0	7.3	149.0
43-44	181	0	349	15	12	2	96	38.7	12595.1	48.0	0.0	14289.9	846656.7	4.0	533.8	213.8
44-45	177	19	383	0	12	2	21	33	16646.5	0.0	1.3	19248.8	577527.5	4.0	5.6	186.4
Simulation #5																
Albert	35-34	178	51	169	0	9	43	50.4	1430.2	0.0	3.4	3155.0	331567.6	9.0	48.0	283.1
	34-33	181	1	194	0	7	23	20.9	2163.4	0.0	0.1	2197.0	15659.6	9.0	7.3	115.5
	33-32	194	0	189	33	7	25	22.3	2000.4	61.6	0.0	3241.8	22785.1	9.0	9.4	114.9
	32-31	187	24	191	0	7	89	40.4	2064.6	0.0	1.6	2944.7	137469.7	9.0	425.3	216.0
Slater	41-42	192	45	175	0	11	92	79.5	1588.0	0.0	3.0	3155.0	1036903.2	9.0	469.8	414.1
	42-43	194	2	325	23	13	28	24.2	10171.3	79.7	0.1	12703.7	114160.9	9.0	13.2	124.7
	43-44	181	0	310	19	13	94	37.5	8827.0	65.9	0.0	10551.5	434428.4	9.0	501.1	207.2
	44-45	177	27	348	0	13	26	22.2	12487.2	0.0	1.8	15625.0	142726.8	9.0	10.6	125.4
Simulation #6																
Albert	35-34	178	58	181	0	8	56	99.1	1757.0	0.0	3.9	4045.0	3231670.9	64.0	106.0	556.7
	34-33	181	0	205	0	9	21	21.6	2552.6	0.0	0.0	2552.6	20084.4	64.0	5.6	119.3
	33-32	194	0	176	53	9	43	29	1615.3	127.2	0.0	3558.2	55026.0	64.0	48.0	149.5
	32-31	187	26	170	0	7	82	39.5	1455.7	0.0	1.7	2231.0	97343.5	64.0	332.7	211.2
Slater	41-42	192	43	153	0	11	97	188	1061.2	0.0	2.9	2231.0	8696400.5	64.0	550.7	979.2
	42-43	194	1	283	17	13	24	22.9	6715.6	58.9	0.1	8080.3	61528.1	64.0	8.3	118.0
	43-44	181	0	280	9	13	96	37.2	6504.3	31.2	0.0	7151.9	287447.9	64.0	533.8	205.5
	44-45	177	14	340	0	13	24	21.3	11645.6	0.0	0.9	13144.3	106047.7	64.0	8.3	120.3

CHAPTER 5

FIELD DATA COLLECTION

In order to supplement the travel time estimates generated by the NETSIM simulation for Bayesian regression, a field data acquisition scheme was devised. This data acquisition scheme (or traffic study) consisted of the following primary activities;

1. Data Collection
2. Data Reduction
3. Analysis

Data collection consists of those tasks associated with the observation and recording of data in the field. Most data collection is done manually (such as turning volumes at an intersection, pedestrian counts, etc..) since they are difficult to accurately obtain in any other fashion. Some types of data can be “observed” by various detection devices (e.g. speeds are often measured by radar). A third method of data collection is videotape. Videotaping has one major advantage over other data acquisition methods: the tape can be reviewed many times, and at reduced speed if desired. This allows for larger sample sizes and greater accuracy (McShane 1990, p. 72). Videotape technology was used in this research study to obtain the necessary field data.

Data reduction involves taking the information in the form recorded in the field and manipulating it into a form which can be interpreted and analyzed. The reduction of videotape involves the entire process of extracting information from the tape and recording it in computer files for manipulation. While the cost of data collection is usually lowest when videotape is used, the cost of data reduction is often higher. The picture is taken in the field, but the “observation”

of the data is done as part of the laboratory reduction procedure (McShane and Roess 1990, p. 72).

Data analysis is the functional interpretation of field data in order to understand the observed situation. This analysis can involve examining the data for trends, using the data for forecasting, or evaluating the relationships between various traffic parameters using multiple linear regression and other types of statistical analyses (McShane and Roess 1990, p. 72).

An overview of the traffic study conducted for this research project is illustrated in Figure 5.1.

5.1 Traffic Study Using Video Technology

Study sites were selected in the Ottawa Central Business District which were inside the NETSIM simulated network and which encompass the four street configurations being modelled: 1) One-way, two lanes, with parking, 2) One-way, one lane, without parking, 3) Two-way, three lanes, with parking, and 4) Two-way, three mixed lanes and one bus lane, without parking.

As mentioned, the video technology was employed to record the traffic patterns for the following reasons;

- provides a continuous, real-time, permanent record of all activity on the street
- is extremely cost-effective when compared to other real-time traffic monitoring devices
- the videocassette recorders, playback machines, and cassettes can be purchased or rented with no difficulty or delay
- the equipment is very easy to operate and transport to different locations

FIGURE 5.1: Flowchart - Field Data Collection Using Video Technology

- the video cassettes can be examined at reduced speeds or paused, which is useful in extracting a lot of information from one frame (McShane and Roess 1990)
- Although video has many advantages over other traffic data collection methods, extracting the desired information from the videotape (data reduction) is very time consuming. It has been estimated that each hour of videotape requires 10 hours of reduction/analysis time (McShane and Roess 1990)

5.2 Site Selection and Traffic Monitoring

In order to carry out the field investigation, it was necessary to locate suitable high rise buildings from which an unobstructed view of the streets below could be achieved. Once these buildings were identified, the building superintendent was approached for permission to carry out the experiment. The next step involved visiting the buildings in question and deciding on the most suitable floor, and the optimal viewing points.

Two buildings were selected for this experiment: Transport Canada at Place de Ville Towers, and the Metropolitan Life building. Figures 5.2 and 5.3 illustrate the experimental sites and the camera locations. From the Transport Canada offices on the 26th floor, two video cameras were set up to record traffic flows on Queen Street from Kent to O'Connor (viewpoint A in Figure 5.2), and on Lyon Street from Albert to Laurier (viewpoint B).

Three video cameras were used on floor 12 of the Metropolitan Life building. The sites of interest included Queen Street from O'Connor to Elgin (viewpoint C on Figure 5.3), Albert Street from O'Connor to Elgin (viewpoint D), and Bank Street from Slater to Lisgar (viewpoint E).

FIGURE 5.2: Videocamera Locations & Filmed Streets

FIGURE 5.3: Videocamera Locations & Filmed Streets

Table 5.1 shows the name and type of the selected streets, the date and time of filming, as well as the potential number of observations for modelling purposes.

Table 5.1: Overview of Field Observations by Video

Street	Street Type	From/To	# of Links	Length (m)	Date	Film Time (peak periods)	Potential Obs. for Modelling ¹
Queen	2-way, 2 lanes, parking	Kent to O'Connor	2	374	June 6-8	am: 4.5 hrs pm: 4.5 hrs	18 18
Queen	2-way, 2 lanes, parking	O'Connor to Elgin	2	370	June 13-15	am: 4.5 hrs pm: 4.5 hrs	18 18 <u>72</u>
Bank	2-way, 1 lane, no parking	Slater to Lisgar	4	350	June 13-15	am: 4.5 hrs pm: 4.5 hrs	27 27 <u>54</u>
Lyon	1-way, 3 lanes, no parking	Albert to Laurier	2	180	June 6-8	am: 4.5 hrs pm: 4.5 hrs	18 18 <u>36</u>
Albert	1-way, 3 mixed lanes, 1 bus lane	Elgin to O'Connor	2	355	June 13-15	am: 4.5 hrs pm: 4.5 hrs	18 18 <u>36</u>
						45 hours	198

NOTES: 1: Potential number of observations based on extracting average values from the video at every 15 minute interval; i.e. each 1½ hour peak period would produce 6 observations (on Bank Street, observations were obtained at 10 minute intervals)

As can be seen in Table 5.1, all of the field data were collected during peak hour traffic conditions, either from 7:30-9:00 or 16:00-17:30, since the peak travel parameters are key factors in planning, design, and maintenance of urban street networks. Furthermore, all of the filming was conducted on Tuesdays, Wednesdays, and Thursdays because it has been shown that the middle part of the week is the optimal time for urban traffic studies due to minimal variations in commuter traffic (TRB HCM 1985). Also, the test dates (i.e. early June) were chosen so that the effect of traffic variations due to vacationers would be insignificant.

It is interesting to note that in actual fact, on Queen St., "No Parking" signs were in evidence for the peak periods (i.e. 7:00-9:00, 15:30-17:30). However, after reviewing the videotape evidence, numerous vehicles were parked on the far right lane along the stretch of the road under study, which had the effect of rendering this lane non-useable for traffic flow for the majority of the peak periods observed. Consequently to predict travel time under real world conditions, it was decided to model this road as if parking were permitted.

5.3 Video Data Reduction and Analysis

This Section will explain the technique employed to extract the necessary data from the video cassettes, and will demonstrate the conversion of this extracted data into modelling variables to be used for Bayesian regression analysis.

Once filming was completed at the different locations and times previously described, the specific information needed for modelling had to be extracted from the video cassettes. The cassettes were viewed on a video cassette recorder (VCR) with 4-heads to ensure a clear picture, particularly when pausing. This data reduction task was found to be extremely time consuming, requiring almost 5 times as much time as the actual set up and filming of the city streets. Also, on particularly sunny days the street shadows from adjacent buildings made it difficult to follow vehicles of a dark shade on the videotape. For the preceding reasons, only 22.5 hours out of the total 45 hours of video tape were extracted for modelling, that is, 99 out of a possible 198 observations (refer to Table 5.1).

The procedure that was established to extract each of the modelling variables from the video cassettes is explained as follows;

VIDEO SCREENING #1

variables extracted: q_{thr} , q_{lt} , q_{rt} , q_{bus} HV, for link 1

procedure: -view point for the first screening is in the centre of the first intersection (i.e. the end of link #1) ;

-at this view point, count the number of vehicles going “through”, “left”, and “right” at the intersection, over the defined time period (10 minutes for Bank Street, 5 minutes for all of the other streets);

-in the preceding count, the number of cars was differentiated from transit buses and heavy vehicles;

-each of the flow values are calculated as: number of vehicles (cars and heavy vehicles) per time period, to obtain “vehicles per minute”;

-total # of buses are converted to “buses per hour”;

-total # of heavy vehicles are converted to a “percentage of total vehicles”

-all values are averaged over 15 minutes for modelling purposes (except for Bank St. where 10 minutes is used).

VIDEO SCREENING #2

variables extracted: q_{thr} , q_{lt} , q_{rt} , q_{bus} HV for link 2

procedure: -view point for the 2nd screening is in the centre of the second intersection (i.e. the end of link #2);

-same procedure as screening #1

VIDEO SCREENING #3

variables extracted: dependent variable, Travtime

procedure: -vehicles entering link 1 were selected at random and tracked until exiting link 2 (approximately one random vehicle was selected each minute);

- the time for each vehicle to traverse the distance of both links is documented (this task was made much easier due to previous recording of the date and time on the portable videocamera picture when filming);
- travel times are averaged for the 15 minute time period (except for Bank St. where 10 minutes is used) resulting in the units “seconds/vehicle”;
- the average travel time is then divided by the length of the two links (from centre of intersection to centre of intersection) resulting in the modelling units “seconds/vehicle-kilometer”.

VIDEO SCREENING #4

variables extracted: Stop

procedure: -by viewing both links at the same time, count the number of vehicles (including buses and heavy vehicles) that come to a complete stop at least once on each link, for each 5 minute time period (except for Bank St. where 10 minutes is used).

-compute a percentage by dividing the number of vehicles stopped over the total number of vehicles, and then average for both links;

–the average “% Stopped” over 15 minutes is used for modelling except for Bank St. where 10 minutes is used).

All of the raw data extracted from the video are shown in Appendix C. Data for each link are included (vehicle counts for left, through, right, bus, and heavy vehicle traffic, # of vehicles stopped at least once) along with observations of travel time through 2 or 3 links. Tables 5.2 to 5.5 contain the video data after being converted into the required modelling variables.

Table 5.2: Field Observations - Queen St.														
Field Data - for Bayesian Regression														
Video Cassette Observations														
Street	Date	Modeling Variables												
		Time	Q _{rr}	Q _{l1}	Q _{l2}	Q _{bus}	HV	Stop	Q _{rr} ³	Q _{l1}	Q _{l2}	Q _{bus} ³	K _{total} ³	TravTime
Queen	June 6	16:00-16:15	8.0	1.30	0.00	8	3.43	79.1	512	1.30	0.00	804.4	51089.8	239.4
		16:15-16:30	7.2	1.50	0.00	16	2.45	76.3	373.25	1.50	0.00	658.5	33967.9	223.4
		16:30-16:45	6.3	1.77	0.00	4	1.77	70.4	246.1	1.77	0.00	518.4	16099.1	188.6
		16:45-17:00	8.3	1.73	0.00	14	1.25	95.8	564.93	1.73	0.00	1000.0	67424.8	244.2
		17:00-17:15	7.6	2.03	0.00	12	0.00	99.0	438.98	2.03	0.00	894.0	78326.9	266.5
Queen		17:15-17:30	6.3	1.77	0.00	16	1.87	95.0	246.49	1.77	0.00	519.7	50063.8	275.0
	June 7	16:00-16:15	7.6	2.07	0.00	12	0.69	96.7	444.78	2.07	0.00	912.7	64410.1	248.0
		16:15-16:30	7.0	1.50	0.00	16	2.59	95.6	343	1.5	0.00	614.1	45623.0	252.2
		16:30-16:45	8.1	1.53	0.00	8	3.30	87.4	531.44	1.53	0.00	894.0	59750.2	243.5
		16:45-17:00	6.5	1.97	0.00	4	2.15	71.9	270.42	1.97	0.00	599.8	27244.9	214.1
Queen		17:00-17:15	7.3	1.63	0.00	16	2.34	76.7	389.02	1.63	0.00	712.9	35127.2	220.0
		17:15-17:30	8.5	1.73	0.00	16	1.21	82.6	621.38	1.73	0.00	1082.2	56897.3	224.8
	June 13	16:00-16:15	5.6	2.13	0.67	4	3.05	83.8	172.5	2.13	0.67	585.7	24248.3	207.6
		16:15-16:30	5.1	1.83	0.50	16	2.54	74.3	132.65	1.83	0.50	410.7	13511.7	192.3
		16:30-16:45	7.4	1.83	0.43	14	1.13	81.9	405.22	1.83	0.43	903.3	58858.9	241.4
Queen		16:45-17:00	5.4	1.73	0.40	4	0.95	84.3	154.57	1.73	0.40	421.9	20139.6	217.7
		17:00-17:15	5.3	1.87	0.50	12	1.59	94.1	146.09	1.8667	0.5	444.8	38417.9	265.2
		17:15-17:30	6.6	1.73	0.67	12	1.45	88.3	287.5	1.73	0.67	729.0	47183.4	240.9
	June 14	16:00-16:15	6.6	1.93	0.63	12	2.84	87	283.16	1.93	0.63	761.9	50202.1	242.3
		16:15-16:30	5.8	1.80	0.47	16	3.12	84	195.11	1.80	0.47	524.9	22188.3	209.0
Queen		16:30-16:45	5.2	1.83	0.43	14	1.53	80	137.92	1.83	0.43	410.7	14011.7	194.6
		16:45-17:00	5.4	1.80	0.40	12	1.75	85	154.57	1.80	0.40	433.2	19770.7	214.4
		17:00-17:15	7.0	2.17	0.47	16	2.97	81	338.12	2.17	0.47	884.7	60535.8	245.4
		17:15-17:30	6.5	1.93	0.57	20	3.43	89	270.42	1.93	0.57	720.9	45725.1	239.3

Table 5.3: Field Observations - Bank St.																	
Field Data - for Bayesian Regression																	
Video Cassette Observations																	
Obs. #	Street	Date	Time	q _{th}	q _{rt}	q _{bus}	HV	Stop	q _{thr} ³	q _{rt}	q _{total} ³	k _{total} ³	q _{bus} ³	HV ²	(Stop X Sigpkm) ³	TravTime	
1	Bank	June 13	16:00-16:10	3.25	1.50	18	3.82	57.2	34.3	1.50	107.2	1739.8	5832.0	14.58	147.0	151.9	
2			16:10-16:20	3.85	1.10	6	3.81	43.6	57.1	1.10	121.3	1503.0	216.0	14.54	65.3	138.8	
3			16:20-16:30	4.70	1.40	36	1.47	55.0	103.8	1.40	227.0	5197.9	46656.0	2.17	130.6	170.4	
4			16:30-16:40	4.10	1.40	24	0.00	48.2	68.9	1.40	166.4	2481.5	13824.0	0.00	88.3	147.7	
5			16:40-16:50	4.65	1.40	12	2.34	56.3	100.5	1.40	221.4	7335.1	1728.0	5.49	139.9	192.7	
6			16:50-17:00	4.80	1.40	18	2.99	58.3	110.6	1.40	238.3	5311.2	5832.0	8.93	155.5	168.8	
7			17:00-17:10	4.35	1.30	36	0.00	61.6	82.3	1.30	180.4	6565.1	46656.0	0.00	184.0	198.8	
8			17:10-17:20	5.25	1.20	24	0.00	38.8	144.7	1.20	268.3	4943.1	13824.0	0.00	46.1	158.5	
9			17:20-17:30	4.00	0.75	30	0.94	50.0	64.0	0.75	107.2	1833.9	27000.0	0.89	98.3	154.6	
10	Bank	June 14	16:00-16:10	4.45	1.65	30	2.94	41.9	88.1	1.65	227.0	3546.6	27000.0	8.65	57.9	150.0	
11			16:10-16:20	5.50	1.25	12	1.42	50.9	166.4	1.25	307.5	8145.1	1728.0	2.02	103.9	178.8	
12			16:20-16:30	3.70	1.40	30	5.10	48.3	50.7	1.40	132.7	3445.6	27000.0	25.99	88.6	177.7	
13			16:30-16:40	4.10	1.90	0	3.96	43.7	68.9	1.90	216.0	3323.3	0.0	15.70	65.7	149.2	
14			16:40-16:50	5.40	1.45	36	2.62	54.2	157.5	1.45	321.4	11430.1	46656.0	6.86	125.3	197.3	
15			16:50-17:00	3.50	1.55	30	4.30	34.5	42.9	1.55	128.8	1090.9	27000.0	18.46	32.4	122.3	
16			17:00-17:10	4.05	1.45	12	1.73	40.5	66.4	1.45	166.4	2184.0	1728.0	2.99	52.2	141.5	
17			17:10-17:20	3.70	0.85	30	0.00	40.7	50.7	0.85	94.2	992.5	27000.0	0.00	53.1	131.5	
18			17:20-17:30	4.15	1.40	24	2.43	45.5	71.5	1.40	171.0	1881.5	13824.0	5.93	74.0	133.5	
19	Bank	June 15	16:00-16:10	5.70	1.10	42	1.32	55	185.2	1.10	314.4	11645.6	74088.0	1.73	127.9	200	
20			16:10-16:20	5.65	1.40	30	1.31	52	180.4	1.40	350.4	11746.2	27000.0	1.71	108.2	193.5	
21			16:20-16:30	5.20	1.55	36	1.99	49	140.6	1.55	307.5	7186.9	46656.0	3.97	94.4	171.5	
22			16:30-16:40	5.05	1.15	30	3.63	44	128.8	1.15	238.3	4232.4	27000.0	13.16	69.1	156.5	
23			16:40-16:50	3.85	1.15	12	2.80	42	57.1	1.15	125.0	1387.6	1728.0	7.81	58.3	133.8	
24			16:50-17:00	5.45	1.35	24	2.70	47	161.9	1.35	314.4	6911.9	13824.0	7.31	83.4	168.1	
25			17:00-17:10	4.60	1.35	24	3.06	44	97.3	1.35	210.6	3092.9	13824.0	9.33	68.2	146.9	
26			17:10-17:20	4.20	0.80	18	1.85	42	74.1	0.80	125.0	1601.1	5832.0	3.43	57.0	140.4	
			17:20-17:30	4.90	1.25	18	3.01	46	117.6	1.25	232.6	3469.3	5832.0	9.05	75.6	147.7	

Table 5.5: Field Observations - Albert St.																	
Field Data - for Bayesian Regression																	
Video Cassette Observations																	
Obs. #	Street	Date	Time	q _{tr}	q _n	q _k	q _{bus}	HV	Slop	q _{tr} ³	(q _{bus} X q _n)	q _k	q _{total} ³	k _{total} ³	HV ²	(Stop X Sigpkm) ³	Trav/Time
1	Albert	June 13	16:00-16:15	8.53	0.13	2.63	156	1.68	51.9	621.4	20.8	2.6	1441.6	18203.6	2.84	84.2	139.7
2			16:15-16:30	8.40	0.10	2.37	128	2.01	49.6	592.7	12.8	2.4	1284.4	15006.9	4.04	73.6	136.2
3			16:30-16:45	8.80	0.23	2.53	144	1.92	50.7	681.5	33.1	2.5	1544.8	19506.5	3.69	78.6	139.7
4			16:45-17:00	8.23	0.23	2.20	208	0.68	47.2	557.4	47.8	2.2	1211.4	13125.5	0.46	63.4	132.8
5			17:00-17:15	8.40	0.20	3.00	160	1.14	53.5	592.7	32.0	3.0	1560.9	21426.2	1.30	92.4	143.7
6			17:15-17:30	7.67	0.03	2.27	156	1.11	45.3	451.2	4.7	2.3	991.0	10156.7	1.23	56.1	130.3
7	Albert	June 14	16:00-16:15	8.80	0.27	2.23	236	0.87	47.3	681.5	63.7	2.2	1442.9	19497.4	0.76	63.8	142.9
8			16:15-16:30	8.17	0.10	2.90	152	1.18	56.5	545.3	15.2	2.9	1393.7	21796.5	1.39	108.8	150.0
9			16:30-16:45	8.30	0.27	2.53	148	2.07	52.4	571.8	40.0	2.5	1367.6	19293.4	4.28	86.8	145.0
10			16:45-17:00	7.67	0.30	2.10	168	1.57	42.7	451.2	50.4	2.1	1021.1	10420.2	2.46	47.0	130.1
11			17:00-17:15	8.57	0.10	2.30	148	2.01	51.0	629.4	14.8	2.3	1320.1	18768.5	4.04	80.0	145.4
12			17:15-17:30	8.43	0.30	2.37	152	1.92	48.2	599.1	45.6	2.4	1367.6	16514.6	3.69	67.6	137.7
13	Albert	June 15	16:00-16:15	8.20	0.17	2.43	148	1.99	48.1	551.4	25.2	2.4	1259.7	14177.4	3.96	67.1	134.5
14			16:15-16:30	7.93	0.20	2.37	148	1.59	45.0	498.7	39.2	2.4	1157.6	12437.2	2.53	55.0	132.4
15			16:30-16:45	8.30	0.27	2.27	196	0.84	48.3	571.8	40.0	2.3	1273.8	15068.5	0.71	68.0	136.7
16			16:45-17:00	8.23	0.13	2.87	148	1.50	53.1	557.4	21.3	2.9	1416.2	18540.1	2.25	90.3	141.4
17			17:00-17:15	8.63	0.27	2.67	164	1.63	50.8	642.7	40.0	2.7	1548.8	21094.1	2.66	79.1	143.3
18			17:15-17:30	7.67	0.20	2.20	148	1.84	46.3	451.2	29.6	2.2	1021.1	10556.1	3.39	59.9	130.7
19	Albert	June 13	7:30-7:45	9.73	0.17	2.77	148	2.60	47.7	922.1	24.7	2.8	2032.3	28006.6	6.77	65.7	143.8
20			7:45-8:00	9.50	0.10	2.73	172	2.48	53.7	857.4	17.2	2.7	1874.5	22084.1	6.15	93.4	136.5
21			8:00-8:15	10.13	0.20	2.33	176	2.46	51.8	1039.5	35.2	2.3	2029.1	35831.0	6.05	83.9	156.2
22			8:15-8:30	8.67	0.20	2.63	188	1.50	49.0	651.7	37.6	2.6	1520.9	15452.5	2.25	71.0	130.0
23			8:30-8:45	10.53	0.13	2.63	200	0.98	53.2	1167.6	26.0	2.6	2347.3	38675.3	0.96	90.8	152.7
24			8:45-9:00	9.10	0.13	3.07	144	1.72	50.9	753.6	18.7	3.1	1860.9	22655.0	2.96	79.6	138.0

As mentioned this video data reduction task was much more time consuming than had been expected. Since the traffic was filmed during peak periods, there were often traffic queues at the intersections which required a great deal of concentration to count the number of vehicles on the video screen. Originally, it was intended to extract the "Stop" variable during screening #1 and #2 but as soon as the flow became too high, it was impossible to keep track of the turning movements, vehicle types, and the stopped vehicles in only one screening.

The following suggestions are offered for similar video data collection work in the future;

- select a video recording location only as high as necessary to view two complete links of the arterial (the higher the camera, the smaller the vehicles will appear on the screen making it difficult to count especially on link #2);
- use a quality video recorder and record on Standard Play (SP) speed to obtain the clearest picture possible (Extended Play (EP) has a faster tape speed so it stores more information for the same tape surface; however it reduces the picture's clarity as compared to standard play);
- only film on a clear day with enough sunlight to illuminate the street (even on a clear day, it is sometimes difficult to see the end of link 2);
- avoid particularly bright sunny days if the street under study is located adjacent to high buildings as these will cast heavy shadows on the viewing zone;
- record the date and time when filming with the portable video recorder (this is essential for later identification of the cassettes and for calculating travel time);
- use a quality VCR with 4 heads, and view the video on the largest television screen available (this will help avoid eye strain from extended viewing).

CHAPTER 6

EXECUTION OF BAYESIAN REGRESSION ANALYSIS

This Chapter describes the execution and results of the Bayesian regression analysis conducted on the traffic models defined in Chapter 3. Section 6.1 leads the reader through the preparation of the input data required by XLBAYES. Section 6.2 explains the criteria upon which the interpretation and evaluation of the Bayesian regression results will be made. In Sections 6.3 to 6.6, the modelling results are presented along with detailed interpretive evaluations, for each of the four street types under study. The different iterations that were attempted to improve on the previous mathematical formulation are described. And finally, Section 6.7 provides an outline of the final models. Appendix D contains the detailed statistical output related to the final models.

6.1 Input and Execution of the XLBAYES Program

As described in Section 2.4 of this report, XLBAYES, version 1.11 (Vemax Management Inc. 1994) is an add-in module to Microsoft EXCEL 5.0 that performs Bayesian Regression according to the concepts and formulas outlined in Chapter 2 (the Bayesian regression formulas are derived in Appendix B). XLBAYES runs within EXCEL by using the built-in *Microsoft Visual Basic computer programming language* which is capable of producing sophisticated programs in a Windows-based environment.

Anyone familiar with EXCEL should have little difficulty running XLBAYES. After loading the program and opening a file, the EXCEL start-up screen appears with an additional menu item called XLBAYES. The step-by-step procedure for performing a Bayesian regression analysis with XLBAYES can be found in, "The Mechanics of Running XLBAYES Version 1.11" (Vemax Management Inc.

1994). As the title suggests, this document concentrates on the “mechanics” of using the software and does not offer any discussion on Bayesian regression concepts and philosophy.

After the XLBAYES menu item is selected, the program prompts the user to define the spreadsheet ranges containing the two data sources required for Bayesian regression:

- 1) the ‘a priori’ information, and
- 2) the experimental data.

1) A Priori Information

As illustrated in Figure 2.2, XLBAYES requires the following prior input parameters (i.e. “the prior”) in order to perform Bayesian regression according to the equations in Appendix B:

- *vector of prior regression coefficients* (b_{prior})
- *variance/covariance matrix of the prior coefficients* ($\text{var/cov}_{\text{prior}}$)
- *degrees of freedom* (v_{prior})
- *variance of the residuals* ($\text{Se}^2_{\text{prior}}$)

The preceding parameters have been coined “the prior”, and they can be obtained by various means as discussed in Section 2.2.1.

As explained in Section 2.2, for this thesis a *model-based* prior was utilized so that the “G-Prior” option was selected within XLBAYES. The user can then run conventional regression analysis on the converted NETSIM MOE (Tables 4.1 to 4.4) to produce: b_{prior} and $\text{Se}^2_{\text{prior}}$. The degrees of freedom (v_{prior}) of the prior information is simply the number of observations (in Tables 4.1 to 4.4) minus the number of independent variables, minus one; i.e. $n-k-1$. At this point, the user “ranges-in” the location of b_{prior} , $\text{Se}^2_{\text{prior}}$, and v_{prior} . Concerning the variance/covariance matrix, XLBAYES has a feature whereby an independent

data set (X's of NETSIM MOE) can be specified in order to automatically derive $\text{var/cov}_{\text{prior}}$. The last prior input is the G-Prior factor which weighs the prior versus the data in the Bayesian posterior formulas (see Section 2.2).

2) Experimental Data

The input requirements for the experimental data are much more straightforward than with the prior information. All that XLBAYES requires from the user are the spreadsheet ranges of the 'y' and 'x' data.

Once the input information is specified and the execute button is pressed, XLBAYES performs the Bayesian regression calculations and writes the resulting models and statistics to an output file. For comparison purposes, a complete statistical summary is provided for each of the:

- prior information,
- experimental data, and
- Bayesian posterior (i.e. combination of prior and data)

The XLBAYES output includes:

- **Probability Density Function (pdf) curves**; normal probability distribution of the value of each coefficient; x-axis represents the value of the regression coefficient while the spread of the curve indicates the standard deviation from the mean value of the coefficient.
- **precision matrix**; used in the Bayesian regression formulas to weigh the prior versus the data
- **variance/covariance matrix**; diagonal terms indicate the variances between regression coefficients while the other terms indicate the covariances between coefficients
- **correlation matrix**; indicates the degree of correlation between each independent variable (diagonal terms = 1; value of 0 = no correlation between the 2 variables; values of -1 or +1 = perfect correlation)

- **regression coefficient means** and associated statistics; t-statistic and standard deviation
- **model residual variance** (Se^2); it is the standard error of the model squared; represents the dispersion in the data set
- **degrees of freedom**; defines the number of knowns minus the number of constraints (i.e. # of observations - # of independent variables - 1 for the constant)
- **G-Prior value** (for the prior model only); factor specified by the user to increase or decrease the influence of the prior in the calculation of the posterior model statistics; a value of 1 was used in this thesis

The “data” model statistics are identical to what would have been obtained from a classical regression analysis on the experimental data. The “prior” model is a regression equation based solely on the output from the NETSIM traffic simulation. The “posterior” model statistics (formulas shown in Section 2.2) reflect both information sources according to Bayes’ Theorem. Specific detail on the modelling results and their interpretation are provided in Sections 6.3 to 6.6.

6.2 Criteria for Judging Bayesian Regression Results

In Section 6.3 to 6.6, the Bayesian modelling results are evaluated for the four street configurations under study. The prior, data, and posterior models are assessed based on the following criteria:

- i. **Model statistics**
 - ⇒ coefficient of multiple determination, R^2
 - ⇒ standard error, Se
- ii. **Coefficient statistics**
 - ⇒ rationality of the sign,
 - ⇒ statistical significance of the coefficient,
 - ⇒ intercorrelation amongst variables,

(i) Model Statistics

The **coefficient of multiple determination, R^2** , (R is the correlation coefficient) is equal to the percentage of the total variation of the dependent variable that can be explained by the independent variables (i.e. by the regression equation). As such, it is a frequently used value to verify the “goodness of fit” of the regression equation. However, “it is difficult to use R^2 to judge the relative fitness of the Bayesian posterior regression model due to the dilemma associated with selecting the appropriate ‘test set’ to judge it against. It seems irrational to judge the model against the field data alone, as it was previously concluded that the number of field observations was insufficient to make reasonable predictions; hence the reason a Bayesian approach to modelling was adopted in the first place. Ideally, it would have been preferred to judge the model against independent, objective (i.e. data not used in the analysis) observations which were collected under stringent quality control; however, this source of data was not available. A seemingly viable hypothesis in judging the relative fitness of the posterior model is to assume that both the field data and the simulated data are *equally representative* of the traffic system being modeled; then the fitness of the posterior model can be judged across the combined prior and data set. Making this assumption, it becomes possible to make general conclusions about the fit of the Bayesian model using R^2 ” (Kajner et al. 1996).

The **standard error of the model, S_e** , represents the expected variation in the estimate of the dependent variable. It is preferred by some analysts over the correlation coefficient because it has the same units as the dependent variable and its magnitude is a physical indicator of the error.

(ii) Coefficient Statistics

When evaluating the acceptability of a regression model, it is essential to assess the **rationality of the mathematical sign** which is a subjective check based on the analyst's prior notion of what the sign should be, positive or negative. Often the sign of the coefficient is dictated by common sense.

A popular method of assessing the statistical significance of the regression coefficients is the **"student t-distribution test"**. The t-test verifies the significance of the coefficients according to the following hypotheses (Koutsoyiannis 1978, pp. 88-89):

$$H_0: b = 0, \quad t < |\alpha_{0.025}|$$

$$H_1: b \neq 0, \quad t \geq |\alpha_{0.025}|$$

Using a two-tail test of the null hypothesis at a 5 percent level of significance, if the t-stat is greater than 2 (or smaller than -2), we reject the null hypothesis, that is the coefficient is significantly different than zero. On the other hand, if the observed t-stat is smaller than 2 (but greater than -2), we accept the null hypothesis, that is the independent variable is statistically insignificant.

The **correlation matrix** provides an indication of the degree of intercorrelation (i.e. correlation or covariance between variables). Naturally, the diagonal terms of the correlation matrix are 1. Concerning the other terms in the matrix, a value of zero suggests that the two variables are perfectly independent (variance in one variable has zero influence on the other) *which is an assumption of linear regression analysis*. A value of 1 or -1 indicates perfect correlation. As a rule of thumb, a correlation value above 0.7 or below -0.7 would imply that the two variables are strongly correlated and one of them should probably be dropped from the model.

The preceding evaluation criteria (model: R^2 , Se; coefficients: sign, t-stat, correlation) are well known and commonly used for assessing classical regression results. However a Bayesian regression analysis introduces some philosophical considerations related to assessing the goodness of fit of the Bayesian posterior model.

As previously mentioned, the prior model is a regression equation which describes the information residing in the 'a priori' information source (i.e. output from the NETSIM simulation) whereas the data model is basically the output from a classical regression conducted on the field data. According to Bayesian philosophy, 'a priori' information reflects the state of knowledge with respect to a system before an experiment is performed. Hence it is logical to use prior information only if it is accurate and rational. This premise will be used in the evaluation of the model results; that is, **the first consideration is to ensure that the prior model statistics are rational and adequate**. Once the prior model is deemed appropriate, then the Bayesian posterior model will be evaluated.

Another important consideration is to ensure that **"traffic flow" or "traffic density"** remains in the predictive equation in order for the model to have some usefulness in transportation applications such as ATIS, planning models, etc.

6.3 Evaluation of Model Results: Street Type 1 - Two Way, Two Lanes

Section 6.3.1 provides an interpretation of the results of the first iteration of the Bayesian regression analysis, that is, for the mathematical form selected in Chapter 3. In Section 6.3.2, subsequent model forms are investigated in an attempt to improve the predictive capability of the model.

6.3.1 Iteration #1

After executing the Bayesian regression analysis according to the procedure described in Section 6.1, the resultant model and coefficient statistics for each of the *prior model*, *data model*, and *posterior model* are presented in Table 6.1.

**TABLE 6.1: Summary of Statistical Parameters (Iteration #1) - Street Type 1-
Two way, Two Lanes**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.78	0.6	0.5			
Se	40.3	11.98	37.8			
COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	139.5	158.9	125.4	5.65	4.21	6.27
q_{thr}^3	0.06	0.11	0.04	0.97	3.1	0.89
q_{rt}	42.3	-2.1	36.9	4.7	-0.11	4.67
q_{lt}	10.3	33.5	4.04	1.01	1.48	0.46
q_{bus}^2	-0.79	-0.01	-0.16	-0.78	-0.32	-2.46
HV^2	-0.63	0.71	0.49	-0.48	0.84	0.58
$(StopxSigpkm)^3$	0.18	0.07	0.18	3.07	1.16	3.62

A section of the XLBAYES output related to the posterior model is shown below.

Posterior

Posterior Correlation Matrix

1	-0.463199	-0.290118	-0.452923	-0.024329	-0.628997	-0.319391
-0.463199	1	0.0826417	0.2471565	-0.37486	0.0092778	-0.010014
-0.290118	0.0826417	1	0.3950402	-0.187205	0.1577284	-0.563531
-0.452923	0.2471565	0.3950402	1	-0.215394	-0.041375	0.0462839
-0.024329	-0.37486	-0.187205	-0.215394	1	0.3297453	-0.04909
-0.628997	0.0092778	0.1577284	-0.041375	0.3297453	1	-0.009759
-0.319391	-0.010014	-0.563531	0.0462839	-0.04909	-0.009759	1

Posterior Regression Coefficients Summary

	Mean	St.Dev.	T-Value
Const	125.37121	19.990671	6.271486
qthr3	0.0353683	0.0396124	0.8928584
qrt	36.856188	7.8902272	4.6711188
qlt	4.0358119	8.77102	0.4601303
qbus2	-0.15729	0.0639901	-2.458038
HV2	0.4949401	0.8535842	0.5798375
(StopXSigg	0.1804235	0.0499001	3.6156924

Degrees of Freedom

72

Residual Variance, Se^2

1430.6874

A graphical representation of the statistical results is provided in Figure 6.1 in terms of normal *probability density functions (pdf)* for each independent variable. Because regression coefficients are assumed to have a normal distribution, the functions shown have the familiar bell-shape. The mean of the probability density function represents the expected value of the coefficient while the shape of the plot indicates the standard deviation (i.e. uncertainty) in the model coefficient estimates. The area under the pdf curve is by definition equal to one; in other words, there is a 100% probability that the value of the coefficient will lie within the curve. Consequently, y-axis values will shift depending on the x-axis scale to ensure that the integral of the pdf curve equals one. In this Figure, the coefficient statistics can be conveniently compared across the Prior, Data, and Posterior models.

Figure 6.1: Probability Distribution Functions for Modelling Coefficients: Street Type 1-Two-Way, Two Lanes

Interpretation of Models

Contrary to what one would have expected, the Bayesian posterior solution ($R^2 = 0.5$) does not provide a better “fit” of the information as compared to the prior ($R^2 = 0.78$) and data models ($R^2 = 0.6$). However, it is important to remember that the R^2 of the posterior model was calculated from the combined set of field data and simulated data, where both data sets have systematic differences. Hence, the standard error is a better measure of the reasonableness of Bayesian models since it is a direct indicator of the predictive accuracy of the models (same units as the dependent variable, travel time (seconds/kilometre)).

The standard error of the Bayesian posterior model (37.8) lies between the range of the data model (11.98) and the prior model (40.3). The average travel time on this street type was found to be 222 seconds/kilometre. Hence the posterior model will predict a value for travel time ± 75.6 seconds/km with 95% confidence (i.e. ± 2 std. error). This means that if a driver planned to travel on this street type during rush hour traffic, he/she could expect to traverse a one kilometre distance in approximately 222 seconds (or 3 minutes, 42 seconds), give or take 76 seconds. This is equivalent to an average speed of 16.2 km/hr. Described another way, assuming that signals were non-existent and the free flow speed on this street type was 50 km/hr, it would take 72 seconds to traverse 1 kilometre; hence 150 seconds (222 - 72) would be wasted at traffic signals or slowing down due to various conflicts.

Flow of through traffic, q_{thr}^3

Based on an examination of Table 6.1 and Figure 6.1, the sign of the regression coefficient is rational (i.e. positive) in all three models. As explained in Section 3.1, it is expected that when the flow of automobiles increases, all vehicles will tend to slow down resulting in greater travel times. The probability density functions (Figure 6.1) indicate that the posterior model is most influenced by the prior information source (i.e. similar value for the coefficient) but that both the

posterior and prior distributions are insignificant. The hypothesis, $t\text{-stat} < 2.0$, implies that the explanatory variable to which that coefficient relates does not in fact influence the dependent variable and should not be included in the function; in other words, there is some probability that the coefficient for q_{thr}^3 is zero (i.e. pdf curve crosses the zero axis). The contribution of the field data seems to be to reduce the uncertainty in the estimate of the posterior coefficient (i.e. narrower distribution).

Flow of right turning traffic, q_R

The posterior model is virtually identical to the prior solution both in the value of the coefficient and its uncertainty. The probability density function suggests that there is a serious discrepancy between the prior information and the field data with respect to the contribution of "right turning flow" to "travel time" since the signs are different. Intuitively one would conclude that there may be some errors associated with the "data" values for q_R since an increase in the number of right turning vehicles should not result in a decrease in travel time. In any case, the Bayesian solution reflects that of the prior model (for this particular variable) because of the more reasonable statistics within the prior information source as compared to the field data.

Flow of left turning traffic, q_L

As expected the sign of the coefficient is positive for all three models indicating that an increase in the number of left-turning vehicles will obstruct traffic flow and increase travel times. The normal probability plots illustrate that all three distributions are insignificant since they cross the zero axis (i.e. some probability that the coefficient is zero). The field data in this situation seems to have no influence on the posterior model since the prior and posterior curves are nearly identical; this is a typical scenario when there is a small data sample size. The pdf plots also show that the posterior model plots outside of both the data and prior models. This occurrence, according to Bayesian interpretation guides (C-

SHRP 1994), indicates that the model is poor. That is, in order to ensure that other variables are within their reasonable ranges, Bayesian regression must push the q_{lt} variable outside of its reasonable range. To resolve this problem would require dropping this variable or making other modifications to the model form.

Flow of bus traffic, q_{bus} ²

In this case, the posterior (coef. = -0.16) lies between the data (-0.01) and the prior (-0.79) which is intuitively appealing. However the sign of the coefficient for all three models is irrational because an increase in the flow of buses should result in a corresponding increase in travel time for the average driver. This would indicate that perhaps there is some inherent error in both the prior and data sources, or that for this street type (two way, 2 lanes), bus flow does not have a significant influence on travel time. A more credible explanation is that other factors not included in the model have some influence over travel time and are pulling the q_{bus} coefficient onto the negative side. The q_{bus} variable should probably be dropped or redefined (e.g. percentage of buses instead of bus flow) for the next iteration of the models.

Proportion of heavy vehicles, HV ²

The pdf for this variable indicates that the field data are definitive as the posterior coefficient mean and uncertainty are virtually identical to the classical regression solution (i.e. the data). The effect of the “prior” information is to shift the posterior distribution slightly towards zero. However all three models are statistically insignificant since the distributions cross zero. Hence one may conclude that the proportion of heavy vehicles in the traffic stream has little or no influence on the average travel time. Consequently a possible action may be to drop this variable altogether for the next iteration.

(Stop X Sigpkm)³

This cluster term demonstrates the most influence on travel time as attested from the high t-statistic (prior: 3.07, data: 1.16, posterior: 3.62) for each model. The sign of the coefficient is rational (i.e. positive) for all three models. The field data seem to have little or no influence on the posterior model since the prior and posterior probability density curves are almost identical. The posterior distribution has a slightly higher peak indicating that its standard deviation (spread) is slightly smaller than that of the prior (since the area under the pdf must equal 1).

Summary

The prior model has the highest R^2 whereas the data model contains the lowest standard error. However, the evaluation of the coefficient statistics indicates that the posterior is the only model that has a rational sign for five out of six independent variables (q_{bus} variable is the exception). This is intuitive since even when one source of information (the prior or the data) possesses the wrong sign, the posterior will usually balance more towards the information that best represents the system being modeled. Having said this, the posterior R^2 is quite low (0.5) and steps need to be taken to improve the fit of the posterior model.

6.3.2 Subsequent Iterations

Additional iterations of the Bayesian regression were conducted in an effort to improve the posterior model results from iteration #1. As discussed in Section 6.2, the criteria for evaluating the models are;

1. as a starting point, make sure the statistical parameters for the prior model are reasonable - make changes to the equation if necessary (i.e. drop or combine variables, modify the functional form, etc.)
2. once the prior statistics are OK, examine the statistics for the posterior model - make changes to the equation if necessary

3. the final equation must have a variable corresponding to "traffic flow" or "traffic density".

Based on the results from iteration #1, the q_{bus} and HV variables will be dropped from the equation because of their irrational sign within the prior model. The results brought upon by this change are summarized below.

TABLE 6.2: Summary of Statistical Parameters (Iteration #2) - Street Type 1- Two way, Two Lanes

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.72	0.71	0.63			
Se	40.4	11.5	40.2			
COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	129.8	165.2	142.4	8.2	4.7	10.33
q_{thr}^3	0.035	0.11	-0.008	0.73	3.5	-0.24
q_{rt}	43.0	-4.0	33.0	5.71	-0.22	4.80
q_{lt}	7.2	36.4	-0.49	0.89	1.79	0.06
$(StopxSigpkm)^3$	0.18	0.06	0.17	3.60	1.12	3.82

From the preceding results, the prior model coefficients are rational (i.e. positive) but insignificant for q_{thr}^3 and q_{rt} . In addition, q_{thr}^3 has a negative sign in the posterior model. Consequently, it seems viable at this stage to combine (add) the three flow variables (q_{thr}^3 , q_{rt} , q_{lt}) into a global q_{total} variable. The "total flow" variable was defined in Chapter 3. Table 6.3 outlines the Bayesian regression results based on this change.

**TABLE 6.3: Summary of Statistical Parameters (Iteration #3) - Street Type 1-
Two way, Two Lanes**

MODEL STATISTICS						
	Prior Model		Data Model	Posterior Model		
R ²	0.58		0.75	0.52		
Se	48.3		10.1	45.0		
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	60.7	70.6	105.7	1.63	2.83	3.68
Q _{total}	12.5	14.1	5.7	2.28	4.6	1.4
(StopxSigpkm) ³	0.33	0.1	0.3	6.15	2.5	6.2

Examining the preceding results, the coefficients for the prior and data models are rational and statistically significant. However the posterior coefficient for q_{total} is insignificant. Furthermore, the standard error of the posterior model is relatively high at 45.0. The average travel time on this street type (based on the field and simulated data) is 217.6 seconds per kilometre. Hence, at a 95% confidence interval (i.e. ± 2 standard error), the posterior model would predict a value of travel time within 90 seconds which is not very precise.

Based on the previous iterations, it appears that a more drastic change is needed to the mathematical form of the models. Although XLBAYES is limited to *linear* models, it is possible to apply a "transform" to an equation to produce a curvi-linear relationship between the variables while retaining a linear model form. It has been shown that the general relationship between travel delay and traffic density is quadratic or exponential; that is, as density increases, delay will increase at an increasing rate (Choudhry, unpublished paper). If the assumption is made that this relationship is also valid for "travel time vs. traffic flow", a log-

linear specification (of the form $\ln y = b_1 + b_2 x$) can be used to approximate it. The log-linear transform was applied to the field data and to the NETSIM data by taking the natural logarithm of travel time. The Bayesian regression was performed once again with the results summarized in Table 6.4.

**TABLE 6.4: Summary of Statistical Parameters (Iteration #4) - Street Type 1-
Two way, Two Lanes**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.58	0.69	0.58			
Se	1.19*	1.06*	1.17*			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	4.22	4.37	4.47	27.85	25.57	42.2
Q_{total}	0.055	0.036	0.028	2.96	2.35	2.12
$(Stop \times Sigpkm)^3$	0.131	0.11	0.12	7.31	5.29	7.87

* in natural logarithmic form

Table 6.4 demonstrates that the coefficients are rational and significant under a log-linear model form. The standard errors for the prior, data, and posterior were computed to be 1.19, 1.06 and 1.17 (in natural logarithmic form) for the prior, data, and posterior models, respectively. To interpret these Se's, it is useful to examine confidence intervals. The average travel time (y) on this street type was found to be 218 seconds per kilometre; taking the natural log of 218 gives 5.384. Hence the 95% confidence interval with respect to the predictive capability of the posterior model is as follows;

$$5.384 - 2(1.17) = 3.044 \Rightarrow e^{3.044} = 21$$

$$5.384 + 2(1.17) = 8.55 \Rightarrow e^{8.55} = 5,187$$

$\Rightarrow$ 95% confidence interval is 21 to 5,187

This means that the log-linear model will predict an average travel time of 218 sec/km but there is a 95% chance that the actual time is as low as 21 and as high as 5,187 ! Consequently, we can safely conclude that the log-linear functional form does not adequately imitate the traffic system being modelled.

Going back to iteration #3, a seemingly viable alternative is to impose a power of 3 to the q_{total} variable.

**TABLE 6.5: Summary of Statistical Parameters (Iteration #5) - Street Type 1-
Two way, Two Lanes**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.59	0.81	0.67			
Se	43.8	10.2	35.7			
COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	120.6	95.5	113.6	8.78	13.6	13.7
q_{total}^3	0.12	0.15	0.13	3.8	5.22	5.3
$(StopxSigpkm)^3$	0.25	0.37	0.26	5.54	6.53	7.7

All coefficients are now rational and statistically significant. The model statistics of the posterior model were calculated to be; $R^2=0.67$, $Se=35.7$. Based on the standard error of the posterior model, the 95% confidence interval (i.e. ± 2 standard error) is:

$$218 - 2 \times 35.7 = 146.6 \quad \text{to} \quad 218 + 2 \times 35.7 = 289.4$$

If one were only interested in being 90% sure of his prediction, the confidence interval would be 159 ($218 - 1.645 \times 35.7$) to 277 ($218 + 1.645 \times 35.7$). Another way of interpreting it is to state that the standard error is 16% of the average prediction. Whether or not the standard error is reasonable is really a subjective assessment which depends on the *required precision* of the model - for example the precision of a model with safety implications to the public is more crucial than a model on traffic flow. According to Manheim, there is no rational, objective way of judging the relative acceptability of a model. While statistics can and should play an important role in assessing the acceptability of models, it is the analyst's subjective judgement which will govern in the end (Manheim 1979, p. 586). Hence, given the stochastic (i.e. random) nature of a signalized arterial traffic system and the inherent variation that exists within such a system, an R^2 of 0.67 and a prediction accuracy of 16% (corresponding to $Se=35.7$) are deemed reasonable.

Consequently the final model that should be used for a two-way, two lane street is the Bayesian posterior model from the last iteration, and is presented in Equation 6.1:

$$\text{Travtime} = \underset{(13.7)}{113.6} + \underset{(5.3)}{0.13 q_{\text{total}}^3} + \underset{(7.7)}{0.26 (\text{Stop X Sigpkm})^3} \quad (\text{Eqn 6.1})$$

This equation was found to be the best balance of the combined prior information (NETSIM simulation data) and field data sources. The values in brackets below the regression coefficients are the "t-statistic" indicating the statistical significance of the coefficient.

6.4 Evaluation of Model Results: Street Type 2 - Two Way, One Lane

6.4.1 Iteration #1

Performing the Bayesian regression analysis on the two-way, one lane model form introduced in Chapter 3 resulted in the following statistical results for each of the *prior model*, *data model*, and *posterior model*.

**TABLE 6.6: Summary of Statistical Parameters (Iteration #1) - Street Type 2-
Two way, One Lane**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.67	0.85	0.62			
Se	36.5	9.8	39.2			
COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	160.6	94.7	148.1	3.22	7.97	8.24
q_{thr}^3	1.18	0.26	0.29	4.67	4.83	2.06
q_{rt}	4.33	0.76	-25.1	0.48	0.08	-3.4
q_{bus}^3	0.05	0.0002	-0.0004	1.31	1.4	-0.86
HV^2	-0.63	0.41	1.64	-0.29	1.08	2.0
$(StopxSigpkm)^3$	0.17	0.36	0.26	4.4	6.17	7.58

Various statistics of the posterior regression model, as produced by the XLBAYES program, are shown below.

Posterior

Posterior Correlation Matrix

1	-0.604059	-0.183267	-0.168736	-0.8554	0.0853152
-0.604059	1	-0.126618	-0.399579	0.3601497	0.1388118
-0.183267	-0.126618	1	-0.141269	0.141852	-0.715981
-0.168736	-0.399579	-0.141269	1	0.2807605	0.0565459
-0.8554	0.3601497	0.141852	0.2807605	1	-0.29894
0.0853152	0.1388118	-0.715981	0.0565459	-0.29894	1

Posterior Regression Coefficients Summary

	Mean	St.Dev.	T-Value
Const	148.08152	17.962534	8.2439107
q thr3	0.2942525	0.142754	2.0612553
qrt	-25.09572	7.2994837	-3.438014
qbus 3	-0.000371	0.0004322	-0.858973
HV 2	1.6401281	0.8203758	1.99924
(Stop X Sig	0.2568692	0.033902	7.5768116

Degrees of Freedom

66

Residual Variance, Se^2

1533.0933

Figure 6.2 represents the *probability density functions (pdf)* for each independent variable. As noted earlier, the x-axis depicts the mean of the regression coefficient while the spread of the normalized curve indicates the uncertainty in the estimated value of the coefficient.

Figure 6.2: Probability Distribution Functions for Modelling Coefficients: Street Type 2-Two-Way, One Lane

Interpretation of Models

Examining the model statistics, the posterior model reflects the prior information source as attested by the similar R^2 (prior: 0.67; posterior: 0.62) and Se (prior: 36.5; posterior: 39.2). A closer examination of both the prior and field data shows that both information sources are substantially different. For example, the data comprises consistently higher q_{thr} values with lower travel times as compared to low q_{thr} values and high travel times within the prior information. Since the data model has satisfactory statistics, this would suggest that there is some inherent deficiency with the prior information source (i.e. NETSIM MOE) in its capability to fit the linear model form. In effect, this variation between both information sources will make it difficult for the Bayesian regression formulas to balance the two data sets and produce reasonable posterior statistics.

Flow of through traffic, q_{thr}^3

Figure 6.2 indicates that the prior information is uncertain in its estimate of the coefficient mean as shown by the large spread in the pdf curve. On the other hand, the data model is very certain that the coefficient for q_{thr}^3 is 0.26. The posterior model is most influenced by the field data (similar coefficient of 0.29) with its uncertainty balanced between the prior information and the data.

Flow of right turning traffic, q_r

The “right turning flow” variable is statistically insignificant according to the field data and the NETSIM simulation data. However, the posterior model suggests that this variable has a significant negative influence on travel time which is counter-intuitive. Since this is a multivariate problem, there may be other factors (either variables already in the equation or variables not included) that are “forcing” this variable towards the negative side. Also, according to the correlation matrix, q_r has a relatively high negative correlation with the (Stop x Sigpkm)³ term (correlation value of -0.716) indicating that the two terms are not completely independent (one of the tenets of linear regression states that each x

variable is completely independent). With a correlation value nearing -1, an increase in one variable will produce a similar decrease in the other variable, and vice versa. This variable should definitely be removed from the equation or modified in subsequent iterations.

Flow of bus traffic, q_{bus} ³

After having viewed the videotape evidence and observed buses blocking traffic when serving passengers, it was concluded that transit buses have a significant impact on the Bank Street traffic patterns. However the statistical results indicate that q_{bus} has little or no influence on average travel times (i.e. coefficient values all very close to zero). Contrary to the data model, both the prior and posterior models are very uncertain with respect to the coefficient value being zero (the spread tends towards infinity). On the other hand, the data model is quite confident that an increase in the number of buses produces a very slight increase in the average travel time.

Proportion of heavy vehicles, HV ²

For this variable, although the prior and data models indicate that heavy vehicles do not have a significant influence on travel time, the posterior model shows that it is in fact significant. However the posterior coefficient (1.64) lies outside the interval between the prior and data means (-0.63 and 0.41, respectively), which suggests that the model is poor. This can be rationalized by assuming that to get the other four variables inside their reasonable ranges, the posterior model must move this variable outside its reasonable range (multivariate problem).

(Stop X Sigpkm)³

Once again, this cluster variable proves to have the most significant and logical influence on travel time as attested by the rational signs and the high t-statistics, for all three models. Examining the normal probability plots, the posterior mean lies between the prior and data. Hence, we can conclude that the formulation of

this cluster variable is more than adequate and that the Bayesian solution (i.e. posterior) provides a good balance between the data and prior information sources.

Summary

In summary, the prior model comprises a negative coefficient for the “heavy vehicle” variable while negative signs are observed in the posterior model for the “right turning flow” and “bus flow” variables. It is essential that subsequent iterations resolve these irrational coefficients. With respect to the model statistics, it is believed that as modifications are made to ameliorate the rationality and significance of the independent variables, improvements to the current posterior model statistics ($R^2=0.62$, $Se=39.2$) will likely be observed.

6.4.2 Subsequent Iterations

According to the model evaluation criteria defined in Section 6.2, the first step in improving the Bayesian results is to ensure that the prior model is reasonable. Based on this premise, the HV^2 variable should be dropped from the equation because of its negative sign. The statistical results of the second iteration are shown in Table 6.7.

**TABLE 6.7: Summary of Statistical Parameters (Iteration #2) - Street Type 2-
Two way, One Lane**

MODEL STATISTICS			
	Prior Model	Data Model	Posterior Model
R^2	0.67	0.84	0.60
Se	36.04	9.9	40.1

COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	146.9	94.96	178.8	11.01	7.96	18.8
q_{thr}^3	1.17	0.23	0.19	4.74	4.75	1.41
q_{rt}	4.21	5.08	-27.17	0.48	0.63	-3.68
q_{bus}^3	0.06	0.0002	-0.0006	2.47	1.4	-1.45
$(Stop \times Sigpkm)^3$	0.17	0.35	0.28	4.44	6.05	8.4

The prior model coefficients have rational signs with only the q_{rt} variable being insignificant (i.e. t-stat < 1.96). However in the posterior model, both q_{rt} and q_{bus}^3 have negative signs which is contrary to the assumption made that the sign for all variables must be positive. Furthermore the standard errors of the prior and posterior models (36.04 and 40.1) are quite high; the 95% confidence interval for the posterior model based on an average time of 222 sec/km is as follows;

$$\text{lower limit: } 222 - 2(40.1) = 141.8 \text{ sec/km}$$

$$\text{upper limit: } 222 + 2(40.1) = 302.2 \text{ sec/km}$$

The preceding observations seem to indicate that a major change is needed to the mathematical form of the models. It may be useful to once again try a log-linear form as was attempted in Section 6.3.1. The results of the log-linear form are shown in the following table.

TABLE 6.8: Summary of Statistical Parameters (Iteration #3) - Street Type 2-Two way, One Lane

MODEL STATISTICS			
	Prior Model	Data Model	Posterior Model
R^2	0.69	0.84	0.58
Se	0.16*	0.06*	0.19*

COEFFICIENT STATISTICS

Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	5.00	4.66	5.15	83.95	63.4	111.6
q_{thr}^3	0.0056	0.001	0.001	5.13	4.92	1.59
q_{rt}	0.028	0.03	-0.13	0.708	0.65	-3.77
q_{bus}^3	0.0003	8.37E-7	-2.7E-6	2.91	1.11	-1.33
$(StopxSigpkm)^3$	0.0007	0.002	0.001	4.4	6.12	8.25

* in natural logarithmic form

Using the same procedure to interpret the natural logarithmic standard errors as was employed in Section 6.3.2, the 95% confidence interval for the posterior model is;

$$\begin{aligned} \ln(222) = 5.4: \quad & \text{lower limit: } 5.4 - 2(0.19) = 5.02 \Rightarrow e^{5.02} = 151.4 \\ & \text{upper limit: } 5.4 + 2(0.19) = 5.78 \Rightarrow e^{5.78} = 323.8 \end{aligned}$$

Compared to the confidence interval obtained in iteration #2 (with a normal linear form), 141.8 to 302.2, the log-linear form does not improve on the precision of the model.

Going back to the results of iteration #2, the next logical iteration will involve combining the flow variables into a q_{total} variable. The statistical parameters of the prior, data, and posterior models as a result of this modification are provided in Table 6.9.

**TABLE 6.9: Summary of Statistical Parameters (Iteration #4) - Street Type 2-
Two way, One Lane**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.67	0.82	0.52			
Se	35.6	10.1	43.8			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	108.9	46.3	178.2	5.75	2.8	10.1
q_{total}	26.05	13.4	0.21	4.9	4.5	0.05
q_{bus}^3	0.04	0.0002	-0.00074	1.9	1.78	-1.7
$(Stop \times Sigpkm)^3$	0.11	0.35	0.19	4.4	5.89	7.4

Examining the prior and data model statistics, all of the coefficient signs are rational with only the q_{bus}^3 variable being insignificant. Contrary to what one would expect, the posterior model statistics are worse than both the prior and data model statistics. If we look closely at the coefficient means for q_{total} and q_{bus}^3 , the value for the posterior (0.21, -0.00074) lies outside of the prior (26.05, 0.04) and data values (13.4, 0.0002). According to Bayesian model interpretation principles (C-SHRP 1994), a possible explanation is that to get other variables (in this case, Stop x Sigpkm) inside their reasonable range requires moving these variables outside of their reasonable range. It may also be that other variables not included in the equation are influencing the model outcomes.

Another major deficiency is the low R^2 (0.52) and high Se (43.8) in the posterior model. In fact, these two indicators have become worse in each subsequent iteration. At this stage, it doesn't seem probable that a minor modification to the

functional form of the equation will have any significant impact. A potentially feasible alternative is to replace the “flow” variable with “density”, even though the argument for using traffic flow over density in the first place was because it is believed to be a more intuitive variable to traffic engineers, and for which data are more readily available (refer to Chapter 3). The Bayesian regression results for this new iteration are shown in Table 6.10.

**TABLE 6.10: Summary of Statistical Parameters (Iteration #5) - Street Type 2-
Two way, One Lane**

MODEL STATISTICS						
	Prior Model		Data Model	Posterior Model		
R ²	0.85		0.89	0.70		
Se	24.3		6.5	34.2		
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	119.9	76.3	118.2	12.4	13.3	10.6
k _{total}	6.4	4.02	5.4	9.77	8.9	6.5
q _{bus} ³	0.04	8.6E-5	-0.001	2.5	1.07	-4.7
(StopxSigpkm) ³	0.06	0.21	0.102	3.2	4.8	4.36

From the preceding results, the replacement of “flow” with a “density” variable has improved the overall fit of the prior, data, and posterior models, as illustrated by the higher R^2 and lower Se. Since the coefficient for q_{bus}^3 has a negative sign, this variable will be dropped for the next iteration. Density to the power of three (k_{total}^3) will be used as this is the more intuitive relationship between density and travel time.

**TABLE 6.11: Summary of Statistical Parameters (Iteration #6) - Street Type 2-
Two way, One Lane**

MODEL STATISTICS						
	Prior Model		Data Model	Posterior Model		
R ²	0.69		0.91	0.63		
Se	34.1		7.02	37.7		
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	182.9	117.3	154.6	23.6	31.6	22.9
k _{total} ³	0.005	0.005	0.005	5.7	9.1	5.3
(StopxSigpkm) ³	0.10	0.23	0.15	4.6	5.2	6.6

The coefficient statistics are now reasonable for all three models. The posterior model statistics are, R^2 (0.63) and Se (37.7). As noted in a previous iteration, the average travel time on this street type was found to be 222 seconds. The 95% confidence interval is then 146.6 ($222 - 2 \times 37.7$) to 297.4 ($222 + 2 \times 37.7$). In other words the standard error is 17% of the average prediction, which is deemed acceptable in the context of an urban peak period traffic flow system.

Although the overall “fit” of the final model (based on R^2 and Se) is not ideal, it is not completely surprising if one considers the variability which is inherent in a traffic system. This variability is even more pronounced on a facility with only one lane in one direction, where any disruption in the traffic system can cause major slowdowns. These disruptions include such events as a parked car in a bus bay resulting in buses blocking downstream traffic, spillover of vehicles from turning pockets into the through traffic stream, truck loading and unloading. In

these types of events, downstream traffic do not have the option of moving to another lane.

Consequently it may be that for this type of street configuration, it is logical to expect that the best a model can do is to predict travel time within ± 75 seconds (or within 62 seconds, with 90% confidence). Hence the model suggested for a two-way, one lane per direction street configuration is shown in Equation 6.2;

$$\text{Travtime} = \underset{(22.9)}{154.6} + \underset{(5.3)}{0.005 k_{\text{total}}^3} + \underset{(6.6)}{0.15 (\text{Stop X Sigpkm})^3} \quad (\text{Eqn 6.2})$$

The values in brackets below the regression coefficients are the "t-stat" indicating the statistical significance of the coefficient.

6.5 Evaluation of Model Results: Street Type 3 - One Way, Three Lanes

6.5.1 Iteration #1

The first Bayesian trial iteration on the model form presented in Chapter 3 resulted in the following model and coefficient statistics;

TABLE 6.12: Summary of Statistical Parameters (Iteration #1) - Street Type 3- One Way, Three Lanes

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R ²	0.93	0.81	0.92			
Se	38.0	16.6	37.5			
COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	191.5	121.5	133.9	8.8	2.6	8.6
q _{thr} ³	-0.04	0.02	0.017	-2.1	4.2	3.2
q _n	14.74	-20.9	19.52	6.3	-0.56	9.9

q _{it}	-17.8	7.63	-2.7	-2.5	0.96	-0.67
q _{bus} ²	0.17	0.004	0.05	1.6	0.16	1.41
HV ²	-8.15	2.66	-2.53	-2.4	0.64	-1.2
(StopxSigpkm) ³	0.088	0.07	0.08	17.2	3.1	19.5

Part of the XLBAYES output is shown below;

Posterior

Posterior Correlation Matrix

1	-0.346048	-0.446742	-0.39665	0.1841276	-0.891413	-0.004606
-0.346048	1	0.0663963	-0.494799	-0.55204	0.4066341	0.1391029
-0.446742	0.0663963	1	0.3552716	-0.051132	0.3666261	-0.466462
-0.39665	-0.494799	0.3552716	1	0.0208295	0.2768999	-0.383957
0.1841276	-0.55204	-0.051132	0.0208295	1	-0.317165	-0.01466
-0.891413	0.4066341	0.3666261	0.2768999	-0.317165	1	-0.138098
-0.004606	0.1391029	-0.466462	-0.383957	-0.01466	-0.138098	1

Posterior Regression Coefficients Summary

	Mean	St.Dev.	T-Value
Const	133.9352	15.565229	8.6047695
qthr3	0.0165289	0.0052376	3.1558245
qrt	19.52157	1.9778836	9.8699289
qit	-2.735492	4.1055253	-0.666295
qbus2	0.0460227	0.0326069	1.4114414
HV2	-2.527482	2.1203686	-1.192001
(StopXSigp	0.0810743	0.0041605	19.486757

Degrees of Freedom

87

Residual Variance, Se²

1407.2623

Normal *probability density functions (pdf)* for each independent variable, for the prior, data, and posterior models are illustrated in Figure 6.3. As noted earlier, the x-axis represents the value of the model coefficient while the width of the normal curve denotes the standard deviation in the estimate of the coefficient mean.

Figure 6.3: Probability Distribution Functions for Modelling Coefficients: Street Type 3-One-Way, Three Lanes

Interpretation of Models

The fit of the predictive equations to the information sources is very good as indicated by the high R^2 's (0.93, 0.81, 0.92, for the prior, data, posterior, respectively). Furthermore, the standard error of the models are fairly reasonable denoting a reliable degree of certainty in the predictions. For example, the average driver can be 95% certain that he can traverse one kilometre on this type of arterial in 289 seconds $\pm$ 75 seconds. This translates to a prediction accuracy of about 25% which is deemed acceptable by the author given the complex traffic system being modelled.

Flow of through traffic, q_{thr} ³

Concerning this independent variable, the data have more of an influence than the prior since the posterior model is virtually identical to the data model. The effect of the prior information is nevertheless important as it reduces the mean coefficient value slightly (a shift of the pdf distribution to the left) and increases the uncertainty in the posterior estimate. Both the data and the posterior coefficients are rational (i.e. positive sign) and statistically significant (i.e. t-stat > 1.96). Hence, the Bayesian solution is advantageous in terms of the q_{thr} variable.

Flow of right turning traffic, q_{rt}

Based on an examination of the probability density functions, the data are uncertain whether q_{rt} has any influence on travel time (i.e. pdf curve crosses y axis). On the other hand, the Bayesian model reflects the prior information source and is quite confident in its estimate of the coefficient. An analysis based solely on classical regression would have likely resulted in this variable being dropped from the equation but the Bayesian approach in essence saves the variable.

Flow of left turning traffic, q_l

On a one-way street, left turns are made from the far left lane (in some cases the two far left lanes are dedicated to left turns) which is generally also used for through traffic. Consequently one would expect that an increase in the number of left turns per minute would result in some through moving vehicles being delayed in the left lane, and hence an overall increase in the average travel time. Based on the preceding hypothesis, only the data model has a rational sign. As a matter of fact, the prior model statistics imply that q_l has a statistically significant negative influence on travel time.

Flow of bus traffic, q_{bus}^2

The mathematical sign of the coefficients is rational for all three models. However this variable is not statistically significant, which comes as no real surprise because on this type of street vehicles can usually circumvent a stopped bus using the two adjacent lanes. The posterior pdf lies between the prior and data models which is intuitively appealing. Examining the correlation matrix, one observes that the q_{bus}^2 term has a relatively high negative correlation with the “proportion of heavy vehicles” variable which means that when q_{bus}^2 increases, HV^2 tends to decrease. This situation is undesirable as it violates one of the assumptions of linear regression which states that all independent variables must not be correlated. Based on the preceding discussion, q_{bus} seems to be a good candidate to drop from subsequent Bayesian regression iterations.

Proportion of heavy vehicles, HV^2

The prior information dictates that HV^2 has a negative influence on travel time while the field data implies a positive affect, both being equally certain in their estimates (i.e. similar standard deviations). Since the uncertainty in both information sources is comparable, it makes sense that the Bayesian posterior distribution lies directly in the middle as Bayes weighs both information sources proportionately. However, neither the classical regression nor the Bayesian

regression models have reasonable statistics: data model has logical sign but very low t-stat, posterior has irrational sign and low t-stat. Hence HV should probably be dropped or reformulated (perhaps inside a cluster term with another variable) in subsequent iterations.

(Stop X Sigpkm)³

As expected, this cluster variable has a positive influence on travel time and is statistically different than zero, for all three models. The Bayesian posterior lies between the prior and data pdf curves with its high degree of certainty reflecting the prior's confidence. Consequently, the Bayesian solution provides a more assured estimate of the coefficient mean as compared to the classical regression solution.

Summary

Based on the overall model statistics, R^2 and S_e , the Bayesian regression model seems adequate. As discussed in Section 6.2, the first Bayesian model evaluation principle implies that the prior model statistics are adequate before interpreting the posterior model. Consequently, the q_{thr}^3 , q_{it} and HV^2 terms should be removed or redefined (perhaps within a cluster term) in subsequent iterations due to their irrational sign within the prior model. These changes will surely have a positive impact on the posterior model parameters.

6.5.2 Subsequent Iterations

Based on the conclusions in the previous Section, a different model form was used in a second Bayesian regression in an effort to improve the posterior model results. For this second iteration, the q_{it} and HV variables were dropped from the equation. The results of the second iteration are shown in Table 6.13.

**TABLE 6.13: Summary of Statistical Parameters (Iteration #2) - Street Type 3-
One Way, Three Lanes**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R ²	0.92	0.78	0.91			
Se	41.1	16.6	37.4			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	128.03	167.9	116.6	12.12	6.17	17.6
q _{thr} ³	-0.02	0.02	0.018	-1.07	4.08	5.2
q _{rt}	19.6	0.04	20.6	9.7	0.001	11.7
q _{bus} ²	0.06	-0.014	0.035	1.00	-0.66	1.14
(StopxSigpkm) ³	0.08	0.06	0.08	18.9	2.96	20.9

The prior model, based on the traffic simulation data, has a negative sign for the q_{thr}^3 variable which is counter-intuitive. However, when balancing this prior information with the influence of the field data, the posterior model has a statistically significant and positive value for q_{thr}^3 , which is an appealing result. Concerning the q_{bus}^2 variable, it is insignificant within the posterior model most likely due to its negative sign in the data model. Hence, this variable was dropped from the next iteration.

**TABLE 6.14: Summary of Statistical Parameters (Iteration #3) - Street Type 3-
One Way, Three Lanes**

MODEL STATISTICS			
	Prior Model	Data Model	Posterior Model
R^2	0.92	0.79	0.91
Se	41.1	16.7	37.5

COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	131.8	157.6	118.1	13.4	7.21	18.2
q_{thr}^3	-0.02	0.02	0.02	-1.17	4.27	7.08
q_{rt}	19.4	9.34	20.5	9.7	0.32	11.6
$(StopxSigpkm)^3$	0.08	0.06	0.08	19.05	2.96	20.8

As shown in Table 6.14, the model derived in iteration #3 is by far superior to the model from iteration #1; R^2 and S_e are comparable but the coefficient statistics of the posterior model are all rational and statistically significant. However, concerns could be raised regarding the prior model negative sign for q_{thr}^3 , and regarding the fact that the left turning flow variable is not included in the equation. Consequently, for the next iteration the three flow variables were combined into a " q_{total} " variable. The results of this iteration are provided in Table 6.15.

**TABLE 6.15: Summary of Statistical Parameters (Iteration #4) - Street Type 3-
One Way, Three Lanes**

MODEL STATISTICS			
	Prior Model	Data Model	Posterior Model
R^2	0.46	0.78	0.37
S_e	134.9	16.4	128.2

COEFFICIENT STATISTICS						
Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	133.4	123.8	173.7	5.3	5.1	8.8
q_{total}^3	0.09	0.01	0.01	3.9	4.2	2.1
q_{bus}^2	-0.01	0.02	-0.12	-0.05	1.11	-1.20
$(StopxSigpkm)^3$	0.05	0.07	0.08	3.7	4.2	7.0

Clearly replacing the individual flow variables with the q_{total}^3 variable does not improve the “fit” of the models as shown by the extremely high standard errors. Perhaps “traffic density” will provide a better fit to the data sets. Hence replacing q_{total}^3 with k_{total}^3 resulted in the following results;

TABLE 6.16: Summary of Statistical Parameters (Iteration #5) - Street Type 3- One Way, Three Lanes

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R^2	0.89	0.97	0.88			
Se	61.5	6.3	55.3			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	172.5	199.1	170.8	17.6	27.7	20.6
k_{total}^3	9.6E-5	5.8E-5	9.4E-5	19.3	14.8	21.7
q_{bus}^2	-0.01	0.02	-0.02	-0.15	2.0	-0.48
$(\text{Stop} \times \text{Sig} \times \text{km})^3$	0.04	0.03	0.04	7.7	4.1	8.7

The results from Table 6.16 indicate that the model with “traffic density” as a variable is superior to the model containing “total flow”, as shown by the posterior R^2 (0.88 as compared to 0.37) and Se (55.3 as compared to 128.2). However the q_{bus}^2 variable has an irrational coefficient. Another iteration was attempted after removing the bus flow variable, resulting in only a minor improvement (posterior R^2 unchanged at 0.88, Se slightly better at 55.1).

The best modelling results achieved thus far for this three lane street configuration are found in iteration #3 (posterior $R^2=0.91$, Se=37.1). Hence, the

Bayesian regression (posterior) model obtained in the third iteration should be used as the final model for this street configuration;

$$\text{Travtime} = \underset{(18.2)}{118.1} + \underset{(7.08)}{0.02 q_{thr}^3} + \underset{(11.6)}{20.5 q_{rt}} + \underset{(20.8)}{0.08 (\text{Stop} \times \text{Sigpkm})^3} \quad (\text{Eqn 6.3})$$

6.6 Evaluation of Model Results: Street Type 4 - One Way, Three Lanes & One Bus Lane

6.6.1 Iteration #1

For a one-way street with three mixed traffic lanes and one dedicated transit bus lane, Bayesian regression analysis produced the following model and coefficient statistics for each of the *prior model*, *data model*, and *posterior model*, as shown in Table 6.17.

TABLE 6.17: Summary of Statistical Parameters (Iteration #1) - Street Type 4- One Way, Three Mixed Lanes & One Bus Lane

MODEL STATISTICS						
	Prior Model		Data Model	Posterior Model		
R ²	0.69		0.73	0.71		
Se	43.1		4.2	38.4		
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	83.04	85.3	37.3	2.1	6.3	1.91
q _{thr} ³	0.002	0.03	0.004	0.94	3.12	2.54
q _{rt} X q _{bus}	0.28	0.08	0.20	0.9	1.13	1.03
q _{it}	35.8	10.1	32.9	4.2	1.5	4.2
HV ²	1.25	0.17	3.9	0.61	0.29	4.2
(StopxSigpkm) ³	0.17	0.14	0.19	4.03	1.11	5.99

Select posterior model statistics are shown below while Figure 6.4 illustrates the normal *probability density functions (pdf)* for each independent variable.

Posterior

Posterior Correlation Matrix

1	-0.440277	-0.674325	-0.835385	-0.361825	-0.199961
-0.440277	1	0.1772657	0.4666933	-0.25769	0.0188246
-0.674325	0.1772657	1	0.5311269	0.0488068	0.1908969
-0.835385	0.4666933	0.5311269	1	0.1291825	0.0144801
-0.361825	-0.25769	0.0488068	0.1291825	1	-0.258844
-0.199961	0.0188246	0.1908969	0.0144801	-0.258844	1

Posterior Regression Coefficients Summary

	Mean	St.Dev.	T-Value
Const	37.308762	19.485729	1.9146711
qthr3	0.0035563	0.0013987	2.5426311
(qrt X qbus)	0.1959248	0.1903602	1.0292317
qIt	32.167998	5.4058181	5.9506253
HV2	3.8703071	0.917276	4.2193485
(StopXSigp	0.1946971	0.0325158	5.9877645

Degrees of Freedom

50

Residual Variance, Se^2

1477.6673

Figure 6.4: Probability Distribution Functions for Modelling Coefficients: Street Type 4- One-Way, Three Mixed Lanes & One Bus Lane

Interpretation of Models

The average values for the coefficient of multiple determination (prior: 0.69; data: 0.73; posterior: 0.71) indicate that the equations provide a reasonable fit of the field data and of the prior information. The other consideration is the model standard error. In this case, the data model has an extremely low standard error (4.2) while the posterior Se (38.4) is significantly higher, but still an improvement over the predictive accuracy of the prior information source (43.1).

The average travel time on this street type based on the field data and the NETSIM traffic simulation was calculated to be 202 seconds per kilometre. Hence using the first iteration Bayesian regression model, a driver can expect to drive over one kilometre in 202 seconds, give or take 77 seconds (2 times S_e). Subsequent iterations should attempt to improve on the predictive accuracy (i.e. S_e) of the model.

Flow of through traffic, q_{thr} ³

Although the traffic simulation results (prior) are not certain ($t\text{-stat} < 1.96$) whether “through flow” affects travel time and delay, the Bayesian posterior model, reflecting the influence of the field data, is sure that “through flow” has a positive influence on travel time.

(q_{rt} X q_{bus})

As illustrated by the probability density functions, all three models indicate that this variable is not statistically significant (i.e. all three curves straddle the zero axis). The posterior solution (1.03) lies between the prior (0.9) and data (1.03) models with its uncertainty (spread of curve) also balanced between the two information sources. This scenario is typical of Bayesian regression results.

Flow of left turning traffic, q_L

The posterior pdf plots between the prior and data curves which is the most typical case according to Bayesian regression interpretation guides (C-SHRP 1994).

Proportion of heavy vehicles, HV^2

The posterior model distribution lies outside of both the data and prior models. Eventhough the coefficient statistics are reasonable (i.e. logical sign and t-stat > 1.96), according to interpretation guides for Bayesian regression (C-SHRP 1994) this situation indicates that the posterior model is questionable in that other variables in the model are driving the HV variable outside of its usual range. To solve this dilemma, either the HV variable needs to be removed or the equation reformulated.

(Stop X Sigpkm)³

The sign is rational for all three models and the variable is statistically significant for the prior and posterior models. The Bayesian regression model plots slightly outside of both the prior and data model curves which is a little unsettling. However given the concerns raised so far, this is of little importance since modifications to the mathematical form of the equation will be made in any case.

Summary

To summarize the discussion on iteration #1, the prior model coefficients are all rational with the q_{thr}^3 , $(q_L \times q_{bus})$, and HV^2 terms being insignificant. The standard error of the prior model is unreasonably high at 43.1. With the constructive influence of the data model, the posterior model statistics are superior to the prior with all variables being significant except $(q_L \times q_{bus})$ and the posterior Se slightly better at 38.4. As explained in Section 6.6.1, the 95% confidence interval is ± 76.8 (2×38.4); so for an average travel time value of 202, the confidence

limits are: 125 ($202 - 2 \times 38.4$) to 279 ($202 + 2 \times 38.4$). Hence the next iterations will focus on lowering the posterior standard error.

6.6.2 Subsequent Iterations

As shown, the q_{thr}^3 , $(q_{rt} \times q_{bus})$, and HV^2 terms are insignificant ($t\text{-stat} < 1.96$) in the prior model. As stated in Section 6.2, it is important that a “traffic flow” or “traffic density” variable remain in the equation; hence, the insignificance of q_{thr}^3 will be ignored at this stage. It is possible that the relationship between the $(q_{rt} \times q_{bus})$ term and travel time is non-linear. Consequently, holding all other variables constant and plotting TravTime vs. $(q_{rt} \times q_{bus})$ gives the following curve;

From the preceding Figure, the $(q_{rt} \times q_{bus})$ term does not seem to have any significant influence on travel time. Nevertheless, this term should remain in the equation simply because it is logical that the combination of vehicles turning right across a transit bus lane will have some influence on the through movements of other vehicles.

Consequently, at this stage a feasible modification to the functional form is to drop the HV^2 variable due to its low t-statistic in the prior model. The results of the second iteration are illustrated in Table 6.18.

**TABLE 6.18: Summary of Statistical Parameters (Iteration #2) - Street Type 4-
One Way, Three Mixed Lanes & One Bus Lane**

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R ²	0.69	0.73	0.60			
Se	47.6	4.1	44.6			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	98.9	86.1	67.1	3.92	6.7	3.2
q _{thr} ³	0.002	0.026	0.005	1.08	3.4	3.2
q _{rt} x q _{bus}	0.3	0.076	0.16	1.15	1.13	3.24
q _{lt}	36.1	9.94	29.2	5.1	1.55	4.7
(StopxSigpkm) ³	0.17	0.14	0.23	4.08	1.15	6.33

The coefficient statistics of the prior and posterior are not much improved over iteration #1, and the posterior standard error has increased from 38.4 to 44.6. Hence, another possibility for improving the models is to apply a log-linear transform to the equation (i.e. taking the natural logarithm of the dependent variable, TravTime). The results are shown in the following Table.

**TABLE 6.19: Summary of Statistical Parameters (Iteration #3) - Street Type 4-
One Way, Three Mixed Lanes & One Bus Lane**

MODEL STATISTICS			
	Prior Model	Data Model	Posterior Model
R²	0.82	0.74	0.80
Se	0.16*	0.029*	0.14*

COEFFICIENT STATISTICS

Model Parameter	Coefficient Mean			t-statistic		
	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	4.6	4.5	4.42	40.3	47.9	60.9
q_{thr}^3	1.6E-5	0.0002	2.3E-5	2.4	3.1	4.3
$q_{rt} \times q_{bus}$	0.0017	0.0006	0.001	1.95	1.2	1.8
q_{lt}	0.18	0.07	0.16	7.2	1.6	7.98
HV^2	0.005	0.001	0.017	0.8	0.33	5.04
$(StopxSigpkm)^3$	0.0009	0.001	0.001	5.8	1.13	7.9

* in natural logarithmic form

To interpret the standard errors, it is necessary to compare the confidence intervals as was previously explained in Section 6.3.2. Hence, taking the average prediction of 202 seconds per kilometre ($\ln(202) = 5.31$), the 95% confidence band is calculated as follows:

		<u>as compared to (iteration #1)</u>
$5.31 - 2(0.14) = 5.03 \Rightarrow$	$e^{5.03} = 153$	125
$5.31 + 2(0.14) = 5.59 \Rightarrow$	$e^{5.59} = 268$	279

The tighter confidence band indicates that the log-linear model represents a better fit of the data sets; that is to say that the variability in the dependent variable is better explained by the log-linear regression equation.

However, the $q_{rt} \times q_{bus}$ term continues to be insignificant. Various attempts were made to improve the log-linear model (i.e. to reduce the standard error, and increase significance of variables): the HV^2 variable was dropped; q_{thr} was used instead of q_{thr}^3 ; all powers were removed for each variable. The modification that proved to have the best results involved removing the power for the through flow and heavy vehicle variables.

TABLE 6.20: Summary of Statistical Parameters (Iteration #4) - Street Type 4- One Way, Three Mixed Lanes & One Bus Lane

MODEL STATISTICS						
	Prior Model	Data Model	Posterior Model			
R ²	0.82	0.72	0.82			
Se	0.165*	0.03*	0.135*			
COEFFICIENT STATISTICS						
	Coefficient Mean			t-statistic		
Model Parameter	Prior Model	Data Model	Posterior Model	Prior Model	Data Model	Posterior Model
Intercept	4.48	4.3	4.16	24.0	26.2	43.8
q _{thr}	0.016	0.04	0.023	2.4	2.9	4.95
q _{rt} X q _{bus}	0.002	0.0005	0.001	1.9	0.99	2.13
q _{lt}	0.18	0.066	0.17	7.2	1.4	8.7
HV	0.04	0.002	0.06	0.12	0.15	3.08
(StopxSigpkm) ³	0.0008	0.001	0.001	5.74	1.1	7.98

* in natural logarithmic form

Although both the prior and data models have some insignificant variables, the Bayesian solution, by balancing the inherent statistics in the two input models, produces a posterior model with acceptable coefficient statistics. The 95% confidence interval for the posterior model is 154 ($e^{5.31 - 2 \cdot 0.135}$) to 265 ($e^{5.31 + 2 \cdot 0.135}$) for an average prediction of 202 seconds per kilometre. Hence, the best equation based on the numerous iterations attempted to improve the predictive power of the model is, in exponential format:

$$\text{Travtime} = \text{EXP} \left[\underset{(43.8)}{4.16} + \underset{(4.95)}{0.023} q_{thr} + \underset{(2.13)}{0.001} (q_{rt} \times q_{bus}) + \underset{(8.7)}{0.17} q_{lt} + \underset{(3.08)}{0.06} HV + \underset{(7.98)}{0.001} (\text{Stop} \times \text{Sigpkm})^3 \right] \quad (\text{Eqn 6.4})$$

Presented in a linear format (format used to perform linear regression):

$$\ln(\text{Travtime}) = \underset{(43.8)}{4.16} + \underset{(4.95)}{0.023} q_{thr} + \underset{(2.13)}{0.001} (q_{rt} \times q_{bus}) + \underset{(8.7)}{0.17} q_{lt} + \underset{(3.08)}{0.06} HV + \underset{(7.98)}{0.001} (\text{Stop} \times \text{Sigpkm})^3 \quad (\text{Eqn 6.4})$$

4.7 Final Model Selection

Based on the Bayesian statistical results and discussions in this Chapter, the following models can be used for the four urban street configurations;

TABLE 6.21: Final Models for the Four Urban Street Configurations

Final Model Form * **	Attributes
<u>TWO-WAY, TWO DIRECTIONAL LANES, WITH PARKING</u> $\text{Travtime} = 113.6 + 0.13 q_{\text{total}}^3 + 0.26 (\text{Stop} \times \text{Sigpkm})^3$ <div style="display: flex; justify-content: space-around; width: 100%;"> (13.7) (5.3) (7.7) </div>	$-R^2 = 0.67$; Se = 35.7 -95% confidence interval = $218 \pm 72 \text{ sec/km}$
<u>TWO-WAY, ONE DIRECTIONAL LANE, NO PARKING</u> $\text{Travtime} = 154.6 + 0.005 k_{\text{total}}^3 + 0.15 (\text{Stop} \times \text{Sigpkm})^3$ <div style="display: flex; justify-content: space-around; width: 100%;"> (22.9) (5.3) (6.6) </div>	$-R^2 = 0.63$; Se=37.7 -95% confidence interval = $222 \pm 75 \text{ sec/km}$
<u>ONE-WAY, THREE LANES, NO PARKING ***</u> $\text{Travtime} = 118.4 + 0.02 q_{\text{thr}}^3 + 20.5 q_{\text{rt}} + 0.08 (\text{Stop} \times \text{Sigpkm})^3$ <div style="display: flex; justify-content: space-around; width: 100%;"> (18.2) (7.1) (11.6) (20.8) </div>	$-R^2 = 0.91$; Se=37.1 -95% confidence interval = $289 \pm 74 \text{ sec/km}$
<u>ONE-WAY, THREE MIXED LANES & ONE BUS LANE, NO PARKING</u> $\text{Travtime} = \text{EXP} [4.16 + 0.023 q_{\text{thr}} + 0.001 (q_{\text{rt}} \times q_{\text{bus}}) + 0.17 q_{\text{lt}} + 0.06 \text{HV} + 0.001 (\text{Stop} \times \text{Sigpkm})^3]$ <div style="display: flex; justify-content: space-around; width: 100%;"> (43.8) (4.95) (2.13) (8.7) (3.1) (7.98) </div>	$-R^2 = 0.82$; Se=0.135 (natural log form) -95% confidence interval = $(e^{5.31 - 2 \times 0.135}) \text{ to } (e^{5.31 + 2 \times 0.135})$, or $154 \text{ to } 265 \text{ (ave pred.}=202)$

NOTES:

- * the values in brackets below each independent variable correspond to the t-statistic;
- ** the traffic flow (q_{thr} , q_{rt} , q_{lt} , q_{total} ; in vehicles per minute) and traffic density (k_{total} ; in vehicles per km) variables reflect automobiles and heavy vehicles but not transit buses
- *** the "left turning flow" variable is not included in the final equation since the variable was determined to have an irrational (i.e. negative) regression coefficient; the attempt made to combine all three flow variables into a "total flow" variable resulted in unreasonable model statistics.

The complete Bayesian regression output statistics from the XLBAYES program for the final models are provided in Appendix D.

CHAPTER 7

MODEL PREDICTIONS

7.1 Relationship Between Traffic Flow, Traffic Density, and Travel Time

After developing prediction models, it is useful to examine if the relationship between the dependent variable and the independent variables is logical. Using the final models derived for the four street types under study (presented in Table 6.21), the travel time predictions are plotted against traffic flow (or traffic density) as illustrated in Figures 7.1 to 7.4. To do so, each independent variable in the equation other than traffic flow (or in the case of street type 2, traffic density) is held at its base case (i.e. mean value).

FIGURE 7.1: Travel Time Predictions Using Bayesian Posterior Model - Street Type 1: Two-Way, Two Lanes Per Direction

FIGURE 7.2: Travel Time Predictions Using Bayesian Posterior Model -
 Street Type 2: Two-Way, One Lane Per Direction

FIGURE 7.3: Travel Time Predictions Using Bayesian Posterior Model -
 Street Type 3: One-Way, Three Lanes

FIGURE 7.4: Travel Time Predictions Using Bayesian Posterior Model - Street Type 4: One-Way, Three Mixed Lanes & One Bus Lane

Figure 7.1 illustrates the relationship between travel time and total traffic flow on a two-way, two lane street when holding the $(\text{Stop} \times \text{Sigpkm})^3$ term at its mean value of 329.76. The curve indicates that as the total flow of vehicles on the street increases, travel time also increases at an increasing rate (i.e. curve is concave). This graph is convenient since one can easily determine the approximate time it will take to traverse one kilometer of this street type for any magnitude of traffic flow.

Figure 7.2 shows the relationship between travel time and traffic density on a two-way, one directional lane facility when holding the $(\text{Stop} \times \text{Sigpkm})^3$ term at its mean value of 90.74. This curve demonstrates that travel time will increase from approximately 170 to 230 seconds per kilometer as traffic density increases from about 8 to 23 vehicles per kilometer.

For the one-way, three lane street type, travel time is plotted against the flow of through moving vehicles keeping q_{tr} and $(\text{Stop} \times \text{Sigpkm})^3$ at their respective

base values of 0.671 and 1081.5 (see Figure 7.3). As expected the relationship between traffic flow and travel time is concave.

Figure 7.4 illustrates the model predictions of the log-linear equation that was derived for the one-way street type with three mixed lanes and one transit bus lane. As the functional formulation of the equation suggests, the relationship between "through flow" and "travel time" is of a natural logarithmic form which has a slight concave curvature.

7.2 Comparison of Model Predictions

It is useful to compare the model predictions of travel time against actual travel times observed in the field. To accomplish this, the independent variable observations from Tables 5.1 to 5.4 were inserted into the final equations from Section 6.7 to obtain travel time predictions. Table 7.1 presents, for the four street configurations under study, the comparison of travel time measured in the field versus travel time estimated by the Bayesian posterior model.

Table 7.1: Comparison of Field Travel Times and Model Predictions

Street Type	Peak Period (1½ hr)	Travel Time (seconds/km)		
		Field Data	Bayesian Model	Difference (%)
1. Two-Way, Two Directional Lanes, Parking Permitted	June 6, 1994 - pm	239.5	298.1	24.5%
	June 7, 1994 - pm	233.7	303.6	29.9%
	June 13, 1994 - pm	227.5	274.2	20.5%
	June 14, 1994 - pm	224.2	277.7	23.9%
2. Two-Way, One Directional Lane, No Parking	June 13, 1994 - pm	164.7	192.7	17.0%
	June 14, 1994 - pm	153.5	185.5	20.8%
	June 15, 1994 - pm	162.1	195.5	20.6%

Table 7.1 (continued)

Street Type	Peak Period (1½ hr)	Travel Time (seconds/km)		
		Field Data	Bayesian Model	Difference (%)
3. One-Way, Three Lanes, No Parking	June 6, 1994 - pm	299.9	292.5	-2.5%
	June 7, 1994 - pm	291.0	294.6	1.3%
	June 8, 1994 - pm	293.8	295.0	0.4%
	June 8, 1994 - am	271.5	256.7	-5.4%
4. One-Way, Three Mixed Lanes & One Bus Lane, No Parking	June 13, 1994 - pm	137.1	143.3	4.6%
	June 14, 1994 - pm	141.8	144.3	1.7%
	June 15, 1994 - pm	136.5	143.3	5.0%
	June 13, 1994 - am	142.9	158.3	10.8%

NOTE: -For each 1½ hour peak period, the average 15 minute travel time values were averaged over the 1½ hour time period

Figures 7.5 to 7.8 illustrate the comparison of the travel time values predicted by the Bayesian regression models against the actual travel times measured in the Ottawa CBD.

Figure 7.5: Comparison of Bayesian Model Predictions With Field Data - Street Type 1: Two-Way, Two Lanes Per Direction

Figure 7.6: Comparison of Bayesian Model Predictions With Field Data -
Street Type 2: Two-Way, One Lane Per Direction

Figure 7.7: Comparison of Bayesian Model Predictions With Field Data -
Street Type 3: One-Way, Three Lanes

Figure 7.8: Comparison of Bayesian Model Predictions With Field Data - Street Type 4: One-Way, Three Mixed Lanes & One Bus Lane

Examining Figure 7.5, the posterior model overpredicts travel time by an average of 24%. It is interesting to look back at the 95 % confidence interval for this street type (refer to Table 6.21): 218 ± 72 sec/km (i.e. ± 2 Se). This confidence interval means that for an actual travel time observation of 218 seconds per kilometer, there is a 95% probability that the posterior model will predict a travel time value between 146 and 290 seconds per kilometer, that is, within 33% of the actual value. However, in most instances the model prediction will be better than 33% of the field value since by definition, the 95% confidence interval is quite wide. As Figure 6.5 demonstrates, for the field data collected in the Ottawa CBD during the month of June 1994, the posterior model prediction is within 24% of the actual travel time measured in the field.

Figure 7.6 demonstrates that, for the two-way, one lane (per direction) facility, the posterior model overpredicts travel time by an average of 20% over the three peak periods monitored. Similarly to the previous street type, this prediction accuracy is within the 95% confidence interval of 34% (i.e. 222 ± 75 sec/km).

Figures 7.5 and 7.6 seem to indicate that there is some inherent bias in the prediction models for two-way streets since the predictions are high by a relatively consistent factor. However it should be remembered that the models are being gauged against the field data set which is intrinsically noisy (hence the reason why the Bayesian method was used in the first place). If the models were compared against a large high quality field data set and still overpredicted travel time in a consistent fashion, then the functional form of the models would need to be re-evaluated.

The travel time predictions provided by the posterior model for the one-way, three lane street configuration are very good, as illustrated in Figure 7.7. In fact, according to Table 6.22 the model underpredicts travel time by 2% and 5% during two peak traffic periods: afternoon of June 6, 1994, and morning of June 8, 1994, respectively. The model overpredicts travel time by 1% and 0.4% during the other two monitoring periods. Hence, even though the 95% confidence interval for this model was found to be ± 74 sec/km (i.e. a difference of 26% of the average prediction), the actual model predictions based on this field data set in Ottawa are much more accurate.

The prediction accuracy of the model for the fourth street type (one-way, three mixed lanes & one bus lane) is also very good, as shown in Figure 7.8. The posterior model only overpredicts travel time by an average difference of 6%.

Based on the assessment of Figures 7.5 to 7.8, the model predictions on the one-way street types are superior to the predictions on two-way streets. This

may be explained by the greater variability in traffic patterns (caused by increased vehicle friction and a higher chance for traffic obstructions) on two-way streets as compared to one-way streets. For example, the first street type has two lanes in one direction but the far right lane is being used for parking; consequently any vehicle movements (such as right and left turns, parking manoeuvres, bus service, truck loading) will have a significant impact on the one moving lane. The same can be said for the other two-way street type which only has one lane in either direction.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This thesis documented the use of a Bayesian regression analysis towards the development of peak period travel time models in a downtown city centre. The author believes that the final models can be used in their current form to provide reasonable predictions of actual travel times on various street configurations in the central business district of medium to large cities. These models can be useful to transportation engineers and planners in any application where travel time estimates are needed, such as in the identification of high congestion locations on city streets, in Advanced Traveller Information Systems, in the economic analysis of transportation alternatives, and in the evaluation of route improvements. It is important to remember that the models are not applicable under highly unstable traffic conditions corresponding to a Level-Of-Service F.

The following conclusions are made in relation to the overall purpose of the thesis and in relation to each of the specific research objectives stated in Chapter 1.

THESIS GOAL

The purpose of the thesis was to *investigate the practicality of using a Bayesian regression methodology towards the development of travel time models for multi-link streets in a central business district (CBD);*

- the Bayesian regression approach was demonstrated to be useful in building predictive models where classical regression fails; namely, when dealing with a small experimental data sample size;

- the Bayesian methodology was shown to derive reasonable predictive equations even when one of the two information sources (the NETSIM traffic simulation or the field data) have insignificant statistics;
- the use of a Bayesian modelling approach forces the user to derive a model using a systematic approach;
- the Bayesian regression software (XLBAYES) provides a user-friendly and intuitive platform for developing Bayesian models;

THESIS OBJECTIVES

1) The first stated objective of the thesis involved *developing arterial traffic models for one-way and two-way downtown streets*;

- models predicting “travel time” on four common urban street configurations were developed using intuitive contributory variables for which data are readily available within transportation agencies;
- after performing numerous Bayesian regression iterations for the four street types, the final models have reasonable statistics given the stochastic nature of an urban traffic flow system (please see Table 6.21 in Section 6.7 for an outline of the final models);
 - the coefficient of multiple determination (R^2) for the four models ranged from 0.63 to 0.91;
 - the 95% confidence interval (based on the model standard error, Se) was found to be in the range of ± 50 to ± 75 seconds per kilometer;
 - interpreted another way, Se was calculated to be between 12 and 17% of the average prediction;
- the model statistics proved to be superior for the one-way street configurations (R^2 of 0.91 and 0.82; Se of 37.1 and 0.135 (natural log form)) as compared to the two-way streets (R^2 of 0.67 and 0.63; Se of 35.7 and 37.7); this may be explained by the stochastic nature of interrupted-flow systems - two-way streets are more sensitive to vehicle friction and also to variations in traffic patterns (especially in the case of a two-way street with

one lane per direction), and hence it is more difficult to make reliable travel time predictions for these streets;

- the average difference between travel time measured in the field and travel time estimated by the Bayesian models, as a percentage of the field travel time, was 24% and 20% for two-way streets, and 2% and 6% for one-way streets; also it seems that three of the four models overestimate travel time while the model for one-way, three lane streets slightly underestimates travel time;

Concerning the prediction accuracy of the models, it is important to remember that traffic flow on a signalized arterial is a stochastic system which is intrinsically noisy; in other words, the system has random noise - using regression (Bayesian or classical), all of this random noise is contained in the model standard error, Se .

2) The second specific objective involved *qualifying and quantifying the influence of various roadway, traffic and signalization characteristics on the duration of trips in a central business district*;

- for three of the four street types under study, "traffic flow" ("total flow", or disaggregated into "through", "left turning", and "right turning" flow) was determined to be statistically significant with respect to travel time;
- for the two-way street with one lane per direction, traffic flow was computed to be insignificant; consequently "traffic density" was employed and found to be significant (note: although "traffic density" has been proven in past research to be a good indicator of travel delay, the author felt that "traffic flow" was a more intuitive and common variable which is why it was used in the first place);
- $(Stop \times Sigpkm)$, or the product of "percent of vehicles stopped" and "number of signals per kilometer", was used as a proxy for traffic interruptions - this cluster term was found to have a significant positive

influence on travel time in all cases; this result is intuitive since the “% of vehicles stopped” is a measure of the traffic signal efficiency, and “# of signals per km” has an obvious influence on delay and travel time;

- the statistical results indicated that “bus flow” and “% of heavy vehicles” do not have a significant influence on travel time in most of the equations;
- for the one-way street with a transit bus lane, the combination of “bus flow x right turning flow” was found to be significant which is logical since the right turning vehicles must manoeuvre across the bus lane to make the right turn.

3) The third objective of this thesis implied the *development of a field data collection procedure using videotape technology, and the assessment of its viability.*

- for monitoring traffic flow on downtown streets, the video recorder was found to be a viable, inexpensive and effective tool;
- although video equipment is not costly, the data reduction aspect of the procedure was observed to be time consuming and tedious;
- a step-by-step procedure was developed for recording and extracting the field data from the video cassettes; various means were defined during this exercise to facilitate the process - these are presented as recommendations in Section 8.2.

4) The final thesis objective involved *evaluating the various capabilities of the TRAF-NETSIM software, and in particular its usefulness in providing input data for the development of regression models of traffic flow;*

- TRAF-NETSIM was determined to be a very useful tool for simulating urban street networks and producing a wealth of output measures of effectiveness (MOE) related to the performance of the network;

- however, the proper use of the program requires the user to spend a considerable amount of time searching for and preparing the correct input data (such as turning movements and signal timing plans at each intersection of the network, lane configurations, pedestrian flow, bus routes, etc.); alternatively assumptions or estimates can be made for many of the input values;
- the actual data input process of NETSIM was found to be time-consuming and prone to data entry mistakes (the data input structure could be improved upon by integrating dynamic links between related input fields); most program execution errors require the modification of numerous input data which are often related to the same basic error - hence much time could be saved if these input fields were dynamically linked;
- concerning NETSIM's usefulness in providing regression data, the output MOE can be conveniently exported to a word processor and subsequently entered into a spreadsheet for regression analysis.

8.2 Recommendations

Concerning the use and improvement of the travel time models for central area streets, the following suggestions are made:

- it is believed that the models can successfully be used in city centres other than Ottawa as long as they are applied to similar street configurations (i.e. same # of lanes, parking, etc...);
- the Bayesian posterior models should be validated based on a real-world application (e.g. identifying a congested segment on a given city street and assessing whether the model predicts with reasonable accuracy);
- to improve on the existing models using a Bayesian modelling approach, the following is suggested;
 - collect additional field data on the same four street types;

- use the existing posterior models as future “priors” (i.e. model-based prior);
- additional field data are then used to update the prior models in order to generate a new set of posterior models with superior prediction accuracy;
- using this approach, this procedure can be repeated as many times as desired - the real benefit of the Bayesian modelling methodology will then become apparent as all of the inherent information from previous modelling efforts will be reflected in each new set of posterior models (i.e. no information is lost or ignored);
- owing to the scope of this research, the predictive equations were developed using ranges of values corresponding to peak-hour traffic conditions; it would be beneficial to extend the range of values to cover off-peak conditions as well - this will provide for travel time predictions for a full 24 hour period (for use in Advanced Traveller Information Systems, for example);
- the models were developed based on field data collected during the month of June; hence due to seasonal variations in traffic patterns, the models may need to be calibrated for use during other distinctly different periods of the year such as;
 - peak summer months; due to reduced traffic flow as a result of vacationers and the increased presence of pedestrians and bicycles,
 - winter months; due to reduced speeds as a result of snow and ice conditions;
- since an interrupted-flow arterial traffic system is stochastic in nature and intrinsically noisy, future research can investigate the use of other modelling techniques such as fuzzy logic¹⁴ and neural networks¹⁵ which may be better suited than “regression” to handle the random noise;

¹⁴ *Fuzzy logic, or fuzzy set theory, provides a means of modelling conditions which are inherently imprecisely defined, or which change over time. Fuzzy logic starts with and builds on a*

Regarding field data acquisition using video technology, the following recommendations are made;

- select the video recording location only as high as necessary to view two segments of the road (the higher the camera, the smaller the vehicles will appear on the screen making it difficult to clearly view the second segment);
- use a quality video recorder and record on Standard Play (SP) speed to obtain the clearest picture possible (using Extended Play (EP) makes the picture more blurry);
- only film on a clear day (even on a clear day, it is sometimes difficult to see the end of the second street segment);
- avoid particularly sunny days if the street under study is adjacent to high buildings as these will cast heavy shadows on the viewing zone;
- record the date and time when filming with the video recorder (this is essential for later identification of the cassettes and for calculating travel time);
- use a quality VCR with 4 heads, and view the video on the largest television screen available (this will help avoid eye strain from extended viewing).

set of user-specified human language rules regarding the system being modelled. The fuzzy systems convert these rules to their mathematical equivalents which simplifies the job of the system designer and results in much more accurate representations of the way systems behave in the real world. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. (The MathWorks Inc. 1996)

¹⁵ *Evolving from neuro-biological insights, neural network technology involves a network comprised of computational units, called neurons, organized in a series of layers that relate a series of input variables to one or more outputs. The neural network learns from the input data and successively adjusts the interconnecting weights between neurons until an acceptable threshold on the predictions is achieved. At the core of neural computation are the concepts of distributed, adaptive, and nonlinear computing. (NeuroDimension Inc. 1995)*

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APPENDIX A

A DISCUSSION ON BAYES' THEOREM

Bayes' Theorem, named after Reverend Thomas Bayes^a, "gives a mathematical procedure for updating your prior belief about a value of the parameter to produce a posterior distribution for the parameter, one determined subsequent to your having observed the outcome of an experiment bearing on the value of the unknown parameter. Thus, Bayes' Theorem provides a vehicle for changing, or updating, the degree of belief about a parameter in light of more recent information. It is a formal procedure for merging knowledge obtained from experience, or theoretical understanding of a random process, with observational data". (Press 1989, pp. 15-16)

In essence, Bayes' Theorem can be used in the estimation of "posteriori" probabilities when "a priori" probabilities and sample information are available. Described in a different way, this statement says that Bayesian analysis enables new information, in the form of sample data, to update or revise the best estimates of the probabilities that existed prior (a priori) to the collection of the sample data, to ultimately achieve improved posterior (posteriori) probabilities.

In mathematical terms, Bayes' theorem for continuous random variables can be explained as follows (Zellner 1971, pp. 13-17). Let y denote a random observation vector, and α a random parameter vector (α may include the model coefficients, or

^a Thomas Bayes was a Presbyterian minister and mathematician who lived in England in the 1700s (born circa 1702 and died April 17, 1761). Bayes' theorem is attributed to Bayes' manuscript ("An Essay Towards Solving a Problem in the Doctrine of Chances" - Bayes 1763) on inverse probability in which he proposed a method for making probability inferences about the parameters of a binomial distribution conditional on some observations from that distribution. The theorem has since been generalized to be applicable beyond the binomial distribution, to any sampling distribution.

variances and covariances of disturbance terms, etc.). Then, the conditional probability, $p(\alpha | y)$, of α given that y has occurred (or is known) is given by;

$$p(\alpha | y) = p(\alpha) p(y | \alpha) / p(y) \quad (1)$$

where; $p(\alpha | y)$ = joint probability density function, pdf
 $p(y) \neq 0$

This expression can be rewritten as follows;

$$\begin{aligned} p(\alpha | y) &\approx p(\alpha) p(y|\alpha) \\ &\approx \text{prior pdf} \times \text{likelihood function} \end{aligned} \quad (2)$$

where $\approx$ denotes proportionality, $p(\alpha | y)$ is the *posterior pdf* for the parameter vector α , given the sample information y , $p(\alpha)$ is the *prior pdf* for the parameter vector α , and $p(y|\alpha)$, viewed as a function of α , is the so-called *likelihood function*. Equation 2 is a statement of Bayes' Theorem, a simple mathematical result in the theory of probability (Zellner 1971, p. 14).

Note that the joint posterior pdf, $p(\alpha | y)$, has all of the prior and sample information incorporated in it. The prior information enters the posterior pdf via the prior pdf, whereas all the sample information enters via the likelihood function.

In modelling applications, we are usually interested in calculating the model coefficients, b (where b is the vector of coefficients), and the standard deviation of the estimates, s . y remains the vector of sample observation. In this case, the application of Bayes' Theorem yields the following *posterior pdf* for b and s ,

$$p(b,s | y) \approx p(b,s) p(y | b,s) \quad (3)$$

where $p(b, s)$ is the *prior pdf* and $p(y | b, s)$ is the *likelihood function*.

APPENDIX B

DERIVATION OF BAYESIAN LINEAR REGRESSION EQUATIONS

Within a linear modelling framework, the mechanism in which the *prior information* and the *objective data* are combined to arrive at the posterior modelling parameters (regression coefficients, b_{post} , variance of the coefficients, S_{post}^2 , standard error of the model, Se_{post} , covariances, etc) is explained by a *Bayesian analysis of the normal linear regression model*^a.

Similarly to classical regression, Bayesian regression analysis utilizes the "least squares" technique to estimate the model coefficients. The difference with the Bayesian methodology is that as a first step, the *prior* modelling parameters are computed followed by the *new data* parameters. Using matrix algebra, the two sets of regression coefficients are subsequently combined using the following relationship, in matrix form (Zellner 1971);

$$\begin{aligned} b_{\text{post}} &= \text{posterior regression coefficients vector} & (1) \\ &= \frac{(X_{\text{data}}^t X_{\text{data}}) b_{\text{data}} + A_{\text{prior}} b_{\text{prior}}}{X_{\text{data}}^t X_{\text{data}} + A_{\text{prior}}} \end{aligned}$$

where;

$$\begin{aligned} X_{\text{data}} &= \text{matrix of independent variable observations} \\ b_{\text{data}} &= \text{vector of regression coefficient means, based on the data} \\ b_{\text{prior}} &= \text{vector of regression coefficient means, based on the prior information} \\ A_{\text{prior}} &= \text{prior precision matrix} \\ &= \left[\frac{\text{Var/Covar}_{\text{prior}} (v_{\text{prior}} - 2)}{v_{\text{prior}} (Se_{\text{prior}})^2} \right]^{-1} \end{aligned}$$

$\text{Var/Covar}_{\text{prior}}$ = variance/covariance matrix of the prior information

^a Bayesian linear regression analysis is described in detail by various authors; Press 1989; Pilz 1991; Raiffa and Schlaiffer 1961; and Zellner 1971.

As can be seen in equation (1), the balance between the prior information source and the experimental data is dictated by the prior precision matrix, A_{prior} . As A_{prior} increases, the 'a priori' information has a greater influence on the Bayesian posterior model. When A_{prior} decreases, the prior has less weight.

Now to explain how equation (1) was arrived at, we will refer to the mathematical derivation of the Bayesian regression formulas according to Zellner (Zellner 1971). Let us begin with the simple univariate linear equation ^b;

$$y_i = b_0 + b_1 x_i + u_i \quad (2)$$

where y_i = i^{th} observation on the dependent variable,

x_i = i^{th} observation on the independent variable,

u_i = i^{th} unobserved value of the random disturbance or error variable,

b_0, b_1 = regression parameters

Now let us extend this to the multiple regression model. If we assume that an $n \times 1$ vector of observations, Y , on our dependent variable satisfies;

$$Y = X b + u \quad (3)$$

where b = a $k \times 1$ vector of regression coefficients =

$$\begin{bmatrix} b_0 \\ \dots \\ \dots \\ b_k \end{bmatrix}$$

^b It is important to note that the relation in equation (2) is linear in b_0, b_1 and u_i , hence the term linear regression. However, the relation need not be linear in the underlying variables. Transformations can be applied to the equation or cluster variable terms can be utilized to approximate a non-linear relationship.

u = an $n \times 1$ vector of disturbance or error terms,

X = an $n \times k$ matrix, with n observations and k independent variables

$$= \begin{bmatrix} x_{10} & x_{11} & \dots & x_{1k} \\ x_{20} & x_{21} & \dots & x_{2k} \\ \dots & \dots & \dots & \dots \\ x_{n0} & x_{n1} & \dots & x_{nk} \end{bmatrix}$$

For example, x_{21} refers to the second observation (e.g. the observation in year 2 if we're taking annual measurements) of the second of $k+1$ independent variables.

It is assumed that the elements of u are normally and independently distributed, each with zero mean and common variance s^2 and thus $u \sim N(0, s^2 I)$. Under these assumptions, the *likelihood function* is given by (Zellner 1971);

$$p(Y | b, s) = (2\pi)^{-n/2} s^{-n} \exp\{-[vs^2 + (b - b_{\text{data}})' X' X (b - b_{\text{data}})] / 2s^2\} \quad (4)$$

where b_{data} = vector of regression coefficients derived from the data

$$= (X' X)^{-1} X' Y \quad (5)$$

$X' X$ = known as the *precision matrix*

X' = transpose of the X matrix (also denoted as X^t)

v = degrees of freedom (equals # of observations, n , minus # of independent variables, k)

$$= n - k$$

s^2 = standard error (i.e.: std deviation of the variability in Y unexplained by the regression equation)

$$vs^2 = (Y - X b_{\text{data}})' (Y - X b_{\text{data}}) \quad (6)$$

The prior probability density function, pdf, for the multiple regression model can be written as;

$$p(\mathbf{b}, s) \approx s^{-k} \exp\{-(\mathbf{b} - \mathbf{b}_{\text{prior}})' A (\mathbf{b} - \mathbf{b}_{\text{prior}}) / 2 s^2\} \times s^{-(v_{\text{prior}} + 1)} \exp\{-v_{\text{prior}} s_{\text{prior}}^2 / 2 s^2\} \quad (7)$$

where $A_{\text{prior}} = \text{prior information precision matrix (shown earlier)}$
 $\mathbf{b}_{\text{prior}} = \text{prior regression coefficients vector}$

The values of the prior parameters, $\mathbf{b}_{\text{prior}}$, A_{prior} , s_{prior} , v_{prior} , must first be derived from the prior information source and input into equation (7).

Let's re-introduce Bayes' Theorem (Equation 3 in APPENDIX A), where the *posterior pdf* for $\mathbf{b}$ and s is;

$$\text{Bayes' Theorem: } p(\mathbf{b}, s | \mathbf{y}) \approx p(\mathbf{b}, s) p(\mathbf{y} | \mathbf{b}, s)$$

Hence, inserting equation (4) (likelihood function) and equation (7) (prior pdf) into Bayes' Theorem yields;

$$p(\mathbf{b}, s | \mathbf{Y}) \approx s^{-k} \exp\{-(\mathbf{b} - \mathbf{b}_{\text{post}})' M (\mathbf{b} - \mathbf{b}_{\text{post}}) / 2 s^2\} \times s^{-(v_{\text{post}} + 1)} \exp\{-v_{\text{post}} s_{\text{post}}^2 / 2 s^2\} \quad (8)$$

$$\begin{aligned} \text{where; } M &= \text{posterior precision matrix} \\ &= (X' X)_{\text{data}} + A_{\text{prior}} \end{aligned} \quad (9)$$

$$\mathbf{b}_{\text{post}} = \text{posterior regression coefficients vector} \quad (1)$$

$$= \frac{(X' X) \mathbf{b}_{\text{data}} + A \mathbf{b}_{\text{prior}}}{M}$$

$$s_{\text{e}} = \text{posterior standard error}$$

$$v_{\text{post}} s_{\text{e}}^2 = v_{\text{prior}} s_{\text{prior}}^2 + v_{\text{data}} s_{\text{data}}^2 + (\mathbf{b}_{\text{data}} - \mathbf{b}_{\text{post}})' X' X (\mathbf{b}_{\text{data}} - \mathbf{b}_{\text{post}}) + (\mathbf{b}_{\text{prior}} - \mathbf{b}_{\text{post}})' A (\mathbf{b}_{\text{prior}} - \mathbf{b}_{\text{post}}) \quad (10)$$

$$\begin{aligned}
 v_{\text{post}} &= \text{posterior degrees of freedom} \\
 &= v_{\text{data}} + v_{\text{prior}} - k
 \end{aligned}
 \tag{11}$$

$$\text{Var/Cov}_{\text{post}} = (M)^{-1} (v_{\text{post}} \text{Se}_{\text{post}}^2) / (v_{\text{post}} - 2) \tag{12}$$

Relationship Between Classical and Bayesian Regression

It is useful to demonstrate how classical regression is actually a special case of Bayesian regression. Let's assume that we do not have any prior knowledge whatsoever regarding the modelling parameters, not even what the sign should be on the regression coefficients. In Bayesian terms, this is called a "diffuse prior".

Since there is no prior information, A and b_{prior} equal zero and the posterior precision matrix, $M = X'X + A$ becomes;

$$M = X'X$$

and Equation (1); $b_{\text{post}} = \{ (X'X) b_{\text{data}} + A b_{\text{prior}} \} / M$

can be rewritten as;

$$b_{\text{post}} = X'X b_{\text{data}} / X'X$$

$$b_{\text{post}} = b_{\text{data}}$$

This simple analysis proves that when there is no prior information, Bayesian regression is equivalent to Classical regression analysis.

APPENDIX C
FIELD DATA TABLES

Traffic Flow - Queen Street EB, June 6, 16:00-16:15											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	%	
		All Vehicles *		Bus		HV					
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%			
16:00-16:05	Kent to Bank	38	9	1	0	1	0	2.04	45	92	
	Bank to O'Connor	36	6	1	0	0	1	2.27	30	68	
	ave flow per min, q	7.4	1.5	12	0			2		80	
16:05-16:10	Kent to Bank	46	9	1	0	2	0	3.45	53	91	
	Bank to O'Connor	47	5	1	0	1	1	3.64	32	58	
	ave flow per min, q	9.3	1.4	12	0			4		75	
16:10-16:15	Kent to Bank	38	3	0	0	2	0	4.55	41	93	
	Bank to O'Connor	34	7	0	0	2	0	4.65	31	72	
	ave flow per min, q	7.3	1	0	0			5		83	
	15 min ave modeling variables:	8.00	1.30	8.00	0			3.4		79.4	
Travel Time Observations - June 6, Queen Street											
Kent to O'Connor: 2 links (374 m)											
	random vehicle #	Time to Traverse Both Links (seconds)									
		16:00-16:05	16:05-16:10	16:10-16:15							
	1	100	105	88							
	2	97	80	95							
	3	101	73	103							
	4	82	81	85							
	5	88	92	73	AVE						
	average	93.6	86.2	88.8	89.5						
Traffic Flow - Queen Street EB, June 6, 16:15-16:30											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	%	
		All Vehicles *		Bus		HV					
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%			
16:15-16:20	Kent to Bank	47	3	2	0	0	0	0.00	50	96	
	Bank to O'Connor	42	10	2	0	0	0	0.00	40	74	
	ave flow per min, q	8.9	1.3	24	0			0		85	
16:20-16:25	Kent to Bank	30	5	1	0	1	0	2.70	27	73	
	Bank to O'Connor	23	9	1	0	2	0	5.71	23	66	
	ave flow per min, q	5.3	1.4	12	0			4		69	
16:25-16:30	Kent to Bank	39	10	1	0	0	1	1.96	47	92	
	Bank to O'Connor	35	8	1	0	2	0	4.35	26	57	
	ave flow per min, q	7.4	1.8	12	0			3		74	
	15 min ave modeling variables:	7.20	1.50	16.00	0			2.5		76.3	
Travel Time Observations - June 6, Queen Street											
Kent to O'Connor: 2 links (374m)											
	random vehicle #	Time to Traverse Both Links (seconds)									
		16:15-16:20	16:20-16:25	16:25-16:30							
	1	70	78	101							
	2	123	42	76							
	3	104	54	90							
	4	87	95	79							
	5	81	89	84	AVE						
	average	93	71.6	86	83.5						
Traffic Flow - Queen Street EB, June 6, 16:30-16:45											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	%	
		All Vehicles *		Bus		HV					
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%			
16:30-16:35	Kent to Bank	41	7	1	0	0	0	0.00	46	94	
	Bank to O'Connor	34	12	1	0	0	0	0.00	21	45	
	ave flow per min, q	7.5	1.9	12	0			0		69	
16:35-16:40	Kent to Bank	28	6	0	1	1	0	2.78	23	64	
	Bank to O'Connor	22	10	0	0	0	1	3.03	26	79	
	ave flow per min, q	5	1.6	0	6			3		71	
16:40-16:45	Kent to Bank	37	6	0	0	1	0	2.27	43	98	
	Bank to O'Connor	26	12	0	0	1	0	2.56	17	44	
	ave flow per min, q	6.3	1.8	0	0			2		71	
	15 min ave modeling variables:	6.27	1.77	4.00	2.00			1.8		70.3	
Travel Time Observations - June 6, Queen Street											
Kent to O'Connor: 2 links (374m)											
	random vehicle #	Time to Traverse Both Links (seconds)									
		16:30-16:35	16:35-16:40	16:40-16:45							
	1	86	99	60							
	2	92	80	52							
	3	86	62	39							
	4	80	63	60							
	5	94	51	54	AVE						
	average	87.6	71	53	70.5						
Traffic Flow - Queen Street EB, June 6, 16:45-17:00											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	%	
		All Vehicles *		Bus		HV					
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%			

		Through	Right Turn	Through	Right Tur	Through	Right Tur	%	stopped	Stops
16:45-16:50	Kent to Bank	40	6	2	0	0	0	0.00	44	92
	Bank to O'Connor	38	9	1	1	0	0	0.00	47	98
	ave flow per min, q	7.8	1.5	18	6			0		94
16:50-16:55	Kent to Bank	44	7	1	0	1	0	1.89	50	94
	Bank to O'Connor	45	10	1	0	1	0	1.75	57	100
	ave flow per min, q	8.9	1.7	12	0			2		97
16:55-17:00	Kent to Bank	38	8	1	0	1	0	2.08	47	98
	Bank to O'Connor	43	12	1	0	1	0	1.75	54	95
	ave flow per min, q	8.1	2	12	0			2		96
15 min ave modeling variables:		6.27	1.33	14.00	2.00			1.2		95.8
Travel Time Observations - June 6, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	16:45-16:50	16:50-16:55	16:55-17:00						
	1	75	98	90						
	2	89	106	77						
	3	102	83	109						
	4	92	78	89						
	5	80	105	97	AVE					
	average	87.6	94	92.4	91.3					
Traffic Flow - Queen Street EB, June 6, 17:00-17:15										
		Volume/Flow (veh/min or veh/hr)								
Time Period	Link	All Vehicles *		Bus		HV		%	No. of veh	%
		Through	Right Turn	Through	Right Tur	Through	Right Tur		stopped	Stops
17:00-17:05	Kent to Bank	41	8	2	0	0	0	0.00	51	100
	Bank to O'Connor	34	17	2	0	0	0	0.00	51	96
	ave flow per min, q	7.5	2.5	24	0			0		98
17:05-17:10	Kent to Bank	37	5	0	0	0	0	0.00	42	100
	Bank to O'Connor	39	13	0	0	0	0	0.00	52	100
	ave flow per min, q	7.6	1.8	0	0			0		100
17:10-17:15	Kent to Bank	42	6	1	0	0	0	0.00	49	100
	Bank to O'Connor	35	12	1	0	0	0	0.00	47	98
	ave flow per min, q	7.7	1.8	12	0			0		99
15 min ave modeling variables:		7.60	2.03	12.00	0.00			0.0		99.0
Travel Time Observations - June 6, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	17:00-17:05	17:05-17:10	17:10-17:15						
	1	86	87	111						
	2	120	114	112						
	3	97	101	89						
	4	86	97	83						
	5	94	112	106	AVE					
	average	96.6	102.2	100.2	99.7					
Traffic Flow - Queen Street EB, June 6, 17:15-17:30										
		Volume/Flow (veh/min or veh/hr)								
Time Period	Link	All Vehicles *		Bus		HV		%	No. of veh	%
		Through	Right Turn	Through	Right Tur	Through	Right Tur		stopped	Stops
17:15-17:20	Kent to Bank	43	10	1	0	1	0	1.82	55	100
	Bank to O'Connor	47	5	1	0	1	0	1.85	54	100
	ave flow per min, q	9	0	12	0			2		100
17:20-17:25	Kent to Bank	43	10	1	0	1	0	1.82	51	93
	Bank to O'Connor	46	6	1	0	1	0	1.85	46	85
	ave flow per min, q	8.9	1.6	12	0			2		89
17:25-17:30	Kent to Bank	44	5	2	0	1	0	1.92	51	98
	Bank to O'Connor	40	8	2	0	1	0	1.96	48	94
	ave flow per min, q	8.4	1.3	24	0			2		96
15 min ave modeling variables:		8.77	1.77	16.00	0.00			1.9		95.0
Travel Time Observations - June 6, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	17:15-17:20	17:20-17:25	17:25-17:30						
	1	137	75	102						
	2	133	87	111						
	3	155	106	96						
	4	102	100	88						
	5	85	79	87	AVE					
	average	122.4	89.4	96.8	102.9					

* "All Vehicles" includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)

Traffic Flow - Queen Street EB, June 13, 16:00-16:15														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										No. of veh stopped	% Stops	
		All Vehicles *			Bus			HV						
		Through	Left Turn	Right Turn	Through	L.T.	R.T.	Through	L.T.	R.T.	%			
16:00-16:05	O'Connor to Metcalfe	36		9	NA	0	0	NA	1	0	NA	2.17	39	85
	Metcalfe to Elgin	20	NA	24	0	NA	0	0	NA	1	2.22	41	91	
	5 min average	5.6	0.9	2.4	0	0	0	0	NA	1	2.20		88	
16:05-16:10	O'Connor to Metcalfe	37		5	NA	1	0	NA	2	0	NA	4.44	33	73
	Metcalfe to Elgin	17	NA	25	1	NA	0	2	NA	0	4.44	32	71	
	5 min average	5.4	0.5	2.5	12	0	0	0	NA	0	4.44		72	
16:10-16:15	O'Connor to Metcalfe	33		6	NA	0	0	NA	1	0	NA	2.50	35	88
	Metcalfe to Elgin	24	NA	15	0	NA	0	1	NA	0	2.50	38	95	
	5 min average	5.7	0.6	1.5	0	0	0	0	NA	0	2.50		91	
15 min ave modeling variables:		5.5?	0.6?	2.1?	4.00	0.00	0.00				3.05			
Travel Time Observations - June 13, Queen Street														
O'Connor to Elgin: 2 links (370m)														
random	Time to Traverse Both Links (seconds)													
vehicle #	16:00-16:0	16:05-16:10	16:10-16:15											
1	67	68	109											
2	52	73	93											
3	75	52	61											
4	79	107	58	Ave travel time per km										
5	87	99	72	207.8										
average	72	79.8	76.8	AVE										
Traffic Flow - Queen Street EB, June 13, 16:15-16:30														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										No. of veh stopped	% Stops	
		All Vehicles *			Bus			HV						
		Through	Left Turn	Right Turn	Through	L.T.	R.T.	Through	L.T.	R.T.	%			
16:15-16:20	O'Connor to Metcalfe	33		7	NA	2	0	NA	1	0	NA	2.33	30	70
	Metcalfe to Elgin	20	NA	18	2	NA	0	0	NA	1	2.44	32	78	
	5 min average	5.3	0.7	1.8	24	0	0	0	NA	1	2.38		74	
16:20-16:25	O'Connor to Metcalfe	30		3	NA	2	0	NA	1	0	NA	2.78	23	64
	Metcalfe to Elgin	19	NA	19	2	NA	0	0	NA	1	2.44	27	66	
	5 min average	4.9	0.3	1.9	24	0	0	0	NA	1	2.61		65	
16:25-16:30	O'Connor to Metcalfe	32		5	NA	0	0	NA	1	0	NA	2.63	31	82
	Metcalfe to Elgin	19	NA	18	0	NA	0	1	NA	0	2.63	33	87	
	5 min average	5.1	0.5	1.8	0	0	0	0	NA	0	2.63		84	
15 min average modeling variables:		5.10	0.50	1.83	16.00	0.00	0.00				2.54		74	
Travel Time Observations - June 13, Queen Street														
O'Connor to Elgin: 2 links (370m)														
random	Time to Traverse Both Links (seconds)													
vehicle #	16:15-16:2	16:20-16:25	16:25-16:30											
1	72	69	30											
2	80	76	88											
3	58	68	79											
4	56	86	65	Ave travel time per km										
5	90	54	96	192.3										
average	71.2	70.6	71.6	AVE										
Traffic Flow - Queen Street EB, June 13, 16:30-16:45														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										No. of veh stopped	% Stops	
		All Vehicles *			Bus			HV						
		Through	Left Turn	Right Turn	Through	L.T.	R.T.	Through	L.T.	R.T.	%			
16:30-16:35	O'Connor to Metcalfe	47		5	NA	2	0	NA	2	0	NA	3.57	55	98
	Metcalfe to Elgin	38	NA	20	2	NA	0	2	NA	0	3.23	51	82	
	5 min average	8.5	0.5	2	24	0	0	0	NA	0	3.40		90	
16:35-16:40	O'Connor to Metcalfe	42		4	NA	0	0	NA	0	0	NA	0.00	31	67
	Metcalfe to Elgin	25	NA	19	0	NA	0	0	NA	0	0.00	40	91	
	5 min average	6.7	0.4	1.9	0	0	0	0	NA	0	0.00		79	
16:40-16:45	O'Connor to Metcalfe	45		4	NA	2	0	NA	0	0	NA	0.00	50	98
	Metcalfe to Elgin	25	NA	16	1	NA	0	0	NA	0	0.00	23	55	
	5 min average	7	0.4	1.6	18	0	0	0	0	NA	0	0.00		76
15 min average modeling variables:		7.40	0.43	1.63	14.00	0.00	0.00				1.13		82	
Travel Time Observations - June 13, Queen Street														
O'Connor to Elgin: 2 links (370m)														
random	Time to Traverse Both Links (seconds)													
vehicle #	16:30-16:3	16:35-16:40	16:40-16:45											
1	70	98	113											
2	128	143	87											
3	73	87	75											
4	90	78	66	Ave travel time per km										
5	83	80	69	241.6										
average	88.8	97.2	82	AVE										
Traffic Flow - Queen Street EB, June 13, 16:45-17:00														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										No. of veh stopped	% Stops	
		All Vehicles *			Bus			HV						
		Through	Left Turn	Right Turn	Through	L.T.	R.T.	Through	L.T.	R.T.	%			

[illegible]

Traffic Flow - Queen Street EB, June 7, 16:00-16:15										
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	% Stops
		All Vehicles *		Bus		HV				
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%		
16:00-16:05	Kent to Bank	40	8	2	0	0	0	0.00	50	100
	Bank to O'Connor	35	15	2	0	0	0	0.00	48	92
	5 min average	7.5	2.3	24	0			0		96
16:05-16:10	Kent to Bank	38	7	0	0	1	0	2.17	44	96
	Bank to O'Connor	38	12	0	0	1	0	1.96	50	98
	5 min average	7.6	1.9	0	0			2		97
16:10-16:15	Kent to Bank	43	7	1	0	0	0	0.00	49	96
	Bank to O'Connor	35	13	1	0	0	0	0.00	48	98
	5 min average	7.8	2	12	0			0		97
	15 min ave modeling variables:	7.63	2.07	12.00	0			0.0		96.7
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374 m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	16:00-16:05	16:05-16:10	16:10-16:15						
	1	118	96	104						
	2	95	85	108						
	3	79	89	93						
	4	87	90	85						
	5	89	84	89	AVE					
	average	93.6	88.8	95.8	92.7					
Traffic Flow - Queen Street EB, June 7, 16:15-16:30										
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	% Stops
		All Vehicles *		Bus		HV				
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%		
16:15-16:20	Kent to Bank	37	7	2	0	1	0	2.13	45	96
	Bank to O'Connor	32	8	2	0	1	0	2.33	40	93
	5 min average	6.9	1.5	24	0			2		94
16:20-16:25	Kent to Bank	32	9	1	0	1	0	2.33	43	100
	Bank to O'Connor	29	6	1	0	1	0	2.70	35	95
	5 min average	6.1	1.5	12	0			3		97
16:25-16:30	Kent to Bank	38	8	1	0	1	1	4.08	49	100
	Bank to O'Connor	42	7	1	0	1	0	1.96	46	90
	5 min average	8	1.5	12	0			3		95
	15 min ave modeling variables:	7.00	1.50	16.00	0			2.8		95.8
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	16:15-16:20	16:20-16:25	16:25-16:30						
	1	89	88	108						
	2	110	96	96						
	3	100	105	90						
	4	90	78	101						
	5	86	90	88	AVE					
	average	95	91.4	96.6	94.3					
Traffic Flow - Queen Street EB, June 7, 16:30-16:45										
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	% Stops
		All Vehicles *		Bus		HV				
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%		
16:30-16:35	Kent to Bank	38	10	1	0	1	0	2.00	49	98
	Bank to O'Connor	36	7	1	0	0	1	2.22	33	73
	5 min average	7.4	1.7	12	0			2		86
16:35-16:40	Kent to Bank	47	8	1	0	2	0	3.45	57	98
	Bank to O'Connor	46	8	1	0	1	1	3.51	50	88
	5 min average	9.3	1.6	12	0			3		93
16:40-16:45	Kent to Bank	42	4	0	0	2	0	4.17	44	92
	Bank to O'Connor	34	9	0	0	2	0	4.44	34	76
	5 min average	7.6	1.3	0	0			4		84
	15 min ave modeling variables:	8.10	1.53	6.00	0.00			1.3		87.4
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	16:30-16:35	16:35-16:40	16:40-16:45						
	1	100	80	103						
	2	97	92	88						
	3	89	78	82						
	4	76	109	111						
	5	86	102	73	AVE					
	average	89.6	92.2	91.4	91.1					
Traffic Flow - Queen Street EB, June 7, 16:45-17:00										
Time Period	Link	Volume/Flow (veh/min or veh/hr)							No. of veh stopped	% Stops
		All Vehicles *		Bus		HV				
		Through	Right Turn	Through	Right Tur	Through	Right Tur	%		

		Through	Right Turn	Through	Right Turn	Through	Right Turn	%	stopped	Stops
16:45-16:50	Kent to Bank	40	7	1	0	0	0	0.00	47	98
	Bank to O'Connor	35	13	1	0	0	0	0.00	22	45
	5 min average	7.5	2	12	0			0		71
16:50-16:55	Kent to Bank	31	7	0	0	1	0	2.56	27	69
	Bank to O'Connor	21	11	0	0	1	1	5.88	27	79
	5 min average	5.2	1.8	0	0			4		74
16:55-17:00	Kent to Bank	37	7	0	0	1	0	2.22	44	98
	Bank to O'Connor	30	14	0	0	1	0	2.22	19	42
	5 min average	6.7	2.1	0	0			2		70
15 min ave modeling variables:		6.47	1.93	4.00	0.00			2.1		71.9
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	16:45-16:50	16:50-16:55	16:55-17:00						
	1	96	67	67						
	2	83	98	85						
	3	90	77	76						
	4	96	82	83						
	5	87	63	51	AVE					
	average	90.4	77.4	72.4	80.1					
Traffic Flow - Queen Street EB, June 7, 17:00-17:15										
Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *		Bus		HV		%	No. of veh stopped	% Stops
		Through	Right Turn	Through	Right Tur	Through	Right Tur			
17:00-17:05	Kent to Bank	46	5	2	0	0	0	0.00	48	91
	Bank to O'Connor	40	12	2	0	0	0	0.00	41	76
	5 min average	8.6	1.7	24	0			0		83
17:05-17:10	Kent to Bank	28	11	1	0	1	0	2.44	30	73
	Bank to O'Connor	28	6	0	1	2	0	5.41	23	62
	5 min average	5.6	1.7	6	6			4		68
17:10-17:15	Kent to Bank	40	7	1	0	0	1	2.04	47	96
	Bank to O'Connor	37	8	1	0	1	1	4.17	30	63
	5 min average	7.7	1.5	12	0			3		79
15 min ave modeling variables:		7.30	1.63	14.00	2.00			2.3		76.7
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	17:00-17:05	17:05-17:10	17:10-17:15						
	1	105	79	79						
	2	81	85	77						
	3	75	58	80						
	4	88	69	95						
	5	92	80	91	AVE					
	average	88.2	74.2	84.4	82.3					
Traffic Flow - Queen Street EB, June 7, 17:15-17:30										
Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *		Bus		HV		%	No. of veh stopped	% Stops
		Through	Right Turn	Through	Right Tur	Through	Right Tur			
17:15-17:20	Kent to Bank	40	6	2	0	0	0	0.00	45	94
	Bank to O'Connor	40	8	1	1	0	0	0.00	46	92
	5 min average	8	1.4	18	6			0		83
17:20-17:25	Kent to Bank	41	8	1	0	1	0	1.96	39	76
	Bank to O'Connor	45	13	1	0	1	0	1.67	47	78
	5 min average	8.6	2.1	12	0			2		77
17:25-17:30	Kent to Bank	47	7	1	0	1	0	1.79	46	82
	Bank to O'Connor	43	10	1	0	1	0	1.82	40	73
	5 min average	9	1.7	12	0			2		77
15 min ave modeling variables:		8.23	1.73	14.00	2.00			1.2		82.8
Travel Time Observations - June 7, Queen Street										
Kent to O'Connor: 2 links (374m)										
	random	Time to Traverse Both Links (seconds)								
	vehicle #	17:15-17:20	17:20-17:25	17:25-17:30						
	1	78	74	60						
	2	102	67	88						
	3	92	89	94						
	4	107	94	88						
	5	74	67	87	AVE					
	average	90.8	78.2	83.4	84.1					
* "All Vehicles" includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)										

Traffic Flow - Queen Street EB, June 14, 16:00-16:15													
Time Period	Link	Volume/Flow (veh/min or veh/hr)											
		All Vehicles *			Bus			HV			No. of veh stopped	%	
		Through	Left Turn	Right Turn	Through	L. T.	R. T.	Through	L. T.	R. T.			%
16:00-16:05	O'Connor to Metcalfe	45	6	NA	1	0	NA	1	0	NA	1.89	48	9
	Metcalfe to Elgin	26	NA	21	1	NA	0	1	NA	0	2.04	43	88
	5 min average	7.1	0.6	2.1	12	0	0				1.96		
16:05-16:10	O'Connor to Metcalfe	42	7	NA	1	0	NA	1	0	NA	1.96	41	80
	Metcalfe to Elgin	23	NA	20	1	NA	0	0	NA	1	2.22	41	9
	5 min average	6.5	0.7	2	12	0	0				2.08		
16:10-16:15	O'Connor to Metcalfe	39	6	NA	1	0	NA	2	0	NA	4.17	36	75
	Metcalfe to Elgin	22	NA	17	1	NA	0	2	NA	0	4.76	40	95
	5 min average	6.1	0.6	1.7	12	0	0				4.46		85
	15 min average modeling variables	6.58	0.63	1.93	12.00	0.00	0.00				2.84		90
Travel Time Observations - June 14, Queen Street													
O'Connor to Elgin: 2 links (370m)													
	random	Time to Traverse Both Links (seconds)											
	vehicle #	16:00-16:05	16:05-16:10	16:10-16:15									
	1	88	77	82									
	2	99	87	79									
	3	111	93	96									
	4	68	80	104	AVE travel time per km								
	5	101	104	76	242.3								
	average	93.4	88.2	87.4	89.667								
Traffic Flow - Queen Street EB, June 14, 16:15-16:30													
Time Period	Link	Volume/Flow (veh/min or veh/hr)											
		All Vehicles *			Bus			HV			No. of veh stopped	%	
		Through	Left Turn	Right Turn	Through	L. T.	R. T.	Through	L. T.	R. T.			%
16:15-16:20	O'Connor to Metcalfe	41	5	NA	1	0	NA	1	0	NA	2.08	44	92
	Metcalfe to Elgin	26	NA	17	1	NA	0	1	NA	0	2.22	36	80
	5 min average	6.7	0.5	1.7	12	0	0				2.15		86
16:20-16:25	O'Connor to Metcalfe	30	4	NA	2	0	NA	1	0	NA	2.70	31	84
	Metcalfe to Elgin	17	NA	22	2	NA	0	0	NA	1	2.38	31	74
	5 min average	4.7	0.4	2.2	24	0	0				2.54		75
16:25-16:30	O'Connor to Metcalfe	38	5	NA	1	0	NA	2	0	NA	4.35	40	87
	Metcalfe to Elgin	22	NA	15	1	NA	0	2	NA	0	5.00	34	85
	5 min average	6	0.5	1.5	12	0	0				4.67		86
	15 min average modeling variables	6.00	0.47	1.63	16.00	0.00	0.00				3.12		84
Travel Time Observations - June 14, Queen Street													
O'Connor to Elgin: 2 links (370m)													
	random	Time to Traverse Both Links (seconds)											
	vehicle #	16:15-16:20	16:20-16:25	16:25-16:30									
	1	92	75	50									
	2	83	92	77									
	3	63	64	89									
	4	54	89	98	AVE travel time per km								
	5	103	59	72	200								
	average	79	75.8	77.2	77.3								
Traffic Flow - Queen Street EB, June 14, 16:30-16:45													
Time Period	Link	Volume/Flow (veh/min or veh/hr)											
		All Vehicles *			Bus			HV			No. of veh stopped	%	
		Through	Left Turn	Right Turn	Through	L. T.	R. T.	Through	L. T.	R. T.			%
16:30-16:35	O'Connor to Metcalfe	36	5	NA	2	0	NA	2	0	NA	4.44	36	80
	Metcalfe to Elgin	18	NA	20	2	NA	0	2	NA	0	4.76	36	86
	5 min average	5.4	0.5	2	24	0	0				4.60		83
16:35-16:40	O'Connor to Metcalfe	37	4	NA	0	0	NA	0	0	NA	0.00	33	80
	Metcalfe to Elgin	19	NA	19	0	NA	0	0	NA	0	0.00	35	92
	5 min average	5.6	0.4	1.9	0	0	0				0.00		86
16:40-16:45	O'Connor to Metcalfe	30	4	NA	2	0	NA	0	0	NA	0.00	29	81
	Metcalfe to Elgin	15	NA	16	1	NA	0	0	NA	0	0.00	19	59
	5 min average	4.5	0.4	1.6	18	0	0				0.00		70
	15 min average modeling variables	6.17	0.43	1.63	16.00	0.00	0.00				1.53		80
Travel Time Observations - June 14, Queen Street													
O'Connor to Elgin: 2 links (370m)													
	random	Time to Traverse Both Links (seconds)											
	vehicle #	16:30-16:35	16:35-16:40	16:40-16:45									
	1	85	75	66									
	2	65	85	47									
	3	96	103	40									
	4	79	74	55	AVE travel time per km								
	5	70	79	61	194.8								
	average	79	83.2	53.8	72.0								
Traffic Flow - Queen Street EB, June 14, 16:45-17:00													
Time Period	Link	Volume/Flow (veh/min or veh/hr)											
		All Vehicles *			Bus			HV			No. of veh stopped	%	
		Through	Left Turn	Right Turn	Through	L. T.	R. T.	Through	L. T.	R. T.			%

Traffic Flow - Bank Street SB, June 15, 16:00-17:30											
		Volume/Flow (veh/min or veh/hr)									
Time Period	Link	All Vehicles *			Bus	HV		%	Total Vehicles	No. of veh. stopped	% Stops
		Through	Left Turn	Right Turn	Through *	Through	Right Turn				
16:00-16:10	Slater to Laurier	55	NA	14	7	1	0	1.30	77	43	56
	Laurier to Gloucester	56	NA	8	7	1	0	1.33	75	40	53
	10 min ave modeling variables	5.70	NA	1.10	42.00				1.32		56
16:10-16:20	Slater to Laurier	53	NA	17	5	1	0	1.32	76	38	54
	Laurier to Gloucester	60	NA	11	5	1	0	1.30	77	41	53
	10 min ave modeling variables	5.65	NA	1.40	30.00				1.31		53
16:20-16:30	Slater to Laurier	49	NA	19	6	1	1	2.63	76	38	56
	Laurier to Gloucester	55	NA	12	6	1	0	1.35	74	36	48
	10 min ave modeling variables	5.20	NA	1.65	36.00				1.36		48
16:30-16:40	Slater to Laurier	49	NA	16	5	1	1	2.78	72	35	48
	Laurier to Gloucester	52	NA	7	5	2	1	4.48	67	27	40
	10 min ave modeling variables	5.05	NA	1.15	30.00				1.63		40
16:40-16:50	Slater to Laurier	36	NA	14	2	1	1	3.70	54	25	46
	Laurier to Gloucester	41	NA	9	2	1	0	1.89	53	20	38
	10 min ave modeling variables	3.65	NA	1.15	12.00				2.80		42
16:50-17:00	Slater to Laurier	51	NA	16	4	2	0	2.74	73	37	51
	Laurier to Gloucester	58	NA	11	4	2	0	2.67	75	33	44
	10 min ave modeling variables	5.45	NA	1.35	24.00				2.70		47
17:00-17:10	Slater to Laurier	43	NA	18	4	2	0	2.99	67	30	45
	Laurier to Gloucester	49	NA	9	4	1	1	3.13	64	28	44
	10 min ave modeling variables	4.60	NA	1.35	24.00				3.08		44
17:10-17:20	Slater to Laurier	39	NA	10	3	1	0	1.89	53	23	43
	Laurier to Gloucester	45	NA	6	3	1	0	1.82	55	22	40
	10 min ave modeling variables	4.20	NA	0.80	18.00				1.86		42
17:20-17:30	Slater to Laurier	44	NA	17	3	1	1	3.03	66	26	38
	Laurier to Gloucester	54	NA	6	3	1	1	2.99	67	35	52
	10 min ave modeling variables	4.60	NA	1.25	18.00				3.01		46
Travel Time Observations - June 15, Bank Street											
Slater to Nepean - 3 links (325m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	16:00-16:10	16:10-16:20	16:20-16:30	16:30-16:40	16:40-16:50	16:50-17:00	17:00-17:10	17:10-17:20	17:20-17:30	
	1	88	45	54	66	39	55	27	62	59	
	2	62	64	49	62	44	45	48	43	33	
	3	55	67	72	36	61	56	41	54	46	
	4	71	55	61	42	33	72	66	57	42	
	5	56	71	46	58	47	59	35	52	50	
	6	87	84	67	35	57	60	57	30	38	
	7	38	66	58	59	27	39	59	25	54	
	8	63	51	39	49	40	51	49	42	62	
	AVE	65.0	62.9	55.8	50.9	43.5	54.8	47.8	45.8	48.0	
	Ave Travel Time per km	200.0	193.5	171.5	156.5	133.8	168.1	146.9	140.4	147.7	
* *All Vehicles* includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)											

Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
16:45-16:50	Albert to Slater	77	21	NA	2	2	0	NA	1.96	102	85	83
	Slater to Laurier	81	16	9	2	2	0	0	1.82	110	45	41
	5 min average	15.8	3.7	0.9	24				1.89			62
16:50-16:55	Albert to Slater	59	20	NA	2	0	0	NA	0.00	81	67	83
	Slater to Laurier	60	13	5	1	0	0	0	0.00	79	35	44
	5 min average	11.8	3.3	0.5	18				0.00			64
16:55-17:00	Albert to Slater	75	18	NA	1	0	0	NA	0.00	94	86	91
	Slater to Laurier	77	17	7	1	0	0	0	0.00	102	42	41
	5 min average	15.2	3.5	0.7	12				0.00			66
	15 min ave modeling variables	14.30	3.50	0.70	16.00				0.83			64
Travel Time Observations - June 6, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:45-16:50	16:50-16:55	16:55-17:00								
	1	74	61	46								
	2	53	86	61								
	3	35	48	52								
	4	17	13	43								
	5	62	44	57	AVE							
	average	48.2	50.4	51.8	50.1333							
Traffic Flow - Lyon Street SB, June 6, 17:00-17:15												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
17:00-17:05	Albert to Slater	66	21	NA	2	2	0	NA	2.20	91	72	79
	Slater to Laurier	62	18	6	1	1	0	1	2.25	89	29	33
	5 min average	12.8	3.9	0.6	18				2.22			56
17:05-17:10	Albert to Slater	81	13	NA	1	1	0	NA	1.04	96	74	77
	Slater to Laurier	80	17	7	1	1	0	0	0.94	106	49	46
	5 min average	16.1	3	0.7	12				0.98			62
17:10-17:15	Albert to Slater	90	16	NA	0	0	0	NA	0.00	106	99	93
	Slater to Laurier	91	19	9	0	0	0	0	0.00	119	76	64
	5 min average	18.1	3.5	0.9	0				0.00			79
	15 min ave modeling variables	15.67	3.47	0.73	10.00				1.07			65
Travel Time Observations - June 6, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	17:00-17:05	17:05-17:10	17:10-17:15								
	1	54	73	85								
	2	35	64	53								
	3	19	43	64								
	4	69	22	78								
	5	56	54	48	AVE							
	average	46.6	51.2	65.6	54.4667							
Traffic Flow - Lyon Street SB, June 6, 17:15-17:30												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
17:15-17:20	Albert to Slater	81	16	NA	4	2	0	NA	1.94	103	82	80
	Slater to Laurier	82	17	7	2	2	0	0	1.82	110	47	43
	5 min average	16.3	3.3	0.7	36				1.88	106.50		61
17:20-17:25	Albert to Slater	65	17	NA	1	1	0	NA	1.19	84	65	77
	Slater to Laurier	65	15	5	1	0	1	0	1.15	87	27	31
	5 min average	13	3.2	0.5	12				1.17	85.50		54
17:25-17:30	Albert to Slater	50	21	NA	3	1	0	NA	1.33	75	53	71
	Slater to Laurier	54	11	3	2	1	0	0	1.41	71	19	27
	5 min average	10.4	3.2	0.3	30				1.37	73.00		49
	15 min ave modeling variables	12.23	3.23	0.50	26.00				1.47			55
Travel Time Observations - June 6, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	17:15-17:20	17:20-17:25	17:25-17:30								
	1	57	63	33								
	2	38	55	37								
	3	49	29	56								
	4	64	42	26								
	5	48	39	58	AVE							
	average	51.2	45.6	42	46.2667							
* *All Vehicles* includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)												

Traffic Flow - Lyon Street SB, June 7, 16:00-16:15												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus	HV			%			
		Through	Left Turn	Right Turn	Through	Through	Left Turn	Right Turn	%			
16:00-16:05	Albert to Slater	86	23	NA	2	2	0	NA	1.77	113	84	74
	Slater to Laurier	89	15	7	2	2	0	0	1.74	115	48	42
	5 min average	17.5	3.8	0.7	24				1.75			58
16:05-16:10	Albert to Slater	83	17	NA	1	0	1	NA	0.98	102	86	84
	Slater to Laurier	85	16	6	1	0	0	0	0.00	108	45	42
	5 min average	16.8	3.3	0.6	12				0.49			63
16:10-16:15	Albert to Slater	64	20	NA	2	1	0	NA	1.15	87	68	78
	Slater to Laurier	64	14	5	1	1	1	0	2.33	86	34	40
	5 min average	12.8	3.4	0.5	18				1.74			56
15 min ave modeling variables		15.20	3.50	0.60	16.00				1.33			60
Travel Time Observations - June 7, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:00-16:05	16:05-16:10	16:10-16:15								
	1	52	44	28								
	2	26	59	52								
	3	47	54	75								
	4	53	66	51								
	5	70	33	45	AVE							
	average	49.6	51.2	50.2	50.3333							
Traffic Flow - Lyon Street SB, June 7, 16:15-16:30												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus	HV			%			
		Through	Left Turn	Right Turn	Through	Through	Left Turn	Right Turn	%			
16:15-16:20	Albert to Slater	81	17	NA	3	2	0	NA	1.94	103	82	80
	Slater to Laurier	79	16	8	3	1	1	0	1.85	108	50	46
	5 min average	16	3.3	0.6	36				1.90			63
16:20-16:25	Albert to Slater	50	20	NA	2	1	0	NA	1.37	73	51	70
	Slater to Laurier	52	13	5	3	0	0	1	1.35	74	24	32
	5 min average	10.2	3.3	0.5	30				1.36			51
16:25-16:30	Albert to Slater	63	16	NA	1	2	0	NA	2.44	82	65	79
	Slater to Laurier	66	15	5	1	1	1	0	2.25	89	25	28
	5 min average	12.9	3.1	0.5	12				2.34			53.7
15 min ave modeling variables		12.03	3.23	0.63	26.00				1.87			56
Travel Time Observations - June 7, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:15-16:20	16:20-16:25	16:25-16:30								
	1	54	47	54								
	2	66	53	26								
	3	91	48	41								
	4	36	35	26								
	5	16	31	74	AVE							
	average	52.6	42.8	44.2	46.5333							
Traffic Flow - Lyon Street SB, June 7, 16:30-16:45												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus	HV			%			
		Through	Left Turn	Right Turn	Through	Through	Left Turn	Right Turn	%			
16:30-16:35	Albert to Slater	90	24	NA	1	1	0	NA	0.86	116	80	69
	Slater to Laurier	86	17	5	1	1	0	0	0.91	110	40	36
	5 min average	17.6	4.1	0.5	12				0.89			53
16:35-16:40	Albert to Slater	83	26	NA	1	1	1	NA	1.79	112	82	73
	Slater to Laurier	83	14	6	0	1	0	0	0.96	104	55	53
	5 min average	16.6	4	0.6	8				1.37			63
16:40-16:45	Albert to Slater	78	18	NA	3	2	1	NA	2.94	102	93	91
	Slater to Laurier	85	13	7	2	2	0	0	1.83	109	51	47
	5 min average	16.3	3.1	0.7	30				2.39			69
15 min ave modeling variables		16.63	3.73	0.63	16.00				1.65			82
Travel Time Observations - June 7, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:30-16:35	16:35-16:40	16:40-16:45								
	1	68	76	68								
	2	80	47	41								
	3	93	33	41								
	4	55	77	56								
	5	35	54	76	AVE							
	average	66.2	57.4	56.4	60							
Traffic Flow - Lyon Street SB, June 7, 16:45-17:00												
Volume/Flow (veh/min or veh/hr)												

Traffic Flow - Lyon Street SB, June 8, 16:00-16:15														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus Through	HV			%					
		Through	Left Turn	Right Turn		Through	Left Turn	Right Turn						
16:00-16:05	Albert to Slater	76	22	NA	2	2	1	NA		2.91	103	89	86	
	Slater to Launer	79	11	6	2	2	0	0		2.00	100	57	57	
	5 min average	15.5	3.3	0.6	24					2.46			72	
16:05-16:10	Albert to Slater	77	19	NA	1	1	0	NA		1.02	98	67	68	
	Slater to Launer	74	16	5	1	0	0	1		1.03	97	50	52	
	5 min average	15.1	3.5	0.5	12					1.03			60	
16:10-16:15	Albert to Slater	81	23	NA	2	1	0	NA		0.93	107	98	92	
	Slater to Launer	82	17	9	2	1	0	0		0.90	111	72	65	
	5 min average	16.3	4	0.9	24					0.92			70	
15 min ave modeling variables:		15.63	3.60	0.97	20.00					1.67			78	
Travel Time Observations - June 8, Lyon Street														
Albert to Launer: 2 links (180m)														
	random	Time to Traverse Both Links (seconds)												
	vehicle #	16:00-16:05	16:05-16:10	16:10-16:15										
	1	77	48	47										
	2	36	54	97										
	3	41	91	61										
	4	56	35	49										
	5	87	50	65	AVE									
	average	59.4	55.6	63.8	59.6									
Traffic Flow - Lyon Street SB, June 8, 16:15-16:30														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus Through	HV			%					
		Through	Left Turn	Right Turn		Through	Left Turn	Right Turn						
16:15-16:20	Albert to Slater	90	17	NA	1	1	0	NA		0.92	109	77	71	
	Slater to Launer	93	17	8	1	1	0	0		0.83	120	48	40	
	5 min average	18.3	3.4	0.8	12					0.88			55	
16:20-16:25	Albert to Slater	66	20	NA	2	2	0	NA		2.22	90	73	81	
	Slater to Launer	65	21	6	2	1	1	0		2.08	96	32	33	
	5 min average	13.1	4.1	0.6	24					2.15			57	
16:25-16:30	Albert to Slater	80	15	NA	1	1	0	NA		1.03	97	76	78	
	Slater to Launer	82	18	7	1	1	0	1		1.82	110	53	48	
	5 min average	16.2	3.3	0.7	12					1.42			63.3	
15 min ave modeling variables:		15.87	3.60	0.76	16.00					1.46			59	
Travel Time Observations - June 8, Lyon Street														
Albert to Launer: 2 links (180m)														
	random	Time to Traverse Both Links (seconds)												
	vehicle #	16:15-16:20	16:20-16:25	16:25-16:30										
	1	47	19	71										
	2	74	39	55										
	3	89	59	68										
	4	50	63	21										
	5	61	55	37	AVE									
	average	64.2	47	50.4	53.8667									
Traffic Flow - Lyon Street SB, June 8, 16:30-16:45														
Time Period	Link	Volume/Flow (veh/min or veh/hr)										Total Vehicles	No. of veh stopped	%
		All Vehicles *			Bus Through	HV			%					
		Through	Left Turn	Right Turn		Through	Left Turn	Right Turn						
16:30-16:35	Albert to Slater	81	19	NA	1	0	0	NA		0.00	101	90	89	
	Slater to Launer	80	19	7	1	0	0	0		0.00	107	41	38	
	5 min average	16.1	3.8	0.7	12					0.00			64	
16:35-16:40	Albert to Slater	63	21	NA	2	0	0	NA		0.00	86	69	80	
	Slater to Launer	65	18	6	2	0	0	0		0.00	89	40	45	
	5 min average	12.8	3.7	0.6	24					0.00			63	
16:40-16:45	Albert to Slater	89	18	NA	2	2	0	NA		1.80	111	88	79	
	Slater to Launer	90	17	9	2	1	1	0		1.67	120	47	39	
	5 min average	17.8	3.5	0.9	24					1.73			59	
15 min ave modeling variables:		15.60	3.67	0.73	20.00					0.98			62	
Travel Time Observations - June 8, Lyon Street														
Albert to Launer: 2 links (180m)														
	random	Time to Traverse Both Links (seconds)												
	vehicle #	16:30-16:35	16:35-16:40	16:40-16:45										
	1	52	15	77										
	2	46	47	62										
	3	55	62	56										
	4	47	47	19										
	5	65	88	33	AVE									
	average	53	51.8	49.4	51.4									
Traffic Flow - Lyon Street SB, June 8, 16:45-17:00														
Volume/Flow (veh/min or veh/hr)														

Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
8:15-8:20	Albert to Slater	83	26	NA	1	1	1	NA	1.79	112	93	83
	Slater to Laurier	80	29	8	1	1	1	0	1.67	120	47	39
	5 min average	16.3	5.5	0.8	12				1.73			61
8:20-8:25	Albert to Slater	66	27	NA	0	2	0	NA	2.11	95	77	81
	Slater to Laurier	58	22	8	0	1	0	1	2.22	90	45	50
	5 min average	12.4	4.9	0.8	0				2.16			66
8:25-8:30	Albert to Slater	74	31	NA	1	1	0	NA	0.93	107	84	79
	Slater to Laurier	74	30	5	1	1	0	0	0.90	111	57	51
	5 min average	14.8	6.1	0.5	12				0.92			65
	15 min ave modeling variables	14.50	5.50	0.70	8.00				1.30			84
Travel Time Observations - June 8, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	8:15-8:20	8:20-8:25	8:25-8:30								
	1	58	73	45								
	2	79	65	68								
	3	83	45	74								
	4	58	29	58								
	5	63	44	60	AVE							
	average	68.2	51.2	61	60.1333							
Traffic Flow - Lyon Street SB, June 8, 8:30-8:45												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
8:30-8:35	Albert to Slater	79	29	NA	1	1	0	NA	0.91	110	88	80
	Slater to Laurier	58	24	6	1	1	0	1	2.20	91	38	42
	5 min average	13.7	5.3	0.6	12				1.65			61
8:35-8:40	Albert to Slater	71	23	NA	2	2	0	NA	2.04	98	71	72
	Slater to Laurier	57	28	5	2	2	0	0	2.13	94	40	43
	5 min average	12.8	5.1	0.5	24				2.08			58
8:40-8:45	Albert to Slater	69	20	NA	0	1	1	NA	2.20	91	62	68
	Slater to Laurier	48	18	7	0	1	0	0	1.35	74	32	43
	5 min average	11.7	3.8	0.7	0				1.77			56
	15 min ave modeling variables	12.73	4.73	0.60	12.00				1.80			58
Travel Time Observations - June 8, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	8:30-8:35	8:35-8:40	8:40-8:45								
	1	56	64	55								
	2	45	63	32								
	3	39	28	38								
	4	52	32	47								
	5	35	45	41	AVE							
	average	45.4	46.4	42.6	44.8							
Traffic Flow - Lyon Street SB, June 8, 8:45-9:00												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV				Total Vehicles	No. of veh stopped	% Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn	Right Turn			
8:45-8:50	Albert to Slater	81	33	NA	1	2	1	NA	2.54	118	82	69
	Slater to Laurier	54	23	10	1	2	0	0	2.22	90	47	52
	5 min average	13.5	5.6	1	12				2.38	104.00		61
8:50-8:55	Albert to Slater	71	26	NA	1	2	0	NA	2.00	100	75	75
	Slater to Laurier	53	29	7	1	1	1	0	2.17	92	37	40
	5 min average	12.4	5.5	0.7	12				2.09	96.00		58
8:55-9:00	Albert to Slater	91	23	NA	0	2	0	NA	1.72	116	99	85
	Slater to Laurier	71	28	13	0	2	0	0	1.75	114	56	49
	5 min average	16.2	5.1	1.3	0				1.74	115.00		67
	15 min ave modeling variables	14.03	5.40	1.30	8.00				2.07			82
Travel Time Observations - June 8, Lyon Street												
Albert to Laurier: 2 links (180m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	8:45-8:50	8:50-8:55	8:55-9:00								
	1	48	61	78								
	2	35	52	74								
	3	65	39	55								
	4	50	47	45								
	5	39	55	39	AVE							
	average	47.4	50.8	58.2	52.1333							
**All Vehicles* includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)												

Traffic Flow - Albert Street WB, June 13, 16:00-16:15												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV			Total Vehicles *	No. of veh. stopped	% Stops	
		Through	Left Turn	Right Turn		Through	Through	Left Turn				%
16:00-16:05	Egin to Metcalfe	40	NA		3	16	1	NA	1.67	44	18	40.9
	Metcalfe to O'Connor	39		32	NA	16	1	0	1.14	72	46	63.9
	5 min average	7.9		3.2	0.3	182			1.40			52.4
16:05-16:10	Egin to Metcalfe	40	NA		1	9	1	NA	1.96	42	27	64.3
	Metcalfe to O'Connor	45		25	NA	9	1	1	2.47	72	35	48.6
	5 min average	8.5		2.5	0.1	108			2.21			58.4
16:10-16:15	Egin to Metcalfe	44	NA		0	14	1	NA	1.69	45	25	55.6
	Metcalfe to O'Connor	48		22	NA	14	1	0	1.18	71	27	38.0
	5 min average	9.2		2.2	0	168			1.44			48.8
	15 min ave modeling variables:	8.63		2.63	0.13	156.00			1.36			61.4
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random vehicle #	Time to Traverse Both Links (seconds)										
		16:00-16:05	16:05-16:1	16:10-16:15								
	1	48	50	37								
	2	61	44	61								
	3	61	66	44								
	4	37	51	52								
	5	25	57	52								
	average	46	53.6	49.2	49.6							
Traffic Flow - Albert Street WB, June 13, 16:15-16:30												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV			Total Vehicles *	No. of veh. stopped	% Stops	
		Through	Left Turn	Right Turn		Through	Through	Left Turn				%
16:15-16:20	Egin to Metcalfe	44	NA		1	11	1	NA	1.75	46	18	39.1
	Metcalfe to O'Connor	47		27	NA	11	1	0	1.18	75	41	54.7
	5 min average	9.1		2.7	0.1	132			1.66			48.9
16:20-16:25	Egin to Metcalfe	40	NA		0	8	1	NA	2.04	41	23	56.1
	Metcalfe to O'Connor	43		23	NA	8	2	0	2.63	68	33	48.5
	5 min average	8.3		2.3	0	96			2.34			52.3
16:25-16:30	Egin to Metcalfe	36	NA		2	13	1	NA	1.92	39	20	51.3
	Metcalfe to O'Connor	42		21	NA	13	1	1	2.56	65	31	47.7
	5 min average	7.8		2.1	0.2	156			2.24			48.5
	15 min ave modeling variables:	8.40		2.37	0.10	128.00			2.01			49.8
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random vehicle #	Time to Traverse Both Links (seconds)										
		16:15-16:20	16:20-16:2	16:25-16:30								
	1	37	53	56								
	2	44	39	42								
	3	48	63	48								
	4	42	47	50								
	5	53	58	45								
	average	44.8	52	48.2	48.3							
Traffic Flow - Albert Street WB, June 13, 16:30-16:45												
		Volume/Flow (veh/min or veh/hr)										
Time Period	Link	All Vehicles *			Bus	HV			Total Vehicles *	No. of veh. stopped	% Stops	
		Through	Left Turn	Right Turn		Through	Through	Left Turn				%
16:30-16:35	Egin to Metcalfe	40	NA		1	15	2	NA	3.45	43	27	62.8
	Metcalfe to O'Connor	42		20	NA	15	0	2	2.53	64	29	45.3
	5 min average	8.2		2	0.1	180			2.99			54.1
16:35-16:40	Egin to Metcalfe	44	NA		5	10	2	NA	3.28	51	21	41.2
	Metcalfe to O'Connor	50		27	NA	10	1	1	2.25	79	28	35.4
	5 min average	9.4		2.7	0.5	120			2.78			38.3
16:40-16:45	Egin to Metcalfe	40	NA		1	11	0	NA	0.00	41	33	80.5
	Metcalfe to O'Connor	48		29	NA	11	0	0	0.00	77	30	39.0
	5 min average	8.8		2.9	0.1	132			0.00			59.7
	15 min ave modeling variables:	8.80		2.33	0.23	144.00			1.92			50.7
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random vehicle #	Time to Traverse Both Links (seconds)										
		16:30-16:35	16:35-16:4	16:40-16:45								
	1	27	55	70								
	2	58	46	40								
	3	49	37	63								
	4	36	58	59								
	5	66	34	46								
	average	47.2	46	55.6	49.6							
Traffic Flow - Albert Street WB, June 13, 16:45-17:00												
		Volume/Flow (veh/min or veh/hr)										

Time Period	Link	All Vehicles *			Bus	HV			%	Total Vehicles *	No. of veh. stopped	Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn				
16:45-16:50	Egin to Metcalfe	34	NA	3	24	1	NA	1.61	38	17	44.7	
	Metcalfe to O'Connor	44	20	NA	24	0	1	1.12	65	25	38.5	
	5 min average	7.8	2	0.3	288			1.37			41.8	
16:50-16:55	Egin to Metcalfe	41	NA	2	14	0	NA	0.00	43	23	53.5	
	Metcalfe to O'Connor	43	18	NA	14	1	0	1.32	62	23	37.1	
	5 min average	8.4	1.8	0.2	168			0.68			45.3	
16:55-17:00	Egin to Metcalfe	41	NA	2	14	0	NA	0.00	43	25	58.1	
	Metcalfe to O'Connor	44	28	NA	14	0	0	0.00	72	37	51.4	
	5 min average	8.6	2.8	0.2	168			0.00			54.8	
	15 min ave modeling variables:	8.25	2.20	0.25	206.00			0.00			47.2	
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:45-16:50	16:50-16:55	16:55-17:00								
	1	36	44	67								
	2	39	48	51								
	3	52	50	47								
	4	45	53	56								
	5	43	38	40	AVE							
	average	43	46.2	52.2	47.1							
Traffic Flow - Albert Street WB, June 13, 17:00-17:15												
Volume/Flow (veh/min or veh/hr)												
Time Period	Link	All Vehicles *			Bus	HV			%	Total Vehicles *	No. of veh. stopped	Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn				
17:00-17:05	Egin to Metcalfe	39	NA	1	15	0	NA	0.00	40	20	50.0	
	Metcalfe to O'Connor	40	33	NA	15	0	1	1.12	74	37	50.0	
	5 min average	7.8	3.3	0.1	180			0.58			50.0	
17:05-17:10	Egin to Metcalfe	42	NA	3	11	2	NA	3.45	47	23	48.9	
	Metcalfe to O'Connor	44	31	NA	11	1	1	2.27	77	43	55.8	
	5 min average	8.6	3.1	0.3	132			2.88			52.4	
17:10-17:15	Egin to Metcalfe	39	NA	2	14	0	NA	0.00	41	25	61.0	
	Metcalfe to O'Connor	48	26	NA	14	0	0	0.00	74	41	55.4	
	5 min average	8.7	2.6	0.2	168			0.00			58.2	
	15 min ave modeling variables:	8.40	3.00	0.20	180.00			1.14			29.8	
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	17:00-17:05	17:05-17:10	17:10-17:15								
	1	42	66	46								
	2	48	42	69								
	3	36	48	56								
	4	51	38	41								
	5	60	50	72	AVE							
	average	47.4	48.8	56.8	51.0							
Traffic Flow - Albert Street WB, June 13, 17:15-17:30												
Volume/Flow (veh/min or veh/hr)												
Time Period	Link	All Vehicles *			Bus	HV			%	Total Vehicles *	No. of veh. stopped	Stops
		Through	Left Turn	Right Turn		Through	Through	Left Turn				
17:15-17:20	Egin to Metcalfe	39	NA	0	13	1	NA	1.89	40	15	37.5	
	Metcalfe to O'Connor	39	26	NA	13	0	1	1.27	66	24	36.4	
	5 min average	7.8	2.6	0	156			1.58			36.9	
17:20-17:25	Egin to Metcalfe	37	NA	0	17	0	NA	0.00	37	20	54.1	
	Metcalfe to O'Connor	40	20	NA	17	0	0	0.00	60	17	28.3	
	5 min average	7.7	2	0	204			0.00			41.2	
17:25-17:30	Egin to Metcalfe	37	NA	1	9	1	NA	2.08	39	26	66.7	
	Metcalfe to O'Connor	38	22	NA	9	1	0	1.43	61	30	49.2	
	5 min average	7.5	2.2	0.1	108			1.76			57.9	
	15 min ave modeling variables:	7.82	2.27	0.03	156.00			1.11			45.3	
Travel Time Observations - June 13, Albert Street												
Egin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	17:15-17:20	17:20-17:25	17:25-17:30								
	1	26	38	30								
	2	54	64	64								
	3	34	46	45								
	4	73	37	36								
	5	33	49	65	AVE							
	average	44	46.8	48	48.3							
* "All Vehicles" includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)												
* total vehicles does not include transit buses in the dedicated bus lane												

Traffic Flow - Albert Street WB, June 14, 16:00-16:15																	
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops						
		All Vehicles *			Bus	HV		% Vehicles *									
		Through	Left Turn	Right Turn		Through	Left Turn										
16:00-16:05	Elgin to Metcalfe	40	NA	2	23	1	NA	1.52	43	20	46.5						
	Metcalfe to O'Connor	49	21	NA	23	0	1	1.06	71	26	36.6						
	5 min average	8.9	2.1	0.2	278	0	NA	1.29			41.8						
16:05-16:10	Elgin to Metcalfe	42	NA	3	14	0	NA	0.00	45	28	62.2						
	Metcalfe to O'Connor	47	27	NA	14	0	0	0.00	74	39	52.7						
	5 min average	8.9	2.7	0.3	188	0	0	0.00			57.5						
16:10-16:15	Elgin to Metcalfe	39	NA	3	22	1	NA	1.54	43	19	44.2						
	Metcalfe to O'Connor	47	19	NA	22	0	1	1.12	67	28	41.8						
	5 min average	8.6	1.9	0.3	284	0	1	1.33			43.0						
	15 min ave modeling variables	9.30	2.23	0.27	288.00			0.87			47.3						
Travel Time Observations - June 14, Albert Street																	
Elgin to O'Connor: 2 links (355m)																	
	random	Time to Traverse Both Links (seconds)				Ave travel time per km 142.9											
	vehicle #	16:00-16:05	16:05-16:1	16:10-16:15													
	1	38	67	53													
	2	53	42	37													
	3	47	54	42													
	4	73	43	54													
	5	53	59	46	AVE												
	average	52.8	53	46.4	50.7												
Traffic Flow - Albert Street WB, June 14, 16:15-16:30																	
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops						
		All Vehicles *			Bus	HV		% Vehicles *									
		Through	Left Turn	Right Turn		Through	Left Turn										
16:15-16:20	Elgin to Metcalfe	40	NA	1	13	0	NA	0.00	41	22	53.7						
	Metcalfe to O'Connor	38	32	NA	13	0	1	1.19	71	38	53.5						
	5 min average	7.8	3.2	0.1	158	0	1	0.60			53.6						
16:20-16:25	Elgin to Metcalfe	43	NA	1	11	2	NA	3.51	46	25	54.3						
	Metcalfe to O'Connor	40	30	NA	11	2	0	2.41	72	40	55.6						
	5 min average	8.3	3	0.1	132	2	0	2.98			55.0						
16:25-16:30	Elgin to Metcalfe	38	NA	1	14	0	NA	0.00	39	25	64.1						
	Metcalfe to O'Connor	46	25	NA	14	0	0	0.00	71	41	57.7						
	5 min average	8.4	2.6	0.1	168	0	0	0.00			60.9						
	15 min ave modeling variables	8.17	2.90	0.10	162.00			1.18			59.3						
Travel Time Observations - June 14, Albert Street																	
Elgin to O'Connor: 2 links (355m)																	
	random	Time to Traverse Both Links (seconds)				Ave travel time per km 150.0											
	vehicle #	16:15-16:20	16:20-16:2	16:25-16:30													
	1	51	36	71													
	2	64	59	68													
	3	48	43	53													
	4	34	69	49													
	5	62	53	39	AVE												
	average	51.8	52	56	53.3												
Traffic Flow - Albert Street WB, June 14, 16:30-16:45																	
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops						
		All Vehicles *			Bus	HV		% Vehicles *									
		Through	Left Turn	Right Turn		Through	Left Turn										
16:30-16:35	Elgin to Metcalfe	38	NA	2	15	1	NA	1.79	41	17	41.5						
	Metcalfe to O'Connor	38	31	NA	15	1	0	1.18	70	43	61.4						
	5 min average	7.6	3.1	0.2	180	1	0	1.48			61.4						
16:35-16:40	Elgin to Metcalfe	36	NA	2	9	2	NA	4.08	40	26	65.0						
	Metcalfe to O'Connor	43	22	NA	9	2	0	2.63	67	35	52.2						
	5 min average	7.9	2.2	0.2	108	2	0	3.38			58.6						
16:40-16:45	Elgin to Metcalfe	44	NA	4	13	1	NA	1.81	49	27	55.1						
	Metcalfe to O'Connor	50	23	NA	13	1	0	1.15	74	29	39.2						
	5 min average	8.4	2.3	0.4	158	1	0	1.38			47.1						
	15 min ave modeling variables	8.30	2.63	0.27	148.00			2.07			62.3						
Travel Time Observations - June 14, Albert Street																	
Elgin to O'Connor: 2 links (355m)																	
	random	Time to Traverse Both Links (seconds)				Ave travel time per km 148.0											
	vehicle #	16:30-16:35	16:35-16:4	16:40-16:45													
	1	37	67	35													
	2	60	55	44													
	3	26	52	57													
	4	45	59	50													
	5	63	57	65	AVE												
	average	46.2	58	50.2	51.5												
Traffic Flow - Albert Street WB, June 14, 16:45-17:00																	
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops						
		All Vehicles *			Bus	HV		% Vehicles *									
		Through	Left Turn	Right Turn		Through	Left Turn										

Traffic Flow - Albert Street WB, June 15, 16:00-16:15												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus	HV		% Vehicles *				
		Through	Left Turn	Right Turn		Through	Left Turn					
16:00-16:05	Elgin to Metcalfe	44	NA	1	12	1	NA	1.72	46	20	43.5	
	Metcalfe to O'Connor	48	30	NA	12	1	0	1.10	79	41	51.9	
	5 min average	8.2	3	0.1	144			1.41			47.7	
16:05-16:10	Elgin to Metcalfe	37	NA	0	10	1	NA	2.08	38	19	50.0	
	Metcalfe to O'Connor	41	21	NA	10	2	0	2.70	64	29	45.3	
	5 min average	7.8	2.1	0	120			2.39			47.7	
16:10-16:15	Elgin to Metcalfe	38	NA	4	15	1	NA	1.79	41	21	51.2	
	Metcalfe to O'Connor	40	22	NA	15	1	1	2.53	64	30	46.9	
	5 min average	7.6	2.2	0.4	180			2.18			48.0	
	15 min ave modeling variables	8.20	2.43	0.17	148.00			1.88			48.1	
Travel Time Observations - June 15, Albert Street												
Elgin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:00-16:05	16:05-16:1	16:10-16:15								
	1	54	53	50								
	2	38	57	43								
	3	44	62	47								
	4	52	37	55								
	5	39	45	40	AVE							
	average	45.4	50.8	47	47.7							
Traffic Flow - Albert Street WB, June 15, 16:15-16:30												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus	HV		% Vehicles *				
		Through	Left Turn	Right Turn		Through	Left Turn					
16:15-16:20	Elgin to Metcalfe	37	NA	1	9	1	NA	2.08	39	25	64.1	
	Metcalfe to O'Connor	39	24	NA	9	1	0	1.37	64	27	42.2	
	5 min average	7.8	2.4	0.1	108			1.73			53.1	
16:20-16:25	Elgin to Metcalfe	36	NA	3	15	1	NA	1.82	40	22	55.0	
	Metcalfe to O'Connor	42	22	NA	15	1	0	1.25	65	17	26.2	
	5 min average	7.8	2.2	0.3	180			1.53			40.6	
16:25-16:30	Elgin to Metcalfe	40	NA	2	13	1	NA	1.79	43	19	44.2	
	Metcalfe to O'Connor	44	25	NA	13	0	1	1.20	70	27	38.6	
	5 min average	8.4	2.5	0.2	166			1.50			41.4	
	15 min ave modeling variables	7.93	2.37	0.20	148.00			1.59			45.0	
Travel Time Observations - June 15, Albert Street												
Elgin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:15-16:20	16:20-16:2	16:25-16:30								
	1	31	66	33								
	2	65	48	71								
	3	61	32	25								
	4	49	44	56								
	5	34	51	39	AVE							
	average	48	48.2	44.8	47.0							
Traffic Flow - Albert Street WB, June 15, 16:30-16:45												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus	HV		% Vehicles *				
		Through	Left Turn	Right Turn		Through	Left Turn					
16:30-16:35	Elgin to Metcalfe	40	NA	1	13	0	NA	0.00	41	28	63.4	
	Metcalfe to O'Connor	42	27	NA	13	0	0	0.00	69	37	53.6	
	5 min average	8.2	2.7	0.1	156			0.00			58.5	
16:35-16:40	Elgin to Metcalfe	42	NA	2	14	0	NA	0.00	44	23	52.3	
	Metcalfe to O'Connor	42	20	NA	14	1	0	1.30	63	21	33.3	
	5 min average	8.4	2	0.2	168			0.65			42.8	
16:40-16:45	Elgin to Metcalfe	35	NA	5	22	1	NA	1.59	41	19	46.3	
	Metcalfe to O'Connor	48	21	NA	22	1	1	2.15	71	29	40.8	
	5 min average	8.3	2.1	0.5	264			1.87			43.8	
	15 min ave modeling variables	8.30	2.27	0.27	296.00			0.84			46.3	
Travel Time Observations - June 15, Albert Street												
Elgin to O'Connor: 2 links (355m)												
	random	Time to Traverse Both Links (seconds)										
	vehicle #	16:30-16:35	16:35-16:4	16:40-16:45								
	1	66	51	45								
	2	55	58	35								
	3	42	53	39								
	4	59	39	51								
	5	41	41	53	AVE							
	average	52.6	48.4	44.6	48.5							
Traffic Flow - Albert Street WB, June 15, 16:45-17:00												
Time Period	Link	Volume/Flow (veh/min or veh/hr)								Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus	HV		% Vehicles *				
		Through	Left Turn	Right Turn		Through	Left Turn					

[illegible]

Traffic Flow - Albert Street WB, June 13, 7:30-7:45											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus Through	HV		%			
		Through	Left Turn	Right Turn		Through	Left Turn				
7:30-7:35	Elgin to Metcalfe	50	NA	0	18	1	NA	1.45	51	31	60.8
	Metcalfe to O'Connor	48	27	NA	18	2	0	2.11	77	22	28.6
	5 min average	9.8	2.7	0	216			1.78			44.7
7:35-7:40	Elgin to Metcalfe	48	NA	2	10	2	NA	3.23	52	38	69.2
	Metcalfe to O'Connor	53	32	NA	10	1	2	3.06	88	30	34.1
	5 min average	10.1	3.2	0.2	120			3.14			51.7
7:40-7:45	Elgin to Metcalfe	46	NA	3	9	2	NA	3.33	51	22	43.1
	Metcalfe to O'Connor	47	24	NA	9	2	0	2.44	73	37	50.7
	5 min average	9.3	2.4	0.3	108			2.89			46.9
	15 min ave modeling variables:	9.73	2.77	0.37	148.00			2.86			47.7
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	7:30-7:35	7:35-7:40	7:40-7:45							
	1	63	41	53							
	2	70	65	37							
	3	45	39	61							
	4	35	54	58							
	5	58	60	27	AVE						
	average	54.2	51.8	47.2	51.1						
						Avg travel time per link					
						143.8					
Traffic Flow - Albert Street WB, June 13, 7:45-8:00											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus Through	HV		%			
		Through	Left Turn	Right Turn		Through	Left Turn				
7:45-7:50	Elgin to Metcalfe	49	NA	0	15	1	NA	1.54	50	35	70.0
	Metcalfe to O'Connor	46	31	NA	15	1	1	2.13	79	29	36.7
	5 min average	9.8	3.1	0	180			1.83			53.4
7:50-7:55	Elgin to Metcalfe	53	NA	1	15	2	NA	2.82	56	37	66.1
	Metcalfe to O'Connor	48	28	NA	15	1	2	3.26	77	38	49.4
	5 min average	10.1	2.8	0.1	180			3.04			57.7
7:55-8:00	Elgin to Metcalfe	41	NA	2	13	1	NA	1.75	44	21	47.7
	Metcalfe to O'Connor	48	25	NA	13	2	1	3.37	76	40	52.6
	5 min average	8.9	2.5	0.2	166			2.66			50.2
	15 min ave modeling variables:	9.80	2.73	0.10	172.00			2.66			53.3
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	7:45-7:50	7:50-7:55	7:55-8:00							
	1	44	57	40							
	2	37	64	37							
	3	54	49	35							
	4	49	50	53							
	5	60	39	59	AVE						
	average	48.8	51.8	44.8	48.5						
						Avg travel time per link					
						138.5					
Traffic Flow - Albert Street WB, June 13, 8:00-8:15											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh stopped	% Stops
		All Vehicles *			Bus Through	HV		%			
		Through	Left Turn	Right Turn		Through	Left Turn				
8:00-8:05	Elgin to Metcalfe	51	NA	2	17	1	NA	1.41	54	36	66.7
	Metcalfe to O'Connor	56	23	NA	17	1	1	2.04	81	38	46.9
	5 min average	10.7	2.3	0.2	204			1.72			56.8
8:05-8:10	Elgin to Metcalfe	53	NA	1	17	1	NA	1.39	55	35	63.6
	Metcalfe to O'Connor	49	17	NA	17	1	0	1.19	67	21	31.3
	5 min average	10.2	1.7	0.1	204			1.29			47.8
8:10-8:15	Elgin to Metcalfe	54	NA	3	10	2	NA	2.90	59	41	69.5
	Metcalfe to O'Connor	41	30	NA	10	2	3	5.81	76	25	32.9
	5 min average	9.8	3	0.3	120			4.38			51.2
	15 min ave modeling variables:	10.13	3.33	0.20	176.00			2.46			51.8
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	8:00-8:05	8:05-8:10	8:10-8:15							
	1	58	44	45							
	2	48	68	39							
	3	69	72	61							
	4	46	37	57							
	5	76	42	72	AVE						
	average	59.4	52.2	54.8	55.5						
						Avg travel time per link					
						158.2					
Traffic Flow - Albert Street WB, June 13, 8:15-8:30											
Time Period	Link	Volume/Flow (veh/min or veh/hr)							Total Vehicles *	No. of veh	% Stops
		All Vehicles *			Bus Through	HV		%			
		Through	Left Turn	Right Turn		Through	Left Turn				

		Through	Left Turn	Right Turn	Through	Through	Left Turn	%	Vehicles *	stopped	Stops
8:15-8:20	Elgin to Metcalfe	42	NA	1	20	0	NA	0.00	43	20	46.5
	Metcalfe to O'Connor	44	24	NA	20	1	1	2.22	70	26	37.1
	5 min average	8.8	2.4	0.1	240			1.11			41.8
8:20-8:25	Elgin to Metcalfe	51	NA	0	15	1	NA	1.49	52	40	76.9
	Metcalfe to O'Connor	43	30	NA	15	2	0	2.22	75	22	29.3
	5 min average	9.4	3	0	180			1.86			53.1
8:25-8:30	Elgin to Metcalfe	37	NA	5	12	1	NA	1.82	43	26	60.5
	Metcalfe to O'Connor	43	25	NA	12	1	0	1.23	69	30	43.5
	5 min average	8	2.5	0.5	144			1.53			52.0
	15 min ave modeling variables	8.27	2.83	0.30	144.00			1.46			48.0
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	8:15-8:20	8:20-8:25	8:25-8:30							
	1	30	52	58							
	2	55	62	42							
	3	64	38	37							
	4	49	34	28							
	5	44	50	49	AVE						
	average	48.4	47.2	42.8	46.1						
Traffic Flow - Albert Street WB, June 13, 8:30-8:45											
		Volume/Flow (veh/min or veh/hr)									
Time Period	Link	All Vehicles *			Bus	HV			Total	No. of veh	%
		Through	Left Turn	Right Turn	Through	Through	Left Turn	%	Vehicles *	stopped	Stops
8:30-8:35	Elgin to Metcalfe	51	NA	1	17	1	NA	1.43	53	30	56.6
	Metcalfe to O'Connor	49	27	NA	17	1	1	2.11	78	29	37.2
	5 min average	10	2.7	0.1	204			1.77			46.9
8:35-8:40	Elgin to Metcalfe	53	NA	2	13	0	NA	0.00	55	36	65.5
	Metcalfe to O'Connor	52	32	NA	13	0	0	0.00	84	34	40.5
	5 min average	10.5	3.2	0.2	156			0.00			53.0
8:40-8:45	Elgin to Metcalfe	50	NA	1	20	1	NA	1.39	52	36	69.2
	Metcalfe to O'Connor	61	20	NA	20	1	0	0.98	82	41	50.0
	5 min average	11.1	2	0.1	240			1.18			58.6
	15 min ave modeling variables	10.38	2.83	0.13	240.00			0.98			53.2
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	8:30-8:35	8:35-8:40	8:40-8:45							
	1	39	41	65							
	2	48	48	58							
	3	47	65	47							
	4	53	57	78							
	5	65	53	51	AVE						
	average	50.4	52.8	59.4	54.2						
Traffic Flow - Albert Street WB, June 13, 8:45-9:00											
		Volume/Flow (veh/min or veh/hr)									
Time Period	Link	All Vehicles *			Bus	HV			Total	No. of veh	%
		Through	Left Turn	Right Turn	Through	Through	Left Turn	%	Vehicles *	stopped	Stops
8:45-8:50	Elgin to Metcalfe	45	NA	2	9	0	NA	0.00	47	25	53.2
	Metcalfe to O'Connor	48	29	NA	9	0	1	1.15	78	26	33.3
	5 min average	9.3	2.9	0.2	108			0.57			43.3
8:50-8:55	Elgin to Metcalfe	39	NA	1	13	1	NA	1.85	41	35	85.4
	Metcalfe to O'Connor	46	31	NA	13	1	1	2.17	79	25	31.6
	5 min average	8.5	3.1	0.1	156			2.01			66.5
8:55-9:00	Elgin to Metcalfe	51	NA	1	14	2	NA	2.94	54	23	42.6
	Metcalfe to O'Connor	44	32	NA	14	1	1	2.17	78	46	59.0
	5 min average	8.5	3.2	0.1	168			2.58			50.8
	15 min ave modeling variables	8.19	3.07	0.13	144.00			1.72			60.9
Travel Time Observations - June 13, Albert Street											
Elgin to O'Connor: 2 links (355m)											
	random	Time to Traverse Both Links (seconds)									
	vehicle #	8:45-8:50	8:50-8:55	8:55-9:00							
	1	38	33	54							
	2	75	43	41							
	3	60	64	52							
	4	50	40	35							
	5	42	47	61	AVE						
	average	53	45.4	48.6	49.0						
* "All Vehicles" includes automobiles and heavy vehicles (i.e. more than 4 tires touching the pavement)											
* total vehicles does not include transit buses in the dedicated bus lane											

APPENDIX D

DETAILED BAYESIAN REGRESSION OUTPUT - FINAL MODELS

[illegible]

R INFORMATION									
POSTERIOR									
r Data		Prior Precision Matrix				Posterior Precision Matrix			
110.592	87.1151	50	17595.01	10300.45		77	23215.77	12750.51	
85.184	333.043	17595.01	8334667	4096161		23215.77	9659587	4626310	
394.3704	172.009	10300.45	4096161	3221329		12750.51	4626310	3481245	
1103.37	477.882								
383.7123	91.9537	GPrior Variance/Covariance Matrix				Posterior Variance/Covariance Matrix			
216	150.535	188.7655	-0.27156	-0.25828		68.43	-0.12221	-0.08823	
373.248	44.6029	-0.27156	0.00103	-0.00044		-0.12221	0.00059	-0.00034	
578.7037	124.79	-0.25828	-0.00044	0.002009		-0.08823	-0.00034	0.001146	
462.4877	394.575								
438.976	36.0875	GPrior Correlation Matrix				Posterior Correlation Matrix			
110.592	82.4492	1	-0.61576	-0.41947		1	-0.60798	-0.31499	
115.2643	369.126	-0.61576	1	-0.30714		-0.60798	1	-0.40966	
230.7224	229.851	-0.41947	-0.30714	1		-0.31499	-0.40966	1	
830.584	381.709								
538.029	118.849	Prior Regression Coefficients Summary				Posterior Regression Coefficients Summary			
208.8797	248.479		Mean	St.Dev.	T-Value		Mean	St.Dev.	T-Value
262.144	96.9683	Const	120.5956	13.7392	8.777484	Const	113.5596	8.272243	13.72779
512	143.795	qtotat3	0.12199	0.032099	3.800403	qtotat3	0.128743	0.024299	5.298239
305.2744	508.055	(Stop X Si	0.24823	0.044816	5.538811	(Stop X Si	0.260603	0.03386	7.696476
427.525	73.6233								
110.592	102.162	Degrees of Freedom				Degrees of Freedom			
106.0477	239.044	47				74			
343	268.087								
650.963	523.607	Residual Variance, Se^2				Residual Variance, Se^2			
238.328	157.481	1914.648				1271.666			
208.8797	150.535	GPrior g Value							
394.3704	65.4508	1							
394.3704	118.849								
262.144	463.254								
362.9757	47.7137								
106.0477	130.926								
106.0477	310.344								
195.112	69.4569								
524.907	381.709								
238.328	73.6233								
216	220.897								
323.771	77.953								
564.9256	157.481								
524.907	508.055								
416.275	24.4294								
106.0477	107.538								
93.16504	333.043								
343	248.479								
681.472	421.167								
296.2963	113.099								
208.8797	157.481								
394.3704	28.7313								
636.056	143.795								
486.8243	448.927								
373.248	41.6304

ONE-WAY, 3 LANES - FINAL BAYESIAN MODEL RESULTS									
FIELD DATA									
TravTime	Const	q_{thr}^3	q_{rt}	$(StopXSigpkm)^3$	Sample Data Precision Matrix				
303.3333	1	4855.426	0.4	978.3688	24	79643.37	16.1	25955.39	
288.1481	1	2763.647	0.6	1052.994	79643.37	2.86E+08	53623.72	88948377	
370	1	4826.809	0.8	1427.239	16.1	53623.72	11.22111	17700.1	
278.5185	1	2924.207	0.7	1220.24	25955.39	88948377	17700.1	29383393	
302.5926	1	3845.296	0.733333	1301.587					
257.037	1	2317.436	0.5	762.1462	Sample Data Variance/Covariance Matrix				
279.6296	1	3869.893	0.6	1003.931	477.6562	-0.02966	-395.075	-0.09415	
258.5185	1	2213.943	0.6	814.7274	-0.02966	1.96E-05	0.023177	-4.7E-05	
333.3333	1	4769.912	0.6	1086.835	-395.075	0.023177	858.163	-0.23812	
297.037	1	3994.451	0.8	1328.938	-0.09415	-4.7E-05	-0.23812	0.00038	
307.7778	1	3894.594	0.8	1570.889					
269.6296	1	2924.207	0.6	993.1302	Sample Data Correlation Matrix				
331.1111	1	3820.804	0.666667	1594.946	1	-0.30634	-0.61707	-0.22114	
299.2593	1	3994.451	0.7	937.3733	-0.30634	1	0.178585	-0.5466	
285.5556	1	3796.416	0.733333	1101.513	-0.61707	0.178585	1	-0.41725	
308.8889	1	4941.957	0.633333	1009.391	-0.22114	-0.5466	-0.41725	1	
251.4815	1	2282.588	0.633333	935.9877					
286.2963	1	3069.698	0.6	1198.674	Regression Coefficients Summary				
274.0741	1	2478.645	0.8	925.1761		Mean	St.Dev.	T-Value	
236.6667	1	1685.159	0.433333	733.8331	Const	157.56	21.85535	7.209219	
245.5556	1	2497.005	0.866667	750.5869	q_{thr}^3	0.018933	0.00443	4.273471	
334.0741	1	3048.625	0.7	1212.466	q_{rt}	9.340451	29.29442	0.318847	
248.8889	1	2064.554	0.6	909.789	$(StopXSig)$	0.05769	0.019481	2.961286	
289.6296	1	2763.647	1	1104.631					
					Degrees of Freedom				
					20	-			
					Residual Variance, Se^2				
					267.2199				

PRIOR INFORMATION										POSTERIOR									
GPrior Data					Prior Precision Matrix					Posterior Precision Matrix									
1	246.099	0	22.75902		70	23603.58	109.4667	79100.81		94	103247	125.5667	105056.2						
1	101.6296	0.8	1588.916		23603.58	12647030	23551.87	26324114		103247	2.99E+08	77175.59	1.15E+08						
1	538.029	0.733333	422.1282		109.4667	23551.87	722.6756	220341.7		125.5667	77175.59	733.8967	238041.8						
1	650.963	0	2371.793		79100.81	26324114	220341.7	2.03E+08		105056.2	1.15E+08	238041.8	2.33E+08						
1	416.275	0.333333	37.05926		GPrior Variance/Covariance Matrix					Posterior Variance/Covariance Matrix									
1	120.0664	10.8	3050.455		97.1842	-0.14391	-6.24695	-0.01241		42.00289	-0.0093	-2.32111	-0.01199						
1	208.8797	0	1729.037		-0.14391	0.000403	0.011203	-8.3E-06		-0.0093	8.1E-06	0.001016	-8.5E-07						
1	140.608	3.6	368.3089		-6.24695	0.011203	4.019158	-0.00338		-2.32111	0.001016	3.102291	-0.00263						
1	394.3704	0	72.38137		-0.01241	-8.3E-06	-0.00338	1.81E-05		-0.01199	-8.5E-07	-0.00263	1.47E-05						
1	729	1.4	1729.037		GPrior Correlation Matrix					Posterior Correlation Matrix									
1	1236.528	2.066667	112.9798		1	-0.72758	-0.31608	-0.29569		1	-0.5041	-0.20334	-0.48228						
1	578.7037	0	3607.2		-0.72758	1	0.278502	-0.09689		-0.5041	1	0.202695	-0.07818						
1	110.592	1.866667	91.17969		-0.31608	0.278502	1	-0.39563		-0.20334	0.202695	1	-0.38929						
1	201.9176	0	422.1282		-0.29569	-0.09689	-0.39563	1		-0.48228	-0.07818	-0.38929	1						
1	201.9176	0	15.63438		Prior Regression Coefficients Summary					Posterior Regression Coefficients Summary									
1	85.184	0.466667	1000.6			Mean	St.Dev.	T-Value			Mean	St.Dev.	T-Value						
1	323.771	1.2	343.2058		Const	131.8413	9.858205	13.37376		Const	118.0721	6.480964	18.21829						
1	486.8243	0	2745.647		qthr3	-0.0235	0.020064	-1.17104		qauto thr3	0.020138	0.002845	7.077421						
1	427.525	0.733333	42.90073		qtr	19.40069	2.004784	9.677199		qtr	20.48424	1.761332	11.62997						
1	44.1117	11.13333	3847.604		(StopXSig)	0.081096	0.004257	19.04857		(StopXSig)	0.079955	0.003835	20.84955						
1	201.9176	0	1456.577		Degrees of Freedom					Degrees of Freedom									
1	140.608	2.266667	319.2702																
1	450.6296	0	72.38137																
1	592.704	2.2	1393.257																
1	1000	1.933333	182.0722																
1	681.472	0	3726.11																
1	151.7037	2.133333	72.38137																
1	333.293	0	64.03841																
1	352.8936	0	2.371793																
1	135.269	0.6	1393.257																
1	474.552	1.2	319.2702																
1	362.9757	0	3156.856																
1	287.496	0.4	72.38137																
1	52.03437	10.06667	3377.025																
1	151.7037	0	1657.99																
1	89.11496	3.266667	166.4748																
1	278.8717	0	42.90073																
1	486.8243	1.866667	1456.577																
1	903.2963	2	138.0041																
1	486.8243	0	3607.2																
1	54.872	2.333333	198.6145																
1	135.269	0	64.03841																
1	254.037	0	1.0006																
1	85.184	0.666667	1802.085																
1	305.2744	1.066667	579.051																
1	305.2744	0	3156.856																
1	246.099	0.666667	42.90073																
1	15.0083	11.2	3490.848																
1	67.25363	0	1000.6																
1	93.16504	1.8	166.4748																
1	323.771	0	64.03841																
1	427.525	2.2	1877.163																
1	1000	1.733333	198.6145																
1	474.552	0	3265.704																
1	46.656	2.2	166.4748																
1	163.3683	0	182.0722																
1	314.432	0	12.71133																
1	140.608	0.466667	1729.037																
1	450.6296	1.266667	319.2702																
1	486.8243	0	3050.455																
1	394.3704	0.733333	15.63438																
1	67.25363	12.2	3377.025																
1	163.3683	0	1877.163																
1	49.2963	2.4	151.7947																
1	305.2744	0	138.0041																
1	383.7123	2.333333	2198.318																
1	866.4317	1.4	72.38137																
1	697.0776	0	3156.856																
1	106.0477	1.733333	151.7947																
1	323.771	0	296.4741

ONE-WAY, 3 MIXED LANES & ONE BUS LANE														
FIELD DATA														
In(time)	Const	q _{bu}	(q _{tr} X q _{bu})	q _s	HV	(StopXSigpkm) ³	Sample Data Precision Matrix							
4.9396	1	8.5333	20.8	2.63	1.684	84.24883	24	206.6	741.4667	57.43333	39.28809	1807.018		
4.9138	1	8.4	12.8	2.37	2.013	73.47378	206.6	1790.967	6371.751	493.3611	340.9157	15660.15		
4.9396	1	8.8	33.6	2.53	1.918	78.60898	741.4667	6371.751	27751.2	1757.191	1155.46	54069.79		
4.8886	1	8.2333	48.533333	2.2	0.675	63.52008	57.43333	493.3611	1757.191	138.9167	93.58378	4376.68		
4.9675	1	8.4	32	3	1.141	92.53077	39.28809	340.9157	1155.46	93.58378	70.77207	2974.726		
4.8701	1	7.6667	5.2	2.27	1.111	56.27202	1807.018	15660.15	54069.79	4376.68	2974.726	141005.6		
4.9622	1	8.8	62.933333	2.23	0.874	64.00655	Sample Data Variance/Covariance Matrix							
5.0109	1	8.1667	15.2	2.9	1.185	108.7563	0.027143	-0.00212	-5E-11	-0.00683	-9.5E-05	0.000102		
4.9766	1	8.3	39.466667	2.53	2.073	86.82709	-0.00212	0.000221	-2.2E-06	0.000484	-5.3E-05	-1E-05		
4.8686	1	7.6667	50.4	2.1	1.569	46.8748	-5E-11	-2.2E-06	2.98E-07	-3.6E-06	2.9E-06	1.81E-07		
4.9792	1	8.5667	14.8	2.3	2.011	80.2267	-0.00683	0.000484	-3.6E-06	0.002273	8.79E-06	-3.6E-05		
4.9247	1	8.4333	45.6	2.37	1.923	67.57248	-9.5E-05	-5.3E-05	2.9E-06	8.79E-06	0.000207	1.36E-06		
4.9013	1	8.2	24.666667	2.43	1.988	67.27222	0.000102	-1E-05	1.81E-07	-3.6E-05	1.36E-06	8.67E-07		
4.8858	1	7.9333	29.6	2.37	1.585	55.10349	Sample Data Correlation Matrix							
4.9179	1	8.3	52.266667	2.27	0.839	68.00616	1	-0.8666	-5.5E-07	-0.86884	-0.0401	0.662094		
4.9517	1	8.2333	19.733333	2.87	1.499	90.42951	-0.8666	1	-0.26981	0.682993	-0.24833	-0.75093		
4.9648	1	8.6333	43.733333	2.67	1.631	79.29664	-5.5E-07	-0.26981	1	-0.14013	0.368952	0.355883		
4.8729	1	7.6667	29.6	2.2	1.835	59.80002	-0.86884	0.682993	-0.14013	1	0.012813	-0.8023		
4.9688	1	9.7333	24.666667	2.2	2.602	65.68837	-0.0401	-0.24833	0.368952	0.012813	1	0.101716		
4.9165	1	9.5	17.2	2.2	2.478	93.68375	0.662094	-0.75093	0.355883	-0.8023	0.101716	1		
5.0514	1	10.133	35.2	2.2	2.457	83.97924	Regression Coefficients Summary							
4.8672	1	8.6667	37.6	2.2	1.498	70.87816	Mean	St.Dev.	T-Value					
5.0283	1	10.533	26.666667	2.2	0.984	90.62809	Const	4.311178	0.164751	26.1678				
4.9275	1	9.1	19.2	2.2	1.715	79.33351	qthr	0.043043	0.014855	2.897585				
							(qtr X qbu	0.000539	0.000546	0.988225				
							qtr	0.066421	0.04768	1.393054				
							HV	0.002174	0.014386	0.151123				
							(StopXSig	0.001015	0.000931	1.090518				
							Degrees of Freedom							
							18							
							Residual Variance, Se ²							
							0.000927							

ONE-WAY, 3 LANES 1 BUS LANE

FINAL RESULTS

Prior Precision Matrix									
32	521	961.0667	44.06667	112	6150.407				
521	9342.449	16660.92	607.4489	1813.467	96166.29				
961.0667	16660.92	86701.8	64.87111	3415.467	120347.7				
44.06667	607.4489	64.87111	144.7422	156.8	10431.67				
112	1813.467	3415.467	156.8	416	21618.63				
6150.407	96166.29	120347.7	10431.67	21618.63	2639741				
GPrior Variance/Covariance Matrix									
0.034983	-0.00084	-4.7E-05	-0.00202	-0.00432	-5.2E-06				
-0.00084	4.21E-05	7.16E-07	6.41E-05	8.96E-06	5.93E-08				
-4.7E-05	7.16E-07	7.93E-07	1.24E-05	-2.8E-06	2.04E-08				
-0.00202	6.41E-05	1.24E-05	0.000626	-6.6E-05	-1.1E-07				
-0.00432	8.96E-06	-2.8E-06	-6.6E-05	0.001247	-8.9E-08				
-5.2E-06	5.93E-08	2.04E-08	-1.1E-07	-8.9E-08	2.15E-08				
GPrior Correlation Matrix									
1	-0.6915	-0.28057	-0.43334	-0.65478	-0.19136				
-0.6915	1	0.123939	0.39515	0.039106	0.062412				
-0.28057	0.123939	1	0.557647	-0.0896	0.156599				
-0.43334	0.39515	0.557647	1	-0.07524	-0.03132				
-0.65478	0.039106	-0.0896	-0.07524	1	-0.01729				
-0.19136	0.062412	0.156599	-0.03132	-0.01729	1				
Posterior Precision Matrix									
56	727.6	1702.533	101.5	151.2881	2154.382				
727.6	11133.42	23032.68	1100.81	2154.382	4570.926				
1702.533	23032.68	114453	1822.062	4570.926	250.3838				
101.5	1100.81	1822.062	283.6589	250.3838	14808.35				
151.2881	2154.382	4570.926	250.3838	486.7721	24593.35				
2154.382	4570.926	250.3838	14808.35	24593.35	27807.46				
Posterior Variance/Covariance Matrix									
0.008991	-0.00027	-3.6E-05	-0.0015	-0.00046	-5.4E-07				
-0.00027	2.1E-05	5.4E-07	4.43E-05	-3.6E-05	-2.8E-08				
-3.6E-05	5.4E-07	4.51E-07	6.96E-06	4.6E-07	1.32E-08				
-0.0015	4.43E-05	6.96E-06	0.00038	1.37E-05	-5.6E-08				
-0.00046	-3.6E-05	4.6E-07	1.37E-05	0.000354	-4.7E-07				
-5.4E-07	-2.8E-08	1.32E-08	-5.6E-08	-4.7E-07	1.31E-08				
Posterior Correlation Matrix									
1	-0.61766	-0.57267	-0.81404	-0.25941	-0.05007				
-0.61766	1	0.175539	0.495645	-0.4166	-0.05363				
-0.57267	0.175539	1	0.531609	0.03639	0.1716				
-0.81404	0.495645	0.531609	1	0.037465	-0.02509				
-0.25941	-0.4166	0.03639	0.037465	1	-0.21568				
-0.05007	-0.05363	0.1716	-0.02509	-0.21568	1				
Posterior Regression Coefficients Summary									
Mean	St.Dev.	T-Value	Mean	St.Dev.	T-Value				
Const	4.477348	0.186715	Const	4.157028	0.094822	43.84016			
qthr	0.015587	0.006486	qthr	0.022694	0.004581	4.953533			
(qtr X qbu	0.001727	0.000891	(qtr X qbu	0.001434	0.000672	2.134682			
qit	0.179512	0.025017	qit	0.170462	0.019493	8.744674			
HV	0.00422	0.035315	HV	0.058027	0.018819	3.083389			
(StopXSlg	0.000841	0.000147	(StopXSlg	0.000915	0.000115	7.983739			
Degrees of Freedom	26		Degrees of Freedom	50					
Residual Variance, Se^2	0.027247		Residual Variance, Se^2	0.018322					
GPrior g Value	1								

One-Way, Three Mixed Lanes One Bus Lane- FINAL BAYESIAN MODEL RESULTS