URBAN GOODS MOVEMENT: PROVIDING PRIORITY FOR TRUCKS ALONG A MAJOR ARTERIAL

by

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B.A.Sc., The University of British Columbia, 1997

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Department of Civil Engineering)

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April 2004

Library Authorization

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Title of Thesis: Urban Goods Movement: Providing Priority For Trucks Along A Major Arterial

Degree: Master of Applied Science Year: 2004

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ABSTRACT

The economy of a major urban area is dependent on a transportation system that permits the efficient movement of people and goods. Urban goods movement is a complex and multi-faceted task that is often overlooked in transportation planning. Commercial vehicle operators are faced with mounting levels of congestion delay as they compete for limited road space with ever-growing commuter traffic. No major urban area today is immune to the problems linked with growing traffic congestion and its negative impacts to economic competitiveness and industrial productivity.

The Knight Street corridor in the City of Vancouver is a major truck route that serves the Port of Vancouver and various industrial areas to the north. Towards the south, this corridor connects to the Lower Mainland's highway system providing trucks access to the United States and the rest of Canada. The Knight Street corridor is designated as a truck route and consequently carries a high percentage of heavy vehicles.

A transportation microsimulation model, Paramics, was used to evaluate various strategies to benefit truck movements along the Knight Street corridor. Paramics includes a suite of tools for modelling the interaction and dynamic effects of vehicle movements. A significant amount of time was dedicated to the calibration and validation of the model to actual turning movements and travel times. Travel time was used to ensure the accuracy of the model using global positioning system (GPS) technology.

Because of high vehicle volumes and a large proportion of truck activity and consequent congestion problems, several strategies to enhance the movement of trucks along the Knight Street corridor were modelled using the microsimulation model. Signal coordination improvement strategies were investigated to facilitate the movement of trucks along Knight Street as well as the impacts of an exclusive truck/bus lane. Transyt-7F was used to calculate the signal offsets for two-way coordination along the corridor. Signal offsets were adjusted for varying proportions of heavy vehicles which is not typically accounted for in traditional signal coordination studies. A scenario was also set up with variable signal coordination offsets to further enhance the efficiency of the normal signal coordination plan. The impact of additional left turn capacity was also modelled for travel time benefits.

The modelling results of an exclusive truck and bus only lane shows the travel time benefits to heavy vehicles. Trucks see a 14% and 9% reduction in travel times northbound and southbound along the entire corridor respectively. Since one lane of capacity is removed for automobiles, they see a 7% and 5% increase in travel time in the northbound and southbound directions respectively.

Using Transyt-7F to develop a two-way signal coordination plan for Knight Street resulted in an average 13% savings in travel time along the corridor. There was also a significant reduction in travel time variability which is an important consideration for truck operators. Having a higher proportion of trucks reduces travel time along the corridor as heavy vehicles reduce the average platoon speed. Having 20% and 25% trucks along the corridor reduced travel time by 3% and 5% respectively over the base case of 15% trucks. The platoon speeds were reduced in Transyt-7F to reflect the slower travel speed with more trucks to develop two-way signal coordination strategies for higher proportions of heavy vehicles. Travel times along the corridor were reduced by approximately 12% with higher proportions of heavy vehicles with signal coordination.

As travel times vary significantly throughout the two hour peak period, variable signal offsets were tested for travel benefits over the fixed offset scenario. Signal offsets were adjusted to reflect the changing travel times with a marginal decrease in travel times over the fixed offset strategy.

A Combination of signal coordination with an exclusive truck/bus lane was modelled for travel time benefits as well. Northbound auto and truck travel times were reduced by 8% and 21% respectively, while southbound auto and truck travel times increased by 20% and 3% respectively. Higher intersection approach volumes are the cause of the increase in southbound travel time as 14% more vehicles are attracted to the corridor.

Increasing left turn bay capacity at four key intersections was modelled with a resulting 3% reduction in travel times in both directions. Adding this capacity also resulted in 15% more approach volumes at the four improved intersections. Delay at the northbound approach to 49th Ave and 57th Ave were reduced significantly as through movement vehicles were no longer blocked by left turning vehicles.

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PREFACE

The demand for freight traffic is driven by the production and consumption of goods as raw materials and finished goods are transported from manufacturing plants to warehouses and ultimately, to retail outlets. This thesis deals exclusively with motor transport of freight through urban areas: trucking. As such, the movement of heavy vehicles along a major urban arterial is investigated for travel benefits through various corridor management strategies. Specifically, the following questions are investigated:

- What modifications to signal offsets should be made to accommodate a high proportion of heavy vehicles.
- What are the impacts of an exclusive truck and bus lane.
- What are the impacts to heavy vehicles of additional left turn bay capacity.

Ultimately a balance between the competing needs of commuter and freight traffic is sought for the efficient movement of people and goods.

Urban goods movement is a topic that has been understudied in the transportation and urban planning field. This is surprising, especially considering that the cost of freight movement is comparable to that of people movement. Not only does urban freight have economic significance, it also has considerable impacts to the environmental well being of an urban area. Perhaps this topic has been neglected due to its inherent complexity and deficient data sources as well as a lack of understanding from citizens and consumers of the vital link between efficient goods movement and the cost of wares. A better understanding of urban goods movement is vital for the effective planning and funding of transportation infrastructure.

Motivation for carrying out this research is as follows: the longer a truck is required to deliver its goods, the more it costs in monetary terms to move those goods. As the cost of goods rises with increasing traffic congestion, the cost of living increases proportionately. This relationship holds for any urban area faced with mounting congestion problems.

Methods to enhance the efficiency and capacity of truck movement along major urban arterials form the basis of research for this thesis paper. Special through movement consideration for trucks is given at intersections that typically only give geometric considerations for trucks. Trucks also require special attention at intersections due to their mass and furthermore, their slower performance relative to commuter traffic.

Various corridor management strategies were modelled for travel time benefits. A microsimulation model was used to carry out the analysis of this research. A commercially available microsimulation model, Paramics, was calibrated to evaluate the impacts of the various corridor improvements. Paramics is comprised of a suite of modelling applications used to simulate and analyse the behaviour of traffic flows and vehicle interaction. Unlike a static demand forecasting model, microsimulation models are stochastic and able to capture the random behaviour inherent in traffic. A significant amount of time was dedicated to ensure the accuracy of the model. Over 300 turning movements were used to ensure that model results reflected observed vehicle turning movements. Global positioning system (GPS) technology was also used to ensure the accuracy of the model calibration in terms of travel time.

It is hoped that this research would increase the awareness of the trucking industry to transportation planning organizations not only due to its economic significance but its social and environmental implications as well. It is an issue that we have to live with especially for anyone living and commuting in an urban environment.

ACKNOWLEDGEMENTS

The author would like to acknowledge the financial contributions towards the research project from the Greater Vancouver Transportation Authority and the City of Vancouver. Without their financial assistance and expertise, this research would not have been possible.

The author would like to give special recognition for the following individuals who contributed towards this research project:

- Dr. Tarek Sayed, University of British Columbia – Research Advisor
- Clive Rock, Manager, Greater Vancouver Transportation Authority
- Clark Lim, Senior Transportation Engineer, Greater Vancouver Transportation Authority
- Wayne Pledger, Manager, City of Vancouver
- Melina Scholefield, Transporation Engineer, City of Vancouver
- Cameron Scott, Technical Assistant, City of Vancouver

Recognition is also given to the assistance given by the staff at Port Vancouver and Transport Canada. Without their assistance, this project would not have been carried out as thoroughly as originally anticipated.

Finally, a big thank you to all my family and friends who have supported me throughout my academic years. Their patience and support have been instrumental in my achievements to date. Without their love and caring throughout the good times and bad I would not be where I am today.

CHAPTER I – Introduction to Urban Goods Movement

The movement of freight is a complex and heterogonous activity the cost of which typically comprises on the order of five percent of the gross domestic product (GDP) of an urban area (Ogden, 1992). This estimate varies between cities depending on the size and physical layout of distribution centres and goods movement infrastructure. The production and consumption of goods is the major driver of the demand for freight movement within an urban area. The geographic location and physical layout of warehouses and distribution centres plays a significant role in determining the efficiency of moving goods through a developed urban area.

Population in the Greater Vancouver region has been growing at a rate of 2.5% per annum between 1986 and 2001[1]. Comparatively, inward and outward tonnage at the Port of Vancouver has grown 1.6% per annum in the same time period. These statistics highlight the importance of the freight industry in terms of growth, but in terms of economic significance as well. Continued population growth will require more truck trips to handle the increased demand for commodities and Vancouver will continue to gain importance as an international gateway for trade as it continues to expand its port-related capacity.

Ogden (1992) points out that there are three main points to the economic significance of urban freight. The portion of the GDP related to urban freight is roughly five percent, urban freight costs are comparable to people movement costs and the cost of urban freight increases more than people movement costs as city size increases.

Many studies have shown that the cost associated with freight movement is comparable to that of people movement. This is a revealing estimate considering that "urban-transportation studies in the past rarely addressed the issues and problems involving goods movement in any substantive fashion" (Chatterjee et al, 1989). The problems associated with goods movement have been largely neglected throughout the development of major cities. Very little consideration has been given to the efficient movement of goods through urban areas with respect to land use planning ie, location of distribution centres. Poor data collection practices for goods movement has led to inadequate analytical

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[1] *Source: Population Section, BC Stats, Ministry of Management Services, Government of British Columbia.*

capabilities to thoroughly understand the inter-relationship between freight movement and people movement. A goods movement strategy for a local area produces benefits that permeate not only to the regional economy but to the provincial and national economy as well. Cooperation between all levels of government is required in order to meet the complex needs of the freight industry.

1.1 Characteristics of the Freight Industry

There are several factors that have lead to significant changes in the freight industry over the past several decades. More and more goods are being delivered by truck as opposed to rail. This is due to the fact that most manufacturers and retailers today operate on a 'just-in-time' inventory system and trucks are better suited for providing this type of service. Rail service is more suited to low-value, long-haul bulk commodities such as grain and coal that are not as time sensitive. Consequently, trucks are better suited for intra- and inter-urban movement of smaller and lighter goods that are more time-sensitive.

Intermodalism is a key concept that has driven the freight industry towards increased containerization of products. Large steel containers are used to hold the cargo as it is transported by different modes. The standard of measurement is twenty-foot equivalent units (TEU) for container traffic. Intermodal rail yards connecting marine, rail and surface transportation are serving the needs of products that are shipped in large containers. These intermodal facilities allow for the efficient pick-up and drop-off of large containers between different modes of transport.

The Port of Vancouver is a good example of an intermodal facility located at the north end of Knight Street. In 2001, the Port of Vancouver handled 72.9 million tonnes of cargo, 81% of which was bulk, 5% general and 14% container. Container freight consisted of 1.147 million TEU's (Port Vancouver, 2001). The port loads and unloads marine, rail and truck freight between all these modes. As such the truck volumes along Knight Street are highly correlated to freight movement at Port Vancouver's two intermodal terminals along the Burard Inlet: Centerm and Vanterm. Container traffic has grown by 15% per annum over the past five years (Port Vancouver, 2002). Current projections indicate that container traffic will double over the next twenty years (Port Vancouver). This growth continued in the future will undoubtedly result in comparable increases in truck activity accessing the port along the Knight Street corridor as 57% of all port terminal traffic in containers connects with truck transport (Transport Canada, 2002).

1.2 Statement of the Problem

The study of urban goods movement has been largely overlooked in transportation planning perhaps due to the complexity and limited data sources. Many cities have limited land resources to expand their road networks which has forced planning authorities to investigate more efficient use of existing infrastructure. Globalization of the economy has large corporations seeking to locate in regions with effecient goods movement capacity to benefit their own economic competitiveness. Increased public awareness of the harmful effects of truck related air and noise pollution in urban areas is also creating pressure to better understand freight flows and their impacts to the environment and community livability. The goods movement industry is particularly affected by congestion because of high operating costs and tighter schedules. There are a number of strategies to make better use of existing urban corridors, namely:

- Signal coordination
- Exclusive lane use (high occupancy, truck/bus)
- Channelization of turn movements
- Peak hour restrictions

Each of these strategies enhances the movement of vehicles on an urban arterial without the addition of more lanes. The Knight Street corridor in the City of Vancouver is an ideal candidate for investigating these types of mobility enhancements for the goods movement industry. This corridor has no room to expand with an ever-growing volume of trucks from container handling expansion at the Port of Vancouver. Population and employment growth are also driving the growth in the number of automobiles and therefore this corridor requires the investigation of these types of corridor strategies.

1.3 Study Objectives

The purpose of this paper is to evaluate the benefits of various corridor enhancement strategies on a congested urban truck route. A systematic approach is used to examine various scenarios that provide special consideration for the movement of trucks. A microsimulation model, Paramics, is coded and calibrated in order to examine each scenario using a standardized evaluation methodology. The study process is outlined as follows:

- Code and calibrate the Paramics microsimulation model for the Knight Street corridor.
- Validate the model using observed traffic counts and travel time information.
- Develop an evaluation methodology for each scenario to be tested.
- Code and run individual scenarios.
- Evaluate the effectiveness of each scenario for benefiting truck movements.

The various scenarios look at the improvement of mobility along a heavily used truck corridor without adding lane capacity. The following strategies are modelled for their effectiveness at enhancing the movement of trucks along the Knight Street corridor:

- Conversion of outside lanes to exclusive truck/bus lanes
- Signal coordination
- Signal coordination with increasing percentage of trucks
- Signal coordination with variable offsets
- Signal Coordination with an exclusive truck/bus lane
- Additional left turn bay capacity

How trucks benefit from each of these improvements is the principal objective of this thesis. This research work is part of a more comprehensive study by the City of Vancouver entitled the 'Clark/Knight Corridor Whole Route Analysis' which investigates various issues and possible solutions along the corridor. The Whole Route Analysis will review conditions and issues on the corridor in a holistic manner so that transportation, land use and community livability considerations can be better integrated into any major goods movement initiatives (City of Vancouver, 2002).

1.4 Thesis Organization

This thesis is organized into seven chapters. Chapter two presents a literature review of the current practice in urban goods movement modelling as well as backgournd information on the goods movement industry. Chapter three discusses land use issues and the current operating and travel conditions along the Knight Street corridor. The current conditions include vehicle volumes and classification and travel times. Chapter four outlines the procedures used to code and calibrate the Paramics microsimulation model. All aspects of model development are covered including road and transit network coding, detailed lane configuration, signal phasing and programming logic and demand estimation. Model validation based on turning movements and travel times is covered as well as a genetic algorithm-based parametric optimization of global behaviour variables. Chapter five discusses the standardized evaluation methodology and the various corridor strategies that are tested. Chapter six illustrates all of the results from the model runs which are systematically evaluated and subsequently discussed. Chapter seven presents the conclusions and recommendations based on the findings of the research objectives as well as future research directions.

CHAPTER II – Literature Review

The majority of the research written on the subject of urban goods movement points to the lack of data resources in order to make conclusive observations. The inherent complexity and heterogeneity of this subject matter also precludes many researchers from pursuing advanced studies on the trucking industry. Another factor which impedes the development of urban freight modelling is the commercially sensitive nature of the data that is required to develop models (Holguín-Veras et al, 2001). Notwithstanding the above reservations, however, research work is being undertaken and advances in the understanding of freight movements are being made. These advances are being made because of increasing global economic trends such as just-in-time delivery and e-commerce as well as how the goods movement industry impacts the economic competitiveness of an urban region. Conclusions made in one study, however might not apply to other urban areas due to their unique and differing geo-spatial and socio-economic characteristics. The distribution of freight activity within an urban area is highly dependent on the physical layout of distribution centres, intermodal yards and industrial areas. The above points to the needs and also the complexities of developing an effective freight planning and modelling process.

There has been increased survey and model development activity for freight movements within the last decade. There has also been more work to model truck flows explicitly and not simply as a percentage of automobile flows. New Federal legislation has placed a greater emphasis on traffic management, travel demand reduction and intermodal planning, in an effort to move toward shifting travel demand to match the supply of services available (Metropolitan Washington Council of Governments, 1996). The ability to transport goods efficiently to, from and within the urban area are critical elements in the promotion of continued economic development and furthermore, the planning of roads must be cognizant of the needs and requirements of the goods movement industry (Gravel, 1991).

Modelling of urban freight has historically been categorized into two main groups: commodity-based models and truck trip-based models. Both of these types of models are typically a sub-component of a larger commuter-based model. In either case, the truck component is built into the framework of a more comprehensive travel demand-forecasting model such as the urban transportation modelling system (UTMS), or more commonly known as the four-step modelling process:

1. Trip Generation
2. Trip Distribution
3. Modal Split
4. Trip Assignment

This modelling process is based on a gravity distribution model where the propensity to make a trip is based on travel impedance or cost. These models are mainly used to estimate demand and are static and deterministic in nature. There are two main types of freight demand-forecasting models:

- Truck trip-based models
- Commodity-based models

Both methodologies follow the four-step modelling process with no mode split stage for the truck trip-based models. The basic distinctions between these two spatial interaction models are highlighted in the following sections.

There has been an increase in the use of dynamic microsimulation models to determine the impacts of changes to transportation supply. These models use fixed-demand (usually estimated from a demand-forecasting model) and are more used for corridor and operations related activities to evaluate the effect of transportation investment. Microsimulation models are dynamic and stochastic in how they behave and are carried out. The following sections describe the various types of models used for freight planning activities.

The following sections give a background to urban goods movement and describe the factors that influence the goods movement industry. The various types of models used to simulate truck travel are described later in this chapter.

2.1 Factors Influencing Demand for Freight

As mentioned before, freight activity is a very fragmented and complex process with many direct and indirect factors. The production and consumption of goods are the key forces driving the demand for freight as businesses require raw materials to be manufactured into goods which are then transported to meet consumer demand. The following list describes some of the main factors influencing the demand for freight (NCHRP Report 388, 1997):

- **Economic Activity** – the level of economic activity of a region has a direct influence on the demand for freight as goods and resources are shipped between manufacturing plants. As such, the demand for freight is closely linked to the gross domestic product (GDP) which measures economic activity in dollars rather than weight or volume.
- **Location and Distribution of Industrial Zones** – the geographic location of raw materials, manufacturing plants and distribution centres has a direct influence on the level of freight activity. The way a region is developed and spread out in terms of land use has a very significant effect on the distance the freight needs to be transported. The proximity of a manufacturing plant to a highway or rail line has obvious impacts on the efficiency of moving raw materials and finished goods to and from the plant. The location pattern of these industrial zones has an impact on the length of haul and mode of transport.
- **Globalization of Trade** – the increased globalization of business has resulted in tremendous growth in international trade over the passed several decades. As companies move their production facilities to countries with reduced labour rates, more international trade will continue to grow. Most of this trade is intermodal and there is a need to standardize containers and their shipping and handling equipment. As such, the growth in containerized freight is expected to double over the next decade as intermodalism continues.

There are political factors that directly influence international freight movement such as international trade agreements, quotas and tariff restrictions (NCHRP Report 388, 1997). Some of the other direct influences on the demand for freight include the following:

- International Trade Agreements
- Just-in-Time Delivery Practices
- Carrier-Shipper Alliances

- Centralized Warehousing

There are a multitude of indirect factors that impact the costs and service of the freight industry. Some of the indirect influences on the demand for freight include (NCHRP Report 388, 1997):

- Economic Regulation and Deregulation
- International Transportation Agreements
- Intermodal Operating Agreements
- Fuel Prices
- Publicly Provided Transportation Infrastructure
- User Charges and Other Taxes
- Government Subsidization of Carriers
- Environmental Policies and Restrictions
- Safety Policies and Restrictions
- Congestion

The last several decades have shown to be very volatile for the freight industry which has seen tremendous change in technology, regulation, mode of transport and levels of demand. The above mentioned factors have all contributed, albeit to varying degrees, to the changes in the freight industry.

2.2 Urban Goods Movement and the Trucking Industry

The transportation sector has seen significant changes in the industry over the past several decades. Increased deregulation and privatization has lead to fierce competition in the trucking industry. The Canadian trucking industry underwent significant change with the 1987 Motor Vehicle Transportation Act (MVTA) which relaxed entry restrictions into the inter-provincial trucking market. Adequate insurance and compliance with safety regulations are now the only requirements for licensing (McKeown). Private companies now have more control over determining schedules and setting fares. Governments have been eager to offload services and regulatory functions of the trucking industry as the industry continues to become more privatized.

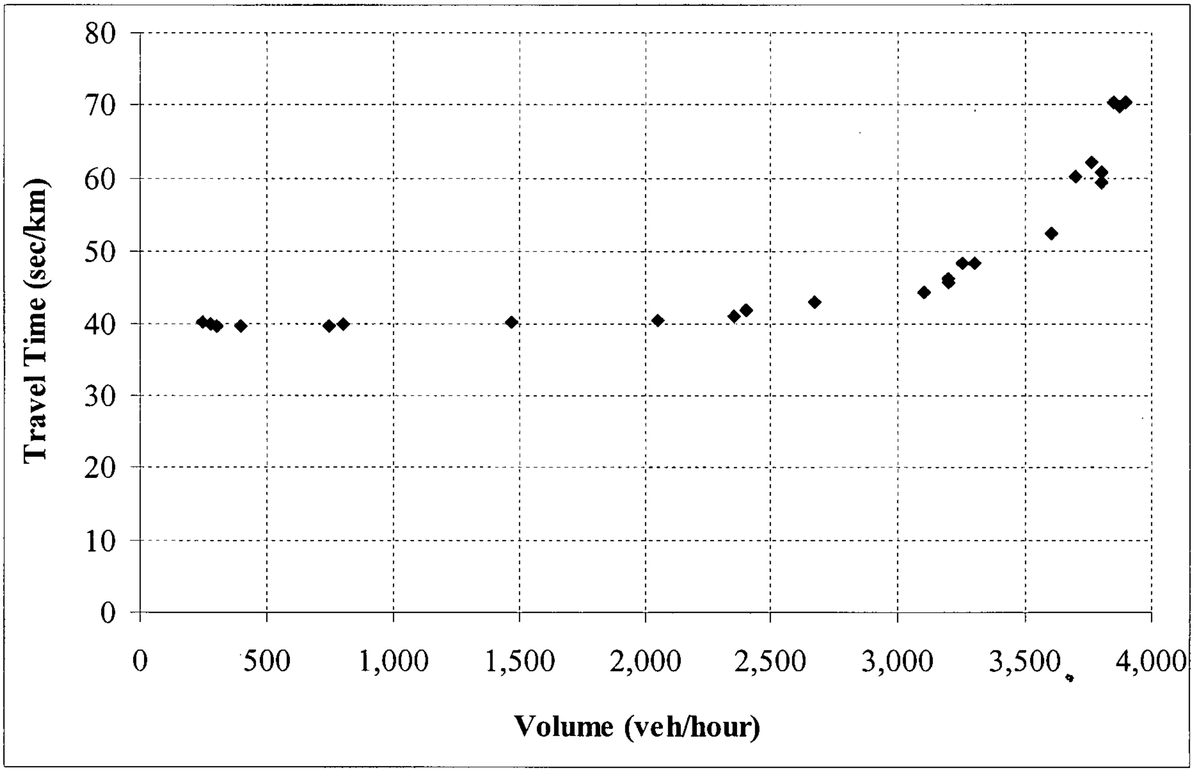
The productivity and efficiency of the trucking industry has a direct impact on the cost of transportation services, which, in turn, directly impacts the final cost of goods produced and consumed (BC Trucking Association). As such, the efficient movement of trucks through an urban area is directly attributable to the cost of living. Growing commuter congestion has a negative impact not only to personal travel time, but to the cost of transporting goods as well. As trucks require longer time periods to transport their goods, more operating cost is incurred in order to deliver them to their final destination: consumers.

Transport costs for manufactured goods are typically of the order of 2-8 percent of the cost of production with transport's cost declining as the product value increases (Ogden, 1992). The transportation cost component of unprocessed goods is much higher as the value to weight ratio is much lower. For example, transport costs represent over three quarters of the final demand price for gravel, sand and stone (Ogden, 1992). These statistics highlight the importance of an efficient goods movement system as the transport price component of goods is significant for raw materials and manufactured goods.

2.3 Congestion Delay and Economic Development

In terms of traffic performance, the delay associated with increased vehicle volumes on any road facility increases exponentially as the vehicle volume approaches the roadway capacity. Travel speed data on the Port Mann Bridge illustrates this relationship graphically in Figure 1. The theoretical capacity of the northbound direction on the Port Mann Bridge is approximately 3,800 vehicles per hour (for two lanes). As vehicle volumes approach this capacity level, the travel delay increases asymptotically.

Figure 1.1 – Volume-Delay at the Port Mann Bridge



This relationship highlights the importance of effective transportation planning in order to minimize the delay impacts associated with traffic congestion. Another important aspect of congestion delay is the decrease in travel time reliability as vehicle volumes increase. Travel times become unstable as vehicle volumes increase as there seems to be a strong relationship between vehicle volumes and travel time reliability. This is significant as an important factor in freight movements is scheduling, especially for time-sensitive goods. Heavy costs can be incurred if a time-sensitive product cannot be delivered in accordance to a strict schedule. The entire trip chain can be disrupted if a truck is forced to travel slowly through traffic congestion and unable to adhere to a predetermined schedule. The extra costs associated with inefficient scheduling are passed on directly to the consumer.

Several studies highlight the inextricable link between traffic congestion and economic development. The actual economic impacts of traffic congestion can differ by metropolitan area, depending on its economic profile and business location pattern (Weisbrod, 2002). As such, it is difficult not only to assess the economic impacts of congestion delay to business but to compare results between urban areas as well. At a very high level of aggregation, however, the basic relationship between traffic congestion and economic development is still evident. There seems to be a consensus among transportation officials of the importance of the freight transportation system as a pillar of the economic vitality of the New York metropolitan region (Holguín-Veras et al, 2001). When considering the economic global competitiveness of a region like the GVRD, not enough emphasis can be placed on maintaining an efficient freight transportation system.

Some regions fail to recognize the importance of an efficient freight transportation system and consequently suffer sluggish economic development. These factors highlight the importance of holistic transportation planning practices that include freight as part of infrastructure planning.

2.4 Classification of Trucks and Truck Ownership

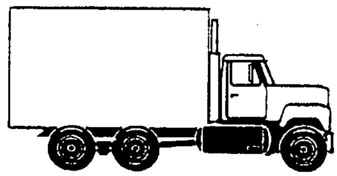
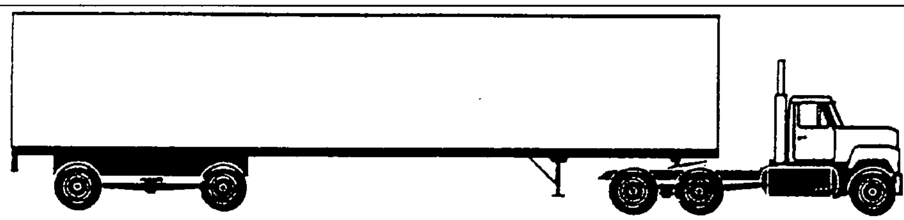
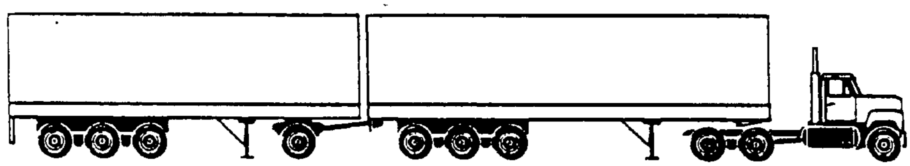
There is considerable variation in the types of trucks that make up the Lower Mainland trucking fleet. The main classification distinction between trucks is obviously based on size. Light trucks are typically cube vans used for shorter and more frequent delivery trips of very time-sensitive goods from a warehouse to retail outlet. Light trucks are more maneuverable through dense CBD areas where they might have to drop off wares in a back alley or tight parking spot. Heavy trucks are usually articulated and have three or more axles. Heavy trucks are used for less frequent long-haul inter-city trips to deliver goods usually between distribution centres and warehouses. The following figure illustrates some of the different types of light and heavy trucks.

Figure 1.2 – Types of Trucks (1999 Lower Mainland Truck Freight Study)

Light Truck – Cube Van	
Light Truck – Flat Bed	
Light Truck – Panel Van	
Heavy Truck – Single Unit	
Heavy Truck - Combination	
Heavy Truck - Combination	

The following figure illustrates the difference between an articulated and non-articulated truck and provides an example of a combination vehicle.

Figure 1.3 – Truck Configuration Types (1995 National Roadside Survey)

Non-Articulated	
Articulated – Combination Tractor and Trailer	
Articuated – Combination Tractor and Two Trailers	

Notwithstanding the above descriptions, there is a multitude of truck types used for various purposes ranging from small repair/service vans to specialized dangerous goods tankers to massive combination trucks.

There are four main types of truck ownership (Ogden, 1992):

- **For-Hire Carriers** – trucks owned by commercial carriers who carry freight for others.
- **Private Carries** – who carry their own freight with their own trucks (e.g. a retail store).
- **Personal Use** – trucks or vans owned by skilled labourers who carry their own tools and supplies to a work site.
- **Government** – trucks used by governments at all levels to carry out its various functions.

Certainly there are distinctions within these broad categories, but delving into the intricacies of truck ownership and regulation is beyond the scope of this thesis. What is obvious is that there is a great amount of disparity among truck owners and operators creating a very heterogeneous and competitive industry.

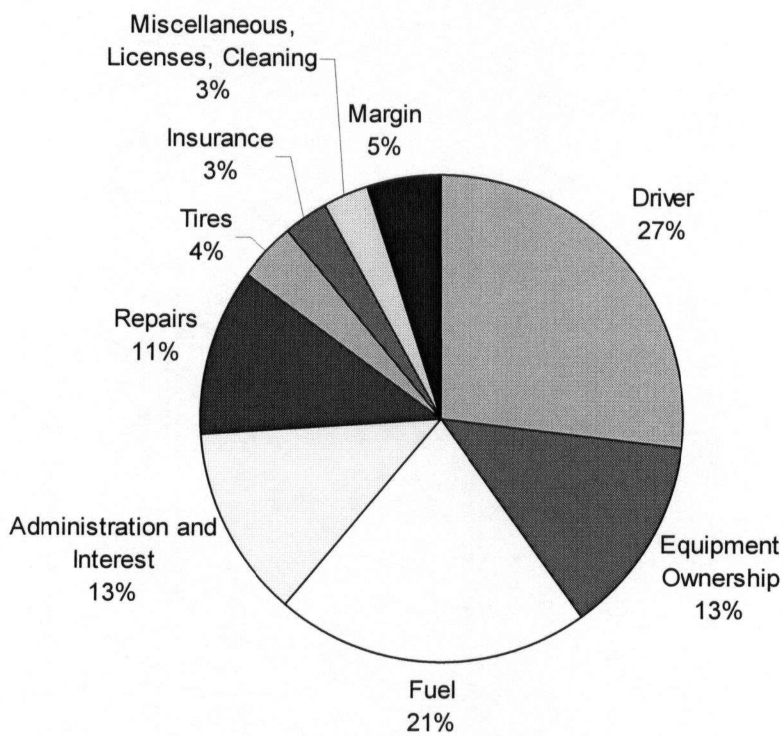
2.5 Truck Operating Costs

A major factor in goods movement is the operating cost of trucks. As noted earlier, the longer a truck is required to deliver its goods, the greater the cost component of those goods is attributable to their delivery. Truck operating costs vary significantly with particular circumstances associated with the specific haul, especially with (Transport Canada, 2001):

- Vehicle configuration
- Commodity and customer service characteristics
- Hauling distance
- Utilization efficiency (trip payload and annual truck utilization)
- Region of operation (local economic cost and regulatory/taxation factors)
- Right of way conditions (surface, gradient, congestion, practical speeds)
- Driver attitude and expertise

A more specific break down of operating costs shows that the two largest components of operating a truck are the driver costs (27%) and fuel costs (21%). The following illustration shows the cost components of intra Provincial truck operating costs (Transport Canada, 2001). This illustration highlights the sensitivity of congestion to the delivery of goods as the driver wage and fuel costs are directly related to the amount of time required to transport. Not only does traffic congestion cause longer travel times, but stop and go traffic has a significant impact on fuel consumption as heavy vehicles are required to constantly accelerate.

Figure 1.4 – Intra Provincial Truck Operating Cost Components



Note: equipment ownership includes depreciation plus financing interest.

2.6 Truck Trip-Based Models

As the name suggests, truck trip-based models estimate the number of truck trips made within a specified time period. These models tend to be more common as truck counts along road segments are more readily available than commodity-type information. The following table illustrates the process utilized to model truck trips (Holguín-Veras et al, 2001).

Table 2.1 – Modelling Process for the Truck Trip-Based Methodology

Step:	Approach:
Trip Generation ↓	Trip generation rates or zonal regression models
Trip Distribution ↓	Gravity models (singly or doubly constained) or intervening opportunities
Trip Assignment	Standard traffic assignment techniques

During the trip generation stage, multi-variate linear-regression techniques are employed in order to determine appropriate trip rates for various land use categories. Employment estimates by different industry sectors are typically used as surrogate variables to calculate the number of truck trips. In the case of the GVRD transportation model, 'special generators' were chosen as areas with high truck activity unique from other industrial areas (1999 Lower Mainland Truck Freight Study). The ports, intermodal yards and airport are examples of special generator locations were exceptionally high volumes of truck activity occur. Instead of employment, container movement estimates were used as surrogate variables for truck trip production and attraction.

A gravity model is then used to distribute the trips according to a trip diary survey. Trip length distributions are calibrated at this point to match trip lengths in the survey responses. Complete origin-destination matrices for different types of truck trips are produced and subsequently fed into the trip assignment stage which loads the trips onto a digital road network. The following subsections describe various truck trip-based models developed in various regions.

Estimating Truck Travel Patterns in the New York City Area – the authors of this research attempt to develop truck OD matrices with limited observed data for the Bronx area in New York City. Matrix estimation was developed for three separate truck classes: commercial vans, medium trucks (two-axle, six-tire and three-axle single unit) and heavy trucks (trucks with four or more axles and all tractor trailers). Matrices were also developed for three time periods: morning peak, midday and afternoon peak. A total of nine truck matrices were developed.

Three types of data were used to develop and validate the matrix estimation. Link volume data, origin-destination and originating/terminating data were used in estimating the truck flows. "In summary, estimation of the trip matrices is treated as a large-scale linear programming problem in which the objective is to minimize the weighted sum of all deviations from the observed values" (List and Turnquist, 1994). The constraints of this problem are identified as the truck classes, the network definition and the link use coefficients provided by the traffic assignment algorithm.

The matrices were assigned to the network of highways and roads in the Bronx area of New York City. Heavy truck flows were concentrated on the expressway system with a large concentration of truck activity in areas with a large proportion of truck trip ends. The data set used in this study was extensive enough to break truck classes down into commodity groups. The authors propose to used this model for "goods mobility enhancements" such as dedicated-use lanes, new and improved freeway ramps, truck-only highways and intelligent vehicle-highway systems-elated services for commercial operations (List and Turnquist, 1994).

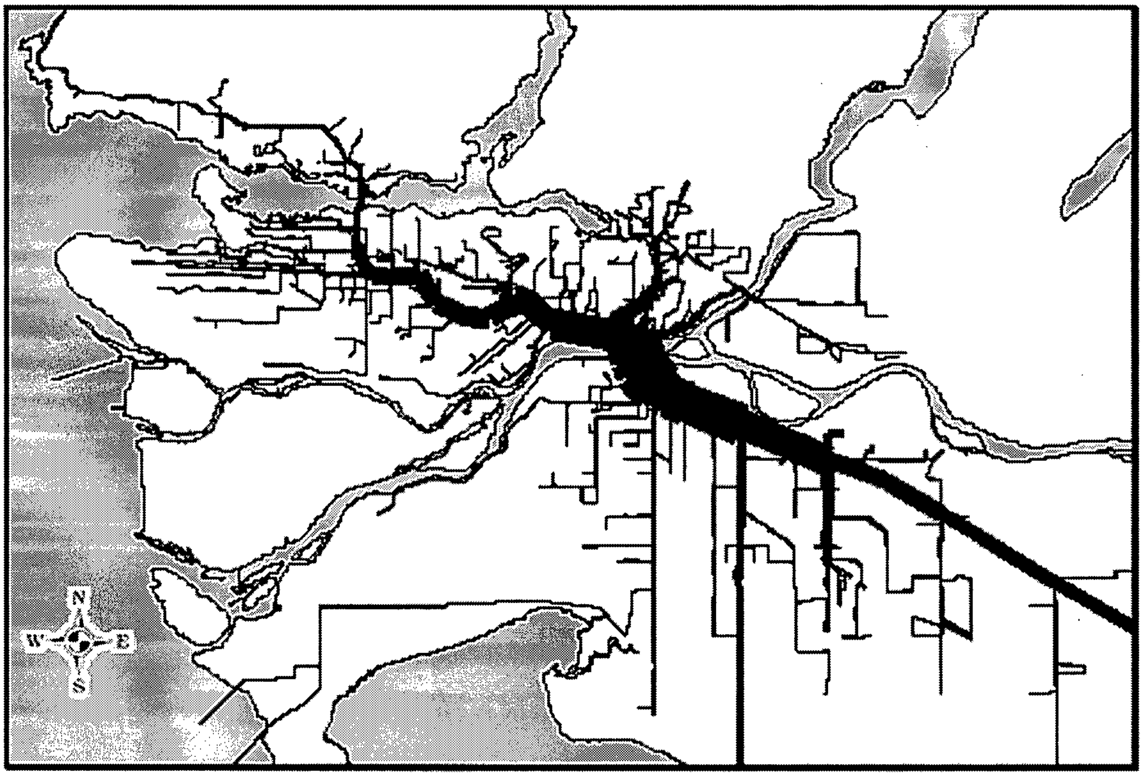
1999 Lower Mainland Truck Freight Study (Vancouver, B.C.) – this was a comprehensive study of the trucking and goods movement industry in the Greater Vancouver and Fraser Valley region. There were four main components to this study:

- Internal trip diary survey
- Vehicle volume and classification survey
- Special generator and external surveys
- Truck demand forecasting model development

The internal survey consisted of a mail-back survey of truck drivers who made their trip within the Lower Mainland. The survey was used to calibrate the trip generation and trip distribution component of internal truck trips. The vehicle volume and classification counts were performed to get 24 hour vehicle volume and truck counts at major screen line locations. The special generator survey was a road-side survey of trucks at locations with high truck activity such as the airport, port and inter-modal yards. The external survey was also a road-side survey of trucks entering and exiting the Lower Mainland's highway system. The final component of the study was the calibration and validation of a 24 hour truck model. The modelling procedure followed the traditional four-step transportation modelling process without the mode split stage as there was only one mode of travel modelled.

This study provided reliable and comprehensive data that established a 1999 baseline of truck movements for the Lower Mainland. Future truck demand and activity can be estimated with the use of this model as indicated in the following illustration (1999 Lower Mainland Truck Freight Study, Summary of Findings).

Figure 2.1 – General Catchment Area of Trucks Using Port Mann Bridge



line segment thickness is proportional to truck volume

The above illustration highlights the routes and catchment area of all trucks using the Port Mann Bridge on a 24 hour basis. Peak hour factors were used in the trip generation stage to develop morning peak hour estimates of truck activity. This enabled integration of the truck model with the regular a.m. peak hour commuter model in EMME/2. Vehicle and truck volumes can now be modelled in the same environment with exclusive consideration for both people and goods movement requirements.

2.7 Commodity-Based Models

These models are based upon the notion that since the freight system is basically concerned with the movement of commodities, the movement of these should be modelled directly (Ogden, 1992). There appears to be limited development of commodity-based models due to the difficulty of obtaining data to calibrate these models. The data tends to be commercially sensitive and therefore difficult to attain for model development purposes. These models are used for inter-city movement of freight and therefore useful for determining external flows of trucks to and from a region. Table 2.2 on the following page illustrates the process of modelling commodity flows (Holguín-Veras et al, 2001).

The techniques described include the application of commodity flow databases, the allocation of origins and destinations to the county level using employment shares by industry sector and the use of input-output tables to allocate destinations for commodities based on consumption shares (Holguín-Veras et al, 2001). Conventional input-output analysis develops a set of 'technical coefficients' as the amount of input (in dollars) required from each economic sector to produce an extra dollar worth of output in a given sector (Ogden, 1992). Once the amount of commodity between zones is determined, a vehicle loading model is developed to determine vehicle requirements to transport the goods. Once the number of vehicles is determined between origin-destination zones, a standard gravity distribution model and traffic assignment technique are employed to load the truck trips onto a digital road network. A major drawback to commodity-based models is the inability to effectively model empty truck trips as the methodology has no direct relationship between commodity flow and empty back-haul trips. Nonetheless, these models are useful in determining the inter-city flow of commodities as they relate to the production and consumption of goods. Most often, commodity flow models are aggregate and deal with inter-regional or inter-city flows as described in the following research.

Table 2.2 – Modelling Process for the Commodity-Based Methodology

Step:	Approach:
Commodity Generation ↓	Commodity generation rates or zonal regression models
Commodity Distribution ↓	Gravity models (singly or double constrained) or intervening opportunities
Commodity Mode Split ↓	Logit models based on panel data (rarely done in urban areas)
Vehicle-Trip Estimation ↓	Loading rates based upon previous surveys and complementary empty trip models
Trip Assignment	Standard traffic assignment techniques

Wisconsin Statewide Truck Trip Forecasting Model Based on Commodity Flows and Input-Output Coefficients – the objectives for this research project were to develop a statewide truck travel demand model for Wisconsin using input-output (I-O) econometric data and to validate the model by 'backforecasting' over a 15-year time period. Trip production rates were developed using commodity flow survey (CFS) information from the U.S. Census Bureau along with a private freight database system. The attraction rates were developed using the state-level Input-Output direct coefficients. A value-per-ton ratio for each sector was used to convert dollar amounts of commodity into physical tons. The author notes that "the primary innovation proposed here is to develop better estimates of the initial truck trip attractions by using an I-O model for Wisconsin and county-level data on employment by 28 primary manufacturing and other economic sectors (Sorratini and Smith, 2000).

Truck trips were distributed and assigned to a state-level highway network using the TRANPLAN transportation planning software package. An all-or-nothing assignment technique was finally used to load the truck trips onto the highway network between regions. A good model fit was obtained based on truck counts at several screen line locations.

2.8 Microsimulation Models

The development and application of traffic microsimulation models has been growing steadily over the past several decades. More consideration is being given to the planning process as environmental and economic limitations need to be considered with greater emphasis. Highway expansion is not the trend anymore as regions are limited financially and geographically and realize that they cannot build their way out of congestion problems. No longer is travel demand being met with more and more capacity, but rather how can existing capacity be managed more effectively. Computing power has also allowed for the development of microsimulation models due to their significant processing requirements. For these reasons, the transportation modelling field has received greater attention in the microsimulation modelling practice. Microsimulation models answer the question: how does fixed demand respond to a change in supply? Demand forecasting models answer questions of changes to demand with temporal and socio-economic factors.

The traffic stream model used in microsimulation models is synonymous with the movement of a discontinuous compressible fluid through a grid-like network. The particles that constitute this fluid, the vehicles, do not behave in a predictable manner and therefore consideration is given to the 'randomness' of travel behaviour. Lane choice and route choice behaviour are calibrated in order for the model to behave as realistically as possible. As such, microsimulation models tend to be used to assess the operational characteristics of transportation systems.

Microsimulation models have been used for a number of research projects as well as transportation planning projects. There have been a number of microsimulation studies which investigated the impact of truck lane restrictions as well as the impact of signal optimization methods.

A Simulation Analysis of Traffic Flow Elements for Restricted Truck Lanes on Interstate Highways in Virginia – safety and capacity issues on interstate highways in Virginia prompted this research to look at the operational impacts of exclusive truck lanes. The intent of this restriction on heavy vehicles was to mitigate or reduce conflicts between heavy and light vehicles. The authors point to the lack of research in this area and conclude that 'since the application of exclusive truck lanes are site specific, the use of a computer simulation model is an appropriate means to forecast likely traffic behaviour' (Hoel and Peek, 1999).

Using FRESIM, the researchers tested truck restrictions from the left and right lanes of a freeway section. A higher speed differential between cars and trucks is caused by restricting trucks from the left lane on grades steeper than 4%. For these steeper grades, restricting trucks from the left lane also decreased density and the number of lane changes. Truck restrictions on the right lane caused an increase in the number of lane changes as trucks were required to shift to the next left lane. Overall the researchers concluded that scenario analysis is useful for site specific treatments. In other words, the microsimulation model was useful for determining the effects of lane restrictions for different areas due to their unique characteristics such as vehicle volumes, percent trucks, curvature and grade.

A Microscopic Simulation Study After Freight Lanes Near Merging Areas – growth in domestic road freight and its impact to merge areas was investigated using a microsimulation model. The author proposes the use of dedicated truck lanes near merge zones combined with flow controllers to increase the efficiency at these merge zones. The simulation results show the effectiveness of flow control as the proportion of trucks grows as well as giving support to the concept of freight automation on dedicated lanes.

The authors conclude that "a dedicated lane with flow control is the most promising approach to prevent future problems on motorways as the traffic composition becomes more heterogeneous" (Minderhoud and Hansen, 2001). The main disadvantage to this approach is the restricted capacity of the on-ramp with the flow control. However, the flow of vehicles on the motorway remains optimal.

Evaluation of Traffic Signal Timing Optimization Methods Using a Stochastic and Microscopic Simulation Program – researchers at the University of Virginia investigated the effectiveness of signal coordination methods using the microsimulation model VISSIM. Signal optimization programs Synchro and TRANSYT were investigated for travel benefits under various demand and input conditions.

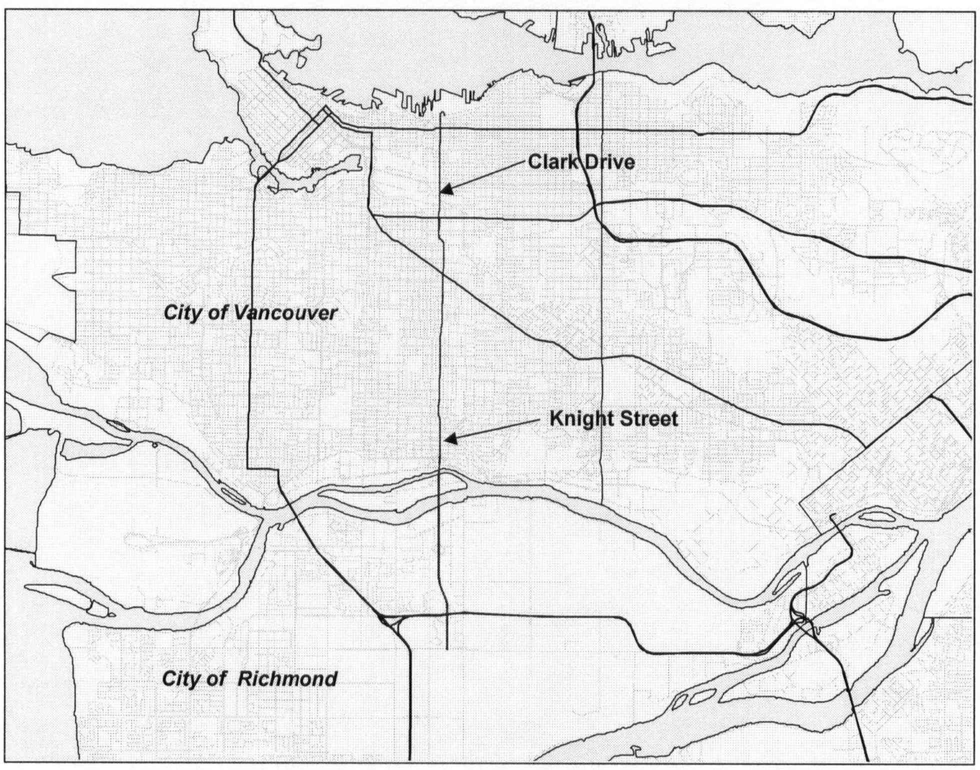
The author notes that "statistical testing and visualization are the most critical aspects of the simulation model calibration and validation" (Park, 2003). Visualization in microsimulation modelling provides a qualitative assurance of the validity of the model and should be incorporated into the model calibration process.

The research showed the effectiveness of a signal coordination strategy under various levels of demand. The revised timing plan showed a 17% saving in travel time along the Lee-Jackson Memorial Highway with a corresponding reduction of 37% in total system delay.

CHAPTER III – Current Travel Conditions & Issues Along Knight Street

The Knight Street corridor is an important goods movement link located in the Greater Vancouver region of British Columbia. It serves partly as a highway facility and partly as a major urban arterial. The entire corridor runs south to north from Westminster Highway in the City of Richmond to Stewart Street in the City of Vancouver. From Stewart Street to the diversion at 14^{th} Ave, the corridor is called Clark Drive and the remainder to the south is called Knight Street[2]. The four-lane Knight Street Bridge crosses the Fraser River between the Cities of Richmond and Vancouver. Figure 1 shows a map of the region highlighting the Knight Street corridor.

Figure 3.1 – Map of the Knight Street Corridor



[2] Throughout this report the entire corridor is referred to as the Knight Street corridor even though it includes a portion called Clark Drive.

For the most part, Knight Street is a 6-lane urban arterial between the Knight Street Bridge and Port Vancouver. A small section from Kingsway to 13th Ave narrows to four lanes. In the City of Richmond, Knight Street is designed to a highway standard with grade-separated interchanges, a dividing median and an operating speed of 80kph. The speed limit at the north end of the bridge slows to 60kph and then to 50kph as it approaches 57th Ave.

Traffic control along Knight Street is widely varied just as land use and the type of cross street varies widely as well. Table 1 illustrates the inventory of traffic control types along Knight Street.

Table 3.1 – Traffic Controller Types Along Knight Street

Controller Type	**Number**
Fixed Time	4
Fixed Time with Actuated Left Turn	5
Semi-Actuated	6
Pedestrian/Bicycle Actuated	10
Fully Actuated	2

The complete corridor is approximately 12 kilometres in length and the average travel time is roughly 20 minutes in either direction. Knight Street serves as a major people and goods movement corridor as it connects Port Vancouver to Highway 91A and consequently the rest of the Lower Mainland highway system.

3.1 Land Use Issues and Historical Context

There is considerable variation in land use type along the Knight Street corridor. In the City of Richmond, the corridor is surrounded by business and warehouse type land use. In the City of Vancouver, Knight Street is mainly surrounded by residential properties. North of 7th Ave, Knight Street is zoned for light industry with small areas of heavy industry. There are few commercial areas along Knight Street which reflects the low pedestrian activity along the corridor.

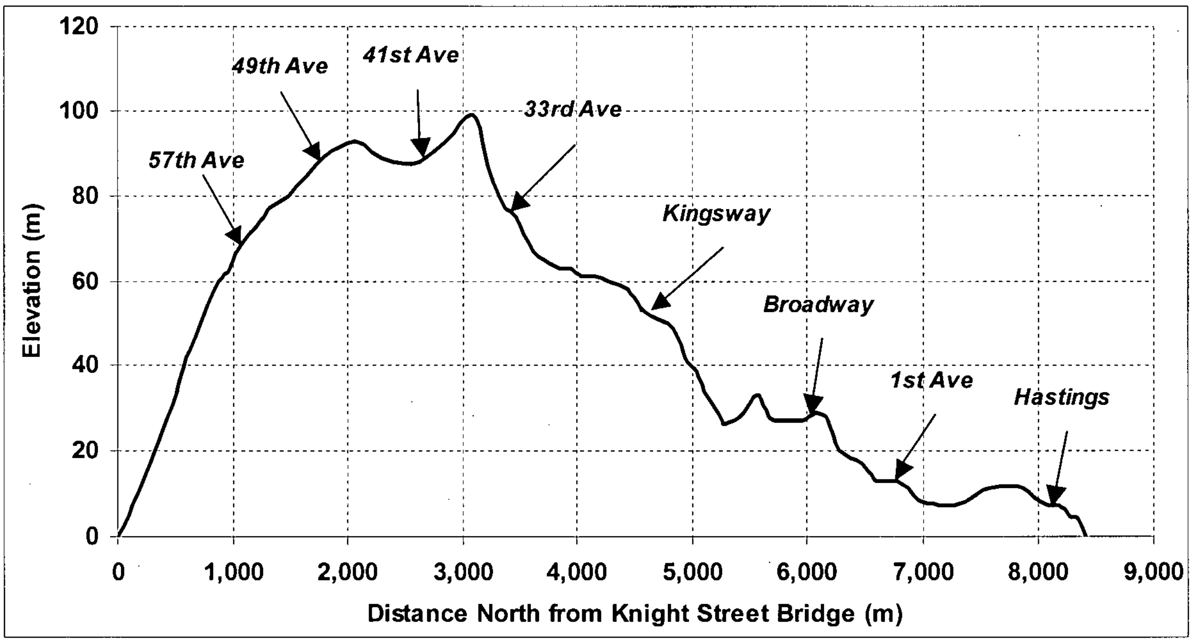
Historically, Knight Street was never a streetcar route, which reflects the automobile oriented style development. The two immediate parallel corridors, Fraser Street and Victoria

Drive were both streetcar routes at one point and hence show their different development patterns. The regional importance of the corridor was entrenched in 1974 when the Knight Street Bridge to Richmond was built to replace the 1905 bridge at Fraser Street (City of Vancouver, 2002). Knight Street was given even more regional significance after the construction of the Alex Fraser Bridge that connected to Knight Street via Highway 91 and the Annacis highway network.

3.2 *Elevation Profile*

Elevation along Knight Street is a significant factor especially for heavy trucks. Grades of 7% are seen along the northbound approach to 57th Avenue and the southbound approach towards 41st Avenue from 33rd Avenue. Figure 2 shows the elevation profile relative to sea level of the Knight Street corridor. The profile is only shown along the Vancouver section as the Richmond section is completely level.

Figure 3.2 – Elevation Profile of the Knight Street Corridor

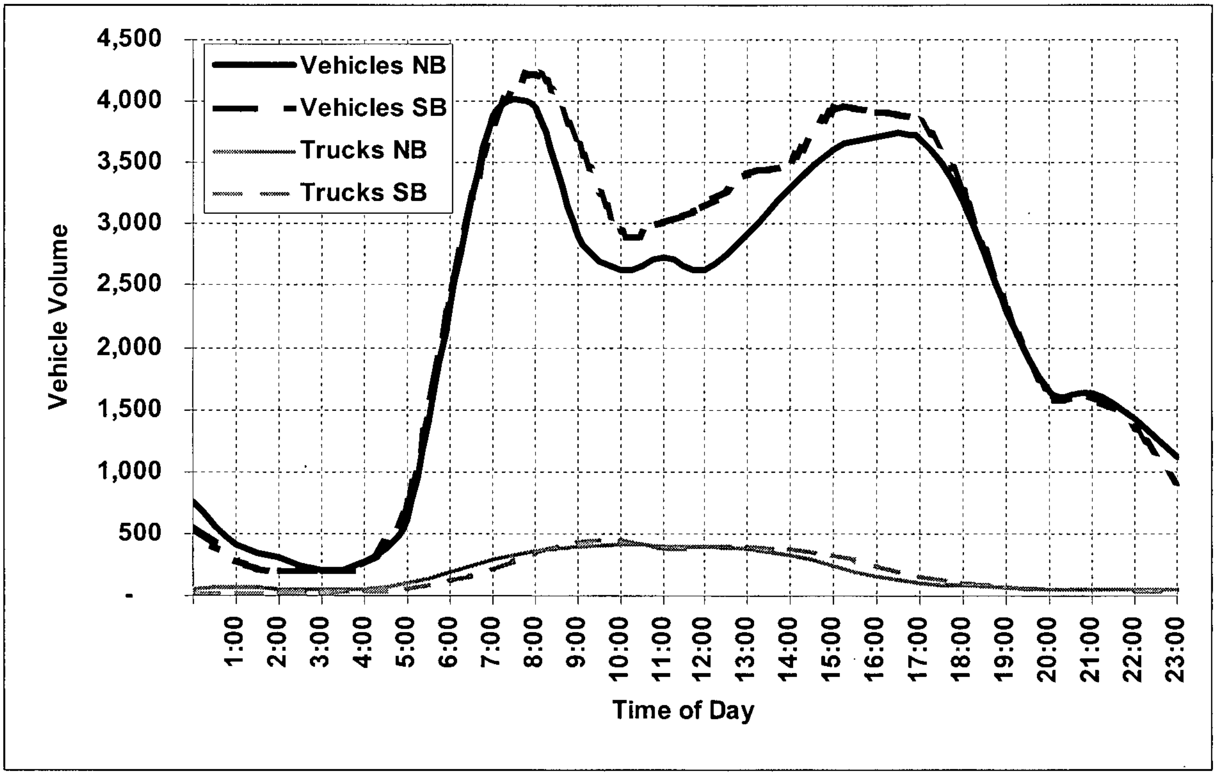


As heavy trucks attempt to travel these grades, their speeds are greatly reduced. This poses a capacity constraint to smaller vehicles as they are required to either wait behind the truck or to maneuver around them. Safety is also a concern as heavy trucks require greater travel distances to slow down when travelling down these steep grades.

3.3 Vehicle Volumes and Classification

The Knight Street Bridge carries over 107,000 vehicles per day, 8,600 of these being trucks. These numbers show that the proportion of trucks is 8% on a daily basis. The peak volume of trucks occurs during the day from 09:00 to 14:00 when truck volumes represent approximately 15% of the traffic stream. Figure 5 shows the hourly volume of total vehicles and trucks for a 24 hour period in the fall of 1999.

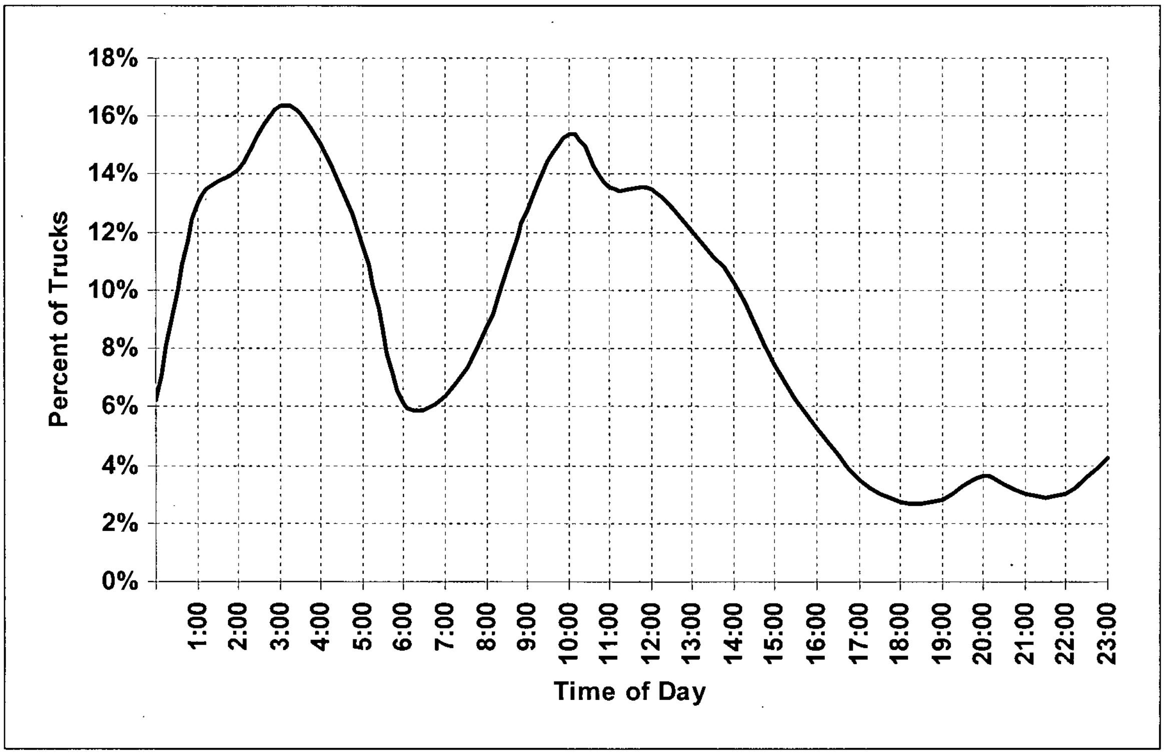
Figure 3.3 – Hourly Vehicle Volumes at the Knight Street Bridge (Fall 1999)



Knight Street is a unique facility in that there is a bi-directional peak in the morning and afternoon. Typically, a bridge crossing will have a very defined peak direction as people travel to and from the central business district (CBD). Strong employment growth in the City of Richmond has resulted in a balance of flows in the morning and afternoon peak periods. This characteristic is efficient in terms of facility utilization as the connection is busy for most of the day, however the balance of peak hour traffic flows creates problems in terms of signal coordination.

The volume of trucks does not follow the typical dual morning and afternoon peak profile associated with commuter travel. Truck volumes tend to peak once during the midday as they are making delivery trips. Trucks also tend to have a peak during night time, but only in terms of percentage of vehicles. As vehicle volumes drop from midnight to 04:00, truck volumes hold steady increasing the proportion of trucks. Figure 4 shows the percentage of trucks along the Knight Street Bridge.

Figure 3.4 – Hourly Percentage of Trucks at the Knight Street Bridge



It is evident from the above illustrations that the Knight Street Bridge is a highly utilized commuter and goods movement crossing. The two competing crossings of the north arm of the Fraser River are Oak Street Bridge to the west and Queensborough Bridge to the east which are approximately 5km and 15km driving distance away from the Knight Street Bridge respectively. Arthur Laing Bridge to the west serves north and southbound vehicle trips across the North Arm of the Fraser River as well. All four crossings are similar 4-lane facilities. The following table illustrates the 1999 24 hour two-way vehicle volumes across these four bridges.

Table 3.2 – 24 Hour Vehicle Volumes Across North Arm of Fraser River

Crossing	Daily Two-Way Vehicle Volume
Knight Street Bridge	107,400
Arthur Laing Bridge	90,822
Oak Street Bridge	90,400
Queensborough Bridge	78,200

There is only one other 4-lane crossing in the Lower Mainland that carries more traffic than the Knight Street Bridge: the Port Mann Bridge which is a severely congested facility operating above capacity for over 12 hours per day.

3.4 Travel Time and Congestion Delay

Travel time data was collected for the purposes of model validation using global positioning system (GPS) technology. A GPS device colleted location and time data along the Knight Street corridor which was subsequently used to calculate average travel times and queue delay and to validate the model. The illustration on the following page shows drive profiles of four trips travelling northbound and southbound during the morning peak period along the entire length of the Knight Street Corridor from Westminster Highway to Powell Street and vice versa.

Queue lengths and times can easily be observed from the second by second GPS data. The sudden jumps in travel time at the approaches to the major intersections show exactly where a queue of vehicles has formed. The jumps in travel time also show how much time is spent in the approach queue to the intersection when the vehicle starts moving again. A real wealth of travel time information is displayed in these drive plots.

Figure 3.5 – Drive Profile Northbound Along the Knight Street Corridor

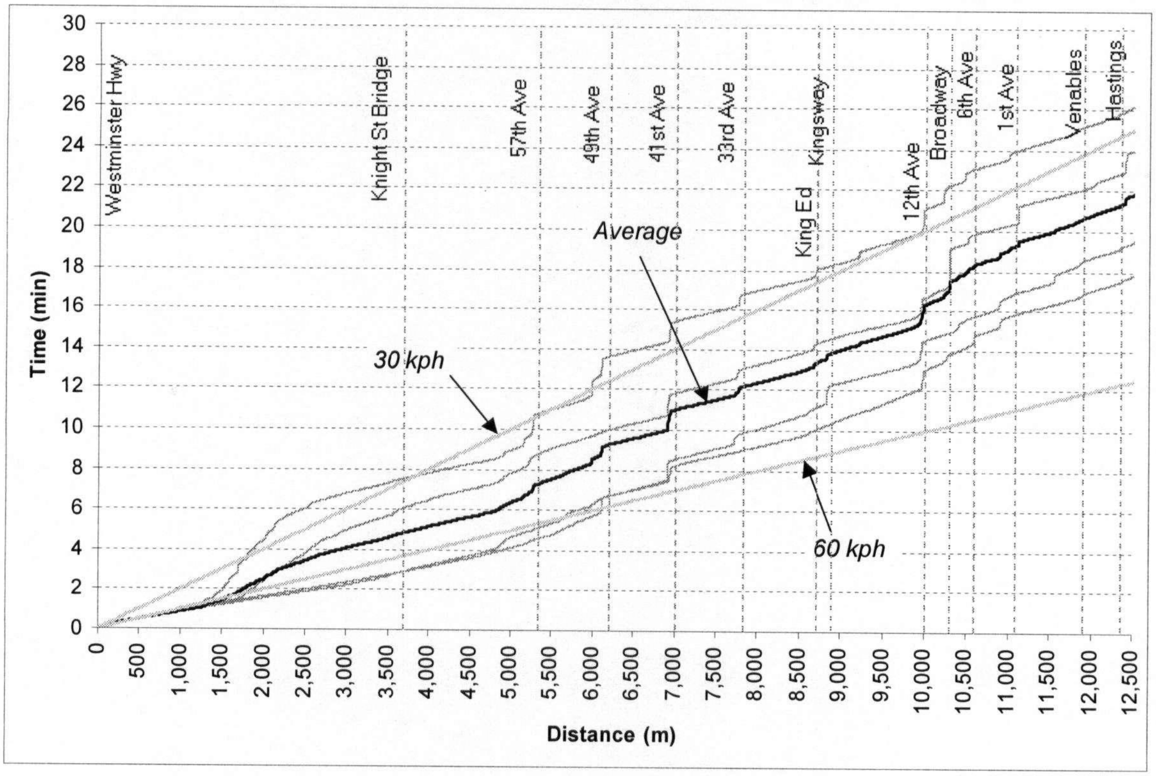
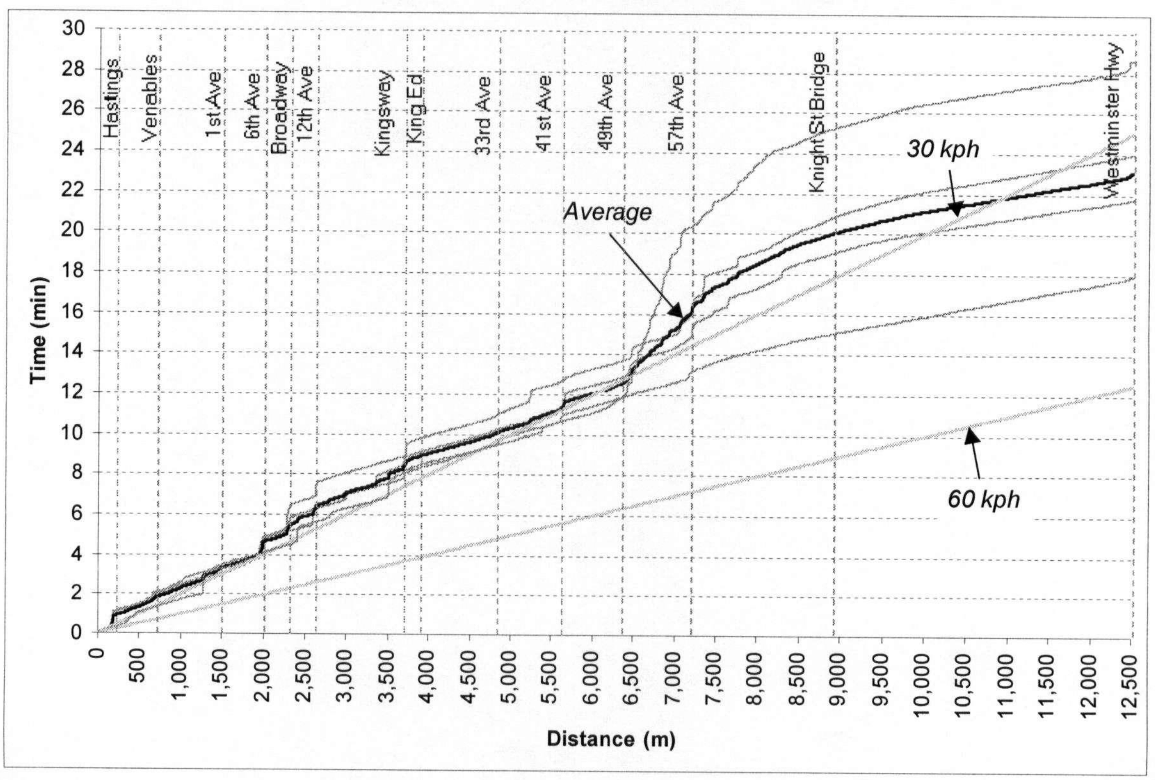


Figure 3.6 – Drive Profile Southbound Along the Knight Street Corridor



As shown in the above illustrations, the average travel time during the morning peak period is approximately 23 minutes in either direction. What is also significant is the amount of variability in travel times. This variation is due to many factors affecting drive performance including heavy vehicle volume, turn volume, signal coordination and incidents. This travel time data was used to calibrate drive times in the microsimulation model. The following table illustrates the northbound and southbound average travel distance and time between major intersections.

Table 3.2 – Average Drive Times Between Major Intersections Along Knight Street

NORTHBOUND	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Westminster Hwy	0.0	0	0	0
Knight St Bridge	3.7	4.9	4.9	45.3
57th Ave	5.4	7.4	2.5	40.8
49th Ave	6.2	9.3	1.9	25.3
41st Ave	7.0	11	1.7	28.2
33rd Ave	7.8	12.1	1.1	43.6
King Edward	8.7	13.4	1.3	41.5
Kingsway	8.9	13.9	0.5	24.0
12th Ave	10.0	16.3	2.4	27.5
Broadway	10.3	17.5	1.2	15.0
6th Ave	10.6	18.4	0.9	20.0
1st Ave	11.1	19.3	0.9	33.3
Venables	11.9	20.7	1.4	34.3
Hastings	12.4	21.5	0.8	37.5
Powell	12.6	22.6	1.1	10.9

SOUTHBOUND	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Powell	0.0	0.0	0.0	0
Hastings	0.2	0.9	0.9	13.3
Venables	0.7	1.8	0.9	33.3
1st Ave	1.5	3.3	1.5	32.0
6th Ave	2.0	4.6	1.3	23.1
Broadway	2.3	5.3	0.7	25.7
12th Ave	2.6	6.1	0.8	22.5
Kingsway	3.7	8.4	2.3	28.7
King Edward	3.9	8.9	0.5	24.0
33rd Ave	4.8	10.0	1.1	49.1
41st Ave	5.6	11.3	1.3	36.9
49th Ave	6.4	12.6	1.3	36.9
57th Ave	7.2	16.1	3.5	13.7
Knight St Bridge	8.9	20.0	3.9	26.2
Westminster Hwy	12.6	23.7	3.7	60.0

3.5 *Knight Street Bridge Level of Service*

The operating level of service (LOS) of a transportation facility is a subjective measure of how the facility is performing. The capacity of the Knight Street Bridge is based on several factors as described in the 1994 version of the Highway Capacity Manual (HCM). The following formula calculates the capacity of a transportation facility:

$$\text{Capacity} = 2{,}200\,\text{pcphpl} \times N \times f_w \times f_{HV} \times f_p \quad \text{where:}$$

N = number of lanes

f_w = factor for restricted lane widths

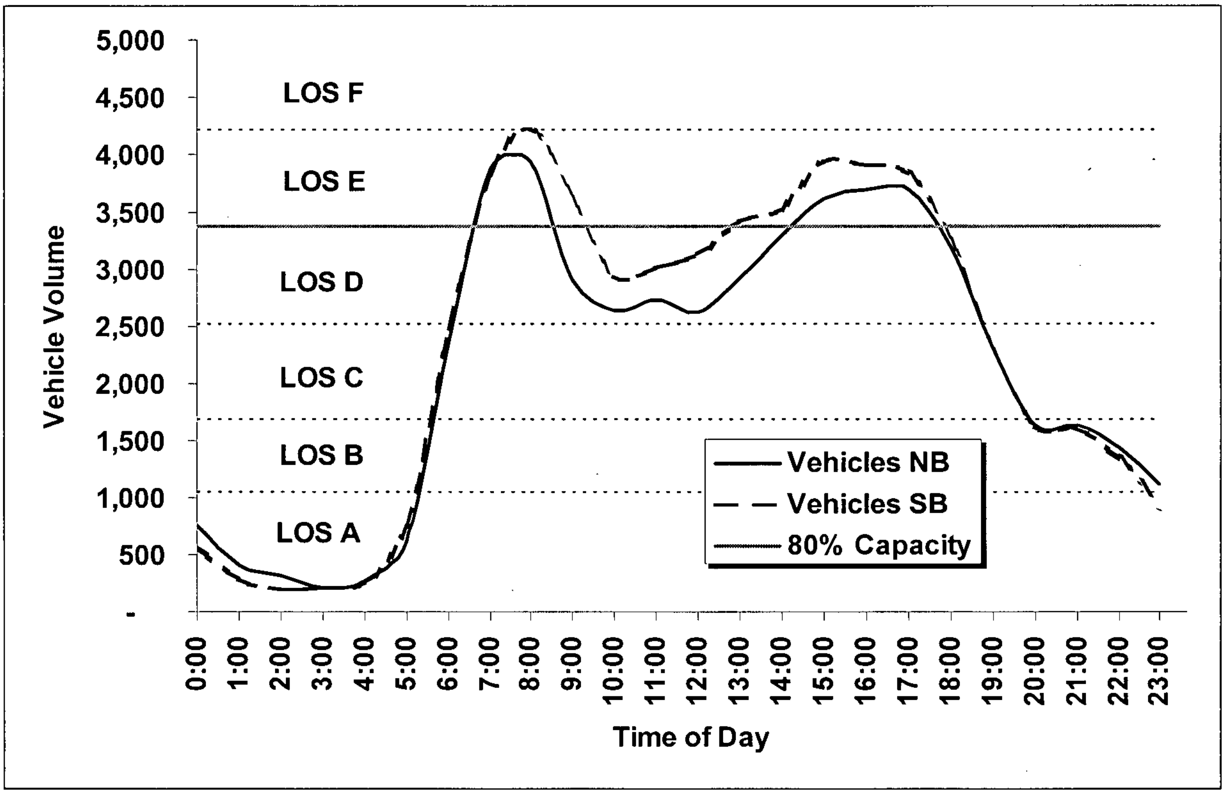
f_{HV} = factor for heavy vehicles

f_p = factor for unfamiliar drivers

(pcphpl = passenger cars per hour per lane)

Based on the above formula, the theoretical capacity of the Knight Street Bridge is 4,200 vehicles per hour per direction. The following graph illustrates the level of service bands for vehicles crossing the Knight Street Bridge. At 80% of capacity, the flow of vehicles becomes very unstable and the onset of congestion begins and queues begin to form. Any vehicle volumes above this level are experiencing congested traffic conditions. From a traffic engineering point of view, a facility is 'failing' in terms of its design capacity. The following figure highlights the 80% design capacity of the Knight Street Bridge.

Figure 3.7 – Design Capacity of the Knight Street Bridge



Based on this analysis, over 49,000 vehicles experience congested conditions along the Knight Street Bridge. This represents almost half of the over 107,000 vehicles that travel over the bridge on a daily basis and is an indication of the severity of congestion at this particular facility.

3.6 Turning Movements and Intersection Level of Service

The City of Vancouver collects turning volumes at intersections on an annual basis as part of their data collection and monitoring program. This data was used as the cornerstone of the model calibration as noted in section 4.8.

3.7 Overall Performance Assessment

Based on the above information and analysis, it is obvious that the Knight Street corridor is highly utilized and serves as a major goods movement corridor. There are a number of land use issues in terms of residential development that are affected by the high volume of truck traffic. Noise and air pollution are a concern of residents along the corridor. Trucks not only have to compete with commuter traffic for road space, but with resident complaints as well for mobility along the corridor.

CHAPTER IV – Model Development & Calibration

The development of the Knight Street corridor sub-area model followed the standard steps for model development and calibration. The following illustrates the development of a microsimulation model using the Paramics software suite (Aitken, 2003):

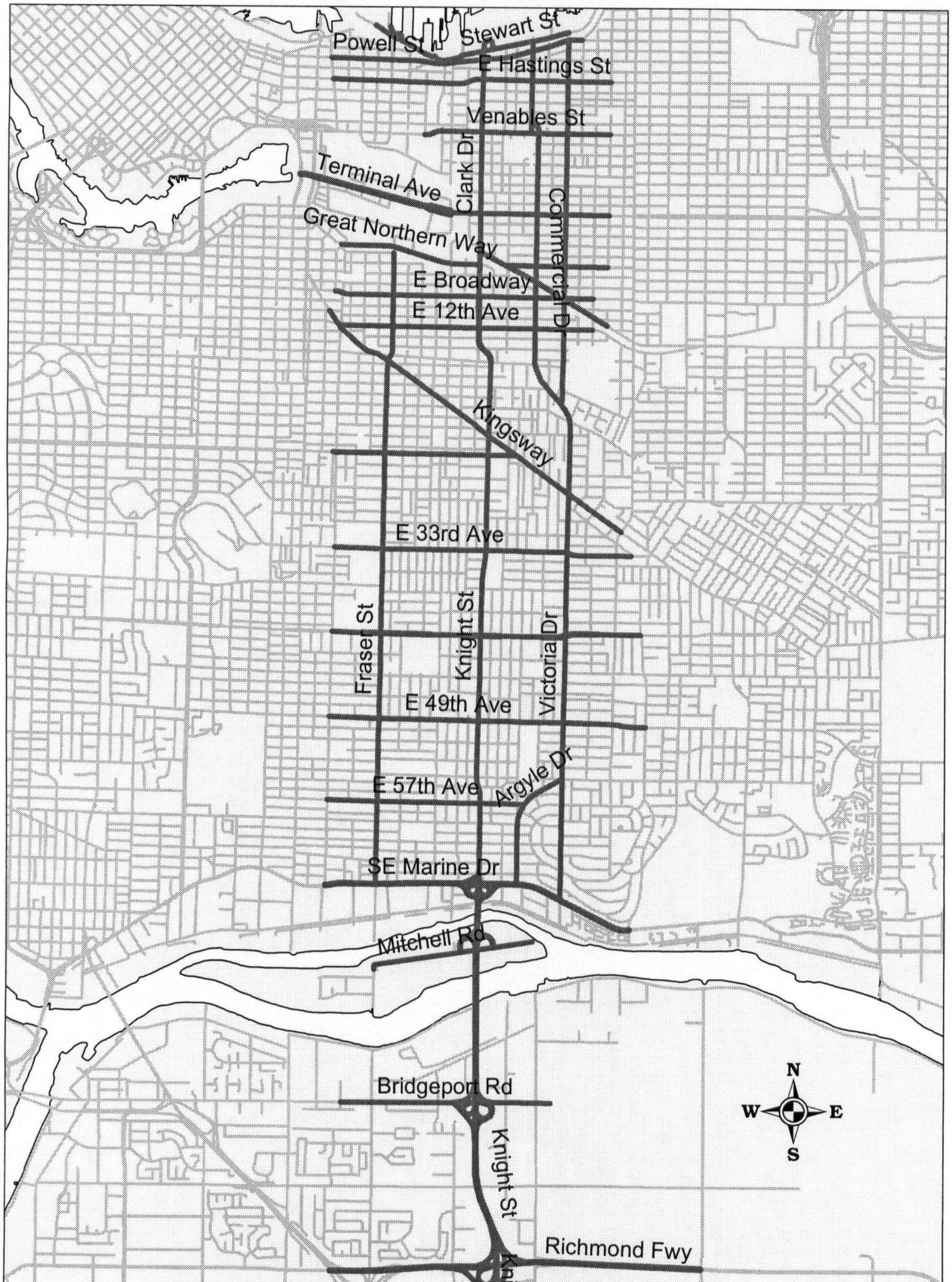
1. Create a new Paramics network and embed a template road geometry file.
2. Build a road network by adding nodes, links and zones and coding detailed lane and junction descriptions (skeleton network).
3. Build demand matrices from origin/destination data and include fixed demand data such as bus routes.
4. Assign traffic using an appropriate assignment technique.
5. Collect and analyze model results.
6. Calibrate base conditions by comparing model results to observed data.
7. Validate the base model against independent data.

The development cycle above represents the standard approach to coding and calibrating a transportation model using any of the various micro simulation software packages. The following sub-sections describe the major stages of model development and calibration for the Knight Street corridor sub-area.

4.1 Skeleton Network Coding

The following diagram (Figure 4.1) illustrates the skeleton network which represents the Knight Street sub-area model. As shown, only arterials and freeways are coded as the effort to include all local streets would be too time consuming and consequently too difficult to calibrate. Ideally every link should be coded, although the effort required to code and calibrate would compromise the accuracy of the model and would be better suited for a more detailed intersection analysis as this study focuses results more at the sub-area level.

Figure 4.1 – Skeleton Network Representation of the Knight Street Corridor

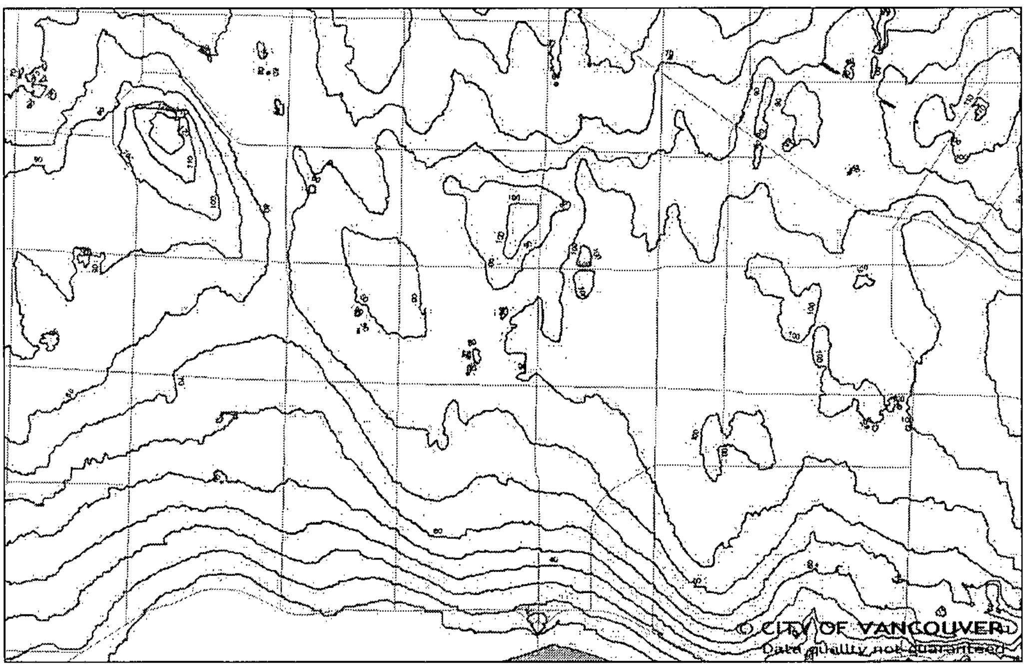


The skeleton road network was based on the digital road atlas for the Lower Mainland. The digital road atlas represents the centreline of all road segments and was used as a template for coding the Knight Street sub-area network. Every intersection is represented by a node as are on and off ramps at freeway interchanges. All road segments are connected between nodes with network links which can be curved to match actual road geomety. The digital road atlas also contains information on the number of lanes and posted speed limit which were coded into each link attribute.

4.2 Coding Node Elevations

As noted earlier, the elevation profile of Knight Street contains significant grades for heavier vehicles. As Paramics is able to account for performance characteristics related to grade, it was necessary to code the node elevations. Elevation contours available from a geographic information system (GIS) was used to code node elevations as shown in the following illustration.

Figure 4.2 - 10 Metre Elevation Contours for Knight Street

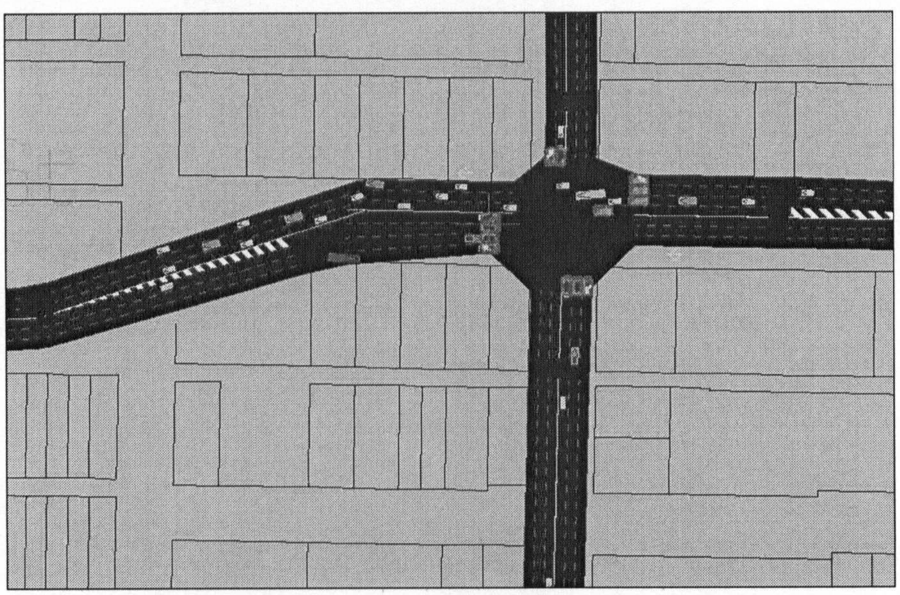


4.3 Detailed Intersection and Lane Configurations

Orthophotos (1999 Aerial) were used to code detailed intersection configuration and lane geometry as shown in the following two illustrations.

Figure 4.3 – Orthophoto of the Clark and Hastings Intersection

Figure 4.4 – Paramics Network of the Clark and Hastings Intersection



As is shown in the previous two illustrations, the available orthophotos were very valuable in terms of saving time during network coding. Typically field visits are required to confirm detailed lane configurations, however the orthophotos were checked to confirm network details in a timely manner.

Signal timing plans were coded according to the specifications of the City of Vancouver. Consideration was given for signal phasing, protected and permissive left turns and turn restrictions as of the most current conditions along the Knight Street corridor.

4.4 Demand Matrices for Cars and Trucks and Fixed Bus Routes

Paramics is unique in terms of its assignment technique as it loads trips onto the network using an origin-destination (OD) fixed demand matrix. Some microsimulation models use fixed turning volumes as inputs to the simulation which does not properly capture distributional impacts from network changes. A total of 41 traffic zones were coded and used to load and unload vehicle trips to and from the digital road network. The complete OD matrix is a 41 by 41 auto demand matrix with 1,681 OD pairs as shown in Appendix D. A separate demand matrix for trucks was developed as well to capture the unique trip characteristics of goods movement vehicles.

The complete demand matrix was coded manually, initially based on EMME/2[3] results factored up from the morning peak hour. The complete matrix was calibrated based on actually turning movements at major intersections. A total of 330 turning movements were used to validate the base model for 1999/2000 year conditions as shown in Appendix C.

The demand matrix is assigned to the network for the morning peak period from 07:00 to 09:00. As vehicle counts indicate, these trips do not load onto the network uniformly throughout this time period. As such, a 'profile' file is used to vary the demand during the assignment period according to 24 hour traffic counts.

Transit vehicles make up a significant portion of vehicles travelling along the Knight Street sub-area network. All transit routes throughout the sub-area were coded according to the fall 2000 itinerary. As such, routes and headways as shown in Appendix B were coded into the model with all pertinent transit stops.

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[3] EMME/2 is the regional transportation demand forecasting model for the AM peak hour (07:30-08:30). It is a static equilibrium demand model used for strategic planning purposes.

4.5 *Trip Assignment Method*

Paramics allows the user to define an assignment method used to affect the route choice of drivers on the network. The most basic assignment method is referred to as the 'all-or-nothing' assignment which considers only travel cost based on distance and free flow travel time. This might be fine for a simple network or corridor model where there is no route choice. The stochastic assignment method addresses next level of complexity in terms of route choice. A percentage of drivers vary their route choice for seemingly no apparent reason other than their perceived travel cost which will vary between individuals. This randomness in travel behaviour is accounted for with a percentage of drivers who will choose to take an other than shortest path (based on distance and travel time) in the assignment method. Paramics allows the user to specify a percentage of drivers who will choose their route on a random basis.

Static transportation models typically utilize some form of feedback algorithm where travel costs are updated based on congestion levels. This assignment method attempts to minimize travel cost as would be expected for a typical commuter. The dynamic feedback assignment method in Paramics accounts for congestion by continuously updating route costs based on congestion levels. The user can specify how frequently these costs are updated which has a significant impact on the behaviour of drivers.

For the Knight Street sub-area model, a combination of the stochastic assignment with the dynamic feedback assignment was used to affect the route choice of drivers. This combination afforded the most realistic assignment technique to impact the route choice of drivers such that route costs were periodically updated and a certain amount of perturbation was allowed. For more information on route assignment, please refer to the Paramics Modeller User Guide[4].

4.6 *Genetic Algorithm-Based Combinatorial Parametric Optimization*

The process of calibrating a traffic model is tedious and time consuming due to the large number of factors that affect travel behaviour. As such, transportation engineers

[4] Available as a pdf file for download at <http://www.paramics-online.com>

require automation techniques to help eliminate the 'guess work' out of developing transportation models. Genetic algorithms are being used for optimization processes more frequently due to their efficient search capabilities.

Genetic algorithms are based on the theory of natural selection as it applies to any optimization process. By simulating natural evolutionary processes, a genetic algorithm can effectively search the problem domain thoroughly on population-based solutions rather than a single solution, and employ heuristics to evolve a better solution (Ma, 2001). The search program iterates through 'generations' of solutions allowing good solutions to reproduce and bad solutions to die. The parameters 'evolve' towards a global optimal solution through a number of generations.

A genetic algorithm-based combinatorial parametric optimization process has been developed to assist in calibrating the behavioural parameters in the Paramics model. Genosim[5] (Ma, 2001) has been developed at the University of Toronto in an effort to automate the calibration of global behavioural variables. Paramics defines a set of global driver behaviour variables used to adjust various characteristics of driver behaviour. The default global variables in Paramics are outlined in the following table.

Table 4.1 – Default Global Behaviour Variables in Parmics

Behaviour Variable	Default Value
Mean Headway	1.0 sec
Mean Reaction Time	1.0 sec
Feedback Interval	300 sec
Perturbation	85%
Familiarity	5%

These parameters were chosen as they are the most sensitive to the model output. These five parameters are defined below:

[5] For a full description of Genosim, refer to Tao Ma's thesis: *Genetic Algorithm-Based Combinatorial Parametric Optimization for the Calibration of Traffic Microscopic Simulation Models*, University of Toronto, April 2001.

1. Mean Reaction Time – the average time for drivers to react to changes in traffic flow (i.e., car following, gap acceptance).
2. Mean Headway – the average time between the front edge of each vehicle.
3. Feedback Period – sets the period of time when link costs are updated and fed back into the route calculation algorithm.
4. Familiarity – the percentage of drivers that are familiar with the road network affecting route choice.
5. Perturbation – the percentage of drivers that are randomized with respect to route choice affecting the stochastic behaviour of drivers.

In order to run Genosim, traffic counts at intersections are required as an input. The optimization process of the Gensosim genetic algorithm attempts to minimize a 'misfit' function. This function describes how well the model is performing relative to actual ground counts of traffic. The following formula describes the global relative error (GRE) function which is minimized in this genetic algorithm:

$$GRE = \frac{\sum_{i=1}^{n} |Q_{real} - Q_{sim}|}{\sum_{i=1}^{n} Q_{real}}$$

where: Q_{real} *= real traffic flows*

Q_{sim} *= simulated or modelled traffic flows*

i *= individual turn movement at intersection*

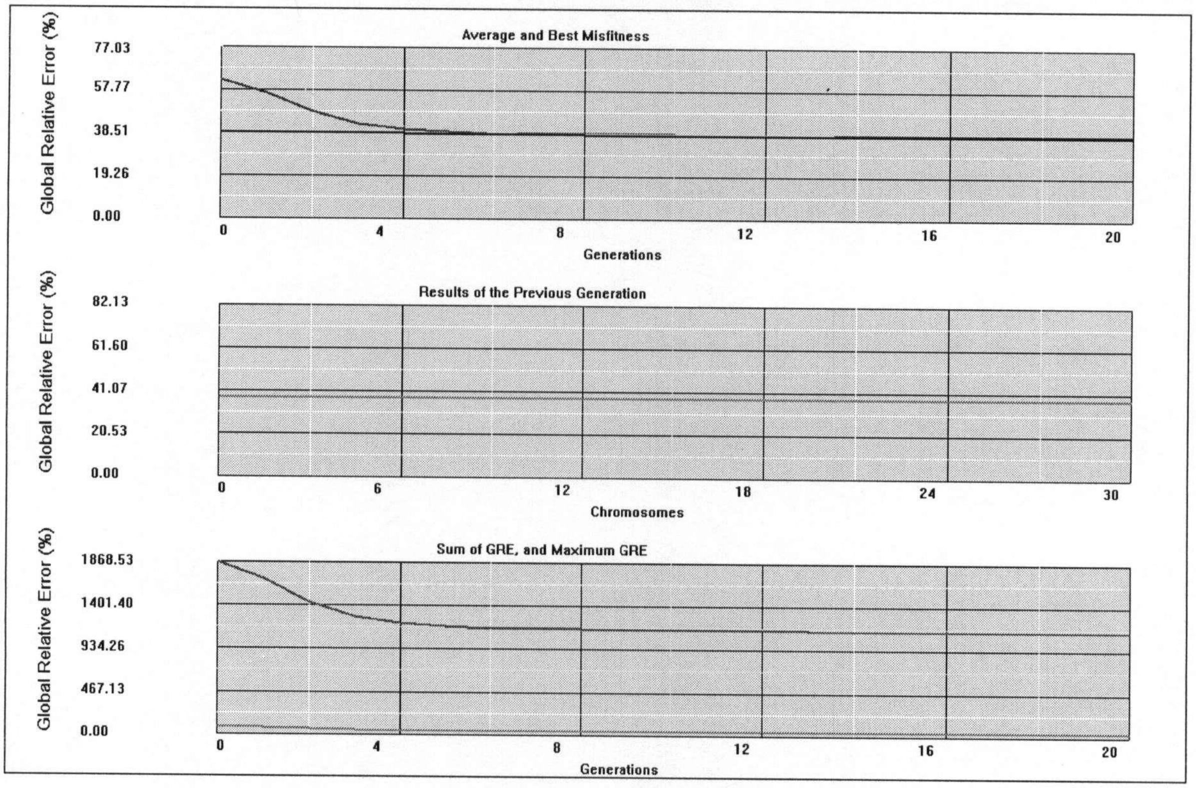
n *= total number of turn movements*

This formula is used as it fully describes the network-wide error comparing real to modelled traffic counts. The five global behaviour variables mentioned previously are manipulated in a way to minimize the GRE function. As Genosim is run, the behaviour variables are optimized to attain a better fit between the modelled turning movements to actual field counts.

Application of Genosim involves setting up the network with a calibrated origin-destination demand matrix. Peak hour adjustment factors were used to scale the 2 hour Knight Street subarea model demand matrix to a one hour peak as required by Genosim. The program is then run making use of the Paramics Processor module which is a batch program for performing multiple model runs.

Running Genosim took over 17 hours of CPU processing time on a Pentium IV 1.9 GHz computer with 768 MB of RAM. This represented just under 300 individual model runs of Paramics to optimize the global behaviour parameters. The following figure shows direct output from Genosim showing the progression of the global relative error as the genetic algorithm optimizes the behaviour parameters.

Figure 4.5 – Genosim Output for Global Relative Error of Progressive Generations



As shown in the above figure, the algorithm converged after approximately ten generations. The algorithm cannot find better solutions and thus the global behaviour parameters have been optimized. The following figure shows further output from Genosim highlighting the genetic algorithm settings as well as the optimized parameter values.

Figure 4.6 – Final Parameter Output from Genosim

Run-Time Setting:	
Number of Generations	20
Population Size	30
Crossover Rate	0.990
Mutation Rate	0.050
Representation	Real
Crossover Option	Two Point
Mutation Option	Gaussian
Algorithm Option	Steady State
Parent Selection	Roulette Wheel

Results of Objective Scores:	
Best Score	37.65
Worst Score	37.93
Mean of Scores	37.78
Standard Deviation	0.12
Variance	0.01
Sum of Scores	1133.27

Optimized Parameter Values:	
Mean Headway	0.92
Mean Reaction Time	0.82
Feedback	60
Familiarity	90.75
Perturbation	11.56

The bottom table of values show the optimized parameter values for the Knight Street subarea model. The following table illustrates the default values as well as the calibrated values for the five behaviour variables.

Table 4.2 – Default and Calibrated Global Behaviour Parameters

Variable Description	Default Value	Calibrated Value
Mean Reaction Time	1.0 seconds	0.92 seconds
Mean Headway	1.0 seconds	0.82 seconds
Feedback Period	300 seconds	60 seconds
Familiarity	85.0%	90.8%
Perturbation	5.0%	11.6%

The mean reaction time and headway are lower compared to the default values probably to get higher vehicle flows along the network. Real observations of traffic flow might show higher values, however, these values are optimized to fit turning volumes. Qualitative observations of the microsimulation model show that the vehicle behaviour seems reasonable as compared to actual driving conditions.

A one-minute feedback period seems reasonable considering the behaviour implications of a higher period. Tests of higher feedback periods showed unusual routing behaviour throughout the network. If, for example, a 5-minute (300 second) feedback period is used, drivers tend to divert trips between each period. Qualitative observations of the microsimulation model with a 5-minute feedback period showed northbound trips diverting between Knight Street and Victoria Drive between feedback intervals. A one minute feedback period resulted in more balanced routing decisions from drivers.

A higher percentage of familiar drivers results in more dispersed travel patterns as drivers have more knowledge of local conditions. This seems reasonable as the Knight Street corridor is primarily a commuter route with very few unfamiliar drivers in the peak period travel times.

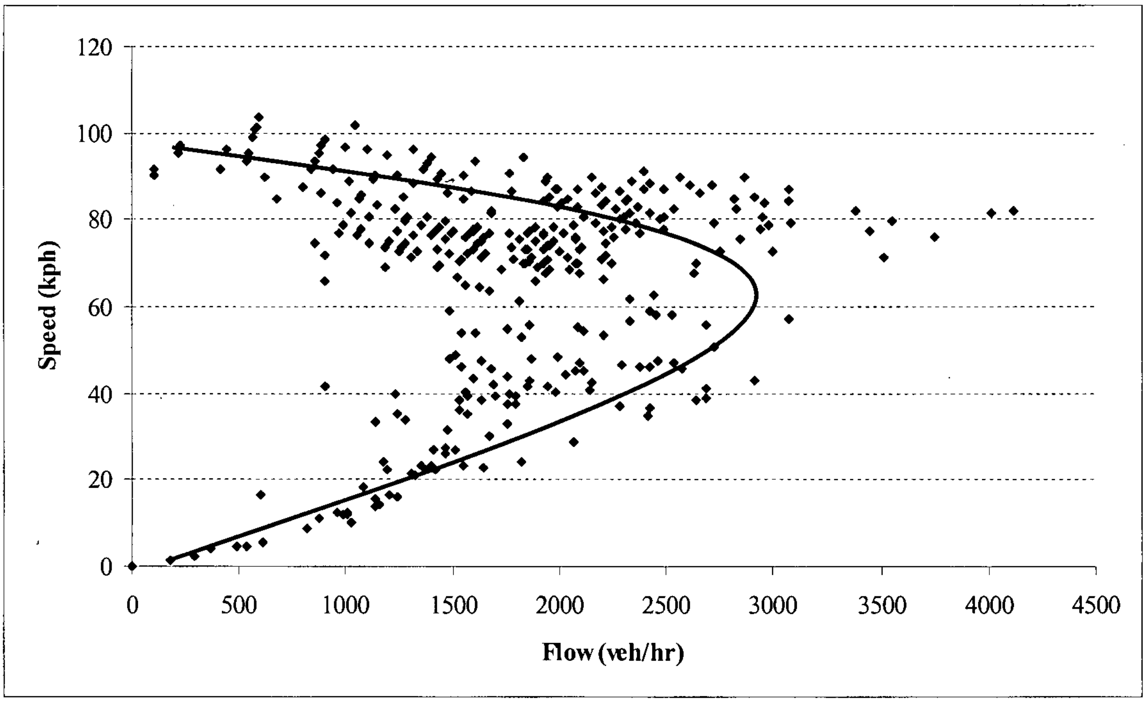
A higher percentage of perturbation also results in more dispersed travel patterns. More drivers will divert to other routes as turn costs are constantly being updated. Essentially every familiar driver has 'perfect' knowledge of the road network and congestion conditions resulting in numerous turn movements to avoid congested locations. This also seems reasonable as the City of Vancouver, with its fine grid network, offers commuters many route choices to avoid congestion.

There are other more localized factors that are used to calibrate specific areas of the model. These factors include link properties such as gradient, visibility and signposting which have only localized impacts and therefore are not calibrated on a system-wide basis.

4.7 Model Behaviour According to Traffic Flow Theory

The analytical techniques used in traffic flow theory are derived from analogies to fluid flow. Expanding on the relationships of speed, flow and density and how they were derived is beyond the scope of this thesis, however the reader is assumed to possess the fundamentals of traffic flow theory. The following graphs simply allude to the fact that the microsimulation model adheres to the basic relationships between speed, flow and density. The following graphs illustrate the relationship between speed, flow and density and how closely the microsimulation model follows these relationships.

Figure 4.7 – Relationship Between Speed and Flow



Each graph contains points taken directly from the Paramics microsimulation model for discrete time periods. The line in each graph represents the best fit regression curve for the points and is not the relationships currently used in the Highway Capacity Manual.

Greenshields model of a linear relationship between speed and density is highlighted in the following illustration.

Figure 4.8 – Relationship Between Flow and Density

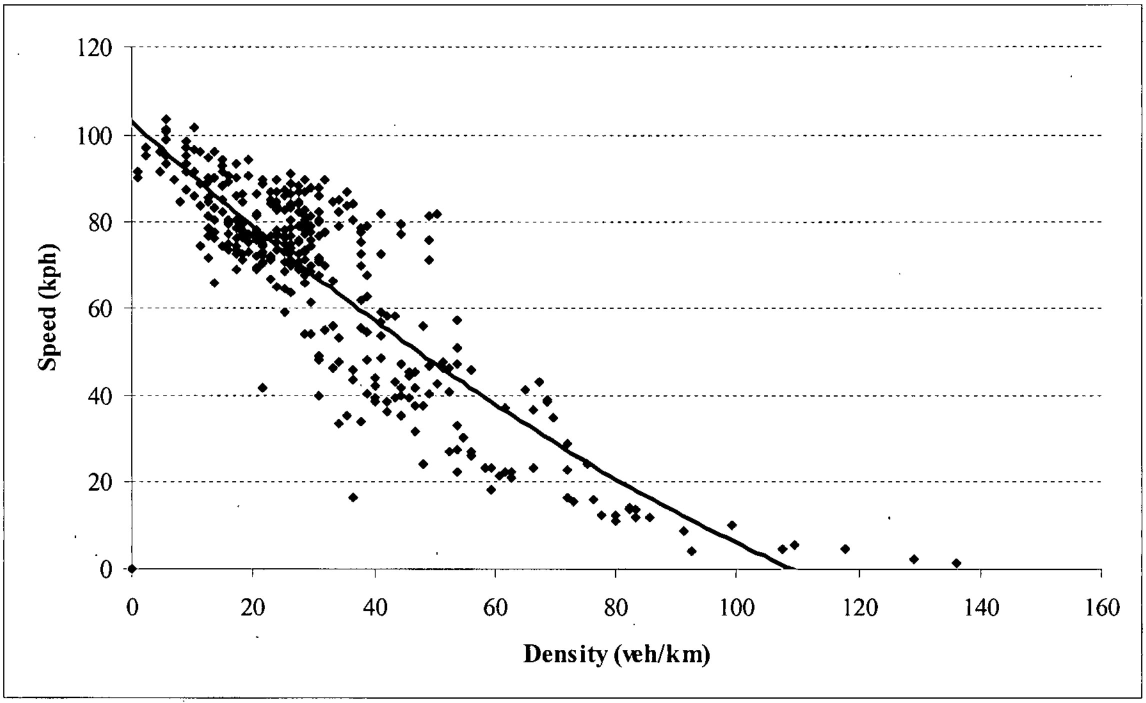
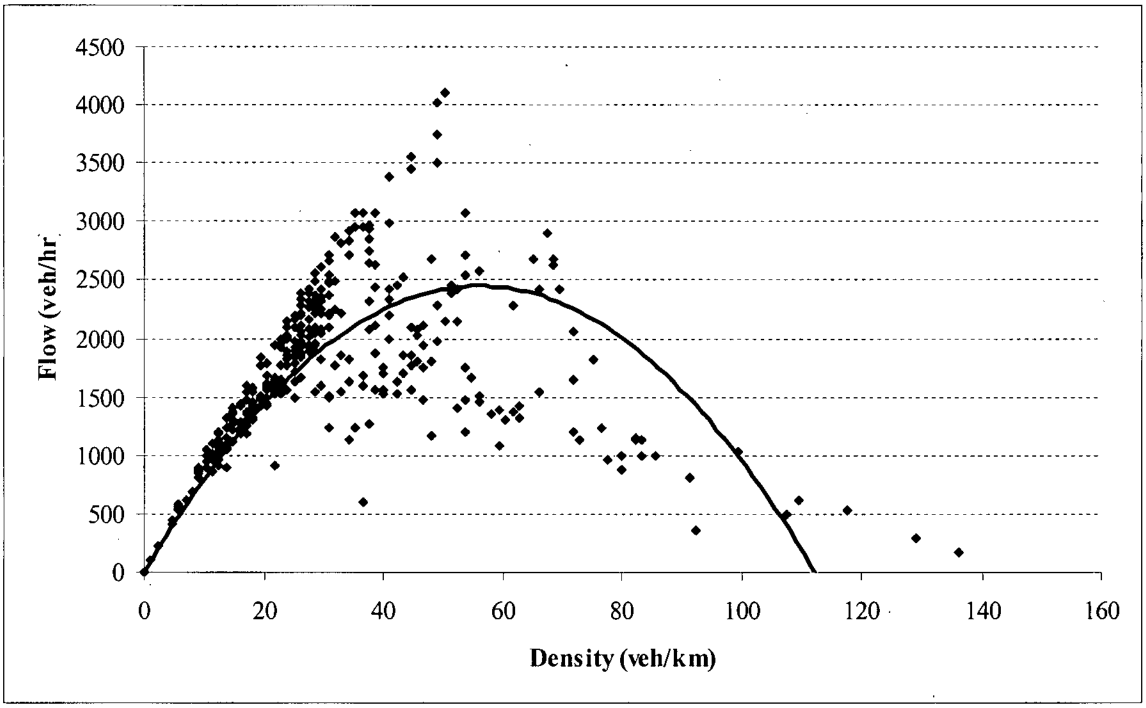


Figure 4.9 – Relationship Between Flow and Density



Without getting into a detailed statistical analysis of how well these relationships hold true within the microsimulation model, the figures illustrate that the model behaves reasonably well to the theory of traffic flow.

Many traffic microsimulation studies point to the fact that visualization of the animated traffic movements is very important in the calibration process. The importance of visualization when using microscopic simulation models cannot be overemphasized (Park, 2003). Simply observing the model and ensuring that the animation of vehicles looks realistic is a key part of the calibration process. It is the point at which sound engineering judgement must be applied to determine whether a model is calibrated properly or not.

4.8 Model Validation Based On Observed Turning Volumes

In order to ensure that the model represents real conditions, a comparison of modelled volumes to actual observed volumes is required. The following point validation error ranges are used by LSC consultants for their model calibration (LSC, 2002).

Table 4.3 – Point Validation Error Ranges for Daily Traffic Volumes

Average Daily Traffic (ADT)	Error Range
<1,000	*±100%*
1,000-3,999	*±50%*
4000-9,999	*±25%*
10,000-14,999	*±15%*
≥15,000	*±10%*

As shown above, these vehicle volumes are for a daily basis. These ranges were modified to account for the peak period. As such, the following standards were used to ensure that the model has been properly validated:

Table 4.4 – Model Validation Standards for Hourly Volumes per Lane

Vehicles per Hour	Allowable Error
> 2,000	*±15%*
1,500-2,000	*±20%*
1,000-1,500	*±25%*
500-1,000	*±30%*
250-500	*±50%*
<250	*no restriction*

The allowable error is the percentage deviation of the modelled results from the actual observed count. Table 4.5 illustrates the observed and modelled turning volumes as well as the error of turning movements along the Knight Street corridor (turn movements along Fraser Street and Victoria/Commercial Drive are illustrated in Appendix C). The following formula illustrates the method used to calculate the model error or deviation for each of the 330 individual turn movements:

$$Error_i\ \% = \frac{(Model\ Turn\ Volume_i - Observed\ Turn\ Volume_i)}{Observed\ Turn\ Volume_i} * 100\%$$

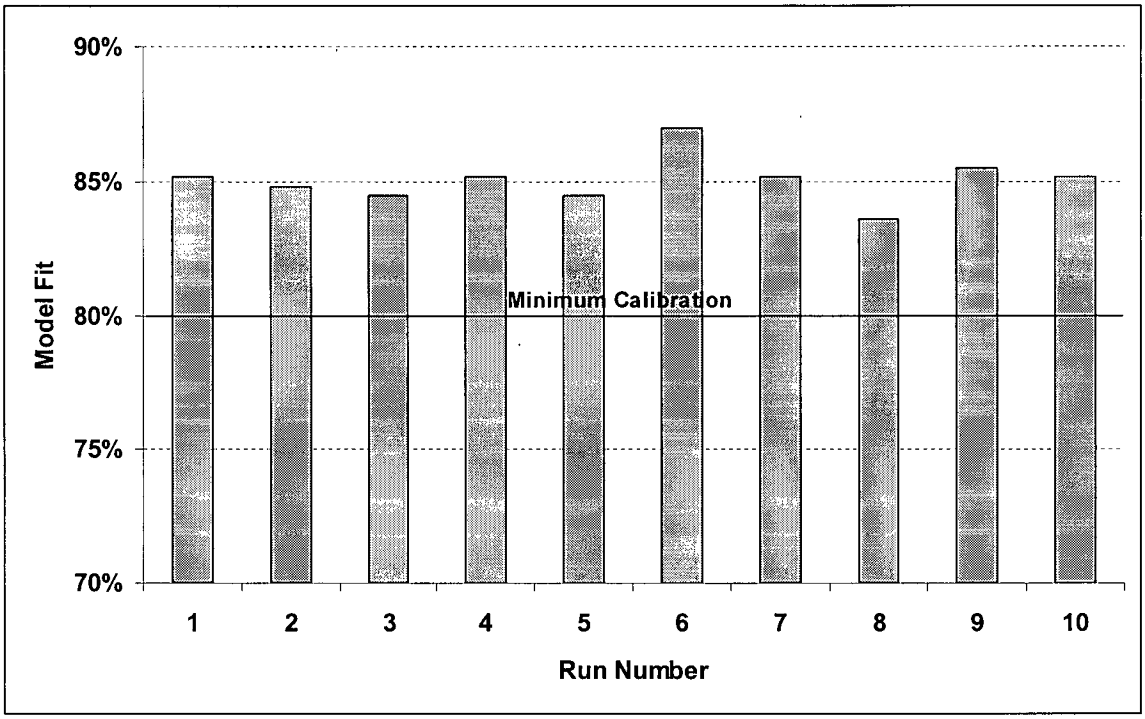
where: i = *individual turn movement*

According to the above formula and allowable error table, 85% of turning movements were within the acceptable guideline. For example, 280 of the 330 individual turning movements fell within the allowable error as outlined in the above table. As long as a minimum of 80% of locations are acceptable, then the model is considered to be calibrated to observed turn volumes. Figure 4.10 shows that ten model runs all lie above the minimum 80% validation criteria showing that the model is stable over these ten runs.

Table 4.5 – Observed and Modelled Turn Volumes Along the Knight Street Corridor

		Northbound				Southbound				Eastbound				Westbound			
Intersection	Data	LT	Thru	RT	Sum	LT	Thru	RT	Sum	LT	Thru	RT	Sum	LT	Thru	RT	Sum
Clark and Powell	*Observed*	333		247	580						965	72	1037	458	3266		3724
	Modelled	201		122	323						1370	124	1494	156	3173		3329
	Deviation	-39.6%		-50.6%	-44.3%						42.0%	72.2%	44.1%	-65.9%	-2.8%		-10.6%
Clark and Hastings	*Observed*	226	610	181	1017	80	773	63	916	67	731	106	904	716	3291	148	4155
	Modelled	367	624	261	1252	139	538	42	719	39	583	357	979	221	3336	59	3616
	Deviation	62.4%	2.3%	44.2%	23.1%	73.8%	-30.4%	-33.3%	-21.5%	-41.8%	-20.2%	236.8%	8.3%	-69.1%	1.4%	-60.1%	-13.0%
Clark and Venables	*Observed*	560	1251	80	1891	14	591	388	993	128	685	175	988	104	1429	52	1585
	Modelled	710	1210	98	2018	159	886	67	1112	9	569	645	1223	143	1691	43	1877
	Deviation	26.8%	-3.3%	22.5%	6.7%	1035.7%	49.9%	-82.7%	12.0%	-93.0%	-16.9%	268.6%	23.8%	37.5%	18.3%	-17.3%	18.4%
Clark and 1st Ave	*Observed*	379	1960	493	2832	92	1508	143	1743		1598	169	1767		3021	231	3252
	Modelled	379	1979	115	2473	118	1517	40	1675		1719	251	1970		3085	42	3127
	Deviation	0.0%	1.0%	-76.7%	-12.7%	28.3%	0.6%	-72.0%	-3.9%		7.6%	48.5%	11.5%		2.1%	-81.8%	-3.8%
Clark and 6th Ave	*Observed*	1003	1119		2122		851	553	1404	1001		742	1743				
	Modelled	816	1458		2274		1098	668	1766	978		652	1630				
	Deviation	-18.6%	30.3%		7.2%		29.0%	20.8%	25.8%	-2.3%		-12.1%	-6.5%				
Clark and Broadway	*Observed*	265	2148	191	2604	513	1348	102	1963	190	1336	127	1653	237	2390	473	3100
	Modelled	61	1952	166	2179	119	1317	297	1733	205	1318	151	1674	251	2439	115	2805
	Deviation	-77.0%	-9.1%	-13.1%	-16.3%	-76.8%	-2.3%	191.2%	-11.7%	7.9%	-1.3%	18.9%	1.3%	5.9%	2.1%	-75.7%	-9.5%
Clark and 12th Ave	*Observed*	106	1877	237	2220	270	1393	31	1694	127	1937	47	2111	230	2644	123	2997
	Modelled	51	1736	231	2018	152	1553	9	1714	183	1596	205	1984	216	2442	265	2923
	Deviation	-51.9%	-7.5%	-2.5%	-9.1%	-43.7%	11.5%	-71.0%	1.2%	44.1%	-17.6%	336.2%	-6.0%	-6.1%	-7.6%	115.4%	-2.5%
Knight and Kingsway	*Observed*	275	2161	27	2463	161	1469	64	1694	91	1295	177	1563	50	3382	181	3613
	Modelled	186	1952	21	2159	204	1736	27	1967	62	1115	287	1464	184	3281	87	3552
	Deviation	-32.4%	-9.7%	-22.2%	-12.3%	26.7%	18.2%	-57.8%	16.1%	-31.9%	-13.9%	62.1%	-6.3%	268.0%	-3.0%	-51.9%	-1.7%
Knight and King Ed	*Observed*	252	2006	21	2279	8	1368	194	1570	257	657	46	960	91	997	20	1108
	Modelled	154	2102	122	2378	53	1888	264	2205	78	616	138	832	39	945	5	989
	Deviation	-38.9%	4.8%	481.0%	4.3%	562.5%	38.0%	36.1%	40.4%	-69.6%	-6.2%	200.0%	-13.3%	-57.1%	-5.2%	-75.0%	-10.7%
Knight and 41st Ave	*Observed*	124	1961	328	2413	97	1761	49	1907	106	1318	114	1538	503	1798	28	2329
	Modelled	193	2495	388	3076	31	2360	56	2447	77	1210	175	1462	284	1877	93	2254
	Deviation	55.6%	27.2%	18.3%	27.5%	-68.0%	34.0%	14.3%	28.3%	-27.4%	-8.2%	53.5%	-4.9%	-43.5%	4.4%	232.1%	-3.2%
Knight and 57th Ave	*Observed*		2784	106	2890	13	2959	16	2988	86	307	340	733	1174	614	36	1824
	Modelled		3253	620	3873	9	3250	10	3269	21	418	283	722	966	557	88	1611
	Deviation		16.8%	484.9%	34.0%	-30.8%	9.8%	-37.5%	9.4%	-75.6%	36.2%	-16.8%	-1.5%	-17.7%	-9.3%	144.4%	-11.7%
Kingsway and King Ed	*Observed*	942	3884		4826		1451	1	1452			342	342				
	Modelled	987	3565		4552		1339	0	1339			791	791				
	Deviation	4.8%	-8.2%		-5.7%		-7.7%	-100.0%	-7.8%			131.3%	131.3%				

Figure 4.10 – Model Calibration: Percentage Fit of 330 Turning Movements



The histograms on the following pages show the deviation of the model results to the observed turning volumes. The average deviation of the modelled turn volume to the observed turn volume is 130 vehicles in a two hour period. This value is not very descriptive unless it is compared to the observed volume as a relative percentage. Figure 4.12 and 4.13 show the relative difference as a percentage of the model results to the observed turning volumes.

Figure 4.11 – Histogram of Deviation of Model Results to Observed Counts

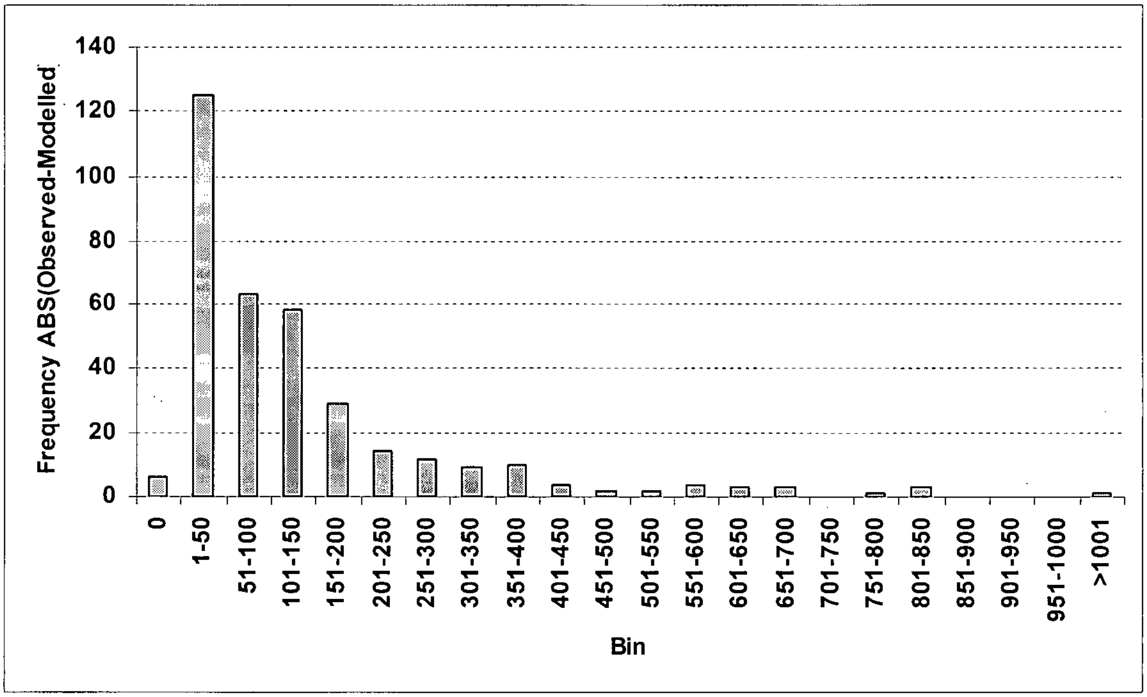


Figure 4.12 – Cumulative Distribution of Model Turn Volume Deviation

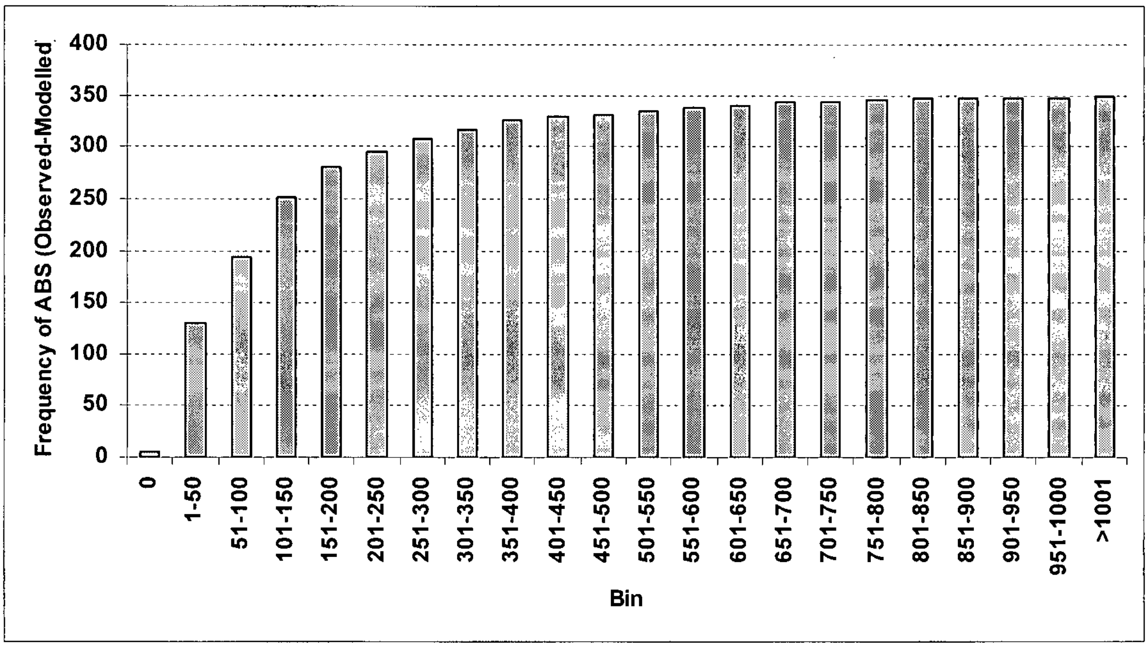


Figure 4.13 – Histogram of Relative Difference of Observed to Modelled Counts

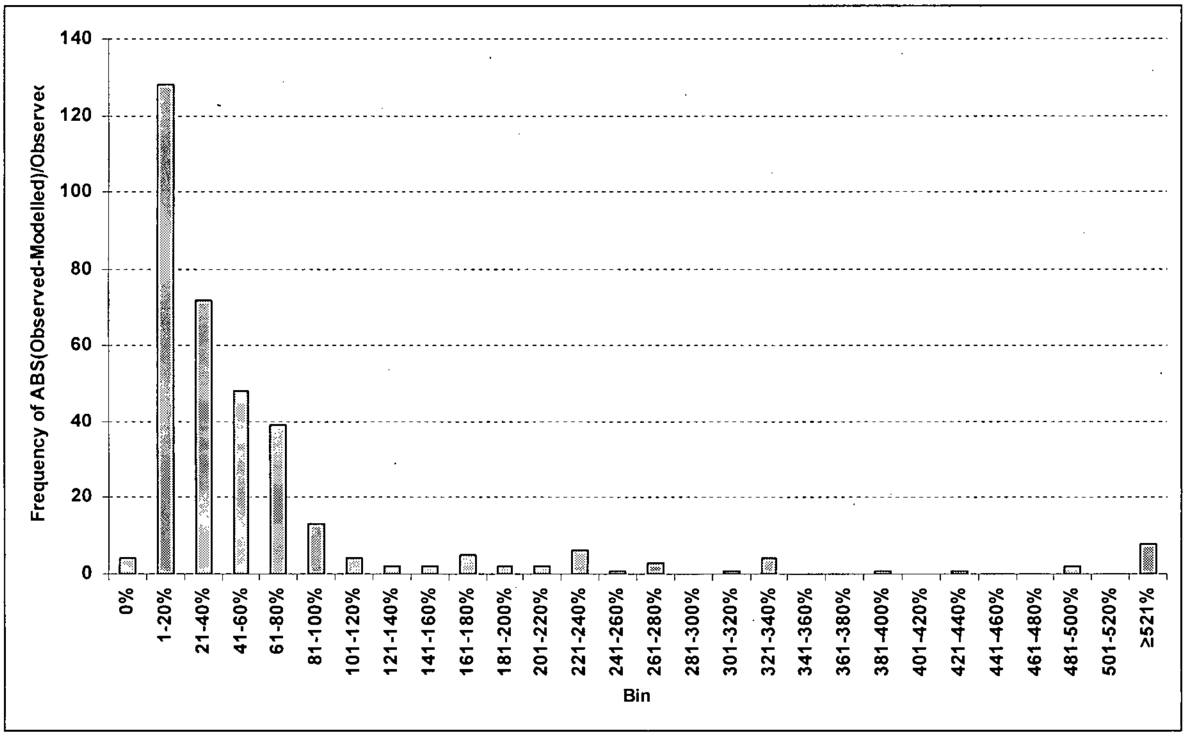
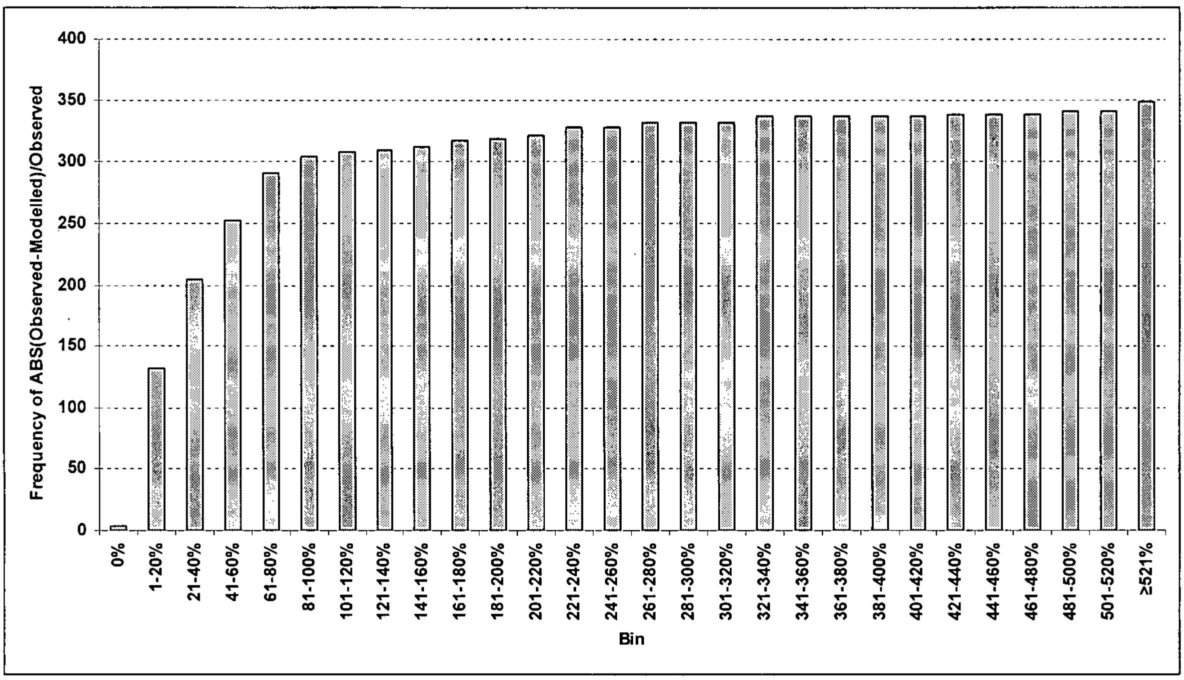


Figure 4.14 – Cumulative Distribution of Relative Deviation from Observed Volumes



The sum of the absolute value of all deviations of the modelled results from the observed turn counts as a percentage of total intersection approach volume is approximately 22%. This is also referred to as the Global Relative Error (GRE) and is shown in the following equation:

$$GRE = \frac{\sum_{i=1}^{n} \left| Q_{real} - Q_{sim} \right|}{\sum_{i=1}^{n} Q_{real}}$$

where: Q_{real} = *real traffic flows*

Q_{sim} = *simulated or modelled traffic flows*

i = *individual turn movement at intersection*

n = *total number of turn movements*

This formula accurately describes the model deviation from actual counts on a system-wide basis. The GRE function is able to fully describe the network-wide error (Ma, 2001). The objective of the model calibration and validation is to minimize the GRE to a point where the model is 'acceptable', or reasonably represents actual travel behaviour and traffic conditions.

4.9 Model Validation Based On Corridor Travel Time

The use of GPS technology allowed the validation of the microsimulation model in terms of corridor travel time. Several runs northbound and southbound along the Knight Street corridor were performed as explained in section 3.4 using GPS receivers. These drive traces show the distance versus time plot of a vehicle as it travels along the corridor. The plot clearly illustrates where the congestion locations occur, namely at intersections and merge areas. The two following illustrations show the average of the actual drive trace (thick black) and the model drive traces in five minute intervals. These plots confirm qualitatively that the model is validated based on drive times as the model runs are within a reasonable range of the actual drive times. The modelled variation in travel times is comparable to the actual variation in travel times as well.

Figure 4.15 – Model vs Actual Northbound Travel Times

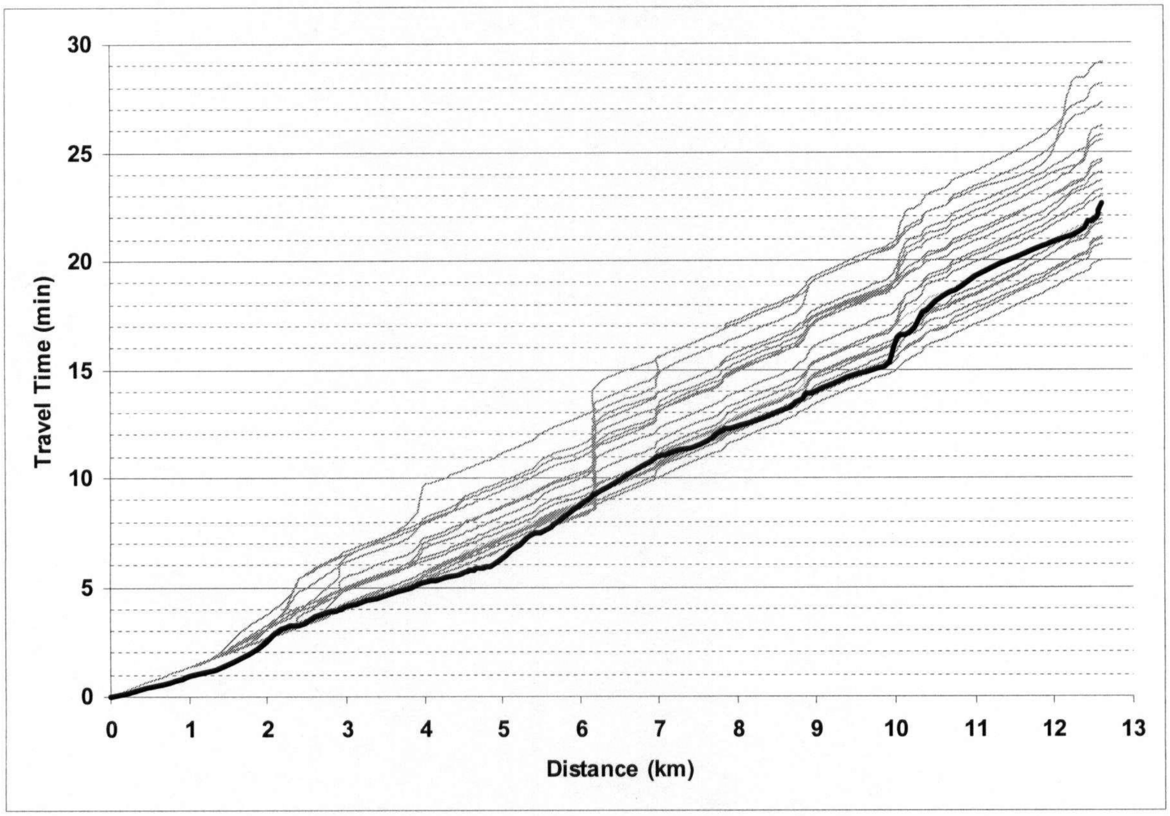
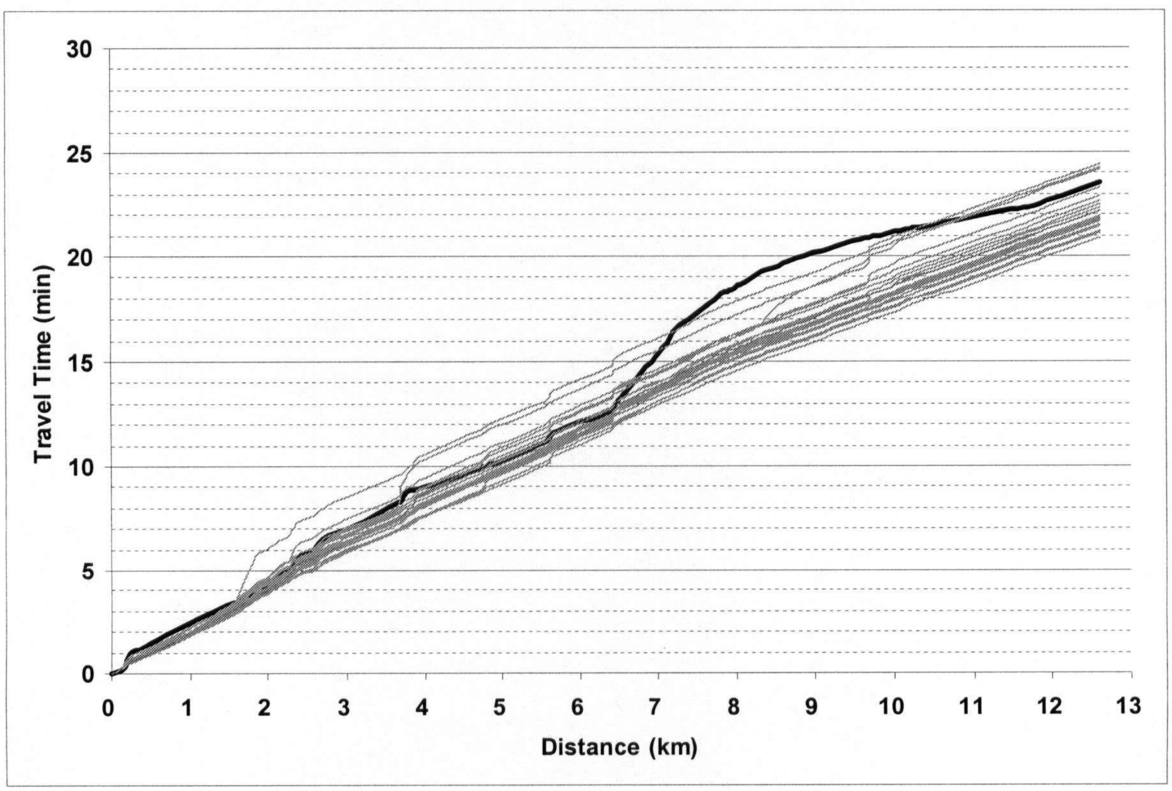


Figure 4.16 – Model vs Actual Southbound Travel Times



CHAPTER V – Modelling Methodology & Analysis

As indicated previously, the Knight Street corridor carries an exceptionally high proportion of truck trips which creates noise and air pollution issues for residents living adjacent to the corridor. Heavy vehicles also pose significant operational problems along the corridor due to their slower acceleration and maneuverability.

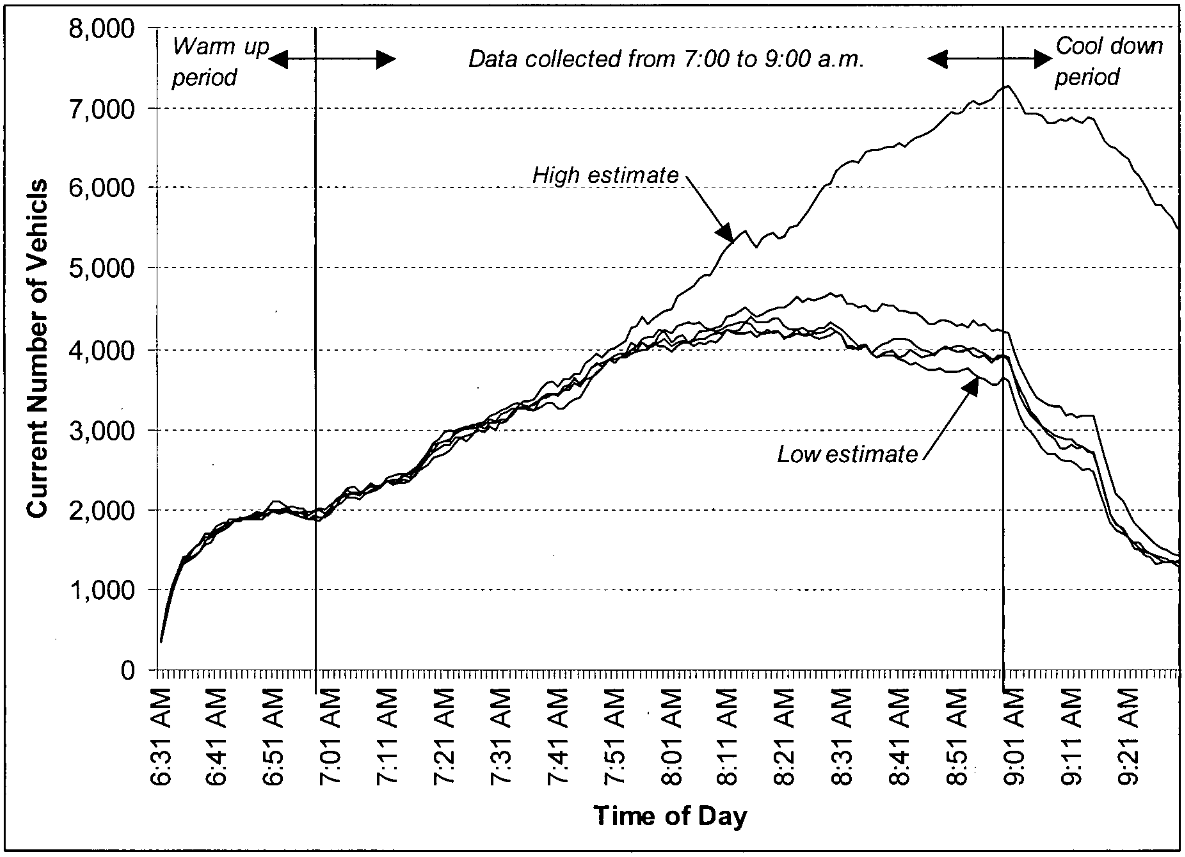
This section details the evaluation methodology and the various corridor management strategies that were tested. The focus of each strategy is to promote the efficient movement of trucks along the Knight Street corridor. A small note on expected results is contained in each sub-section to highlight what intuitively should occur for each scenario. The model results from each of the following scenarios are tabulated and summarized in Chapter 6: Findings and Results.

5.1 Standardized Evaluation Methodology

A standardized method of running and evaluating the results from the microsimulation model was incorporated to ensure consistent results. The model needs to be run several times in order to attain a representative average due to the stochasticity or randomness of the microsimulation model. The model is run five times for each scenario and the highest and lowest runs based on system-wide vehicle volumes are excluded. The average of the remaining three runs is then used as the result for the scenario. Since the model is stochastic and the release of vehicles is based on a random seed assignment, the model needs to be run several times to factor out variability. Each model run will be slightly different from the next due to the randomness of microsimulation models. The graph on the following page shows a plot of system-wide vehicle volume versus time for five model runs.

As can be seen, one of the five runs is clearly an outlier and needs to be excluded from the analysis results. There are situations in microsimulation modelling where the network will simply 'freeze up' due to unstable vehicle flows. The network performance becomes more unstable as it approaches congested conditions. One vehicle waiting to make a left turn could trigger a series of events that could cause a result as shown below where the network has an unusually high build up of vehicles due to a network blockage. As such, it is necessary to remove the high and low model estimates from the five model runs and use the remaining three to take an average.

Figure 5.1 – Model Run Parameters



Also shown in the above illustration is the time period for the model run. The time of day on the x-axis runs from 6:30 to 9:30 a.m. The first half hour warm up period is used to load vehicles onto the network so that data collected from 7:00 to 9:00 a.m. does not start with an empty network. It would be unrealistic to begin collecting data from a completely empty road network as this would not be the case in reality. The final half hour cool down period is not necessary for modelling but is used as a calibration tool. If a network blockage were to occur as in the above illustration, the modeller could easily observe where the blockage has occured during the cool down period. The suspect location could then be corrected for network coding errors or other calibration issues.

Another component of the microsimulation model was the use of the same level of demand for each scenario tested. This measure ensured consistent results between the various corridor strategy scenarios. The same demand matrix was used for all of the scenarios tested. The one exception to this was the scenario that looked at varying proportions of heavy vehicles with signal coordination.

The main criteria for evaluation was the northbound and southbound travel time along the entire length of the corridor. Since each scenario looked at enhancing the efficiency of goods movement, this criteria appeared to be the most significant. The following sub-sections describe the network assumptions made for each scenario.

5.2 Exclusive Truck and Bus Lane

One method of enhancing the movement of heavy vehicles along a corridor is to designate one lane for the exclusive use of trucks and buses. Because of their slower acceleration and deceleration, heavy vehicles create obstacles for regular vehicles. Excessive lane changing and delay are caused when heavy vehicles are mixed with regular commuter automobiles. A significant factor in safety is the speed differential of a heterogeneous mix of vehicle types.

The Knight Street corridor is fully built up through the City of Vancouver and, as such, there is no land capacity to build a new lane exclusively for heavy vehicles. Because most of the corridor through the City of Vancouver is already six lanes, each outside lane could be converted to a truck/bus lane. This would allow heavy vehicles and regular commuter vehicles to travel in their own lane. The goal of this would be to reduce the number of lane changes required for regular automobiles to move around heavy trucks and also to give trucks a more reliable travel time along the corridor. Since trucks make up only 15% of the travel along Knight Street, they should be able to bypass most of the queues at intersection approaches.

5.3 Signal Coordination Strategies

One of the most cost effective approaches to enhance travel time is to coordinate signals along a corridor. Signal coordination also provides benefits to all motorized road users since it does not seem to favour one type of vehicle over another as in the exclusive truck/bus lane. Currently, the Knight Street corridor is uncoordinated along the entire length as most signal cycle lengths vary. In order to coordinate signals, the cycle length must be the same for all intersections for the offset adjustments to be effective.

Transyt-7F was used to calculate an optimum cycle length as well as optimum signal offsets for two-way coordination. The existing signal phasing and splits were coded into Transyt-7F along with the approach volumes at each intersection. This model was then run to calculate an optimum cycle length. Transyt-7F uses a genetic algorithm approach to optimize cycle lengths, splits, offsets and phasing. This search method is very efficient at finding an optimum solution without getting stuck at local optima. The search determined the optimal cycle length to be 80 seconds. Most of the intersections were already at either 75 or 80 second cycle lengths already.

An 80 second cycle length was then coded for each intersection with green time consideration given to east-west movements such that the degree of saturation was not overlooked. This ensured a balanced network so that the north-south coordination along Knight Street did not adversely impact the east-west movements at major intersections. Transyt-7F was run then once more to determine the optimal offsets for each intersection based on the common 80 second cycle length. The fixed offsets on the following page (direct output from Transyt-7F) were used for the 13 intersections along the corridor.

These results served as a pre-processor for the signal coordination scenario in the microsimulation model. This pre-processing was required due to the fact that Paramics does not contain its own signal coordination optimization module.

Not only are the travel times expected to improve, but they are also expected to be more reliable. In other words, there should be less travel time variability when driving from end to end.

Figure 5.2 – Fixed Offset Output from Transyt-7F

```
TRANSYT-7F Release 9.7 -- Genetic Algorithm Optimization

File C:\ubc_thesis\TRANSYT7F\knight80.tin
Simulation Engine: TRANSYT-7F

Genetic Algorithm Input Parameters
----------------------------------
Crossover Probability (%):                 30
Mutation Probability (%):                  1
Convergence Threshold (%):                 0.01
Maximum Number of Allowable Generations:   100
Actual Number of Optimization Generations: 100
Population Size:                           10
Random Number Seed:                        7781
Elitist Method:                            True
Objective Function:                        Disutility Index

Optimization Results  (Offsets only)
--------------------

Node  Cycle       Offset   NS Phasing EW Phasing
    Init Final Init Final Init Final Init Final
 1    80   80     0   41   ---   ---   ---   ---
 2    80   80     0   80   ---   ---   ---   ---
 3    80   80     0   41   ---   ---   ---   ---
 4    80   80     0   70   ---   ---   ---   ---
 5    80   80     0   41   ---   ---   ---   ---
 6    80   80     0   20   ---   ---   ---   ---
 7    80   80     0   50   ---   ---   ---   ---
 8    80   80     0    0   ---   ---   ---   ---
 9    80   80     0   62   ---   ---   ---   ---
10    80   80     0   63   ---   ---   ---   ---
11    80   80     0   58   ---   ---   ---   ---
12    80   80     0   69   ---   ---   ---   ---
13    80   80     0   40   ---   ---   ---   ---

              Control    Total     Fuel        Total   Performance
               Delay     Stops  Consumption Travel      Index
             (sec/veh)    (%)     (lit/hr) (veh-km/hr)

Initial        31.5       84      5255       3176      689.1
Final          28.2       80      5073       3176      640.3

*** The final solution originated in generation #95 ***
```

5.4 *Signal Coordination with Varying Proportion of Trucks*

The effectiveness of the signal coordination scenario is dependent on stable travel times as the offsets are fixed. An important factor for the Knight Street corridor is the percentage of heavy vehicles within the traffic stream. Growth trends in containerized freight indicate that the proportion of heavy vehicles will increase over time and necessary adjustments to the signal timing plan will be required. Currently 15% of the trips along the Knight Street corridor are heavy vehicles.

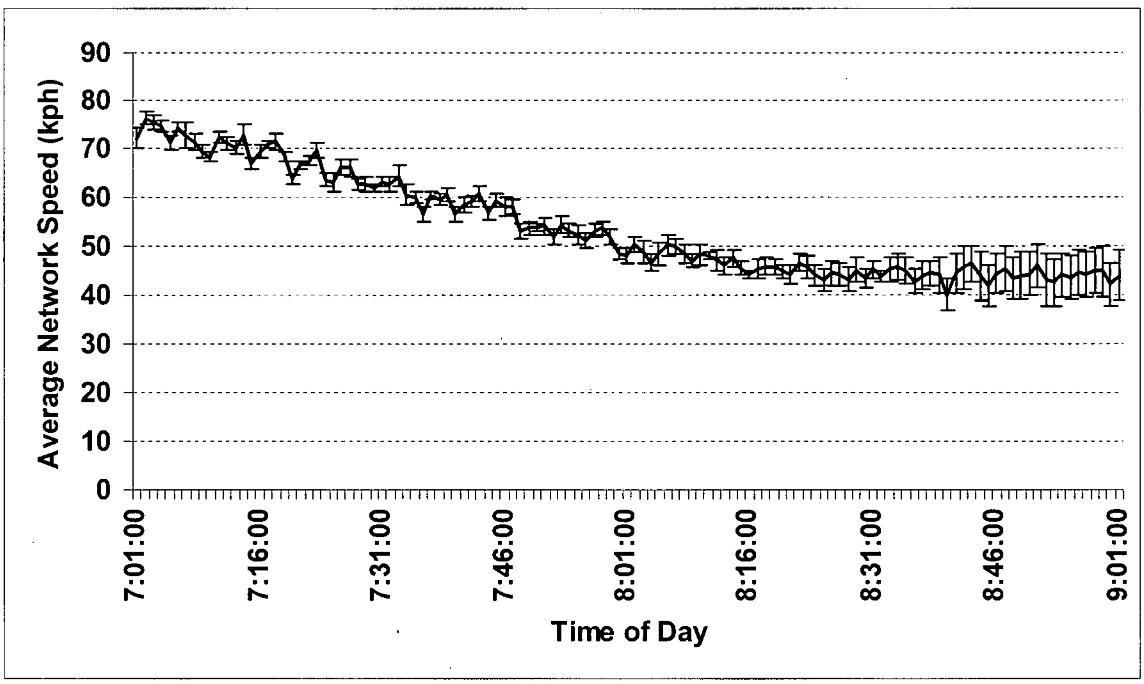
It would be prudent to test higher proportions of heavy vehicles to measure the impact to the performance of the corridor and more importantly, the effectiveness of the signal coordination plan. Proportions of 20% and 25% of heavy vehicles are to be tested to determine the impact to travel times and furthermore, the impact to the signal coordination offsets. Obviously, the more heavy vehicles, the more travel time as trucks have much slower acceleration rates than regular passenger cars.

It is expected that travel times will increase with an increase in the proportion of heavy vehicles. As such, the signal coordination offsets will need to be adjusted to account for the slower performance of the corridor. The effectiveness of the signal coordination plan will be tested with the impact of a higher proportion of heavy vehicles.

5.5 Signal Coordination with Variable Offsets

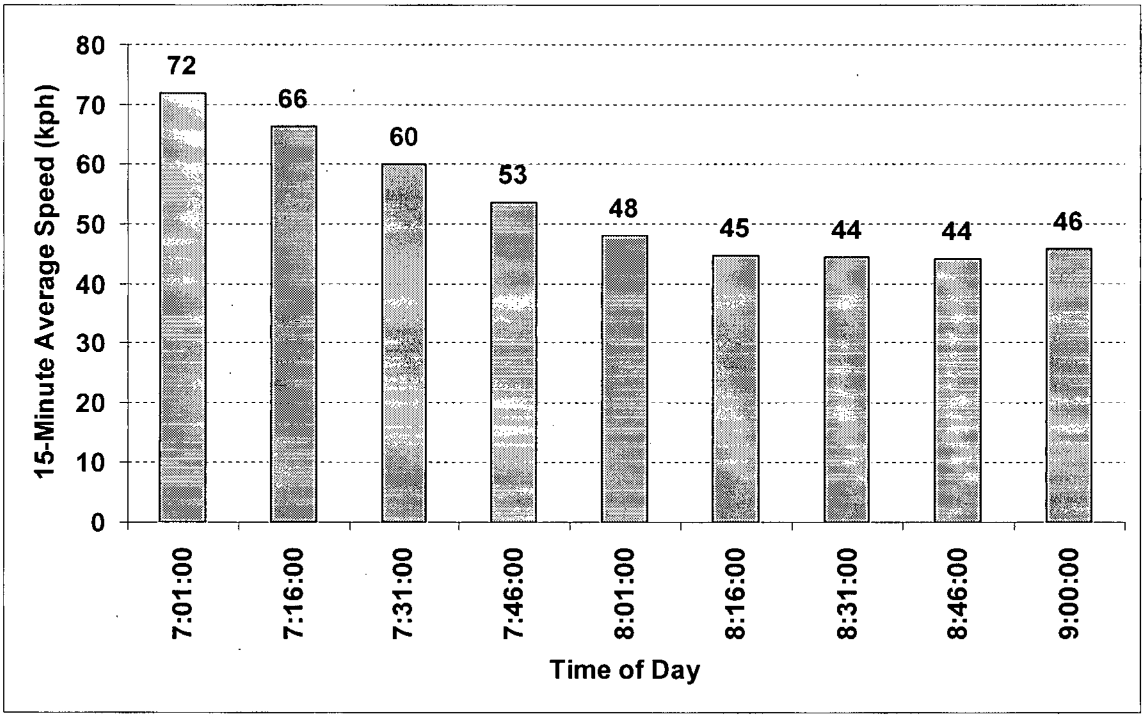
Section 5.3 discussed the methodology used to determine signal offsets for two-way signal coordination along Knight Street. This section investigates the use of variable offsets to account for variations in travel time along the corridor. The following figure shows the variation in network-wide travel speeds for all vehicles throughout the morning peak period.

Figure 5.3 – Discrete Average Network Travel Speed



As shown in the above illustration, the travel speed varies significantly throughout the morning peak period. The solid line is the average of eight model runs with the error bars showing one standard deviation above and below the average. The graph shows that as the network becomes more congested, travel speeds become slower and more variable. It is hoped that by adjusting the offsets to match the changes in travel speeds, a more efficient signal coordination strategy would be developed. Aggregating the above plot into 15 minute increments results in the following illustration.

Figure 5.4 – Average Network Travel Speed for 15 Minute Increments



These 15-minute increments are further aggregated into the following cruise speeds.

Table 5.1 – Variable Offset Cruise Speeds Used in Transyt-7F

Time Period	Cruise Speed
7:00-7:44	60 kph
7:45-7:59	53 kph
8:00-8:14	48 kph
8:15-8:59	45 kph

The above cruise speeds were chosen to properly reflect the travel speeds experienced along the Knight Street corridor in the City of Vancouver as there are no signals along Knight Street in the City of Richmond. The speed limit is 60 kph so the first four 15-minute increments were capped to the speed limit. The two 15-minute periods starting at 7:45 and 8:00 experienced a decrease in average speeds to 53 and 48 kph. These corresponding cruise speeds were used for these two time periods. The final period average speed seemed to be stable around 45 kph. The following set of offsets were developed using Transyt-7F for each 'cruise speed' time period.

Table 5.2 – Variable Offset Plan

		Offset Cruise Speed			
Intersection	**Name**	**60 kph**	**53 kph**	**48 kph**	**45 kph**
1	*Powell St*	66	8	48	48
2	*E Hastings St*	68	70	31	3
3	*Venables St*	46	3	71	36
4	*1st Ave*	79	40	40	42
5	*6th Ave*	70	17	15	17
6	*E Broadway*	18	79	67	74
7	*12th Ave*	45	8	9	8
8	*Kingsway*	6	4	10	10
9	*King Edward*	72	2	3	5
10	*33rd Ave*	44	8	4	6
11	*41st Ave*	53	3	0	0
12	*49th Ave*	70	79	74	45
13	*57th Ave*	44	41	39	12

5.6 Combination of Signal Coordination and Exclusive Truck/Bus Lane

In order to provide the most priority for heavy vehicles, a combination of a truck/bus lane and signal coordination was tested. An exclusive truck and bus only lane with two-way signal coordination was coded in the microsimulation model. This scenario used the same coding as the previous two separate scenarios and was tested to determine if the combined effect of both improvements is additive. There could be some form of combination effect as the results might not be purely additive as one would suspect.

Travel time estimates from traffic zone pairs will be combined to see what impact this scenario will have on the total corridor travel time. Since some road capacity will be taken away from regular automobiles, they might divert to other routes. This is a causal effect from the dynamic assignment method as route costs are updated constantly. Consequently, trucks might divert onto the Knight Street corridor from the other local roads due to the more reliable travel times relieving the local streets of excessive noise and air pollution.

5.7 *Addition of Left Turn Bays*

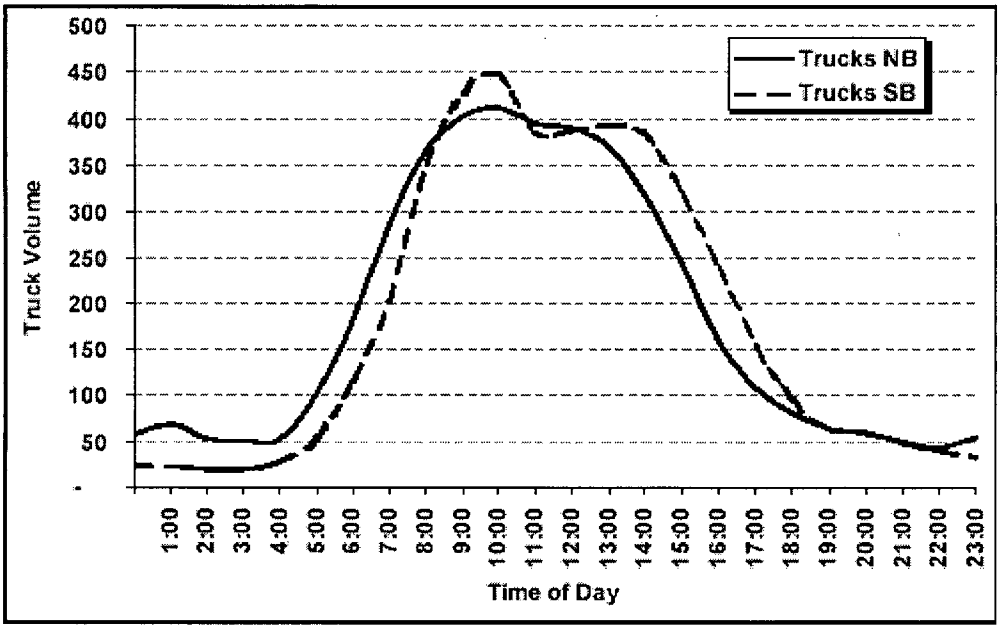
The installation of left turn bays was investigated for travel time and left turn capacity improvements using the Paramics microsimulation model. Various studies have pointed to the lack of capacity along the Knight Street corridor to accommodate left turn movements. Significant delay and vehicle weaving occurs as an entire lane is blocked for left turning vehicles. The following intersections were coded with an additional northbound and southbound left turn lane with permissive left turn signal phasing so as not to reduce the through movement capacity:

- Knight Street and 57th Ave
- Knight Street and 49th Ave
- Knight Street and 33rd Ave
- Clark and 6th Ave (northbound only)

No change was made to the eastbound and westbound movements except for the adjustment of signal timings. The following graph illustrates the average travel speed of all vehicles within the base and protected left turn bay (LTB) scenarios from 07:00 to 09:00 in the morning at the system level.

The Knight St model with permissive left turn movements was also run using day time vehicle volumes to determine the impact on trucks and other vehicles. Based on the vehicle classification counts performed in the fall of 1999, truck volumes begin to peak around 09:00 AM at the tail end of the rush period as shown in the following illustration.

Figure 5.5 – Hourly Truck Volumes at the Knight Street Bridge



Truck volumes also begin to decline at the onset of the afternoon rush period. This single peaking behaviour is not unique to Knight Street as other facilities exhibit similar truck peaking patterns throughout the region. Obviously, this pattern of behaviour is efficient in terms of facility utilization as there is considerably more road capacity for trucks during off-peak hours.

Travel times are expected to be more reliable with left turn bays as through moving vehicles no longer have to wait behind left turning vehicles. Less lane changing is also expected as vehicles are not required to maneuver around left turning vehicles.

CHAPTER VI – Model Results & Discussion

The following subsections describe the various scenarios that were tested along with the model results. As noted in the previous chapter, a total of five model runs were performed for each scenario. The high and low estimates were removed and the average of the remaining three runs are summarized in the following tables and graphs.

A discussion of the results is included to summarize the effects of each corridor strategy. Final conclusions and recommendations are made in Chapter 7: Conclusions and Recommendations.

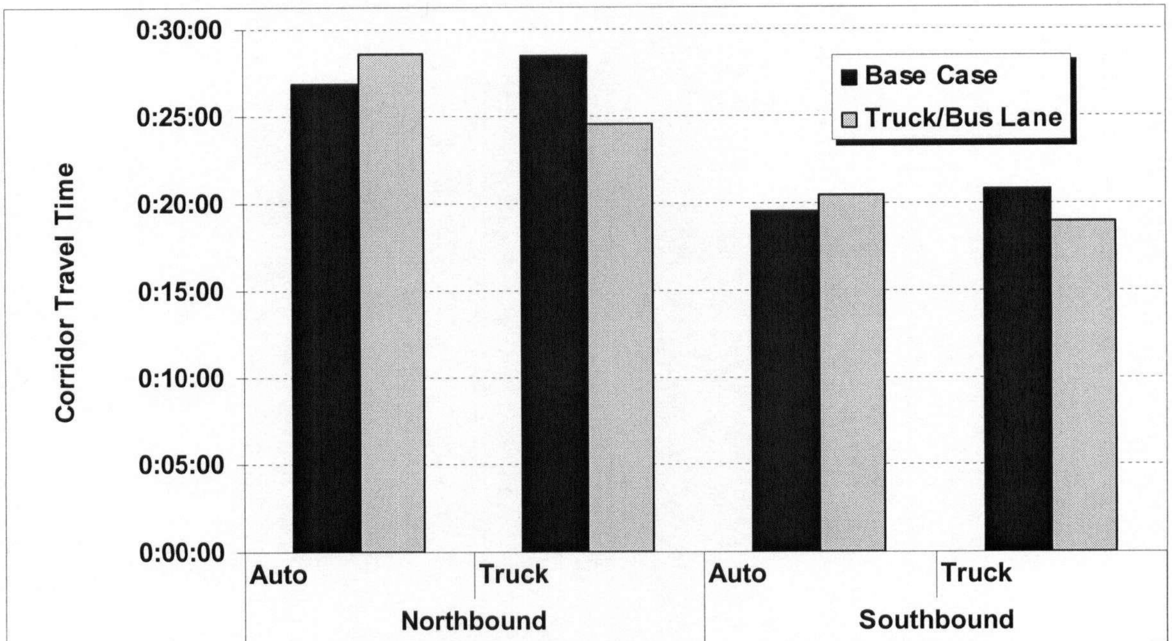
6.1 Exclusive Truck and Bus Lane

A scenario was set up to restrict regular automobiles from using the outside lane through the residential areas of the City of Vancouver from Marine Drive to Powell Street. Most of the corridor along this segment runs as a six lane major arterial. A small section between Kingsway and 12th Avenue narrows to four lanes and hence no restriction was coded for automobiles.

The figure on the following page illustrates the results from the truck/bus lane along the Knight Street corridor. Travel time estimates were taken from a traffic zone pair from the northern and southern ends of the corridor. The travel time estimate is also broken out by automobile and truck.

Immediately obvious is the significant travel time savings for heavy vehicles. Trucks experience an 14% and 9% decrease in travel time in the northbound and southbound directions respectively. The obvious reason for the better travel time performance is the increased capacity available for heavy vehicles. Qualitative observations of the model show that trucks no longer see significant queues at intersection approaches. They can simply bypass the automobile queue by staying in the truck/bus lane. Not only do trucks benefit, but buses see they same benefit as they are allowed to travel in this excusive lane.

Figure 6.1 – Corridor Travel Times for Automobiles and Trucks

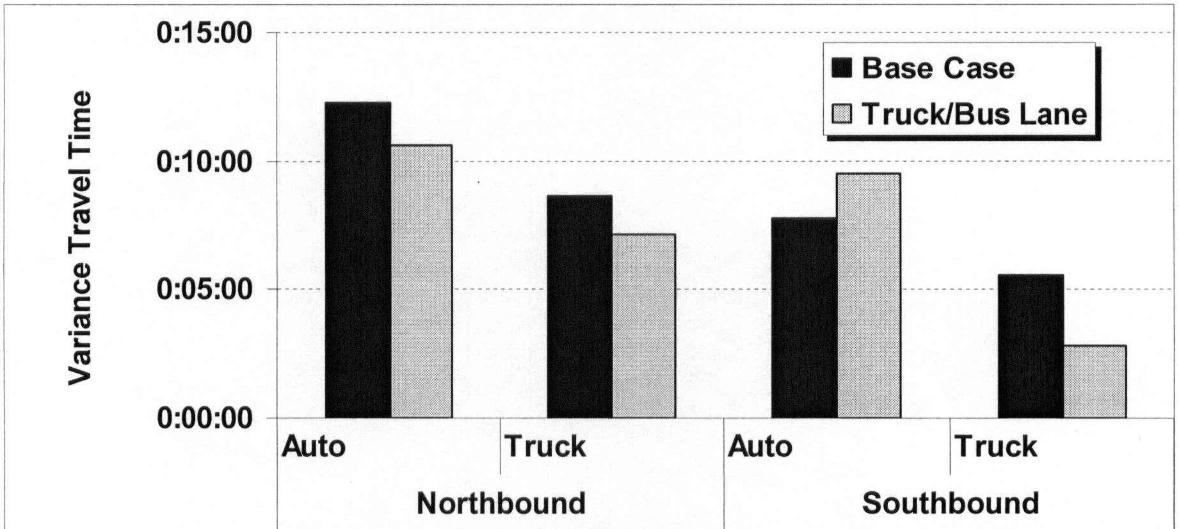


	Northbound Auto	Northbound Truck	Southbound Auto	Southbound Truck
■ Base Case	0:26:48	0:28:28	0:19:34	0:20:50
□ Truck/Bus Lane	0:28:39	0:24:33	0:20:29	0:18:57

Conversely, automobiles see a 7% and 5% increase in northbound and southbound travel times respectively. This is again, obviously due to the decreased corridor capacity for automobiles. Although there is a significant decrease in the number of heavy vehicles that automobiles need to maneuver around, they still have lost an entire lane of capacity in both directions. The increased travel time is simply from the same number of automobiles travelling on one less lane. There does appear to be a combination effect of introducing the exclusive truck/bus lane. Now that automobiles make fewer lane changes to pass heavy vehicles, there seems to be a more stable flow of vehicles along the corridor. Perhaps now that the acceleration rates of the two vehicle types are segregated, there seems to be a smoother flow of operation. This could be analogous to the laminar flow of water where now there is less 'turbulence' resulting from less vehicle interaction between regular automobiles and heavy vehicles.

There was also a noticeable decrease in travel time variability with the exclusive truck/bus lane. As shown in the following figure, travel time variability decreased substantially for trucks.

Figure 6.2 – Change to Auto and Truck Travel Time Variability



	Northbound Auto	Northbound Truck	Southbound Auto	Southbound Truck
Base Case	0:12:17	0:08:36	0:07:49	0:05:37
Truck/Bus Lane	0:10:37	0:07:07	0:09:29	0:02:49

The above figure shows the difference between the average minimum and average maximum travel times for the two hour peak period. Surprisingly, the travel time variability for autos in the northbound direction decreased slightly as well. This shows that the addition of this exclusive truck/bus lane enhances travel time reliability for trucks. This is an important factor for freight shipments operating on a just-in-time delivery system and high value commodities.

6.2 Signal Coordination Along Knight Street

There are significant improvements that could be made to enhance signal coordination along the Knight Street corridor. Historically, signal coordination priority has been given to major east-west arterials such as Hastings, Broadway and Kingsway. The balanced northbound and southbound volumes make it difficult to properly coordinate traffic signals as signal coordination is typically useful for one peak direction. Transyt-7F was used to calculate the optimum cycle length and offsets for the signal coordination scenario.

The following table illustrates the travel time benefits of two-way signal coordination along the Knight Street corridor.

Table 6.1 – Travel Time Savings with Two-Way Signal Coordination

	Corridor Travel Time		
	Northbound	Southbound	Both
Base Case	0:26:49	0:22:11	0:24:20
Coordinated	0:20:34	0:21:51	0:21:11
Reduction	0:06:15	0:00:20	0:03:09

This table shows that two-way signal coordination along the corridor could save approximately 13% on travel time from end to end. Signal coordination could also reduce travel time variability as shown in the following table.

Table 6.2 – Reduction in Travel Time Variability with Signal Coordination

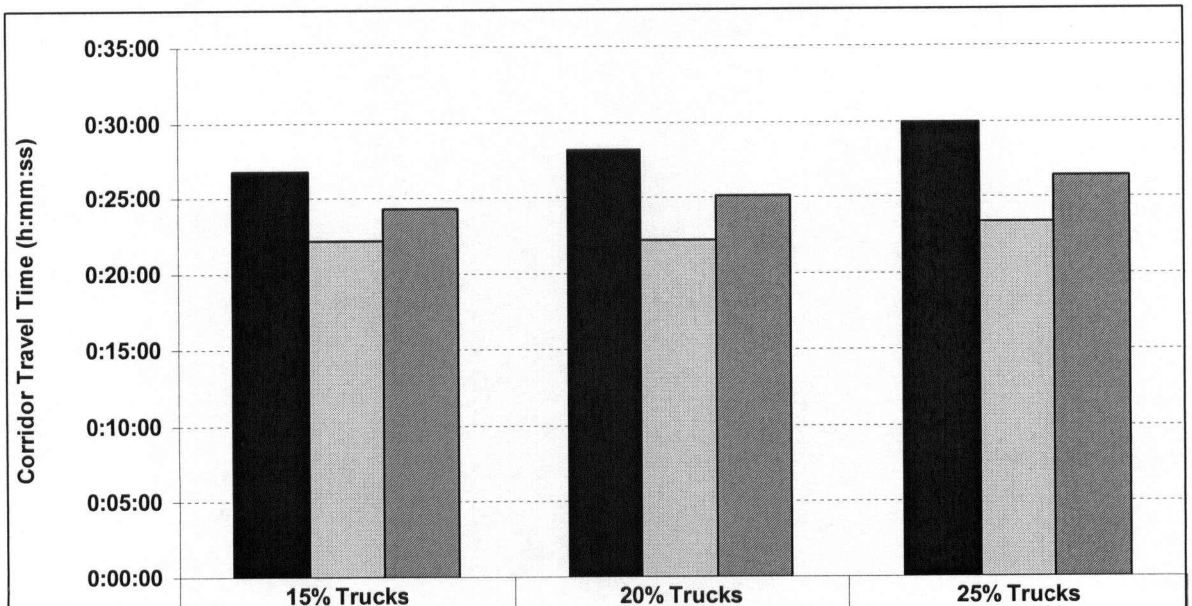
	Travel Time Variation	
	Northbound	Southbound
Base Case	0:14:09	0:12:50
Coordinated	0:09:56	0:11:27
Reduction	0:04:13	0:01:23

The values in the above table represent the difference of the average minimum and average maximum of the corridor travel time during the two hour morning peak period. As mentioned in the previous subsection, travel time variability is a significant factor for freight shipments using just-in-time delivery and tight schedules.

6.3 Signal Coordination with Higher Proportions of Heavy Vehicles

As mentioned in the previous chapter, different proportions of heavy vehicles were tested to determine the impact to signal coordination. Specifically, what adjustments are required to signal coordination to accommodate a higher proportion of heavy vehicles. Before a proper signal coordination strategy can be devised, the impact to travel times of more heavy vehicles along the corridor needs to be determined. The following figure illustrates the impact of a higher proportion of heavy vehicles to the base case if no other changes are made.

Figure 6.3 – Travel Times with Increasing Proportion of Trucks



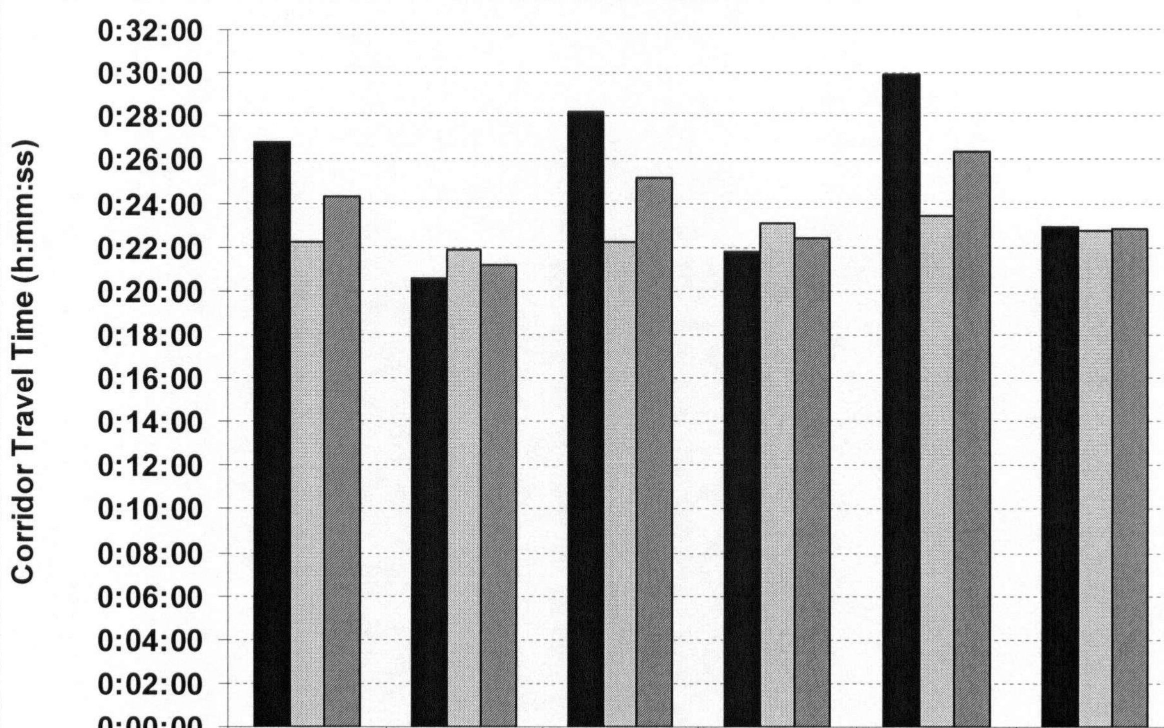
	15% Trucks	20% Trucks	25% Trucks
■ Northbound	0:26:49	0:28:10	0:29:55
□ Southbound	0:22:11	0:22:11	0:23:27
▪ Average	0:24:20	0:25:08	0:26:24

The above illustration shows that increasing the proportion of heavy vehicles to 20% reduces travel times by 3% from the base case. Furthermore, increasing the proportion of heavy vehicles to 25% reduces travel times by 5% from the base case. Obviously the more heavy vehicles in the traffic stream, the slower the average platoon of vehicles. Transyt-7F contains a 'cruise speed' which is defined as follows:

'The cruise speed specified primarily affects the simulation of platoon dispersion' and 'for optimization runs this should be the driver desired speed/travel time.'

Since Transyt-7F does not contain an input parameter for percentage of heavy vehicles, the next best estimate would be to reduce the desired travel speed by the corresponding amount from the above results. The figure on the following page shows that signal coordination shows a relative travel time savings of approximately 12% for the varying proportions of heavy vehicles.

Figure 6.4 – Signal Coordination with Higher Proportion of Trucks

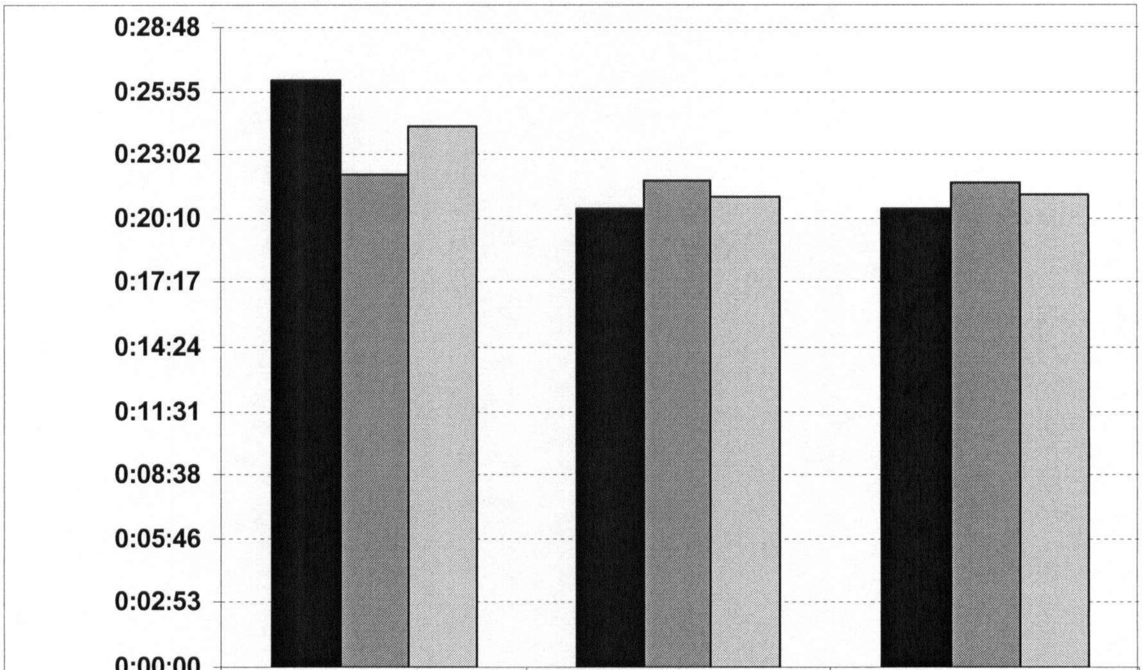


	1	2	3	4	5	6
■ Northbound	0:26:49	0:20:34	0:28:10	0:21:48	0:29:55	0:22:57
□ Southbound	0:22:11	0:21:51	0:22:11	0:23:05	0:23:27	0:22:45
■ Average	0:24:20	0:21:11	0:25:08	0:22:24	0:26:24	0:22:50

6.4 Signal Coordination with Variable Offsets

Using variable offsets to adjust the two-way signal coordination to account for changing travel times resulted in marginal travel time savings over the fixed offset scenario. The following figure shows the travel times with and without variable signal coordination. As shown, travel times are reduced by an average of 13% for both directions along the Knight Street corridor. This is approximately the same savings as having fixed offsets with a two-way signal coordination strategy.

Figure 6.5 – Travel Times with Variable Signal Offsets



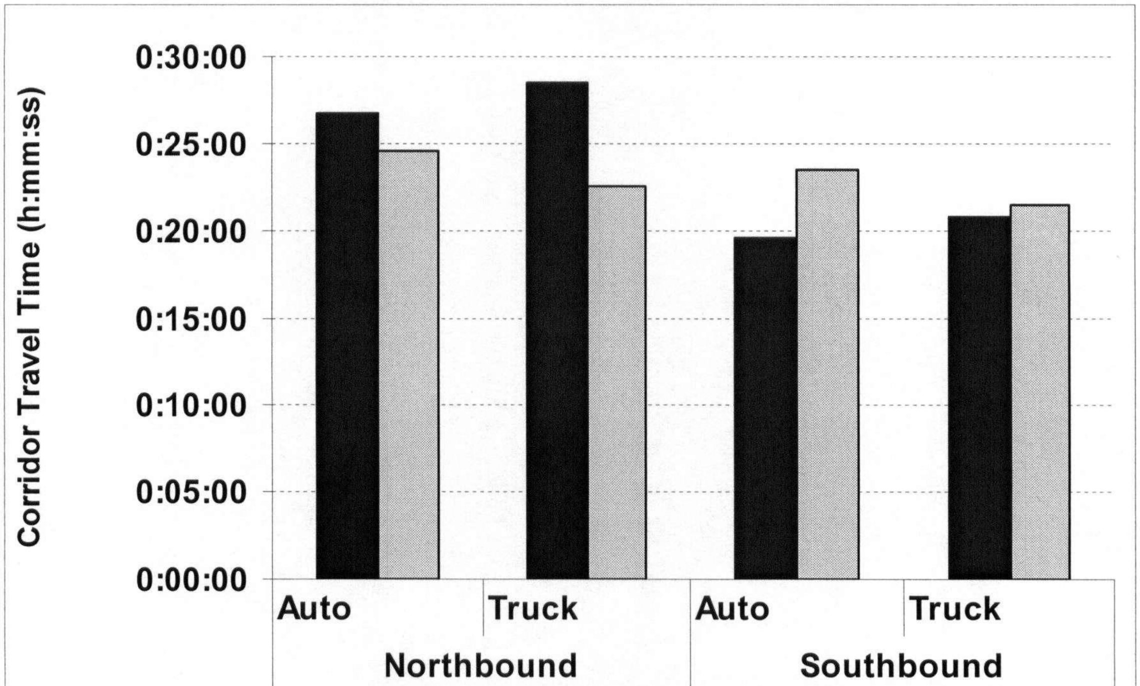
	Base	Coordination	Variable Coordination
■ Northbound	0:26:27	0:20:34	0:20:38
▩ Southbound	0:22:11	0:21:51	0:21:48
□ Average	0:24:20	0:21:11	0:21:14

Even though this scenario accounted for changing travel speeds, perhaps the aggregation level at 15-minutes was too large. A finer adjustment of signal timings to account for more discrete changing vehicle volumes and consequent travel speeds would perhaps account for further savings in travel times. Some form of signal priority for trucks would be suitable to reduce travel times for trucks even further.

6.5 Combination of Signal Coordination and Truck/Bus Lane

The combined effect of signal coordination with an exclusive truck/bus lane was modelled for travel time benefits. The same settings from the individual scenarios of signal coordination and the truck/bus lane were combined into this scenario. The figure on the following page illustrates the changes to travel time for automobiles and trucks along the entire length of the corridor.

Figure 6.6 – Travel Time with Signal Coordination and Truck/Bus Lane



	Northbound Auto	Northbound Truck	Southbound Auto	Southbound Truck
■ Base Case	0:26:48	0:28:28	0:19:34	0:20:50
□ T/B Lane w Coordination	0:24:37	0:22:34	0:23:30	0:21:28

The northbound direction sees a reduction in travel times of 8% and 21% for automobiles and trucks respectively. Conversely, the southbound direction experiences an increase in travel time of 20% and 3% for automobiles and trucks respectively. Although the travel time increased in the southbound direction, the cause is most likely due to a 14% increase in intersection approach volumes. More vehicles seem so be attracted to the Knight Street corridor from the two parallel corridors in the southbound direction due to the enhanced travel time, a result of the dynamic feedback assignment. The net change on the corridor is still a reduction in travel times and perhaps the two-way signal coordination from Transyt-7F attempts to balance the travel times in both directions.

6.6 Additional Left Turn Bay Capacity

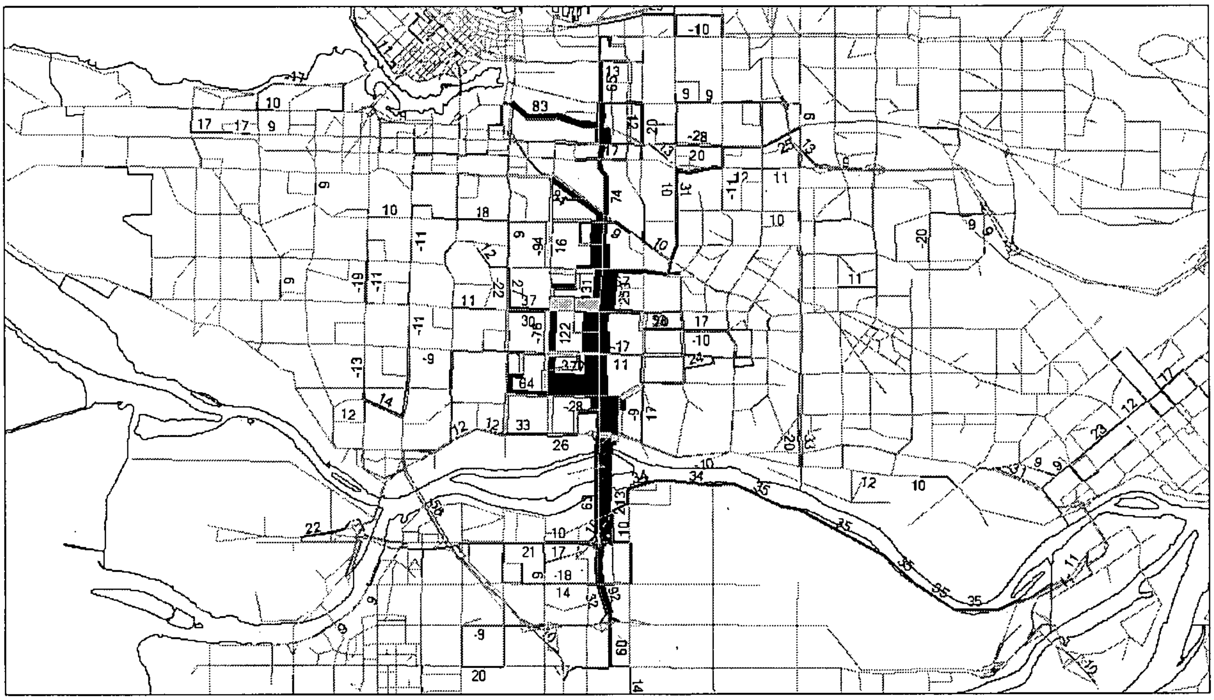
The installation of left turn bays was investigated for travel time and left turn capacity improvements using the EMME/2 demand forecasting model as well as the Paramics microsimulation model. The EMME/2 model was used due to the increase in lane capacity in the corridor which would induce more trips to the Knight Street corridor. Because of the diversion of trips, the demand forecasting model was appropriate since the other scenarios did not add any additional capacity. Various studies have pointed to the lack of capacity along the Knight Street corridor to accommodate left turn movements. Significant delay and vehicle weaving occurs as an entire lane is blocked for left turning vehicles. The following intersections were coded with an additional northbound and southbound left turn lane with permissive left turn signal phasing in the EMME/2 model:

- Knight Street and 57th Ave
- Knight Street and 49th Ave
- Knight Street and 33rd Ave
- Clark and 6th Ave (northbound only)

The EMME/2 model was coded with additional lanes at the four improved intersections to simulate the impact of adding left turn bays as well. Both models were run to get a better understanding of the distributional impacts of changing travel patterns as well as the operational impacts at the intersection level. The following illustration shows the change in travel patterns with the addition of left turn bays.

An additional microsimulation scenario was run with protected-permissive left turn signal phasing in the microsimulation model. No change was made to the eastbound and westbound movements except for the adjustment of signal timings.

Figure 6.7 – Change in Vehicle Volumes with the Addition of Left Turn Bays



Note: black and grey lines indicate an increase and decrease in vehicle volumes respectively.

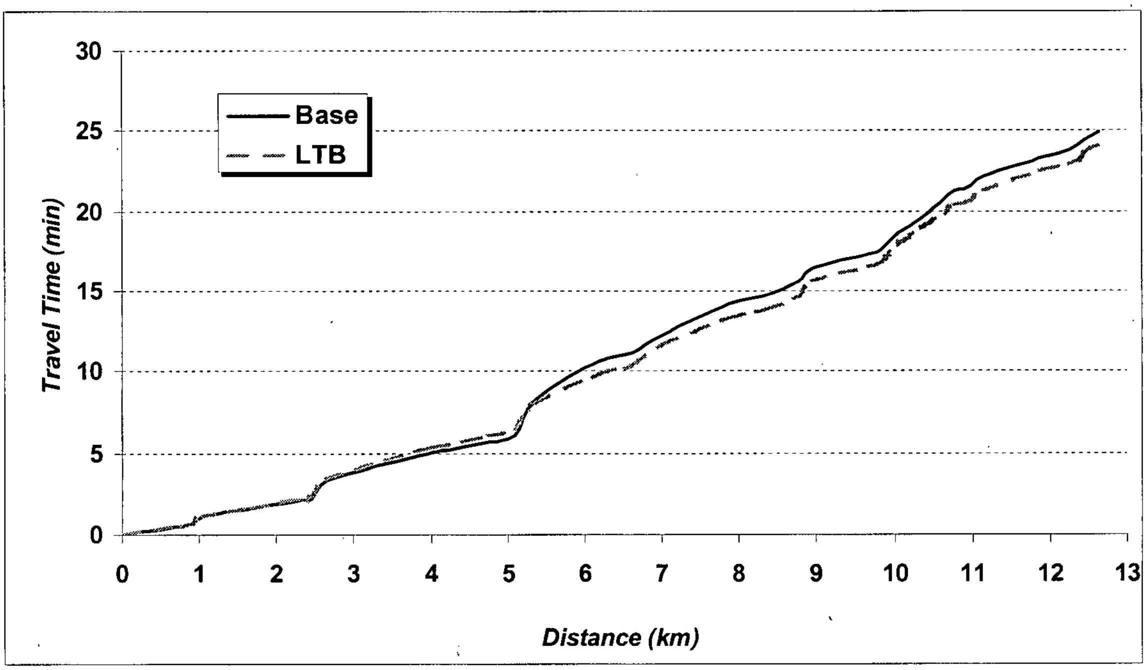
Immediately obvious from the EMME/2 model is the increase (black) in vehicles volumes that are attracted to the Knight Street corridor due to additional left turning capacity. The change in this case is local in nature as the other crossings to the City of Vancouver, namely the Oak Street and Arthur Laing bridges are minimally impacted. This shows that more trips are not necessarily attracted to the City, but rather re-distributed within the City. The volume of vehicles on some of the local roads is reduced (grey) and diverted to the major arterials. For example, trips that can now turn left northbound at 57th Ave are no longer 'rat-running' along Argyle St. The following table indicates the increase in northbound and southbound approach volumes at the four improved intersections.

Table 6.3 – AM Peak Hour Approach Volumes at the Four Improved Intersections

Intersection	Approach	Approach Volume Base	LTB	Change
57th Ave	*Northbound*	2,017	2,438	21%
	Southbound	1,823	2,071	14%
49th Ave	*Northbound*	1,785	1,908	7%
	Southbound	1,574	1,862	18%
33rd Ave	*Northbound*	1,551	1,801	16%
	Southbound	999	1,210	21%
6th Ave	*Northbound*	1,600	1,816	14%
	Total	**11,349**	**13,106**	**15%**

This table shows that there is a need along this major arterial for improved left turn movement to prevent vehicles from using local roads. Travel time along the corridor is marginally impacted as shown in the following illustration.

Figure 6.8 – Northbound Travel Time Along the Knight Street Corridor



From Westminster Highway in Richmond to Powell Street in Vancouver, the savings in travel time are on the order of 3%. As shown in the following table, travel times between key intersections have been improved as the total time savings northbound from end to end is approximately one minute.

Table 6.4 – Average Northbound Drive Times for the Base Scenario

Northbound	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Westminster Hwy	0.0	0.0	0.0	0
Knight St Bridge	4.0	5.0	5.0	48
57th Ave	5.4	8.3	3.4	39
49th Ave	6.6	10.6	2.3	37
41st Ave	7.0	12.3	1.7	34
33rd Ave	7.9	14.1	1.9	33
King Edward	8.8	15.6	1.5	34
Kingsway	9.0	16.5	0.9	33
12th Ave	10.1	18.6	2.2	32
Broadway	10.3	19.5	0.9	32
6th Ave	10.7	20.8	1.3	31
1st Ave	11.2	22.2	1.4	30
Venables	12.0	23.4	1.3	31
Hastings	12.5	24.5	1.0	31
Powell	12.7	25.0	0.5	30

Table 6.5 – Average Northbound Drive Times for the Left Turn Bay Scenario

Northbound	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Westminster Hwy	0.0	0.0	0.0	0
Knight St Bridge	4.0	5.3	5.3	45
57th Ave	5.4	8.1	2.9	40
49th Ave	6.6	9.8	1.7	40
41st Ave	7.0	11.6	1.8	36
33rd Ave	7.9	13.2	1.6	36
King Edward	8.8	14.7	1.5	36
Kingsway	9.0	15.6	0.9	34
12th Ave	10.1	17.9	2.3	34
Broadway	10.3	18.9	1.0	33
6th Ave	10.7	19.9	1.0	32
1st Ave	11.2	21.3	1.4	31
Venables	12.0	22.6	1.3	32
Hastings	12.5	23.6	1.1	32
Powell	12.7	24.1	0.5	31

The southbound drive times were reduced by the same amount as indicated in the following graph and tables.

Figure 6.9 – Northbound Travel Time Along the Knight Street Corridor

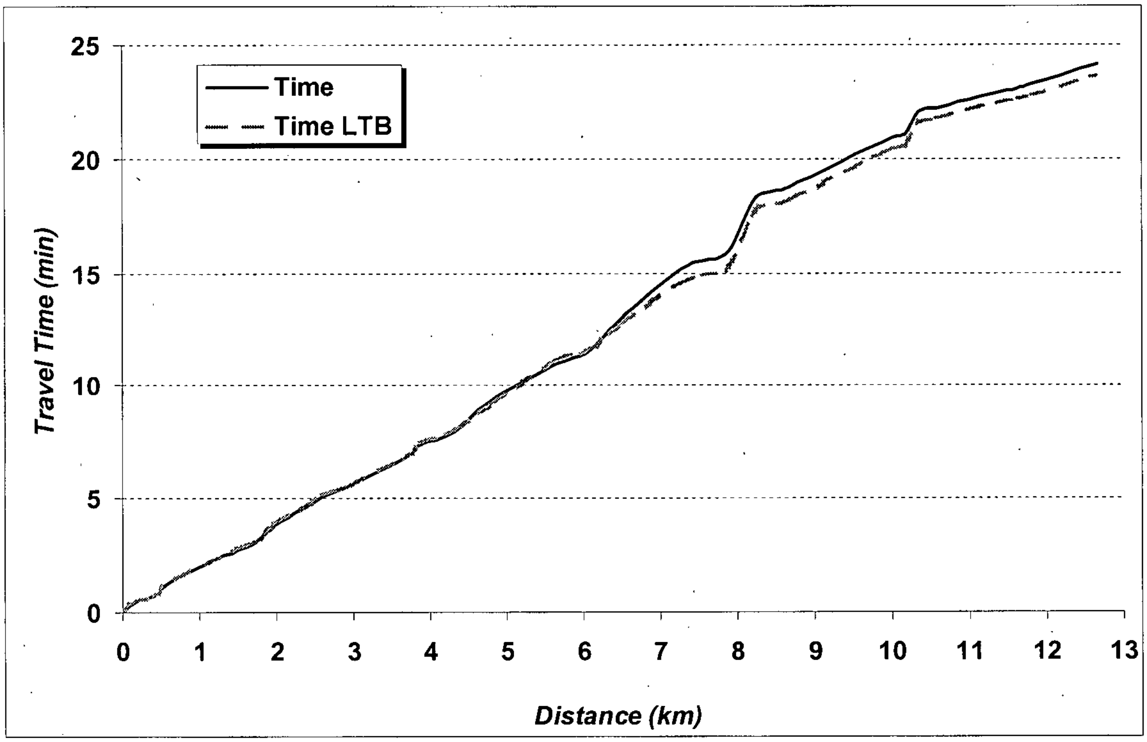


Table 6.6 – Southbound Drive Times for the Base Scenario

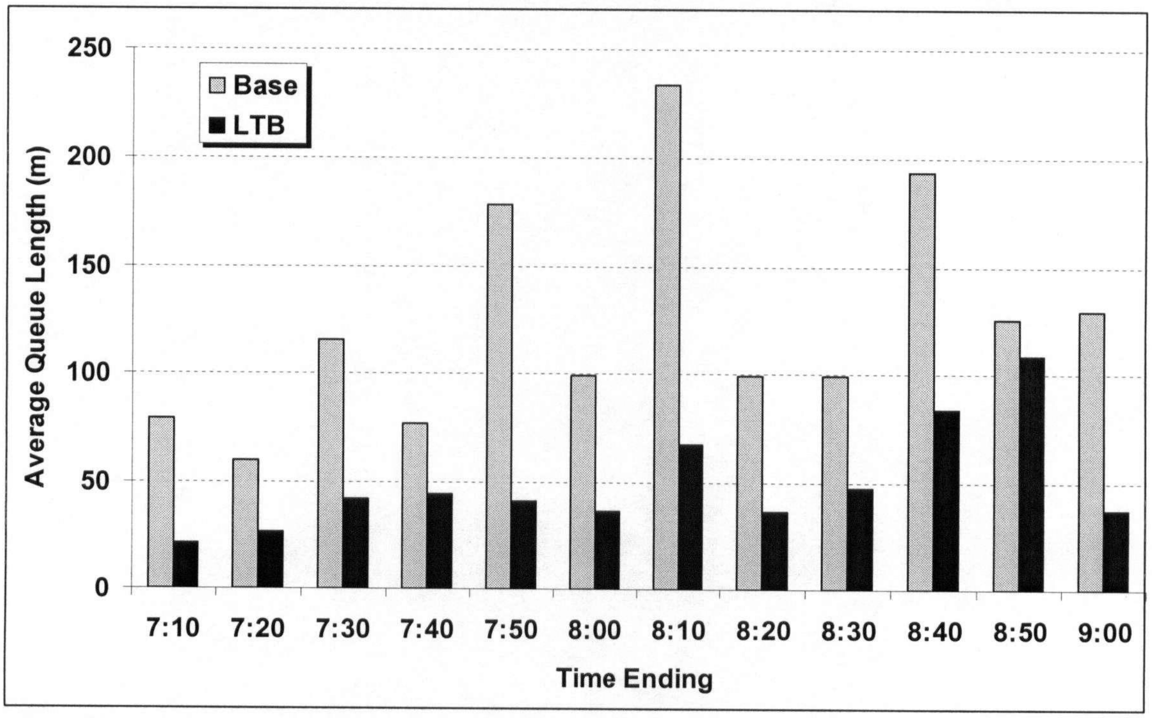
Southbound	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Powell	0.0	0.0	0.0	0
Hastings	0.2	0.5	0.5	24
Venables	0.7	1.5	1.0	28
1st Ave	1.5	2.8	1.2	33
6th Ave	2.0	3.9	1.1	31
Broadway	2.3	4.5	0.6	31
12th Ave	2.6	5.1	0.6	30
Kingsway	3.7	6.9	1.8	32
King Edward	3.9	7.4	0.5	32
33rd Ave	4.8	9.3	1.9	31
41st Ave	5.6	11.0	1.7	31
49th Ave	6.5	12.9	1.9	30
57th Ave	7.3	15.2	2.4	29
Knight St Bridge	8.7	18.8	3.6	28
Westminster Hwy	12.7	24.1	5.4	32

Table 6.7 – Southbound Drive Times for the Left Turn Bay Scenario

Southbound	Cumulative		Average	
Intersection	Distance (km)	Time (min)	Time (min)	Speed (kph)
Powell	0.0	0.0	0.0	0
Hastings	0.2	0.5	0.5	24
Venables	0.7	1.5	1.0	27
1st Ave	1.5	2.8	1.2	33
6th Ave	2.0	3.9	1.2	31
Broadway	2.3	4.5	0.6	30
12th Ave	2.6	5.1	0.6	30
Kingsway	3.7	6.9	1.8	32
King Edward	3.9	7.5	0.6	31
33rd Ave	4.8	9.2	1.7	31
41st Ave	5.6	11.1	1.9	30
49th Ave	6.5	12.7	1.6	31
57th Ave	7.3	14.5	1.8	30
Knight St Bridge	8.7	18.2	3.7	29
Westminster Hwy	12.7	23.7	5.5	32

Some queue lengths are significatnly shortened with the installation of left turn bays as shown in the following illustration. As the approach queue lengths are reduced, less vehicle idling is occurring.

Figure 6.10 – Northbound Average Queue Lengths at 49th Ave and Knight St

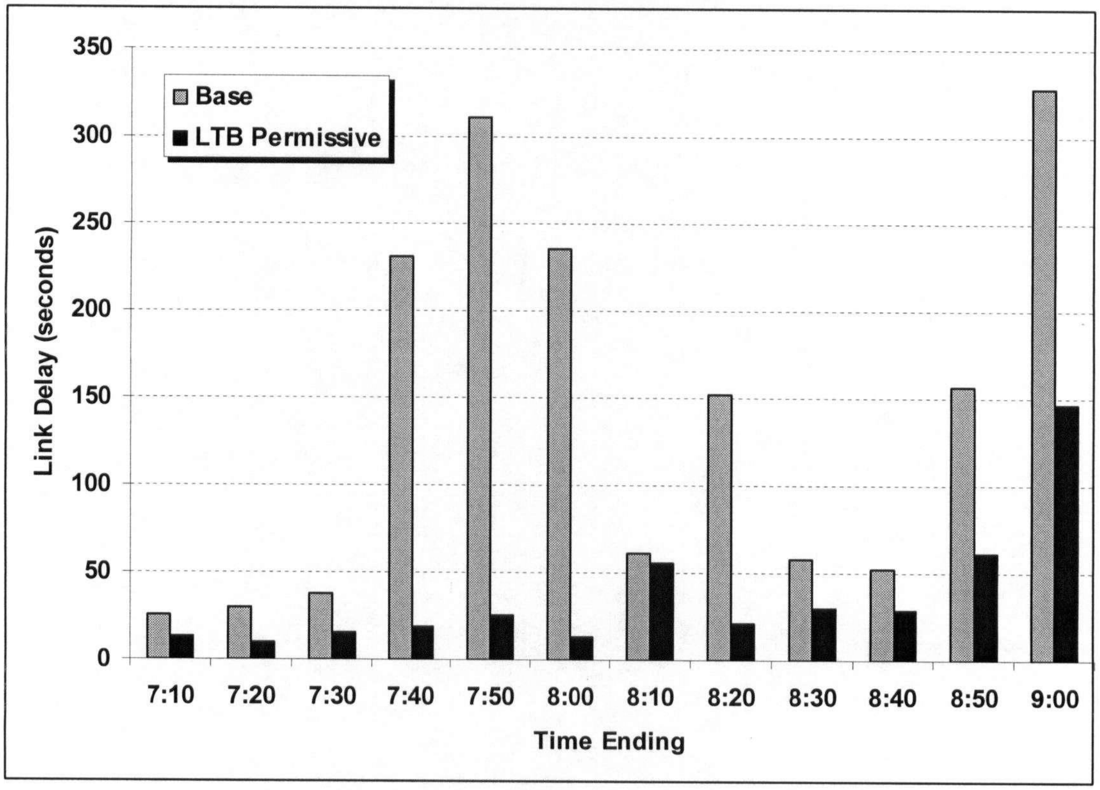


The delay along a network link is the increase in travel time due to congestion. The following illustrates how Paramics calculates delay along a network link:

link delay = simulated travel time – free flow time

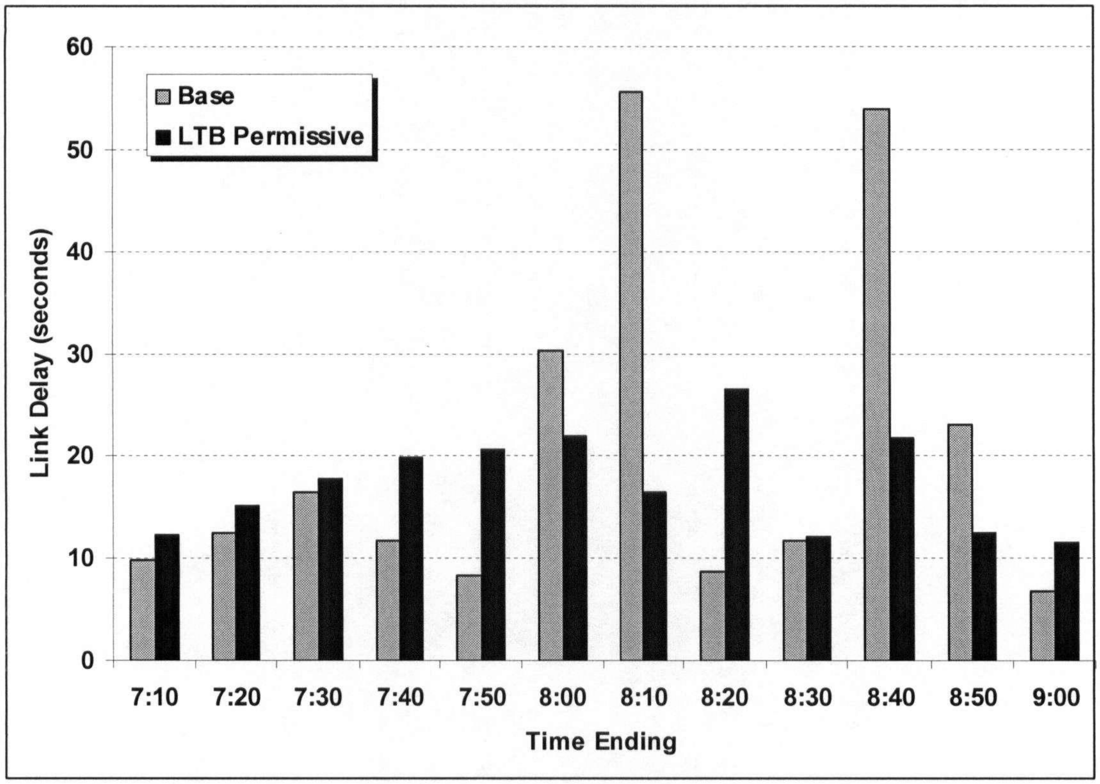
The free flow travel time is the time taken to travel a link with no other vehicles on the link. The following illustrates the link delay for the northbound approach to 49th Avenue at Knight Street during the morning peak period.

Figure 6.11 – Link Delay Northbound at 49th Ave and Knight Street



On average, delay has been reduced from 140 seconds to 37 seconds over the two hour peak period representing a reduction of 74% with the installation of a left turn bay. This figure also shows the variation of delay over time which the microsimulation model is capable of capturing. Travel time variability is an important factor for trucks as they tend to be on strict time schedules. The less variability in travel time for a truck, the better the operator is able to adhere to time schedules and spend less time waiting to make the next delivery trip. The following illustrates the delay for the northbound approach to 57th Ave.

Figure 6.12 – Link Delay Northbound at 57th Ave and Knight Street



Delay has been reduced less dramatically from 21 seconds to 17 seconds over the two-hour peak period for northbound approaching vehicles at 57th Ave. The following illustrations show the average link delay for northbound approaching vehicles at 33rd Ave and 6th Ave and Knight Street respectively.

Figure 6.13 – Link Delay Northbound at 33rd Ave and Knight Street

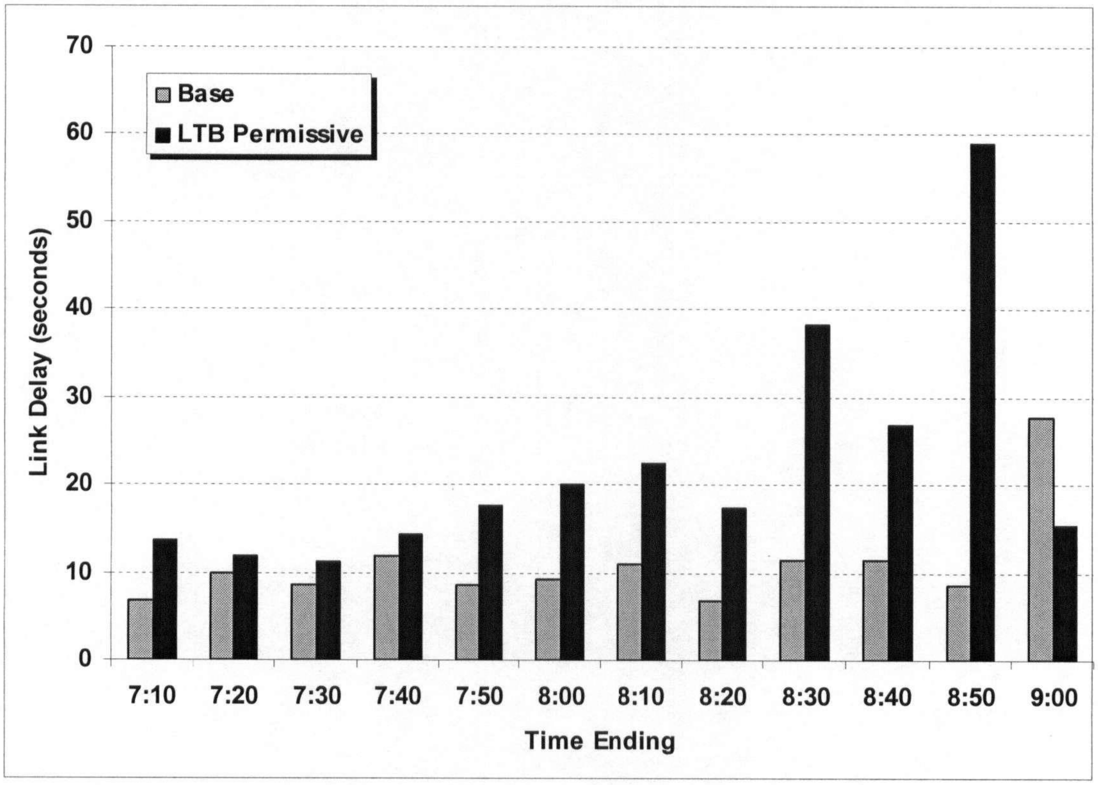
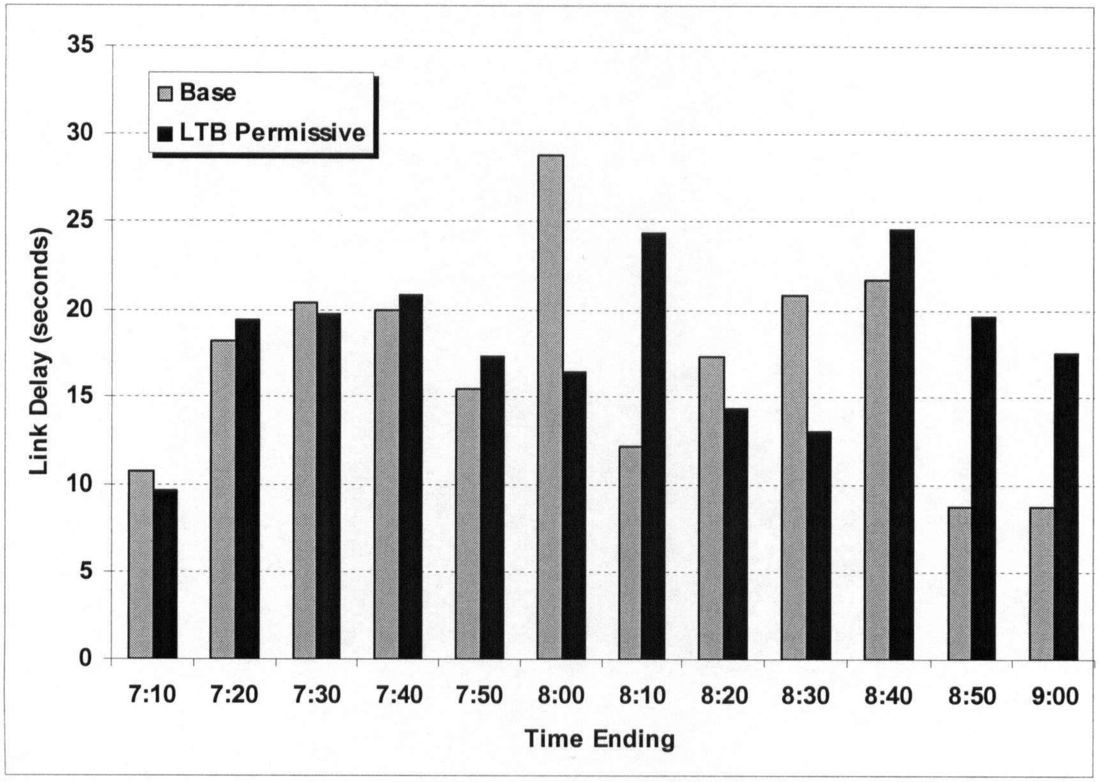


Figure 6.14 – Link Delay Northbound at 6th Ave and Knight Street



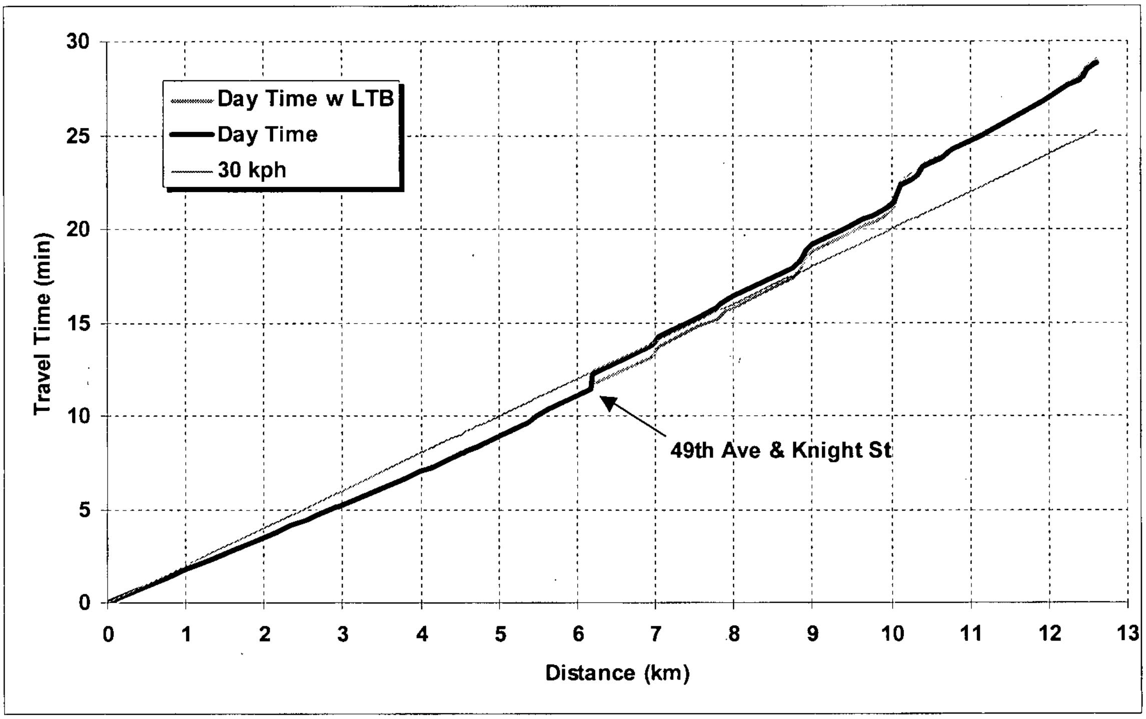
Qualitative observations of the model show that there is less weaving and lane changing behaviour at the four improved intersections as left turning vehicles have their own lane to use and not block other vehicles. The slight decrease in east-west capacity shows some increase in delay for east and westbound approaching vehicles. Queuing at the northbound Marine Drive off-ramp has been substantially reduced as vehicles that would normally divert to Fraser Street and Victoria Drive from the off-ramp will now continue along Knight Street and divert at either 57th Ave or 49th Ave. This is resulting in less weaving and lane changing activity upstream of the off-ramp and consequently less queue delay due to the decreased activity. This particular 'hot-spot' in the base scenario would cause the queue to spill back along the Knight Street Bridge and the McMillan Island northbound on-ramp.

Most of these results have focused on the permissive left turn bay scenario. Adding protected left turn phasing reduces the through movement capacity for vehicles travelling along the Knight St corridor. The priority along this corridor is obviously for north and southbound travel and the addition of left turn bays assists in this regard. The protected phasing, however, reduces the through movement green time enough to cause unnecessary delay for through moving vehicles. As such, the above results focus mainly on the permissive phasing of left turn movements.

6.7 Additional Left Turn Bay Capacity with Day Time Volumes

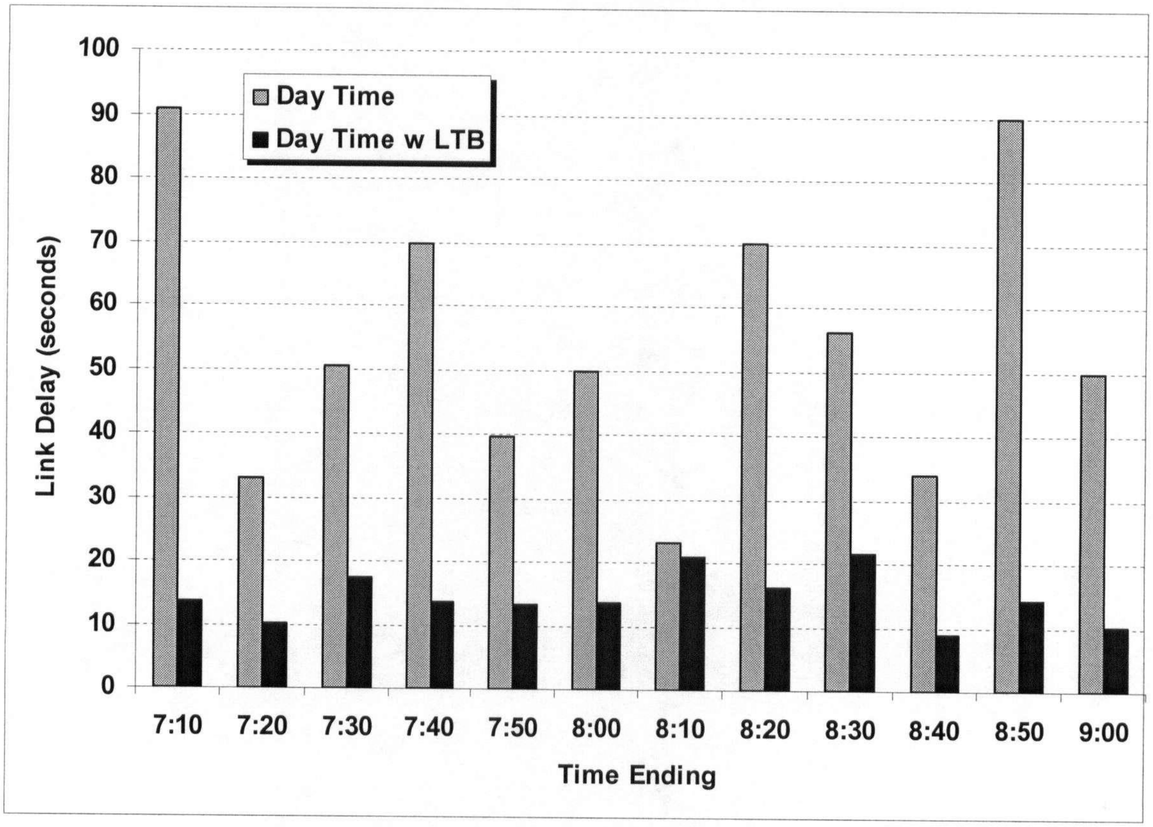
The Knight Street model with permissive left turn movements was run using day time vehicle volumes to determine the impact on trucks and other vehicles since more trucks travel in the midday. The drive trace of vehicles travelling during the day with and without left turn bays in the model are compared in the following illustration.

Figure 6.15 – Northbound Drive Times for Day Time and Day Time With LTB



As shown, there appears to be marginal travel time benefits with the addition of left turn bays. However, at 49th Ave and Knight St, there is less queuing for through moving northbound vehicles as indicated by quicker travel time through this area. Looking closer at the intersection level reveals significant delay reductions as shown in the following illustration.

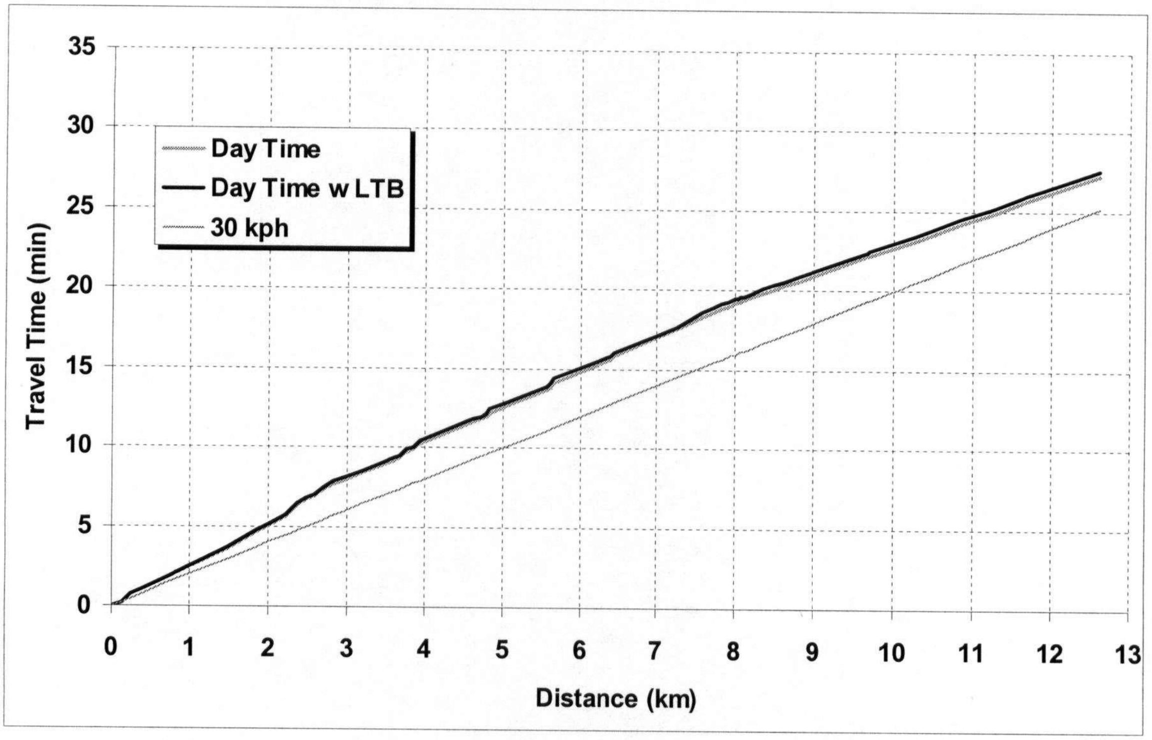
Figure 6.16 – Northbound Day Time Approach Delay at 49th Ave and Knight St



Average approach delay for this intersection is reduced dramatically from approximately 55 seconds to 15 seconds. Travel time reliability is also greatly enhanced as can be shown in the highly variable delay values shown for the day time scenario. Less vehicle idling time would be a direct result of the reduced travel delay.

There appears to be marginal travel time benefit for vehicles travelling southbound with the addition of left turn bays during the day time as shown in the following illustration. Left turn bays do offer significant safety benefits that go beyond the enhancements to travel time as the Knight Street corridor experiences an unusually high accident rate.

Figure 6.17 – Southbound Drive Times for Day Time and Day Time With LTB



CHAPTER VII – Conclusions & Recommendations

The results of this modelling analysis highlight the importance of Knight Street in terms of not only a people movement but goods movement corridor as well. This corridor is unique in many respects. Firstly, the Knight Street corridor carries a significantly high proportion of heavy vehicles and secondly, the vehicle volumes display a balanced, bi-directional peaking characteristic. A high degree of variation in land use type makes this corridor unique and challenging to meet the needs of all its users.

Restricting regular automobiles from using the right lane seems to have a beneficial impact on the travel performance of trucks. Passenger vehicles benefit from not having to weave around trucks to pass them in the outside lane especially along steep grades. Automobiles do see a decrease in capacity, however the corridor as a whole seems to benefit in terms of travel time with the addition of an exclusive truck/bus lane.

Signal coordination appears to offer several benefits to users of the Knight Street corridor without significant cost implications. For signal coordination to be effective, all signals along the corridor must be programmed with the same cycle length. This could pose problems with east-west coordination if major intersections use an alternate cycle length. If the east –west green times do not impact the percentage of saturation, then signal coordination could offer a 13% decrease in travel times from end to end.

Projections of freight activity in the future at Port Vancouver indicate strong growth over the next several decades. As such, it was important to consider an ever increasing percentage of trucks and its impact to the travel performance of the corridor. In particular, the question of what adjustments must be made to signal coordination in order to account for a higher proportion of heavy vehicles. Obviously the average corridor travel speed decreased with an increasing proportion of heavy vehicles. A corresponding adjustment was made to the 'cruise speed' in Transyt-7F to develop an effective two-way signal coordination strategy. The 'cruise speed' adjusted down by 3% and 5% for 20% trucks and 25% trucks respectively. As such, the relative travel time savings were consistently around 12% for each of the scenarios. The benefits of signal coordination were maintained with the necessary adjustments for heavy vehicles.

Travel times vary significantly throughout the two hour peak period as vehicle volumes change. Using variable offsets for signal coordination to account for changing travel times results in marginal travel time benefits over the fixed offset signal coordination strategy.

Combining the exclusive truck/bus lane with signal coordination was modelled to evaluate the impact of both measures on the corridor. The results show a net improvement to travel times along Knight Street. Travel times did, however, increase in the southbound direction due to a significant increase in vehicle volumes. This shows that trips were diverted onto the Knight Street corridor from other routes due to the dynamic feedback assignment method. As the improvements on the corridor show travel time benefits, more vehicles are attracted to the corridor creating more congestion problems. Finding a balance of capacity improvement with diverting too much traffic is a fine balance for transportation engineers to maintain.

The addition of left turn bay capacity shows that there is latent demand for left turn movements. Operationally, there is less lane changing and weaving with the addition of left turn bays. Permissive signal phasing is preferred as protected phasing would reduce through movement capacity. Modelling travel during day time conditions proved insightful as truck volumes tend to peak during the midday. Trucks that travel during the day time have far better travel performance when compared to trucks travelling during the morning peak period as there is lower commuter travel during the midday. This has significant implications to efficient goods movement as truck operating costs are directly related to travel time and travel time reliability.

The results from this research have shown the benefits of several strategies for improving the movement of goods along a congested urban arterial. The microsimulation model has proved to be an effective tool for analyzing the impacts of various corridor improvement strategies.

The economic cost of congestion on the goods movement industry is considerable and affects the cost of living. The cost of goods are reduced if the time to deliver those goods are reduced. The economic competitiveness of a region is also a significant factor for large companies deciding to relocate their operations. All of these factors point to a need to keep trucks moving efficiently and reliably through an urban area such as the City of Vancouver.

7.1 Future Research Directions

Modelling freight movements, according to the literature, has been understudied and not thoroughly considered in transportation planning studies. Further research work in urban goods movement and freight modelling would enable planning organizations to take a more holistic approach to land use and transportation planning. By integrating freight into the standard approach to transportation planning, urban areas could make better use of existing infrastructure as well as enhancing the livability of their region. By locating freight handling facilities in a coordinated approach with other road users, travel can be minimized as well as the negative impacts to the environment.

There are several areas of freight modelling that could be further investigated as outlined in the following sections.

Truck Priority – a microsimulation model could be used to analyze truck priority measures at intersections. Vehicle length can be detected upstream of an intersection and used to adjust green times to minimize truck stops. Compared to regular automobiles, trucks emit substantially more air pollutants as well as cause significantly more pavement damage when the are required to stop at intersections.

Exclusive Truck Lanes – modelling of exclusive heavy vehicle lanes has been investigated on highway facilities. Further research in this area could persuade road authorities to dedicate road space for trucks to bypass congestion locations. A microsimulation model would be useful to perform a detailed study of the impact of removing heavy vehicles from the traffic stream. Many analyzes use a passenger car equivalent factor to account for trucks, however, the interaction of heavy vehicles with automobiles lends itself well to microsimulation analysis especially since every situation is unique.

Commodity Flow Analysis – information on commodity flows would be very useful in determining trucking needs on the road. However, the commercial sensitivity of this type of information precludes researchers from developing comprehensive commodity flow models. Further research in this area would benefit transportation planning organizations in developing long term plans to accommodate truck movements.

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APPENDIX A – Network Description Files

The following are examples of text files used in Paramics to define the Knight Street corridor network properties. The nodes and links form the skeleton of the rode network. The node file contains information on node numbers, x coordinate, y coordinate, elevation and type of node. The link file contains information on the link number, category and gradient.

Figure A.1 – Example of 'Node' text file for Paramics

```
Bounding Box -391264.3 m -4171194.3 m -387867.7 m -4155711.5 m
node         0 at -389678.22 m, -4165275.75 m,     25.00 m   junction
node         1 at -389673.72 m, -4164540.00 m,     68.00 m   junction
node         2 at -389692.03 m, -4163746.00 m,     89.00 m   junction
node         3 at -389671.88 m, -4162921.25 m,     85.00 m   junction
node         4 at -389657.97 m, -4162367.75 m,     91.00 m   junction
node         5 at -389620.19 m, -4162085.25 m,     75.00 m   junction
node         6 at -389605.19 m, -4161162.75 m,     62.00 m   junction
node         7 at -389598.91 m, -4160984.50 m,     58.00 m   junction
node         8 at -389702.72 m, -4159927.25 m,     28.00 m   junction
node         9 at -389702.63 m, -4159618.75 m,     27.00 m   junction
node        10 at -389695.06 m, -4159310.75 m,     20.00 m   junction
...
```

Figure A.2 – Example of 'Link' text file for Paramics

```
link 0 406 category 3 gradient 2.5
link 0 21 category 7 gradient -6.1
link 1 16 category 3 gradient 3.6
link 1 206 category 2
link 1 403 category 3 gradient -4.5
link 1 205 category 2
link 2 223 category 2 gradient -1.8
link 2 17 category 3 gradient -2.4
link 2 222 category 2
link 2 351 category 3
link 3 348 category 2 gradient 1.7
link 3 347 category 3
...
```

APPENDIX B – Transit Routes and Frequencies

The following table summarizes the transit routes that were coded in to the Knight Street microsimulation model. Each route was coded according to the fall 1999 schedule with the frequencies indicated in the table.

Table B.1 – Transit Routes, Description and Frequency

Route Number	Description	Frequency (veh/hr)
099W	99 B-Line westbound	20
099E	99 B-Line eastbound	20
022	Knight/MacDonald	7.5
010E	UBC/Kootenay	6
10W	Kootenay/UBC	6
016E	Arbutus/Renfrew	6
016W	Renfrew/Arbutus	6
008	Fraser	7.5
009E	Alma/Boundary	10
009W	Boundary/Alma	10
019W	Metrotown/Dowtown	5
019E	Downtown/Metrotown	5
020	Victoria/Downtown	10
025E	UBC/Brentwood	5.5
025W	Brentwood/UBC	5.5
041E	UBC/Joyce	8.6
041W	Joyce/UBC	8.6
043E	43 Express	4
043W	43 Express	4
049E	Dunbar/Metrotown	5.5
049W	Metrotown/Dunbar	5.5
100E	Airport/22nd	4
100W	22nd Airport	4
XXE	Powell Buses	20
XXW	Cordova Buses	20

APPENDIX C – Turn Volume Calibration Sheets

The following three tables summarize vehicle volumes comparing the observed to modelled volumes. Each table represents turn volumes for Clark Dr/Knight St, Victoria/Commercial and Fraser Street respectively. The four main columns represent the north, south, east and westbound travel direction respectively. Within these columns are four sub-columns representing the left turn (LT), through (Thru), right turn (RT) and total approach volume (Sum). All counts were taken from 07:00 to 09:00 during the morning commuter rush period. Actual observed counts were taken either in 1999 or 2000 and used to calibration the Knight Street microsimulation model. The following formula illustrates the method used to calculate the model error or deviation:

$$Error_i\ \% = \frac{(Model\ Turn\ Volume_i - Observed\ Turn\ Volume_i)}{Observed\ Turn\ Volume_i} * 100\%$$

where: i = *individual turn movement*

Table C.1 – Observed and Modelled Vehicle Turning Volumes Along Knight St

		Northbound				Southbound				Eastbound				Westbound			
Intersection	Data	LT	Thru	RT	Sum	LT	Thru	RT	Sum	LT	Thru	RT	Sum	LT	Thru	RT	Sum
Clark and Powell	*Observed*	333		247	580						965	72	1037	458	3266		3724
	Modelled	201		122	323						1370	124	1494	156	3173		3329
	Deviation	-39.6%		-50.6%	-44.3%						42.0%	72.2%	44.1%	-65.9%	-2.8%		-10.6%
Clark and Hastings	*Observed*	226	610	181	1017	80	773	63	916	67	731	106	904	716	3291	148	4155
	Modelled	367	624	261	1252	139	538	42	719	39	583	357	979	221	3336	59	3616
	Deviation	62.4%	2.3%	44.2%	23.1%	73.8%	-30.4%	-33.3%	-21.5%	-41.8%	-20.2%	236.8%	8.3%	-69.1%	1.4%	-60.1%	-13.0%
Clark and Venables	*Observed*	560	1251	80	1891	14	591	388	993	128	685	175	988	104	1429	52	1585
	Modelled	710	1210	98	2018	159	886	67	1112	9	569	645	1223	143	1691	43	1877
	Deviation	26.8%	-3.3%	22.5%	6.7%	1035.7%	49.9%	-82.7%	12.0%	-93.0%	-16.9%	268.6%	23.8%	37.5%	18.3%	-17.3%	18.4%
Clark and 1st Ave	*Observed*	379	1960	493	2832	92	1508	143	1743		1598	169	1767		3021	231	3252
	Modelled	379	1979	115	2473	118	1517	40	1675		1719	251	1970		3085	42	3127
	Deviation	0.0%	1.0%	-76.7%	-12.7%	28.3%	0.6%	-72.0%	-3.9%		7.6%	48.5%	11.5%		2.1%	-81.8%	-3.8%
Clark and 6th Ave	*Observed*	1003	1119		2122		851	553	1404	1001		742	1743				
	Modelled	816	1458		2274		1098	668	1766	978		652	1630				
	Deviation	-18.6%	30.3%		7.2%		29.0%	20.8%	25.8%	-2.3%		-12.1%	-6.5%				
Clark and Broadway	*Observed*	265	2148	191	2604	513	1348	102	1963	190	1336	127	1653	237	2390	473	3100
	Modelled	61	1952	166	2179	119	1317	297	1733	205	1318	151	1674	251	2439	115	2805
	Deviation	-77.0%	-9.1%	-13.1%	-16.3%	-76.8%	-2.3%	191.2%	-11.7%	7.9%	-1.3%	18.9%	1.3%	5.9%	2.1%	-75.7%	-9.5%
Clark and 12th Ave	*Observed*	106	1877	237	2220	270	1393	31	1694	127	1937	47	2111	230	2644	123	2997
	Modelled	51	1736	231	2018	152	1553	9	1714	183	1596	205	1984	216	2442	265	2923
	Deviation	-51.9%	-7.5%	-2.5%	-9.1%	-43.7%	11.5%	-71.0%	1.2%	44.1%	-17.6%	336.2%	-6.0%	-6.1%	-7.6%	115.4%	-2.5%
Knight and Kingsway	*Observed*	275	2161	27	2463	161	1469	64	1694	91	1295	177	1563	50	3382	181	3613
	Modelled	186	1952	21	2159	204	1736	27	1967	62	1115	287	1464	184	3281	87	3552
	Deviation	-32.4%	-9.7%	-22.2%	-12.3%	26.7%	18.2%	-57.8%	16.1%	-31.9%	-13.9%	62.1%	-6.3%	268.0%	-3.0%	-51.9%	-1.7%
Knight and King Ed	*Observed*	252	2006	21	2279	8	1368	194	1570	257	657	46	960	91	997	20	1108
	Modelled	154	2102	122	2378	53	1888	264	2205	78	616	138	832	39	945	5	989
	Deviation	-38.9%	4.8%	481.0%	4.3%	562.5%	38.0%	36.1%	40.4%	-69.6%	-6.2%	200.0%	-13.3%	-57.1%	-5.2%	-75.0%	-10.7%
Knight and 41st Ave	*Observed*	124	1961	328	2413	97	1761	49	1907	106	1318	114	1538	503	1798	28	2329
	Modelled	193	2495	388	3076	31	2360	56	2447	77	1210	175	1462	284	1877	93	2254
	Deviation	55.6%	27.2%	18.3%	27.5%	-68.0%	34.0%	14.3%	28.3%	-27.4%	-8.2%	53.5%	-4.9%	-43.5%	4.4%	232.1%	-3.2%
Knight and 57th Ave	*Observed*		2784	106	2890	13	2959	16	2988	86	307	340	733	1174	614	36	1824
	Modelled		3253	620	3873	9	3250	10	3269	21	418	283	722	966	557	88	1611
	Deviation		16.8%	484.9%	34.0%	-30.8%	9.8%	-37.5%	9.4%	-75.6%	36.2%	-16.8%	-1.5%	-17.7%	-9.3%	144.4%	-11.7%
Kingsway and King Ed	*Observed*	942	3884		4826		1451	1	1452			342	342				
	Modelled	987	3565		4552		1339	0	1339			791	791				
	Deviation	4.8%	-8.2%		-5.7%		-7.7%	-100.0%	-7.8%			131.3%	131.3%				

Table C.2 – Observed and Modelled Vehicle Turning Volumes Along Victoria

Intersection	Data	Northbound LT	Northbound Thru	Northbound RT	Northbound Sum	Southbound LT	Southbound Thru	Southbound RT	Southbound Sum	Eastbound LT	Eastbound Thru	Eastbound RT	Eastbound Sum	Westbound LT	Westbound Thru	Westbound RT	Westbound Sum
Commercial and Hastings	*Observed*	152	164	60	376	48	246	233	527	46	1124	36	1206	277	3953	84	4314
	Modelled	103	147	216	466	45	142	99	286	58	802	120	980	128	3411	28	3567
	Deviation	-32.2%	-10.4%	260.0%	23.9%	-6.3%	-42.3%	-57.5%	-45.7%	26.1%	-28.6%	233.3%	-18.7%	-53.8%	-13.7%	-66.7%	-17.3%
Commercial and Venables	*Observed*	490	443	24	957	17	323	31	371	56	499	203	758	12	983	19	1014
	Modelled	202	396	180	778	89	206	95	390	47	574	198	819	145	1580	19	1744
	Deviation	-58.8%	-10.6%	650.0%	-18.7%	423.5%	-36.2%	206.5%	5.1%	-16.1%	15.0%	-2.5%	8.0%	1108.3%	60.7%	0.0%	72.0%
Commercial and 1st Ave	*Observed*	113	950	97	1160	251	539	40	830	57	1915	32	2004	108	3380	214	3702
	Modelled	63	638	225	926	158	386	2	546	83	1732	135	1950	185	3073	58	3316
	Deviation	-44.2%	-32.8%	132.0%	-20.2%	-37.1%	-28.4%	-95.0%	-34.2%	45.6%	-9.6%	321.9%	-2.7%	71.3%	-9.1%	-72.9%	-10.4%
Commercial and Broadway	*Observed*	100	1124	110	1334	113	692	143	948	96	1893	103	2092	149	3303	56	3508
	Modelled	116	775	183	1074	65	426	372	863	177	1305	117	1599	171	2317	26	2514
	Deviation	16.0%	-31.0%	66.4%	-19.5%	-42.5%	-38.4%	160.1%	-9.0%	84.4%	-31.1%	13.6%	-23.6%	14.8%	-29.9%	-53.6%	-28.3%
Commercial and 12th Ave	*Observed*	109	930	39	1078	101	571	147	819	79	1996	35	2110	108	2814	114	3036
	Modelled	229	899	125	1253	76	482	159	717	97	1747	151	1995	131	2534	78	2743
	Deviation	110.1%	-3.3%	220.5%	16.2%	-24.8%	-15.6%	8.2%	-12.5%	22.8%	-12.5%	331.4%	-5.5%	21.3%	-10.0%	-31.6%	-9.7%
Victoria and Kingsway	*Observed*	354	1055	48	1457	144	769	51	964	83	1554	98	1735	67	3286	220	3573
	Modelled	364	1390	180	1934	58	879	58	995	68	1587	425	2080	103	4165	139	4407
	Deviation	2.8%	31.8%	275.0%	32.7%	-59.7%	14.3%	13.7%	3.2%	-18.1%	2.1%	333.7%	19.9%	53.7%	26.7%	-36.8%	23.3%
Victoria and 33rd Ave	*Observed*	276	1332	190	1798	25	949	81	1055	117	895	127	1139	356	1260	21	1637
	Modelled	76	1640	173	1889	103	1045	257	1405	103	306	77	486	182	1203	182	1567
	Deviation	-72.5%	23.1%	-8.9%	5.1%	312.0%	10.1%	217.3%	33.2%	-12.0%	-65.8%	-39.4%	-57.3%	-48.9%	-4.5%	766.7%	-4.3%
Victoria and 49th Ave	*Observed*	116	1409	67	1592	69	1620	148	1837	148	1040	72	1260	98	1423	103	1624
	Modelled	290	911	34	1235	106	893	256	1255	404	781	33	1218	121	570	270	961
	Deviation	150.0%	-35.3%	-49.3%	-22.4%	53.6%	-44.9%	73.0%	-31.7%	173.0%	-24.9%	-54.2%	-3.3%	23.5%	-59.9%	162.1%	-40.8%
Victoria and 54th Ave	*Observed*	59	779	29	867	87	322	618	1027	540	748	61	1349	15	1249	176	1440
	Modelled	157	289	21	467	82	358	603	1043	752	408	0	1160	73	853	204	1130
	Deviation	166.1%	-62.9%	-27.6%	-46.1%	-5.7%	11.2%	-2.4%	1.6%	39.3%	-45.5%	-100.0%	-14.0%	386.7%	-31.7%	15.9%	-21.5%
Victoria and SE Marine	*Observed*	62	112	17	191	200	78	166	444	91	3412	7	3510	109	4549	172	4830
	Modelled	57	67	3	127	336	40	58	434	179	3386	8	3573	102	4223	236	4561
	Deviation	-8.1%	-40.2%	-82.4%	-33.5%	68.0%	-48.7%	-65.1%	-2.3%	96.7%	-0.8%	14.3%	1.8%	-6.4%	-7.2%	37.2%	-5.6%

Table C.3 – Observed and Modelled Vehicle Turning Volumes Along Fraser Street

Intersection	Data	Northbound LT	Northbound Thru	Northbound RT	Northbound Sum	Southbound LT	Southbound Thru	Southbound RT	Southbound Sum	Eastbound LT	Eastbound Thru	Eastbound RT	Eastbound Sum	Westbound LT	Westbound Thru	Westbound RT	Westbound Sum
Fraser and Broadway	*Observed*	283	145	228	656	54	167	32	253	29	1729	111	1869	312	2258	21	2591
	Modelled	313	121	266	700	95	209	26	330	0	1315	211	1526	386	2378	32	2796
	Deviation	10.6%	-16.6%	16.7%	6.7%	75.9%	25.1%	-18.8%	30.4%	-100.0%	-23.9%	90.1%	-18.4%	23.7%	5.3%	52.4%	7.9%
Fraser and 12th Ave	*Observed*	65	660	216	941	47	680	52	779		1766	10	1776		2156	45	2201
	Modelled	210	648	243	1101	97	705	4	806		1811	409	2220		2451	36	2487
	Deviation	223.1%	-1.8%	12.5%	17.0%	106.4%	3.7%	-92.3%	3.5%		2.5%	3990.0%	25.0%		13.7%	-20.0%	13.0%
Fraser and Kingsway	*Observed*	445	725	11	1181	107	665	5	777	104	1196	193	1493	223	3368	104	3695
	Modelled	291	832	11	1134	297	711	45	1053	158	1184	167	1509	72	3310	113	3495
	Deviation	-34.6%	14.8%	0.0%	-4.0%	177.6%	6.9%	800.0%	35.5%	51.9%	-1.0%	-13.5%	1.1%	-67.7%	-1.7%	8.7%	-5.4%
Fraser and King Edward	*Observed*	241	924	49	1214	16	707	145	868	114	681	58	853	95	1389	100	1584
	Modelled	301	943	48	1292	127	743	72	942	100	662	126	888	93	1193	82	1368
	Deviation	24.9%	2.1%	-2.0%	6.4%	693.8%	5.1%	-50.3%	8.5%	-12.3%	-2.8%	117.2%	4.1%	-2.1%	-14.1%	-18.0%	-13.6%
Fraser and 33rd Ave	*Observed*	262	1225	148	1635	111	964	72	1147	50	638	92	780	240	1212	129	1581
	Modelled	64	1017	139	1220	135	779	48	962	84	370	143	597	104	1088	183	1375
	Deviation	-75.6%	-17.0%	-6.1%	-25.4%	21.6%	-19.2%	-33.3%	-16.1%	68.0%	-42.0%	55.4%	-23.5%	-56.7%	-10.2%	41.9%	-13.0%
Fraser and 41st Ave	*Observed*	145	1277	60	1482	99	888	154	1141	242	1299	251	1792	121	1708	89	1918
	Modelled	94	924	98	1116	141	834	51	1026	126	1250	239	1615	105	1844	161	2110
	Deviation	-35.2%	-27.6%	63.3%	-24.7%	42.4%	-6.1%	-66.9%	-10.1%	-47.9%	-3.8%	-4.8%	-9.9%	-13.2%	8.0%	80.9%	10.0%
Fraser and 49th Ave	*Observed*	92	1185	61	1338	127	922	119	1168	67	801	50	918	87	1099	166	1352
	Modelled	128	866	54	1048	211	803	165	1179	108	838	34	980	66	431	140	637
	Deviation	39.1%	-26.9%	-11.5%	-21.7%	66.1%	-12.9%	38.7%	0.9%	61.2%	4.6%	-32.0%	6.8%	-24.1%	-60.8%	-15.7%	-52.9%
Fraser and 57th Ave	*Observed*	102	1048	89	1239	293	786	58	1137	66	331	33	430	75	413	168	656
	Modelled	152	944	103	1199	174	623	103	900	28	445	57	530	52	437	77	566
	Deviation	49.0%	-9.9%	15.7%	-3.2%	-40.6%	-20.7%	77.6%	-20.8%	-57.6%	34.4%	72.7%	23.3%	-30.7%	5.8%	-54.2%	-13.7%
Fraser and SE Marine	*Observed*	67	138	86	291	317	233	267	817	194	2363	65	2622	197	3590	302	4089
	Modelled	68	93	67	228	353	227	160	740	117	2433	65	2615	167	2544	1003	3714
	Deviation	1.5%	-32.6%	-22.1%	-21.6%	11.4%	-2.6%	-40.1%	-9.4%	-39.7%	3.0%	0.0%	-0.3%	-15.2%	-29.1%	232.1%	-9.2%

APPENDIX D – Origin-Destination Matrices for Automobiles and Trucks

Table D.1 – Origin-Destination Matrix for Automobiles

	Destination Traffic Zones																																									
Origin Traffic Zones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	Total
1	0	100	14	2	2	2	2	2	2	2	2	1	2	1	2	2	1	2	2	2	2	2	0	2	2	2	2	2	2	1	2	2	2	15	2	0	0	9	2	0	0	196
2	100	0	150	40	54	22	45	81	45	640	18	88	63	115	15	50	50	90	75	90	90	40	0	45	15	135	50	50	67	13	50	25	25	90	2	100	30	110	50	0	0	2818
3	2	115	0	55	2	2	22	22	94	247	13	38	22	75	2	55	15	55	75	90	15	45	0	35	15	139	2	55	49	18	2	15	2	15	2	100	30	110	50	0	0	1700
4	2	2	2	0	2	2	2	2	2	2	2	1	2	1	1	1	1	1	1	10	1	1	0	1	1	91	1	1	1	1	1	1	1	2	2	13	3	1	2	0	0	164
5	1	2	2	1	0	2970	2	2	2	2	2	1	2	1	2	2	1	2	2	2	2	2	0	1	1	2	2	2	2	1	2	2	2	2	2	11	2	1	2	0	0	3042
6	2	2	2	2	472	0	11	11	11	15	11	1	11	1	1	11	1	10	11	11	10	10	0	10	10	210	10	10	10	1	10	10	10	2	2	12	3	1	2	0	0	930
7	2	35	115	10	2	15	0	15	15	15	15	1	15	1	1	10	1	10	10	10	10	10	0	2835	10	10	10	10	10	1	10	10	10	2	2	12	3	203	103	0	0	3559
8	2	2	2	25	25	15	25	0	2695	35	25	24	25	1125	2	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	10	1	1	1	0	0	4078
9	2	22	50	15	15	15	15	900	0	2	2	2	2	12	2	2	12	12	12	12	12	12	0	12	12	12	12	12	12	12	12	12	12	2	2	90	2	10	50	0	0	1406
10	1	50	300	1	1	1	1	1	1	0	2520	1	1	1	1	10	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	2	110	590	30	710	300	0	0	4649
11	1	55	106	1	1	15	1	1	1	1720	0	1	1	1	1	65	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	0	110	2	270	30	0	0	2400
12	2	22	50	2	2	15	2	2	2	2	15	0	1080	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	2	2	99	2	27	45	0	0	1392
13	2	2	2	2	2	2	2	25	2	33	2	2074	0	1	2	2	2	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	10	1	1	1	0	0	2204
14	2	5	6	2	2	2	2	590	2	35	15	2	2	0	12	2	12	12	12	12	12	12	0	12	12	12	12	12	12	12	12	12	12	2	2	10	2	10	10	0	0	909
15	2	15	36	2	1	1	1	1	1	1	1	32	1	1	0	112	2	2	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	10	2	10	60	0	0	326
16	1	2	2	1	1	1	1	1	1	35	65	1	1	38	2	0	0	1	1	1	2	1	0	1	1	1	1	1	1	1	31	1	1	1	0	10	2	10	10	0	0	232
17	2	25	90	2	2	2	2	2	2	2	2	2	2	2	2	1	0	1900	2	2	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	90	2	110	50	0	0	2326
18	2	2	1	2	2	15	2	2	2	35	2	2	2	1	2	10	2500	0	2	2	2	2	0	2	2	2	2	2	2	1	2	2	2	1	2	10	1	1	1	0	0	2627
19	2	2	1	2	2	15	2	2	2	2	2	2	2	2	2	10	1	2	0	3025	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	10	3	2	2	0	0	3125
20	2	18	90	1	1	11	1	2	2	33	30	0	1	2	2	1	2	2	1600	0	2	2	0	2	2	2	2	2	2	2	2	2	2	2	2	27	2	18	45	0	0	1921
21	2	25	96	2	2	15	2	2	2	35	15	2	2	2	2	10	1	2	2	2	0	1600	0	2	2	2	2	2	2	2	2	2	2	2	2	50	2	20	10	0	0	1929
22	2	18	95	1	1	11	1	2	3	33	1	0	1	1	2	10	1	2	2	2	500	0	0	2	2	205	2	2	2	1	2	2	2	2	2	45	2	18	9	0	0	989
23	2	2	2	2	2	15	1200	2	2	35	2	1	2	1	2	10	1	2	2	2	2	11	0	2	2	202	2	2	2	1	2	2	2	2	2	11	3	2	2	0	0	1543
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	2	2	1	2	2	15	15	2	2	35	2	1	2	1	2	1	1	2	2	2	2	19	0	12	0	1	1	1	1	1	1	1	1	2	2	12	3	2	2	0	0	158
26	2	32	121	2	355	355	75	2	2	2	2	2	2	2	2	10	2	2	2	2	2	120	0	12	1	0	2	2	2	2	2	2	2	2	2	180	2	145	97	0	0	1553
27	2	5	7	2	2	15	2	2	2	35	2	2	2	2	2	1	2	2	2	2	2	19	0	12	1	15	0	300	1	1	1	1	1	2	2	50	2	20	50	0	0	573
28	2	25	90	2	2	2	15	2	105	2	2	2	2	2	2	10	2	2	2	2	2	19	0	12	1	15	1100	0	2	2	2	2	2	2	2	90	2	20	50	0	0	1600
29	2	22	81	2	2	2	2	2	105	2	2	2	2	2	2	10	2	2	2	2	2	19	0	12	1	1	2	10	0	1620	2	2	2	2	2	150	2	20	50	0	0	2149
30	2	5	7	1	1	11	1	2	2	33	1	0	1	2	1	1	2	2	2	2	2	19	0	12	1	1	2	10	1170	0	102	2	2	2	2	45	2	18	45	0	0	1516
31	2	5	7	2	2	2	2	2	2	35	2	2	2	2	1	1	2	2	2	2	2	19	0	10	1	10	2	10	2	10	0	830	2	2	2	10	2	10	0	0	0	1003
32	2	2	70	2	35	15	15	2	205	35	2	2	35	2	1	10	2	2	2	2	2	19	0	10	1	10	2	10	2	12	500	0	0	2	2	10	2	0	0	0	0	1027
33	2	45	140	2	35	15	2	2	2	35	2	2	2	2	1	10	2	2	2	2	2	19	0	10	1	10	2	10	2	12	2	2	0	450	2	30	2	190	80	0	0	1133
34	0	2	60	0	0	0	0	0	0	35	2	0	0	0	0	1	0	2	2	0	2	0	0	0	1	0	0	10	0	0	0	1	400	0	2	10	2	0	0	0	0	532
35	2	15	10	2	2	2	15	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2	0	10	1	10	2	1	2	2	2	1	1	2	0	10	0	0	0	0	0	121
36	2	0	30	0	0	27	0	0	0	90	1	54	0	0	0	0	20	10	20	45	20	27	0	9	10	135	0	0	0	9	0	0	0	0	0	0	100	100	0	0	0	709
37	3	20	20	18	18	81	18	90	135	242	45	81	18	50	20	40	80	20	50	67	50	45	0	18	30	315	0	50	22	36	0	0	0	0	0	250	0	0	0	0	0	1932
38	2	0	55	27	27	27	27	27	27	108	18	45	45	50	0	50	30	50	30	45	30	27	0	0	30	135	50	50	22	45	30	25	25	50	0	50	10	0	500	0	0	1769
39	2	0	0	27	27	27	81	27	27	180	40	81	81	90	90	0	90	0	90	67	90	81	0	27	0	99	0	0	0	0	0	0	0	0	0	0	0	755	0	0	0	2079
40	0	30	70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	130
41	30	30	70	0	0	2	0	0	0	20	10	30	20	20	30	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	40	0	322
Total	197	763	2053	264	1106	3762	1614	1834	3509	3852	2897	2585	1458	1615	216	526	2848	2216	2032	3548	887	2217	0	3143	182	1797	1290	642	1417	1833	799	982	538	675	170	2327	261	2935	1711	40	30	62771

Table D.2 – Origin-Destination Matrix for Trucks

	Destination Traffic Zones																																									
Origin Traffic Zones	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	Total
1	0	15	2	50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	71
2	15	0	0	0	6	3	5	9	5	60	2	10	7	0	0	0	0	0	0	10	0	5	0	5	0	15	0	0	8	2	0	0	0	0	0	0	0	0	0	0	0	167
3	1	0	0	0	1	1	3	3	11	28	2	11	3	0	0	0	0	0	0	10	0	6	0	4	0	16	0	0	6	2	0	0	0	0	0	0	0	0	0	0	0	108
4	50	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	56
5	0	1	1	0	0	330	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	336
6	0	1	1	0	53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	59
7	0	15	35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	315	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	369
8	0	1	1	0	0	0	0	0	255	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	261
9	0	3	6	0	0	0	0	100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	113
10	0	0	0	0	0	0	0	0	0	0	280	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	280
11	0	0	0	0	0	0	0	0	0	180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180
12	0	3	6	0	0	0	0	0	0	0	0	0	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	1	3	5	0	0	149
13	0	1	1	0	0	0	0	0	0	0	0	231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	237
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	2	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	2	5	0	0	23
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	2	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	1	2	1	0	0	22
23	0	1	1	0	0	0	120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	126
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
26	0	13	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	1	5	8	0	0	66
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	0	3	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180	0	0	0	0	0	0	0	0	0	0	0	192
30	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	130	0	0	0	0	0	0	5	1	2	5	0	0	145
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
36	1	0	0	0	0	3	0	0	0	10	0	6	0	0	0	0	0	0	0	5	0	3	0	1	0	15	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	45
37	1	0	0	2	2	9	2	10	15	27	5	9	2	0	0	0	0	0	0	8	0	5	0	2	0	35	0	0	3	4	0	0	0	0	0	0	0	0	0	0	0	141
38	1	0	0	3	3	3	3	3	3	12	2	5	5	0	0	0	0	0	0	5	0	3	0	0	0	15	0	0	3	5	0	0	0	0	0	0	0	0	0	0	0	74
39	1	0	0	3	3	3	9	3	3	20	5	9	9	0	0	0	0	0	0	8	0	9	0	3	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	70	63	105	58	68	352	142	128	292	337	296	281	146	0	0	0	0	0	0	46	0	31	0	330	0	107	0	0	150	194	0	0	0	0	0	53	14	23	33	0	0	3319