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INTELLIGENT TRANSPORTATION SYSTEM APPLICATIONS FOR URBAN COURIER MOVEMENTS

By

Omar Hussain Choudhry, B Eng (Civil)
Carleton University, Ottawa, Canada, 1993

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**INTELLIGENT TRANSPORTATION SYSTEM APPLICATIONS
FOR URBAN COURIER OPERATIONS**

submitted by
OMAR HUSSAIN CHOUDHRY, B ENG (CIVIL)

in partial fulfilment of the requirements for
the degree of Master of Engineering

Chair, Department of Civil and
Environmental Engineering

Thesis Supervisor

Carleton University
Ottawa, Ontario, Canada
October 7, 1996

ABSTRACT

The highly dynamic nature of pick-up and delivery operations results in tremendous potential savings in travel time and other associated operational costs through the implementation of Intelligent Transportation Systems. This thesis examines the potential savings which can be incurred from integration of current technologies used by governments and traffic management centres for data collection of traffic network conditions with route optimization, route scheduling and route guidance systems.

The examination was undertaken on a hypothetical network with varying intersection spacings, levels of traffic volume and service requirements. Findings indicate that while a dynamic route guidance system will demonstrate significant benefits, currently insufficient infrastructure is available to effectively derive this potential. In addition, due to the dynamic nature of courier operations, a route scheduling system will provide sufficient results to justify its use, if couriers receive service calls with a high frequency, close timing and centralized location.

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GLOSSARY OF ACRONYMS

AAPEX	Arterial Analysis Package Executive
AFMS	Advanced Fleet Management Systems
ATIS	Advanced Traveller Information System
ATMS	Advanced Traffic Management System
AVL	Automated Vehicle Location
CAC	Comprehensive Automobile Traffic Control
CBD	Central Business District
CCW	Counter-clockwise Routing Direction
CVO	Commercial Vehicle Operations
CW	Clockwise Routing Direction
DIAD	Delivery Information Acquisition Device (UPS)
DIALS	Delivery Information Automated Look-up System (UPS)
DTD	Door-to-Door Delivery Service
EDI	Electronic Data Interchange
FedEx	Federal Express Corporation
FTM	Freeway Traffic Management
FTMS	Freeway Traffic Management System
GDP	Gross Domestic Product
GIS	Geographic Information System

GVW	Gross Vehicle Weight
ITS	Intelligent Transportation Systems
JIT	Just-In-Time Delivery Service
LOS	Level Of Service
MC	Mobile Communications
MOE	Measures Of Effectiveness
NCHRP	National Cooperative Highway Research Program
P&D	Pick-Up and Delivery Service
PUIO	Pick-Up In Order
RMOC	Regional Municipality of Ottawa-Carleton
SORDS	Simulation Optimum Route Determining System
TSP	Travelling Sales Person
UGM	Urban Goods Movement
UPS	United Parcel Service
VRP	Vehicle Routing Problem
YTC	Yamato Transportation Co. LTD

GLOSSARY OF SYMBOLS

A	=	Service area (km^2)
c_i	=	Capacity of intersection i
C	=	Traffic signal cycle length
C	=	Vehicle load capacity or number of stops
f_a	=	Area type adjustment factor
f_{bb}	=	Bus blockage factor
f_g	=	Approach grade adjustment factor
f_{HV}	=	Heavy vehicle adjustment factor
f_{LT}	=	Left turn adjustment factor.
f_p	=	Parking lane and parking activity adjustment factor
f_{RT}	=	Right turn adjustment factor
f_w	=	Lane width adjustment factor
g	=	Green time assigned to approach link
L	=	Length of service area
N	=	Number of lanes on link
N	=	Number of vehicles assigned to area
P_A	=	Probability that the vehicle is available to service call
$P_{m,i}$	=	Probability of the dispatcher assigning a service call to

		vehicle m from the entire fleet
S	=	Average vehicle speed (km/hr)
s	=	Factored saturation flow rate
S_0	=	Ideal saturation flow rate per lane, 1800 passenger cars per hour per lane
t_m^*	=	Maximum travel time for a vehicle m
t_{sv}	=	Average vehicle service time
$t_{R\text{ AVL}}$	=	Average unit response time with AVL use
$t_{R\text{ NoAVL}}$	=	Average unit response time with no AVL use
t_T	=	Average travel time
V	=	Traffic volume assigned to arterial
w	=	One-half of the width of service area
ρ	=	Vehicle utilization rate.
δ	=	Spatial density of delivery points
δ_T	=	Savings in travel time
σ_ξ	=	Position error

CHAPTER 1

INTRODUCTION

1.1 Background

Transportation needs and issues have been the subject of study for centuries. However, significant societal and physical changes underlie the important role which transportation has undertaken in modern society. The movement of both people and goods has always been an important factor which has influenced the way in which cities are designed, how countries are developed and how the global economy has evolved. The role of transportation in the modern economic system is therefore undeniable.

A simple look at everyday life in any country around the world will illustrate the fact that without the ability for people and goods to be moved, life as we know it would essentially cease to exist. History shows that the development of trading centres served as a central location for the redistribution of goods produced by isolated communities, and later trading routes were created between the larger trading centres and now today's large metropolitan centres serve as both ports of transfer for intercontinental or international movements and as distribution and manufacturing centres for local areas.

It is in these large metropolitan areas, that now the majority of manufacturing, commercial and industrial development and production occurs. The substantial concentration

of employment and population base creates tremendous pressures on the transportation network. In both the developing and developed countries, it is difficult to find a single metropolitan area which is not influenced by the level of demand from automobiles, trucks, bicycles and even pedestrians to render transportation services. This tremendous demand pressure, in turn, can result in up to several hours of congestion and delay daily.

These transportation issues have been the focus of attention for transportation engineers and planners for years, as they attempt to develop methods to reduce traffic congestion. Public agencies are responsible for the construction and maintenance of transportation facilities which sometimes leads to officials taking the position that "people vote not products". Generally, their attention has therefore been geared towards that of passenger transportation, since the frustration and lost time felt by the average person is seen to be greater than the additional costs that result from increased goods transportation costs.

However, several studies have found that there is almost no difference in the costs of Urban Goods Movement (UGM), compared to passenger travel. A United States study (Kearney, 1976) found that the cost of UGM is approximately 5% of GDP, while a Canadian study (Lea, 1971) determined that freight transport costs range between 6% and 18% of income for cities small in size to those with populations of 2 million people and the costs of UGM increases faster than that for passenger travel as city size increases. Similar studies by the Bureau of Transportation Economics in Australia, published in 1978, and a British study by M. S. Hall in 1982 also support the two North American studies. (Ogden, 1992)

Meanwhile, private enterprises continue to operate under the premise that a profit is achievable in both the transportation of goods as well as people. Therefore, any additional

costs incurred by the company is generally incorporated into the product price and thus transferred to the consumer. These additional costs can be viewed in several ways. Roadway delays can result in a loss of productivity, increases in labour and fuel costs, and requires scheduled idling time to account for variations in arrival times. All these factors will inflate the product's final sale price.

In an ever increasingly competitive market place, it is the private enterprises which are attempting to discover new means of delivering their products at a lesser price and cost than their competitors. While most of the progress made within the goods transportation sector has been achieved through private enterprises, public agencies however, did focus on the movement of goods within an urban area during the 1970's and early 1980's.

Focus on the movements of commercial vehicles during this period has been demonstrated by the various regional travel studies conducted in Chicago, the examination of delay in the New York garment district and the development of parking and unloading strategies conducted in Dallas, Calgary and Ottawa. While these studies and demonstration projects are only a few examples of those conducted by public agencies, there is a need for greater attention towards the concerns of effective urban goods movement. One potential solution to some of the problems facing urban goods movement is the continuing growth in the use and development of Intelligent Transportation Systems (ITS).

The focus of the transportation industry therefore has been moving towards examining new technological solutions to problems. The field of ITS has been segmented into several key areas of research. These areas include finding solutions to reduce potential causes of accidents using sensors which determine headway and clearances between vehicles,

dissemination of real-time travel information to travellers to optimize travel time, and by managing current travel demand through roadway sensors for demand-responsive coordination of traffic signals. Of most importance to this research is the area of Commercial Vehicle Operations (CVO), which is also known as Advanced Fleet Management Systems (AFMS).

Through the use of satellite communications, vehicle tracking devices and automatic vehicle identification probes, commercial vehicle operators are capable of maximizing the use of their fleets, reduce costs and become more competitive. Unfortunately, much of this current technology has been focused on the needs of intercity goods transportation providers and has then left the development of intracity goods movement solutions to that of maximizing overall travel parameters. Another dilemma, which is encountered by those involved with urban goods movements, is the large variation in the operation and technological needs for the numerous goods transportation segments.

Urban goods movements can be categorized by the different types of operational sophistication and integration needed for effective service. These categories include dedicated distribution services, hazardous materials, regular line haulage, intermodal transport and courier pick up & delivery services. Characteristics of these different segments, create variation in benefits which can be derived from implementation of ITS strategies. For example, regular line haulage is generally regarded as a highly repetitive and predictable transportation segment which is capable of performing daily operations based upon a scheduled sequence of activities and therefore would not profit as much from ITS.

However, courier pick up & delivery services require a very high degree of

sophistication because of the low level of repetition and the small time horizon available for pickup and delivery operations. The courier industry has experienced continued growth during recent years around the world, and based on these facts, as well as the large variation in demand placed daily on the courier industry, the benefits of ITS implementation appear to be substantial for the courier pick up & delivery companies. For these reasons, a further examination into the actual potential benefits of ITS implementation will be conducted.

1.2 Review of Courier Industry

While the use of computers, fax machines and the Internet have continued to flourish in recent years, there has also been no slowing of the growth seen in the express/courier industry. There has also been substantial changes since the industry first began as a spin-off from the armoured car industry. Initially used for the transfer of cheques, it then became the source for the transfer of prescriptions, photo development labs and eye wear (Khan, 1982). Since then, the U.S. industry began gaining force in the 1960's and the three larger private firms, ie United Parcel Service, Federal Express and DHL, now carry over 3 billion parcels annually. These firms have expanded their operations world-wide over the years and, for example, have engaged in joint ventures with various Japanese firms and now control over 60% of Japan's international operations (Kawata, 1992).

Due to the highly competitive nature of the industry, the larger corporations such as United Parcel Service (UPS), DHL, Federal Express (FedEx), both the Canadian and United States Postal Services, in addition to Purolator Courier in Canada are reluctant to divulge any pertinent information which may allow their competitors to gain a tactical advantage.

Therefore, very little is actually known with regards to the actual state of affairs, e.g. the impact and costs of congestion on their operations and hence the potential benefits of Intelligent Transportation Systems upon the daily activities outside each individual corporation

However, there is some public information available regarding Door to Door Parcel Service (DTD) in Japan. The Yamato Transport Co., Ltd (YTC) reported that between 1988 and 1991, there was an increase of almost 36% in the number of parcels delivered and that the total industry had delivered over 1.5 billion parcels, an increase of over 33% from the 1988 totals (Kawata, 1992). While operational variations are found between the United States and Japanese industries, as a result of geographical, cultural and demographic differences, their main goal is still to deliver their services in an effective and timely manner. This has of course, prompted each corporation to develop their own distinct products which they believe will be of benefit to both their customers and their operations.

For many years, Federal Express has been using barcodes affixed to each package as a means of tracking each package and ensuring that it was sorted to the proper vehicle for final destination delivery. United Parcel Service has more recently developed the DIAD, an acronym for the Delivery Information Acquisition Device, which is a small hand held computer capable of providing the necessary package information in addition to recording the signature of the customer. This technology has provided the organization with the ability to essentially eliminate all paperwork from the delivery process. Both these organizations are also now providing customer information services where the status of each package can be traced to its last known travel point, thus ensuring customers of reliable on-time delivery.

1.3 Rationale for Research

When operating in a service oriented market, it is absolutely necessary to provide the service in a reliable, effective and cost-efficient manner. The courier industry has continually progressed towards improvements in providing reliable, customer oriented service at reasonable rates. There are however, several factors which inhibit further reductions in delivery rates. Urban areas are increasingly suffering from traffic congestion due to a variety of reasons and since the majority of courier services operate within urban areas, the running time of delivery vehicles during and between pick-up and delivery (P&D) activities plays a major role in influencing the rates charged to customers.

Generally, these P&D activities are even further concentrated into areas of heavy commercialization such as a central business district (CBD) which are most affected by roadway congestion. Most pickup and deliveries occur during regular business hours with access and egress from the depot to the delivery area occurring during peak traffic hours.

The move towards more dynamic, real-time traffic information gathered by government organizations will allow drivers to be informed of congestion areas, road closures or any other incident which, without its use, would result in significant delay to be incurred by drivers. The use of Advanced Traffic Management Systems (ATMS) will therefore greatly assist the public and industry to increase efficiency in travel operations.

Secondly, the courier industry operates in a very dynamic market area, whereby new P&D orders are obtained on a continual basis through the working day. To service all these orders, the dispatch center must be capable to communicate quickly and relay accurate information to the drivers. A single channel, two-way radio or the use of a pay-phone call to

dispatch were once the only two viable methods for the dissemination of information. However, recent advancements in data communication devices have increased the potential for improved efficiency for courier operations. These areas, known as Advanced Traveller Information Systems (ATIS) and Mobile Communications (MC), provide the opportunity for organizations to modify and streamline operations for most effective service.

Therefore, any benefits which can be achieved through the multiple categories of ITS will allow courier companies to reduce the charges levied per package and ensure the viability of their organization. With the study of urban goods movement not having been thoroughly conducted by public agencies in the majority of urban centres, let alone a study of courier operations within a city, it was felt that such an examination would provide useful information for courier companies as well as larger urban freight organizations.

The methodology remains essentially the same in the analysis process between goods transporters whether they be less than truck-load, container, intermodal or courier organizations. The difference in benefits is expected to be more pronounced in the courier companies due to their requirement for continually updated scheduling or routing of activities, the larger number of daily activities than the other types of goods movement organizations, in addition to the constant interaction between courier and other vehicles.

1.3.1 Problem Definition: Needs of the Courier Industry

The courier industry, sometimes referred to as the express delivery industry, initially began as an off-shoot of the armoured car service for the delivery and transfer of cheques between banking institutions (Khan, 1982). Since then, the courier industry has flourished

into a door-to-door next day delivery service of parcels ranging from business documents to packages of approximately 75kg. With the pick-up and delivery locations of the various packages ranging from rural to suburban and urban areas, significant differences on operations occur including the methodology for delivery, road geometric conditions and the effects of vehicular and pedestrian traffic.

Unlike many of the sectors involved with the delivery of goods, the courier industry is subjected to a very low rate of repetition and a high expected rate of accuracy. In addition, there is a tremendously small time horizon which must be adhered to with the continuous influx of new pick-ups requested. Due to these factors, technology such as vehicle location and identification can help in maximizing the number of pick-ups made for the company in general and will be studied.

The applicability of improved communication technology is also of great importance to the courier industry. With continuous requests for service, the courier industry requires an ability to timely inform the drivers of new pick-up locations and for drivers to provide the control centre with a log of those packages which have been received. Therefore, this report will examine the needs and benefits which can be derived from improved communication technology.

The industry suffers from the effects of operating and interacting with vehicles and pedestrians in the urban or central business district of every city. These centres generally have the highest concentration of workers and business offices, and thus are most affected by the competition of road space. Significant congestion and delay is typically observed in the CBD during the morning and afternoon peak periods due to vehicular traffic from workers on the

home-based work trips and demonstrates a peaking during the noon period from both vehicular traffic and pedestrians. It is here, through the use of real-time traffic information from the traffic control centres being instituted by different levels of government, it will soon become possible to choose routes which will minimize idling time and operational costs.

In suburban areas, the operational characteristics are far more dependent upon the typical demand observed and the layout of the road network. Unlike the usual grid patterns and high market density found in the downtown cores of most North American cities, suburbs are typified by large areas of low density residences on discontinuous, random and maze-like roads. Courier operations generally are not hindered by congestion in these areas and thus real-time traffic information plays a less significant role.

However, dynamic route guidance systems linked to both an ATIS device for speedier data transmissions and a route optimization program would provide greater benefits. Similarly, courier operations in rural areas would most generally be influenced by timely data communications route optimization and route guidance systems due to the large distances between parallel roadways.

1.4 Scope and Objectives

In examining the courier industry's operational characteristics, it was discovered that several key areas in this industry could benefit from increased use of Intelligent Transportation Systems. The courier industry has attempted to reduce the effects of congestion on their operation by means of shifting the major portion of the trunk-line transportation to off-peak hours. Yet, there remain periods such as the tail end of the

morning rush hour, the noon-hour peaking of traffic and the majority of the afternoon congestion which continue to cause inefficiency in their overall operations of the courier industry.

This high daily interaction, along with the conflict of providing reliable and cost-efficient service against the needs of other vehicles is one major obstacle which warrants investigation. By examining the impacts of congestion on courier activities and the potential of new operational strategies resulting from technological advancements in reducing these impacts, some understanding towards the recoverable costs can be determined. This will be done through the assessment of the use of Commercial Vehicle Operation (CVO) technologies for the courier industry.

Secondly, due to the low level of repetition in activities and small time horizons available, the need for mobile data and information transfer to relay new pick up and delivery activities along with any other pertinent information becomes a powerful tool in increasing operational efficiency over current radio communication devices. This can be performed through a detailed investigation of the available Advanced Traveller Information Systems (ATIS), their applicability to the courier industry and the potential problems which they will help to alleviate.

Finally, the ability to gain advanced knowledge of current roadway conditions, in conjunction with other information from devices such as a dynamic routing system will improve travel time between courier activities and hence reduce idling and running times, fuel costs and potentially labour and vehicle maintenance costs. The combination of ATMS, ATIS and CVO is required to integrate and maximize the potential benefits of each technology for

the overall benefit of the courier industry.

With the various potential benefits available through the introduction of ITS, the next step is to justify the use of these systems by conducting an analysis of daily operations. This could be performed through the study of activities on both a hypothetical network and by actual case studies.

However, companies have not been willing to divulge information which could be used as a tactical advantage in the highly competitive courier industry. Review of demonstration projects, current literature and any available actual data will therefore be used as a basis for this research.

Thus the main objectives of this research are:

1. To investigate and determine the potential benefits of courier vehicles having real-time traffic information;
2. to assess the use of this traffic information in combination with a dynamic route guidance system;
3. to study the applicability of mobile data communications between the dispatcher and driver for the transmission of new pickup locations;
4. to determine the effects of route optimization techniques for the scheduling of activities both using and not using current traffic information; and
5. to study the impact of traffic volume on the potential benefits accrued from the above objectives for a courier vehicle operating at both a metropolitan and CBD level.

1.5 Research Framework

The expectations and plans for the use of Intelligent Transportation Systems are high and tremendously far reaching. Visions for the future of transportation include completely automated highway systems with self-conducting vehicles having the ability to determine the optimum path for a given set of user defined origin and destination points. While technology has not quite yet reached this point, the availability of products to locate and identify individual vehicles, transmit two-way voice and data communications and manage traffic volumes on major roadways are quickly moving towards that goal.

There are many products currently available to industry and government which will aid in the progression towards full ITS implementation. Modification of signal timing plans have historically been the main instrument used by traffic engineers to reduce congestion within the road network. In recent years, Freeway Traffic Management Systems (FTMS) have been the main focus from governmental organizations, in an effort to maximize use of the freeway facilities. Operational FTM systems are found around the world, from Tokyo to London and from Los Angeles to Toronto. These systems are the first step towards the Advanced or Area Traffic Management Systems (ATMS).

Such systems are the backbone for the entire Intelligent Transportation System concept. Through the availability of current traffic information from collectors, arterials and freeways, the organizations operating the ATMS will be initially capable of modifying the traffic signalization system to accommodate the prevailing demand as a means of reducing the overall delay of the roadway network. Using the data from prevailing traffic conditions, dynamic route guidance systems may be either controlled by the central computer system and

therefore maximize the overall system's operation or by the in-vehicle computer which would attempt to minimize the travel time or travel cost for that individual vehicle. The use of these technological innovations for various organizations and industries can only help to streamline operations and reduce costs.

This potential savings is no different for the courier industry which suffers daily from roadway congestion in urban areas. Thus, an investigation into the types of products which can benefit the industry and the overall society, through reductions in operational costs is necessary. The implementation of such systems requires investment in infrastructure by both private industry and the various levels of government.

Since there is little information available and there is some reluctance from private enterprise to invest the required capital in technology which has not yet fully demonstrated its potential benefits, in addition to the fact that governments have been slow in implementing their portion of the required infrastructure, there are few demonstration projects which encompass the scope required for this study.

It must also be noted that the majority of pilot projects involving commercial vehicles have been relegated to rural situations, while urban applications have been focused more on the benefits which can be accrued by the overall traffic stream. As such, it is difficult to perform a comparison of the benefits of any proposed system for the courier industry with observed results from these demonstration projects.

The only project which involves, to some effect, many of the areas considered in this thesis is the field tests to be performed by the Center for Transportation Research at the Virginia Polytechnic Institute and State University titled Commercial Fleet Management.

However, this project will not start until October 1, 1996.

The investigation of the provision of real-time traffic data to companies, so that information such as recurring congestion levels and incident induced congestion locations can be used to re-evaluate the current routing schedule would also be of benefit to the courier industry. If this information is not used to optimize the routing schedule, it could otherwise be used for determining the most cost-effective route to a given destination by means of a dynamic route guidance system. Use of both variations will be analyzed to determine the potential benefits which could be incurred.

Another vital component of the ITS concept is that of data communications. Often referred to as Advanced Traveller Information Systems, the provision of required data to a user, be it store locations, transit schedules or the pre-planning of trip routes will be a powerful tool to the public. Technology has recently provided a means for the transfer of two-way data communications, by means of digital radio transmissions using either the cellular or other dedicated frequencies (Hetu, 1994).

Thus, the courier industry is capable of transferring information regarding new pick-up locations to the appropriate delivery vehicle and driver, and for the driver to inform the control centre of the completion of individual tasks. This provides the companies the knowledge that a package has been received for delivery and begin to track the progress of the package from origin to destination.

The use of two-way communication technology by all service oriented industries will virtually eliminate all needs for telephone call-ins from drivers. This procedure was once in place so that drivers could be given the location of new pick-ups and provide the control

centre with an update as to the packages that have been obtained. With the new technology, reductions in down time can be seen from drivers, which translates into an increase in the number of courier activities which can be performed.

However, individual applications have been instituted in various pilot projects around North America, Europe and Japan. The combination of the results found at these sites will provide the basis for studying the effects of ITS implementation on the courier industry in the hypothetical networks. The general research framework is illustrated in Figure 1-1.

Due to the wide variation in surface street layouts, traffic demand levels and levels of operation for courier companies, as well as other urban goods movement organizations, several hypothetical networks will be used as a basis for the analysis. Using the well-accepted traffic modelling package TRAF-NETSIM, and specifically the NETSIM and NETFLO models, a full traffic analysis of the effects of roadway conditions, in combination with implementation of the ITS technologies, will be conducted to provide the necessary traffic stream information. In using this procedure, the applicability of the results can be used for a large number of cities and locations.

To ensure realistic operational characteristics for the hypothetical networks, an iterative process will be used between the TRAF-NETSIM package and the PASSER II-90. By initially using a 50/50 cycle split, both packages will be executed to determine a signal timing plan which minimizes overall network delay. This goal and objective would be similar to that being sought by local traffic operation centres.

The analysis will demonstrate the benefits that could be achieved by means of

Figure 1-1 Research Framework

implementing the various technological applications within the courier/express delivery industry. The study encompasses the use of real-time traffic information for route guidance by investigating the effect of the timely provision of roadway conditions such as congestion and incidents on the operational characteristics of courier companies.

In addition, the introduction of improved communication technology will provide both information concerning new service calls as well as the use of route scheduling software to determine a more cost-efficient route plan will be studied. The examination will be performed by studying the effects of the volume to capacity ratio on the results, which will provide a basis for use of the results in a multitude of situations and locations. The potential benefits which will be achieved by courier companies who invest in ITS technologies include savings in fuel, labour and maintenance costs, increases in operational efficiency and increases in business.

Benefits which would be seen by the general public include reductions in vehicle emissions, fuel and maintenance costs and improved traffic stream operations. However, the focus of this thesis will be the benefits of implementing the various ITS technologies to the courier companies alone. This will provide an indication of the cost recovery ability which could be expected after implementation.

1.6 Thesis Organization

This thesis is divided into eight remaining sections. First, there is a description of the method in which this thesis topic will be evaluated. Secondly, an investigation of the current status of the courier industry will be conducted to determine and provide the necessary

background to their current operating effectiveness, advancements in the foreseeable future and institutional constraints which affect them. In addition, Chapter 4 includes a detailed description of the current urban traffic conditions which will, in part, highlight the historical growth patterns of traffic and other related parameters, the effects of city size on traffic and the impacts of some city by-laws and regulations which negatively effect both the goods movement industry and the general traffic stream. An investigation of the new and innovative Intelligent Transportation Systems products will then follow.

The next stage involves the modelling of a hypothetical network and traffic stream to determine the potential benefits of the implementation of ITS technology. This will be done using a range of volume to capacity ratios and a range of delivery operation characteristics as a means of reproducing a number of possible real-world situations. The benefits brought forth by implementation of different ITS technologies, will then be studied. Finally, recommendations and future directions will be discussed.

CHAPTER 2

URBAN GOODS MOVEMENT

2.1 Introduction

Over the years, the main focus for freight transportation has been the flow of goods and materials on an intercity basis and its effect on the transportation network outside urban areas, especially on freeways and highways. However, with increased congestion in our major urban centres and greater competition in business, the need for investigation of the effects of congestion on urban goods movement and the costs of transporting these items on the other road users has become far more apparent.

While daily passenger travel in urban areas tend to demonstrate higher demand, or peaking, during the weekday morning and evening home-based work trips in most regions of the world, freight transportation demand is much more dependant upon the type and strength of business activity in a city or area's economy. For example, in industrial and manufacturing districts, one tends to find a high level of demand for the larger and heavier products which would typically be serviced by heavy vehicles. While in the downtown or CBD, there is more likely to be a need for the smaller, lightweight trucks to pick up or deliver packages and parcels.

Freight transportation is the term commonly used when referring to the transportation

of both raw materials and manufactured goods along with the distribution of wholesale and retail goods (Jones, 1995). It can also be segmented into several categories such as regular-line haulage, tramp haulage, intermodal transport, dedicated distribution service and courier/pick-up and delivery service (Schmeck, 1992). Although each of these segments involve both intercity and urban components of freight transport, dedicated distribution service and courier/pick-up and delivery service generally involve a far more significant component of urban goods movement.

The simplest definition of Urban Goods Movement is the portion of freight transport dealing with the movement of any finished good within the urban environment to its market. Therefore, UGM encompasses an extremely broad range of products, from food to delivered packages and from clothing to cars. Each product and the manner in which it is transported is as diverse as the types of products themselves, yet the concerns and considerations are remarkably similar.

The organizational structure of the industry involved and 'perishability' of a product plays a major role in determining the need for repetition and sophistication in its transport. There are three main areas in which gains can be made towards streamlining organizations for increased efficiency and effectiveness, those being at the freight and logistics management level, the fleet management level and at the vehicle management level (Schmeck, 1992).

Logistics, in most goods transport sectors, has become one of the primary focuses for reform and modifications by means of on-line tracking of shipments, computerized data exchange and paperless invoicing, but the move towards fleet and vehicle management changes has been much slower for most of the transport categories mentioned above.

For some, the operational conditions do not require substantial changes and for others, the costs of technological equipment for automatic fleet monitoring and vehicle positioning, on-line route planning, dynamic route guidance and digital communications are not seen as being offset by potential benefits. Just-in-time (JIT) delivery is one of the spin-offs of this business revolution and has become common place in countries like Japan.

The tremendous land prices inhibits companies from expanding their warehousing facilities. This has led companies towards maintaining only a limited supply of raw materials which are now supplied at a more frequent rate. Other examples of the movement towards JIT delivery is that of hospitals and grocery stores, where the supply of certain medical products are ordered from suppliers on a "as needed" basis and foods with shorter shelf lives are transported in smaller, but more frequent shipments.

Generally, the topic of goods transportation is associated with large trucks such as the semi-trailers and double trailers seen upon the majority of freeways. These vehicles play a major role in the movement of goods in an intercity and even an international role. In some North American cities, the busiest of freeways are capable of observing truck percentages near 20 percent of daily traffic (Jones, 1995).

However, their impact on the urban distribution of goods, in terms of both volume carried and kilometres operated is relatively small. Most metropolitan goods movement is associated with the distribution of wholesale goods for retail sale, package delivery, fresh produce and the hauling of manufactured goods to depots. Trucks account for approximately 4.2 percent of vehicles on the road during the peak commute hour, with big rigs accounting for only about 1 percent of the peak hour total in the San Francisco area. (Jones, 1995)

The Chicago Area Transportation Study (CATS), conducted in 1986, found that the total truck population was about 360,000 (Rawling et al., 1987). When this total is segmented by gross vehicle weight (GVW), it is further discovered that 80 percent of the trucks, or approximately 280,000 trucks, have a GVW under 28000 lbs (12.7 tonnes) and thus considered to be small or light trucks and vans.

This type of information becomes very important in identifying the shift in operational characteristics of urban goods movement. For the distribution of goods, the use of smaller vehicles which are suited for operations on city streets, minimizes the impact of congestion and makes parking availability and timely off-loading more important criteria for operational efficiency (Jones, 1995).

2.2 Background of the Courier Industry

The courier industry is both a complex and mysterious industry, where competition between companies is the driving force towards improving operations. In North America, the industry is dominated by the two major private organizations, UPS and Federal Express, and the post offices in Canada and the United States. However, these industry giants are mainly in control of one of the major segments of the package delivery service. While nearly controlling the overnight or next day package delivery component, there are hundreds of small companies which compete for one of the other main categories, that of customers requiring same day delivery.

The package delivery industry can trace its roots to the armoured car industry (Khan, 1982). The pick-up and delivery of money between banking institutions required that a

secured transportation vehicle with three guards perform the required duties. As the use of cheques increased, the need for such security measures in the transfer of cheques had dispelled. The work could be performed by single person, without the risk of theft. It is from here that the courier industry was formed.

It soon became apparent that there was a possibility of courier operations being used for the transfer of goods in the medical and pharmaceutical areas (Khan, 1982). Eventually, the delivery of business and legal documents began to play a more important role in the industry and it has since expanded to include packages and parcels upto about 75 kilograms. The industry began in the late 1960's in the United States, and about 10 years later expanded into the Japanese market.

There are over 1.5 billion parcels delivered annually in Japan and over 3 billion in the United States (Kawata, 1992). The Canadian market is itself substantial, with total sales of approximately \$1.4 billion in 1991, of which about 85 percent is in the domestic market and the remaining 15 percent composed of international sales as shown in Figure 2-1 (ISTC, 1992). With this level of volume, there is clearly a need for optimizing performance characteristics and streamlining operations.

It should be noted that this industry combines both an intercity goods movement and intracity or urban goods movement component. Thus, while there are certain operational characteristics unique for each country or continent, which deal with the transfer of goods and the associated difficulties of transportation between cities, there is also a very key component of the problems faced during the operational phase within the city.

Over the years, innovative technologies and improved logistics have changed the face

of the industry. When customers used to call, operators would wait until several pick up orders had been obtained before using the two-way radio system to contact the appropriate drivers. This meant a delay in performing the required tasks, errors occurring in the transfer of information from dispatcher to driver and that during the busier hours, some customers would be placed on hold and it would take dispatchers significant periods of time to contact a driver because of an overload on the communication system. The tracking of packages was dependent upon the flow of paper documentation and the use of computers was minimal, if not absent

Figure 2-1 Courier Market Distribution - 1991

Source: ISTC (1992)

2.3 Operational Characteristics

The industry has seen substantial changes since its inception. The development of portable computer systems, satellite communications and the creation of industry specific, customized delivery trucks are just some of the innovations which have been integrated into the courier industry. Unlike the majority of other urban goods movement sectors, the courier industry faces some quite unique and challenging obstacles, including a low rate of repetition and the need for a high level of fleet management. While the JIT operator is also faced with similar challenges, they typically are dealing with a well defined market and most frequently with the same clientele, whereas a courier operator would more often deal with a greater number of occasional customers.

2.3.1 Logistics Factors

This fact lends to the credence that the courier operator requires a higher level of flexibility in the management of its fleet. Another restriction which is placed upon the courier industry is the small time horizon available for the completion of its activities. In order for companies such as Federal Express and UPS to consolidate, sort and redistribute the packages under its care, all pick-ups must be made by approximately 5:00pm to ensure delivery by the following morning. Both organizations have created "superhubs" in the midwestern United States, where all packages are sent for processing and sorting, after which the packages are flown to their city of destination. This configuration is shown in Figure 2-2, where packages collected and due for distribution to local, intercity and international locations are processed.

Figure 2-2 Courier Operations and Services

In order to maintain a record on the location of packages after pick-up, the use of a bar coding system with scanners at various check points, such as at the time of pick-up, consolidation, arrival at the superhub, throughout the sorting process and after arrival at the destination city affords the companies with the opportunity to allow customers to monitor their package's progress. This customer service allows the companies to maintain the confidence of the clientele and hence keep their business. UPS and Federal Express each receive almost 100,000 calls from customers daily for purposes of tracking a parcel.

While there has been tremendous effort placed into increasing the efficiency of the transportation and transfer process once out of the urban transportation network, there still

remains significant progress to be made in improving the urban component. The largest factor which affects the efficiency of courier operations within an urban area is the interaction of delivery trucks with other roadway vehicles and with pedestrians.

As cities continue to grow, both in area and in population, there will be a corresponding growth in the extent of congestion on our roadways. In addition, the shift towards a more service oriented economy will increase the need for courier-type services within metropolitan areas. This will only exacerbate the problem of congestion on the transportation network and lead to further inefficiencies. The observed congestion generally is attributed to recurring or travel demand congestion, however, there is also considerable delay caused by weather conditions which hampers driving in northern climates and from non-recurring or incident congestion. These areas will be focused on later in the thesis.

2.3.2 Site Factors

Other operational characteristics are dependent upon the availability of loading and unloading areas at the pick up or delivery site. As the roadway infrastructure within the CBD has required expansion, we have seen more use of conditional parking restrictions on our downtown streets to allow for the conversion of 'parking' lanes into travel lanes during peak periods. This permits an increase in the vehicle capacity of our roadways within the confined right-of-ways of our downtown areas. However, it also limits the time in which the availability of on-street parking is permissible.

Courier vehicles, along with other urban goods movement vehicles, require areas for the loading and unloading of goods. Typically, this need is addressed through either an off-

street or an on-street area. However, there are often difficulties associated with each of these two methodologies. The first is the availability of space for the vehicles. With regards to off-street areas, there are some observable benefits such as:

- a reduction in costs of delivery,
- improved security for vehicles and goods,
- curbside locations are available for other uses,
- a reduction in on-street congestion and
- car parking spaces are not used by delivery vehicles (Ogden, 1992)

However, there is often both an unwillingness by developers to provide such areas which become unleaseable and an insufficient use of these facilities unless the drivers foresee a time benefit that can be derived. The first problem is usually addressed by city laws requiring a minimum number of spaces. It has also been reported that use of off-street facilities in office buildings often range between 70-90 percent of trucks servicing the location, with higher percentages for industrial sites and department stores (Habib et al., 1978). A large percentage of the trucks not using the off-street facilities are usually courier vehicles (TTM Consulting, 1987).

For many buildings which serve as primarily office type buildings, there are typically on-street loading and unloading zones located on a single bounding roadway. This often results in either the courier vehicle operators being required to use more circuitous routes to arrive at the next destination, which in turn yields higher transportation operation costs, or the alternative sometimes chosen by the operator is to stop in a travel lane and leave their hazard lights flashing because of the intended short service time. Observations from a

downtown Brooklyn study found that 98 percent of all pick-up and delivery vehicles were parked within 30 metres of the destination and that if curbside parking was not available, the driver would simply double park the vehicle (Habib et al, 1976)

For courier operators, the need to expedite the courier activity will often force the operator to act as required to minimize servicing time for each location. Thus, if double parking is required for the 3 to 5 minute average service time, the operator will do so. This type of action is also observed in suburban residential areas, where the delivery vehicle simply stops on the roadway and does not enter the house driveway.

The use of travel lanes for stopping by delivery vehicles poses two major traffic problems. The first is the additional costs borne by other roadway vehicles from the blockage created by the parked vehicle. The second is the congestion, fuel and time costs for other vehicles that must be considered, in addition to the potential for accidents due to the required weaving procedure of other vehicles to manoeuvre around the parked vehicle. In research conducted around curbside facilities in Manhattan, the interference caused by double-parked trucks was found to be dependent on the traffic volume. It was concluded that if volumes exceeded 900 veh/hr and truck operations were greater than 50 per hour, curbside loading zones were required (Habib, 1981).

Due to the random nature of the arrival and departures of delivery vehicles from loading areas, the length of time required for stopping and the variation in the size of the delivery vehicles, there is also the potential for inadequate stopping or parking locations. During peak periods, these loading areas are sometimes full and therefore force the delivery vehicles to block a through travel lane (ie. double park).

These actions by trucks can cause significant congestion problems. Modelling of the effect of downtown urban pick-up and delivery operations performed by Habib (1981) estimated that even a minimal level of operation could reduce the effective throughput of a street by approximately 12%. Other research estimating the effect of trucks blocking a single lane on heavily used US urban roads found that a typical pick-up and delivery stop of 12 minutes could result in up to 17 vehicle hours of delay for other vehicles (Kearney, 1975).

2.3.3 Fleet Characteristics

It is also very important to investigate the operational characteristics of the courier industry with respect to the fleet of vehicles. Factors such as the level of utilization, length of stoppages and the effects of size, density and congestion of metropolitan areas on courier operators are significant to their overall efficiency. Through the use of some operational strategies, efficiency gains have been made by maximizing off-peak hour deliveries, improvements to the vehicle themselves and consolidation of certain operations. However, there is still many potential areas for gain.

Truck usage is a major component of inefficiency for trucking in general. The 1986 Chicago study found that the average daily distance travelled increased with vehicle size and the same was found to be true from average number of daily trips with the exception that heavy trucks had the least number of trips, as is shown in Table 2-1.

The measure of truck usage can also be done through the analysis of the time spent travelling. A US study conducted in 1969 indicated that the average utilization of trucks was approximately 175 minutes per day, with light trucks spending more time at rest than heavier

trucks (Smith, 1969). While this may appear counter-intuitive due to typically longer loading and unloading times for heavier trucks at a single site, light trucks, such as those used in the courier industry, have a substantially greater number of short service stops on a daily basis and can therefore cumulatively lead to a large period where the truck is at rest.

Table 2-1 Truck Usage Patterns By Truck Type, Chicago, 1986

Truck Type	Average Daily Distance	Average Daily Trips
	(km)	(number)
Small trucks and vans	90	6.9
Light trucks	91	7.9
Medium trucks	116	9.3
Heavy trucks	173	5.9

Source: Reilly, Rosenbluh and Rawling (1987) p. 36, 41 ; cited by Ogden (1992)

The length of a stoppage will also have an effect on the overall productivity of the organization. Naturally, stop time is dependant upon several factors, such as the size of load, size of truck, type of load (ie containers, pallets or individualized items) and access to delivery and pick up areas. Studies conducted in various US cities found this dwell time to typically range between 15 and 25 minutes (Christiansen, 1979). For the courier industry, it is generally accepted that service times range between 3 and 5 minutes in duration. Only with the innovations brought forward in the areas of dealing with packages such as bar codes, data communications and paperless invoicing, has it been possible to reduce the time required to service each individual package to the 3 to 5 minute range.

Another major effect resulting in operational inefficiencies is the size of the urban area. Many organizations operate using a central warehouse or distribution centre for all activities in a single metropolitan in order to maximize efficiency and cost effectiveness in certain processes through economies of scale. As a result, larger cities require greater stem times, considered as the time from the terminal to the first delivery point, in addition to greater travel distances to complete deliveries. When stem travel is performed during peak-hour traffic, substantial delay and hence larger stem times are incurred which leads to a reduction in the number of service calls which can be undertaken by an individual driver.

In addition, there is a variation in the costs of delivering goods depending upon the environment. It was found that for metropolitan Toronto, freight delivery incurs a 25 percent increase in costs in an inner suburban area relative to delivery in a suburban area, a 46 percent increase at the fringe of the central district and is 2.6 times as much in the city centre. This is due to stop and go conditions being 3 times higher in the city centre and that 40 percent of the increase in stops and starts were caused by congestion. (Barnstead, 1970).

City density also effects the costs incurred in freight delivery through greater congestion. While both density and congestion effects will be further examined in Section 3, it is important to note that each have a significant impact. Data from the US in the 1970's indicated that if delivery of a package in Nashville were to cost \$1, then it would cost \$3 in Washington and \$5.70 in New York City (DOT, US, 1973). These figures demonstrate the relative effect of both city size, density and congestion on the overall costs of delivery operations.

2.4 Current Technology and Operations

In order to determine the current state of technology and procedures used in addressing the additional costs borne by the various organizations, including delay, labour and fuel costs, an attempt to contact UPS, Federal Express and Purolator Courier of Canada was undertaken. Purolator Courier indicated that, while interested in the research, they would be unable to make available much of the information due to limited resources.

UPS stated that due to the competitive nature of the industry, the requested information could not be provided. Both letters are provided in Appendix A. There was however, some general information regarding some of the current technology used in the areas of data communications, vehicle routing and Geographic Information System (GIS), which was acquired at the 75th Transportation Research Board Annual Meeting in Washington D.C. as well as from other research reference material.

2.4.1 Electronic Data Interchange

For several reasons, including the highly competitive and specialized nature of the industry, there is a significant amount of research and development which is conducted by the individual companies for the purpose of operational improvements. Since 1986, the development and use of the advanced logistics has been a key area of focus for UPS. They have seen a tenfold increase in the number of technical employees and a twenty-fold growth in the number of personal computers.

The innovative use of bar codes and scanners to monitor and track the progress of each package, along with the introduction of the Delivery Information Automated Look-up

System (DIALS) to reduce claims and locate packages have improved operational efficiency and customer service (Winters, 1995a)

In order to accelerate access to information within the organization, UPS has also developed the Delivery Information Acquisition Device (DIAD). This portable and hand-held mini-computer is capable of sending and receiving package information from the central computer through an adapter unit in the vehicle and electronically stores a customer's signature. Such innovation has virtually eliminated the need for paper delivery records and therefore added an additional safe guard towards the assurance of a package's delivery. (Winters, 1995a)

2.4.2 Vehicle Location and Routing

Intercity trucking has long used computerized scheduling and routing in operations. In research conducted at the University of Texas at Austin regarding the use of real-time information for route diversion due to new orders in a truckload operation, it was found that savings of over 12 percent in travel distance can be achieved for truckload movements serviced based upon a travel distance minimization optimization (Regan et al, 1994)

After discussions with trucking company operators, it was found that Automatic Vehicle Location (AVL) and two-way communication systems were the most important for carriers operations when demand location and magnitude were highly dynamic (Regan, 1993, cited by Regan et al., 1994). However, the level of detail and complexity of urban area travel does not allow for these procedures to be easily transferred to urban delivery operations (Hsu et al., 1988).

This area of work has been one of the main focal points for research for those involved in delivery operations. The problem can be defined as:

- A set of delivery or pick up orders,
- A set of available vehicles,
- All relevant cost information, and
- Various cost constraints,

used to finding the minimum total costs for the assignment of routes, orders and the sequence of those orders to specific vehicles (Hsu et al., 1988).

The results of such actions would be a reduction in the number of vehicle miles driven, lower fuel costs, lower maintenance costs, reduced driver costs, possible increases in the number of pick-ups per route and the possible reduction in the number of vehicles and drivers needed (Hsu et al., 1988). One such system has shown an average savings of between 5 and 15 percent for the fleet operating cost and upto a 28 percent increase in revenue per mile (Fripp, 1985 cited by Hsu et al., 1988).

Another important factor in vehicle routing is that of sequencing orders, since simply taking orders on a first come first served basis may lead to substantial retracing of vehicle paths. Thus, the sequence of the orders plays an equally important role in the operational efficiency of a delivery operation. There is typically three methods for dispatching orders and routes to specific vehicles. The first would be a simple manual procedure conducted by the dispatcher, the second would involve the use of a order sequence program for each route and the third uses a combination of route grouping and order sequencing to maximize efficiency.

One such field study demonstrated, as shown in Table 2-2 that a more sophisticated

computer optimization procedure could reduce total mileage by 16 to 26 percent, while the lesser would improve total mileage for vehicles by between 11 and 20 percent over simple manual solutions (Hsu et al., 1988).

There is also a proportionate amount of technological innovation created for general use which is used by courier companies. UPS has recently begun the use of Geographic Information System (GIS) for the planning of routes and for vehicle loading. The benefits of using such systems have been seen in the reduction of vehicle mileage, fuel consumption, traffic congestion and the multitude of environmental effects. These findings have prompted the development of ROADNET, a pair of pilot projects in Chicago and Baltimore, where small fleets of vehicles are used in the same metro area daily. (Winters, 1995a)

Table 2-2 Field Test Results Of Computer Optimization

Case	No. of Stops	No. of Routes			Total Miles		
		A	B	C	A	B	C
1	144	9	9	9	570	445	421
2	157	8	8	8	1214	1078	1013
3	130	7	7	7	695	586	532

Notes: Solutions used : A = manual routing; B = resequencing of manual routes; C = computerized routing. Source: Hsu et al. (1988) pg 31.

The preliminary indications have been that the performance and accuracy of GIS is not yet good enough for the desired purposes. UPS has therefore undertaken a five year development project to collect data, survey routes and record streets, addresses and densities for the purpose of future integration into their operational system (Winters, 1995a).

However, with new technologies of data capture, map making and data analysis, improvements to GIS applications continue to be forthcoming.

In an attempt to reduce the effects of incident related traffic congestion on the delivery of packages, UPS joined forces with New York City Police Authorities for the dissemination of incident locations. The intention of this pilot project was to have all incidents, which were attended to by the police, reported to the UPS dispatch centre for further dissemination to the delivery personnel. However, the project did not turn out to be a fruitful venture for UPS for several reasons.(Winters, 1995b)

First, it was expected that when the police arrived at a scene of an incident, there would be an immediate radio report, of which a UPS dispatcher would overhear. Over time, it became apparent that these reports were slow in being sent and sometimes not be sent until after the incident had been cleared. Secondly, the UPS delivery personnel were often the individuals who would report an incident to their dispatch for use by other delivery personnel. For these reasons, the project had not yielded any significant results in decreasing the effects of incident related congestion on the delivery operations and was therefore subsequently terminated.(Winters, 1995b)

2.4.3 Communication Techniques

New technologies such as two-way paging and satellite communications have been useful in eliminating the delay in sending information to drivers. These innovations have provided the opportunity to have information gathered from bar coding and scanners used to track packages for customer service and security reasons to be transmitted quickly and

efficiently. The latest used technology is the two-way paging service. Figure 2-3 illustrates one configuration of a data communication device and the conceptual set-up for the Travelguide unit developed for the Ministry of Transportation of Ontario and to be used initially in the Toronto area.

In Canada, Bell Mobility is providing two-way paging service between dispatchers and 440 couriers from UPS. The service allows dispatchers to send new pick-up customer information while a driver is en-route and with the push of a few buttons, both the driver and dispatcher are aware of the new service call and the dispatcher is informed that the message was received. Drivers used to have a one-way alpha-numeric pager which provided the details of a new pick-up request. The driver would then be required to inform dispatch that the message was received. (Bell, 1994a)

Using the portable DIAD unit, information such as the package tracking number, the name of the customer, the time of pick-up and the customer's signature are sent using the two-way paging service to the UPS mainframe computer. Investigation of these benefits by UPS have shown that significant time savings can be accrued because drivers are no longer required to use public phones to contact the dispatch centre, nor must they use the 1-800 number to confirm receipt of the page. (Bell, 1994b)

The costs of using the Bell Mobility two-way paging systems is also highly competitive in comparison with other methods of communication, while providing greater benefits and ease of use. At a package price of \$60.00 per month, the two-way paging system provides national coverage, confirmation and time stamp for a message, automatic holding of messages until user in range and 200 free messages with subsequent

Figure 2-3 Heti (1994) p 10 Figure 2

Figure 2-3 Illustration of TravelGuide Unit

messages priced up to \$0.06 per message depending on volume. (Bell, 1994c).

2.5 Beneficial Impacts of ITS to Couriers

With the operational requirements of the courier industry being very dependent upon the efficient distribution of packages, the use and integration of ITS into their current

technology would provide substantial benefits. These new systems would create savings in operational costs through the increase in efficiency seen within the organization. The technology that the courier companies currently utilize have already proven that computerization and innovation of certain operational needs and strategies can have a dramatic beneficial effect.

Computer systems have virtually eliminated the need for paperwork. These advancements have not been solely for the use of the courier industry, however, their applicability to the industry has demonstrated that improvements in operations and performance can be made. The benefits can then spawn reductions in costs which, in a competitive market, should mean a lower price for consumers.

There had been an increase of over 30% in the total parcels delivered in Japan during the period of 1988 to 1991, a growth rate which could cause significant operational problems in most industries, yet demonstrated no measurable difficulties for courier companies (Kawata, 1992). While not all of the absorbed growth can be attributed to the effects of new technology such as improved voice and data communications, vehicle routing and package tracking, these systems have played an important part in the increased efficiency within all courier companies.

The potential financial savings to the courier industry is quite substantial for a very small operational efficiency gain. With a combined North American and Japan total demand of approximately 4.5 billion parcels annually, and thus 9.0 billion courier activities, a mere 30 seconds of service time reduction for one percent of the activities will yield a savings of 750 thousand delivery person-hours or 353 person years. Savings such as these may be used in

a multitude of manners and could include the faster delivery of packages which would increase customer satisfaction, provide an opportunity to expand areas serviced by individual delivery personnel or to increase the market share of courier operations.

The remaining question is then how can the benefits, such as the 30 seconds of time savings per package, be achieved using ITS technology. The majority of savings will be accrued through a more efficient transfer of pertinent information to the courier driver. The information will allow for P&D activities to be conducted using a dynamic vehicle routing system to minimize overall travelled vehicle-kilometres. By the re-routing of vehicles to either pick-up newly obtained customer requests for package delivery or to avoid congested areas on the network due to either high traffic demand or incidents, operational gains can be made

Most providers of goods transportation have relegated themselves to believing that the traffic conditions on city streets and highways are out of their control, that no single firm is capable of having a competitive advantage due to lack of control and therefore urban congestion problems are simply a part of their business's operation. While this is currently the case, the increased use of Freeway Traffic Management Systems and actuated or semi-actuated arterial traffic signals will begin to provide real-time traffic information regarding an ever-increasing number of roadways.

This information will eventually be available to the general public and private enterprise. Once this accurate information is provided to the driver, the remaining obstacle to efficient courier operations will be overcome. Courier vehicles will be capable of optimizing their routing schedule in a "as it happens", real-time manner so as to avoid or at

least minimize incurred delay. In conjunction with the reduction in operational costs from less use of congested roadways, courier operators will be capable of reducing fuel costs, vehicle maintenance costs and as mentioned earlier, would also result in lower labour costs

CHAPTER 3

CURRENT URBAN CONDITIONS

3.1 Introduction

When the private automobile was first invented, people did not foresee the extent of problems that would develop in our cities. The automobile was to have eased the difficulties of long distance horse-drawn travel. However, its most prominent use in today's society is for short distance travel in urban areas. In addition, cities are no longer the densely populated areas they once were. The 'urban sprawl' which plagues most cities world-wide has resulted in a decrease in the efficiency of transit based services and been replaced by an auto-dependant society.

There has been a long-standing knowledge regarding the interactive relationship between transportation and urban development. Provision of transportation services to areas yields increased accessibility to land, which in turn results in a need for modified transportation to maintain the desired accessibility. With substantial networks of roadways passing through vast areas of land in every continent, the ability for people to further distance themselves from the urban centre has perpetuated the need for more transportation links.

However, governments are faced with both limited funds and rights of way in urban

areas. Some technological advancements such as real-time traffic signalization, Freeway Traffic Management Systems and Area Traffic Management Systems, discussed further in Chapter 4, have provided an opportunity to reduce the effects of the high traffic demand on the existing transportation network. But over the long run, these gains in effectiveness will not be sustainable without a change in the urban planning process.

3.2 Characteristics and Causes of Congestion

The effects of the high demand on the transportation network can be seen in all major cities by the congestion and resulting delays on vehicle travel time. While the extent of delays varies from city to city, depending upon the population density, land development planning, available alternative routes, wealth and even age of the city, there are certain characteristics which remain constant. First, it is natural to assume that as a city increases in population, there would be a corresponding increase in travel demand.

For example, in small towns and villages, it may be found that there are three peak travel times, all of which correspond to the morning and afternoon home-based work trips and then a peak as people travel home and return from home during lunch. This would be seen where the home-work trip is relatively short. However, at the other end of the spectrum, large metropolitans such as Los Angeles are more likely to experience a single or constant travel demand in its central core during the working hours and two peaks marking the home-work trips in the morning and afternoon on roadways feeding the downtown area.

It is worthy of noting that during the off-peak hours of travel in communities both large and small, the transportation network generally operates near a Level Of Service (LOS)

of rating A or B. Therefore, expansions and modifications to the transportation network only serve to reduce the effects of congestion during the few hours of the highest travel demand.

The nature of land development can also be shown to have significant effects. Cities have grown in occupied land far greater than in population, mainly due to the increase in low density residential development. The lower density removes the efficiency and profitability of providing transit service to these areas and as a result increases private automobile travel. Along with this fact, there has been a shift towards larger and more centralized commercial development. In the past, mixed use developments were constructed whereby smaller shops such as a butcher, baker and vegetable stand prospered. However, large suburban shopping malls are today being built where a one-stop shopping excursion can be undertaken and typically through the use of a private automobile.

In addition, a substantial portion of the workforce is employed in the central business district which is a significant distance from the average place of residence and leads to a clear requirement for personal travel. As mentioned earlier, the reduction in transit efficiency in the suburbs yields a greater propensity of travel to occur by means of private automobile. The combination of centralizing work and activities into core areas and decentralizing residential development has also resulted in a higher dependency upon the private automobile.

Another important root cause in congestion is the availability of alternative routes. Report number 194, conducted by the National Cooperative Highway Research Program (NCHRP) in 1979, found that cities which experienced a low percentage of intersections with congestion but the worst queuing problems tended to have compact CBDs and only a few feeder arterials. However, larger cities tended to exhibit greater congestion and less

oversaturation due to the higher number of arterials providing better diffusion of traffic. For example, Wichita, Kansas had a population of approximately 275,000 people in 1979 and was experiencing congestion of between 50 and 60 minutes. This was attributed to the fact that there was only a single major street within 1 mile in lateral distance (NCHRP, 1979).

Spacings or distances between streets can further lead to congestion in the central area when the location of double parked vehicles are taken into account. In a case study of the downtown Brooklyn area conducted by Habib and Crowley (1976), the incremental traffic delay caused by a 12 minute blockage of a single travel lane of a 3 lane roadway was examined by incorporating the effects of both parking location and volume to capacity ratio.

The results showed that, as expected, delay increased as the volume to capacity ratio increased and are shown in Figure 3-1. It also was found that as the parking location moves towards the mid-block location, the effects on incremental delay are minimized. This would indicate that "bottlenecks" at the ends of the block length increase delay and would most likely be attributed to other drivers not having sufficient time and space for weaving actions to avoid the parked vehicle.

A fourth characteristic which affects congestion is wealth. In many of the western countries, possession of a private automobile is viewed as a necessity and therefore has become the focal point of one's mobility. However in developing countries, the implied need for a automobile is not as significant. In many cases, a reliable transit system is in place, in part due to the significantly higher population density. Secondly, many of the required services are located within a walking proximity which negates the need for lengthy travel, in addition to the fact that the costs associated with the operation and maintenance of a vehicle

exceeds the threshold of affordability for many people

Figure 3-1 Incremental Traffic Delays per 12-minute Blockage

Source Habib & Crowley (1976) p 22 Fig 3

The final characteristic which plays a great part in the nature and extent of travel congestion in a city is the age of the city. It must be noted that until the advent of the automobile, methodologies for travel were relegated to walking and the horse for short distances and for longer distances travel was by either the horse or the steam train. Thus, cities which were constructed before the creation of the automobile can be seen to have a condensed city core, often with mixed-use development. These cities are now being subjected

to increased low density development in the outlying areas, causing significant traffic congestion as commuters attempt to access the central business districts

Other, more modern cities have grown substantially in occupied land, of which most is of the low density nature. Land prices have accelerated the movement of residential development farther and farther from the central core. However, businesses which heavily rely upon being in close proximity to "the action" have maintained their offices within the CBD. As land prices increase in the downtown as well, there has continued to be a movement towards the construction of skyscrapers. These two items combined, propagate the need for access to the downtown and subsequently result in further congestion. For example, in New York City, the two World Trade Centre Towers alone generated between 600,000 and 900,000 person trips daily and when the remaining office buildings are included, the enormous travel demand is certain to put a strain on the transportation system

3.3 Significance of Congestion

The overall costs of transportation delay are tremendous. With millions of automobiles, delivery vehicles and transport trucks using highways and city streets throughout the world daily, delay is inevitable. However, the extent of the delay and its effects on society, the environment and the economy continues to move towards epidemic proportions. Traffic congestion has many root causes, as mentioned in the previous section, but the overall effects are the same. Figure 3-2 illustrates that, 1979, a significant amount of intersections incurred over 30 minutes of congestion within the CBD and on the arterial system for cities of all size.

Figure 3-2 Extent and Duration of Traffic Congestion

Source National Cooperative Highway Research Program (1979) pg 5, Figure 3.

The effects of this congestion on businesses and goods transportation, and specifically the courier industry, are substantial. The most recent and significant research found was recently completed in The Netherlands by the TNO Institute for Policy Studies and the Ministry of Transport in December 1994. The study examined the effects of congestion on three segmented groupings: freight transport, business travel and commuter travel

During the period between 1986 and 1992, vehicle-kilometres increased by nearly 20 percent while vehicle-hours lost grew by almost 30 percent. The study found that in 1992 the total vehicle time lost on the motorway network was about 14.5 million vehicle-hours if traffic jams were only examined and would amount to 35 million vehicle-hours if all levels of congestion were included. Of these totals, approximately 8 percent, or 1.1 to 2.8 million vehicle-hours of delay are incurred by trucks (Korver, 1994). It should be noted that these figures do not include congestion delay incurred on the arterial network and therefore underestimates the total impacts of congestion.

The Tokyo Metropolitan Area is certainly one of the largest and heaviest populated in the world. With nearly 32 million people residing within a 70 kilometre radius of Tokyo, in 1990, a very significant amount of traffic congestion is created. The heavy volume has led up to 2000 hours of traffic congestion annually, of which approximately 700 hours occur with over 500 metres of queued vehicles, as shown in Figure 3-3 (Shiomi, 1993). When converted to daily hours of congestion, the total is anywhere between 5 and 10 hours for both urban streets and freeways. It was estimated that in 1980 there was 4.6 billion person-hr/year of congestion related delay (Tsugawa, 1992). This phenomenon is not limited to the more densely populated countries of Europe and Asia.

Note: Traffic Congestion Basis

Basis of Traffic Congestion		
Categories	Length of Road Occupied by Queued Cars	
First Degree	Above 300m	Below 500m
Second Degree	Above 500m	Below 1,000m
Third Degree	Above 1,000m	

Source: Metropolitan Police Department

Figure 3-3 Hours of Traffic Congestion in the 23 Wards of Tokyo

Source: Tokyo Metropolitan Police Department; cited by Shiomi (1993) p 349, Figure 9

In larger American cities, traffic congestion now occurs throughout the day. Freeways in Dallas, Chicago, Los Angeles, Washington and Long Island suffer from congestion as severe during the noon hour as they do at 7:30am and 5:30pm (Orski, 1986).

No longer are commuters the major group suffering from the congestion problems, now travellers of all types are being affected. Between 1975 and 1985, the percentage of freeways in urbanized areas operating below 35 mph rose from 41 to 56 percent (Lindley, 1987 and US DOT, 1985) and the problem is continuing to worsen. The Texas Transportation Institute estimated that in 1988, the cost of congestion totalled over \$34 billion dollars for the 39 largest cities in North America (Downs, 1992).

In 1990, Highway 401 in Toronto serviced approximately 32,000 vehicles per hour in its heaviest sections which led to three or four hours of congestion daily and 26,000 accidents each year over a 16km stretch (MTO, 1991). A study conducted for the Los Angeles Area noted that 91 kilometres of highway suffered a total delay of 24258 vehicle hours on a daily basis (JHK, 1990). And on Montreal freeways, it was estimated that over 6.5 million vehicle hours of delay are incurred on a yearly basis (SNC/DeLuC, 1988)

3.3.1 Recurring Congestion Impacts

The average commuter will typically be subjected to delay due to recurring congestion (ie excess demand), however, there is also a substantial congestion delay which affects the travelling public through roadway incidents. There are few reports and literature which quantifies both the recurring and incident delay on arterials at a network or city level. Most of the information at the arterial level is on a site specific basis. However, there is substantial information regarding travel delay for urban freeways.

It has been estimated that in 1984, delay on urban freeways in the United States consisted of over 1.2 billion vehicle-hours, where recurring congestion amounted to 485

million vehicle-hours of delay and delay due to incidents comprised of 766.8 million vehicle-hours. Based upon traffic growth supplied by the various state Departments of Transportation, these figures are expected to near the 6.9 billion vehicle-hours of total delay, with about 4.8 billion occurring due to incidents and 2 billion from recurring congestion by the year 2005 (Lindley, 1987).

These totals were further examined for the 37 US cities with populations exceeding 1 million people in 1984. Table 3.1 illustrates the severity of congestion affecting some of these cities and the totals for cities throughout the United States. It also indicates the amount of delay caused by recurring congestion for both 1984 and projected for the year 2005. ITS America estimated that in the United States alone in 1991, 2 billion vehicle-hours of delay is incurred due to traffic congestion and that this value translates into \$30 billion of lost or wasted time, efficiency and fuel (Krakiwsky, 1993).

3.3.2 Incident Congestion Impacts

With nearly 45,000 people killed on American roadways annually and about 2.5 million non-fatal accidents occurring, 61 percent of the total delay afflicting US cities is caused by incidents and this number is expected to increase to nearly 70 percent by the year 2005 (Lindley, 1987). Due to recurring congestion being of a daily nature, while incident caused delay is more of a distributed occurrence, the percentage of delay caused by incidents may appear unusually high. However, the single most important factor for the larger delay is the loss of capacity. The greater the loss of vehicle throughput, the more significant the delay.

Table 3-1 Urban Area Freeway Congestion Statistics, 1984 and 2005

Urban Area	Freeway Miles	Annual Vehicle-Miles (Millions)		Annual Recurring Congested Vehicle-Miles (Millions)		Annual Recurring Vehicle-Hours Delay (Millions)		Annual Incident Vehicle-Hours Delay (Millions)		Total Annual Excess Fuel (Millions Gallons)	
		1984	2005	1984	2005	1984	2005	1984	2005	1984	2005
New York	1,141	26,740	32,567	3,660	6,658	62.7	117.5	155.7	282.5	231.4	430.2
Los Angeles	647	27,131	33,768	5,370	9,406	78.3	180.8	94.7	229.1	191.3	438.1
Chicago	397	9,843	11,850	1,155	2,384	19.7	47.4	24.6	79.4	48.4	135.7
Philadelphia	362	6,238	9,573	428	1,727	4.9	35.1	10.2	73.8	17.4	115.9
San Francisco	602	22,071	29,791	4,262	9,638	72.9	208.5	95.6	349.6	182.1	589.6
Detroit	298	6,665	12,049	885	3,735	16.2	89.3	35.5	421.5	55.3	533.3
Boston	342	8,090	11,207	983	2,971	10.0	57.3	34.8	180.7	52.5	253.4
Houston	245	8,576	17,455	2,103	9,708	39.5	252.1	55.8	704.6	102.4	994.5
Washington	263	6,543	8,562	694	2,290	8.5	41.6	18.9	88.2	31.2	138.4
Dallas	418	9,763	20,223	1,039	7,637	16.3	169	28.9	578	49.6	791.1
Miami	195	4,599	8,158	203	3,182	0.3	69.2	2.5	163.7	5.1	247.4
Cleveland	332	5,046	6,635	348	824	6.1	15.6	4.3	11.6	11.2	28.8
St Louis	248	5,086	7,148	413	1,182	3.8	19.3	4.4	16	9.8	38.7
Atlanta	249	6,456	9,130	743	1,915	15.8	45.5	16.7	56.8	34.6	107.6
Pittsburg	207	2,301	2,927	154	324	1.9	6.5	5.5	14.7	8.4	22.6
Baltimore	195	3,974	6,105	285	1,837	2.9	33.1	6.8	58.7	11.3	98.4
Minneapolis	268	4,486	6,643	531	1,457	11.2	27.7	9.8	35.6	22.2	68
Seattle	230	5,874	9,937	925	3,187	18.5	76.3	25.0	197.2	46.8	286.2
San Diego	157	4,853	6,831	561	1,282	8.6	23.9	5.1	16.8	15	43.8
Tampa	37	870	1,289	40	277	0.1	4.1	0.4	11.2	1.1	17
Denver	179	3,390	4,650	456	942	7.5	19.2	7.6	26.5	16.4	48.3
Phoenix	43	1,013	1,612	69	372	0.2	6.8	0.8	13.7	1.4	22.2
Cincinnati	165	3,012	4,146	285	580	4.3	13.9	3.5	11.9	8.7	26.9
Milwaukee	107	2,146	2,848	177	491	1.9	8.5	1.8	7.6	4.3	17.2
Kansas City	277	3,324	4,417	172	492	1.9	7.2	5.9	11.8	9.1	21
Portland	136	2,418	3,521	116	569	0.5	8.8	3.6	24.2	6	35.9
New Orleans	60	1,073	2,073	340	616	7.7	12.6	10.3	44.7	19.1	61.1
Columbus	133	2,239	2,945	154	315	2.5	6.9	2.2	6.8	5.3	14.5
Norfolk	135	1,998	3,100	740	556	5.0	10.3	4.0	18.4	9.4	31.1
Sacramento	130	3,717	6,047	439	1,271	4.2	30.5	2.5	18.1	7.9	50.9
Buffalo	144	1,559	2,134	20	207	0.2	2.3	0.7	6.2	1	9.7
Indianapolis	139	2,237	3,924	0	572	0.0	7.9	0.2	12.3	0.2	23.1
San Antonio	150	2,768	5,662	391	2,189	5.2	56.7	5.7	157.5	12.6	233.4
Providence	150	1,667	2,331	86	238	0.5	4	0.6	2.1	1.5	6.7
Charlotte	37	665	1,830	71	993	1.3	23.3	2.2	116.5	3.9	146.8
Hartford	123	2,165	2,499	207	294	1.9	5.2	7.0	12.4	10.7	19.1
Salt Lake City	99	1,501	2,771	101	495	2.0	10.7	1.2	5.4	3.4	17
	9040	212,726	308,358	28,606	82,813	445.0	1,754.60	695.0	4,065.80	1,248.0	6,153.2

Source: Lindley (1987) p 29, Table 2.

When an incident occurs, there is typically some portion of the freeway or arterial which is blocked until the vehicle(s) are removed, and thus the roadway capacity is reduced. Some studies have shown that for every minute an incident occupies one or more travel lanes, between 4 and 10 minutes of delay is incurred. The resulting delay is dependent upon the amount of traffic volume and the percentage of capacity reduction. When totalled, an incident which occupies, for fifteen minutes, a single lane of a three lane freeway operating at capacity would result in approximately 2000 vehicle-hours of delay.

3.4 Cost Implications for Courier Industry

Delay is a source of lost productivity and efficiency in the business world and for an industry, such as the courier industry, which operates under very strict time controls, it can be quite detrimental. If packages are delayed during their return to the depot, before being sent to the airport, planes must be delayed which in turn delays operation at the central processing plant. A similar delay is then incurred through the entire return distribution phase of the operation for the organization. As a result, the company's reputation for on-time service is jeopardized and in an industry where competition is very fierce, any edge for a competitor can spell disaster.

For this reason, the selection of depot location, distribution and collection network organization, operational characteristics and the use and efficiency of technology plays a significant role in the minimization of the traffic impact on the courier industry. These areas will receive further attention in Section 5, where some details into the theory and reasons for use behind the importance of these factors is conducted.

There are several costs incurred during normal courier operations which are affected from travel during the peak period. Included are the additional fuel and vehicle operating costs, the greater travel times and thus the longer driver work hours and the increased vehicle wear and maintenance costs. Generally, the benefits used for the evaluation of road improvements for the commercial goods movement operators only examines these costs and fails to determine the impact of companies shifting certain operations to off-peak hours to avoid the congestion.

The costs of congestion were determined to add an extra 40 percent to the cost of goods movement in the Greater Toronto Area, which totalled approximately \$1.9 billion per year and for the Ottawa area, the additional costs were between \$40 and \$50 million per year (TAC, 1992). A survey conducted in Gloucestershire, England in 1976, to examine route choices of various drivers and the potential of route guidance systems, found several key facts to urban travel (TPA, 1977; cited by Jeffery, 1981). As shown in Table 3-2, a difference in total costs between a chosen route and an optimum route for drivers in the survey to range from 5.4 percent to 7.9 percent, with an increase in costs of 7.7 percent for commercial vehicles and for unfamiliar trips, the extra costs incurred for commercial vehicles was 8.2 percent (Jeffery, 1981).

It was estimated by the US Department of Transportation that, in 1991, fuel costs comprised 7.9 percent of total carrier costs, or about \$8.7 billion nationally (Schmitt et al., 1994, cited by Regan et al, 1994). If a total of 10 percent of the trucks obtained a 5 percent reduction in fuel consumption, it was estimated that \$43.5 million could be saved annually.

Table 3-2 Estimates of Times, Costs and Distances for Journeys

Journey Purpose	No. in Sample	Total distance Driven (veh-km) $\times 10^3$	Total time Spent (veh-min) $\times 10^3$	Total Costs (£)	Excess Cost (%)	Excess Cost (£)
Commuting	1207	11.24	13.24	334	7.0	23
Leisure	1395	34.13	32.93	1013	7.9	80
Business	1085	20.69	19.27	2055	5.4	111
Commercial Vehicles	1228	25.30	23.23	2757	7.7	212
Excess Costs from Seeking Optimum Route for Unfamiliar Journeys						
Commuting	41	0.73	0.68	19	24.4	5
Leisure	669	17.53	16.04	458	8.8	40
Business	299	7.28	6.38	678	8.0	54
Commercial Vehicles	237	6.25	5.07	658	8.2	54

Source: Jeffery (1981) p 3, 4; Table 1 & 3.

There has been little or no work investigating the potential savings which could be achieved by either the courier industry or the entire trucking industry's use of ITS technology within an urban area. As such, only estimates based on the percentage of trucks in the vehicle stream can provide some indication as to the extent of savings.

Using the freeway data for annual recurring and incident vehicle-hours of delay for the 37 largest cities in the United States found in Table 3-1 and estimating a 5 percent truck volume and a 0.1 courier vehicle percentage, there would be at least 57 million-vehicle hours

of delay for the entire trucking industry and 1.1 million vehicle-hours of delay for the courier industry alone. It should be noted that the totals listed in Table 3-1 only account for the delay occurring on freeways within these cities and fails to include the delay found on the arterial and collector road network. Therefore, the estimated delays incurred by the trucking and courier industry are substantially underestimated.

CHAPTER 4

PRESENT SYSTEMS AND NEW TECHNOLOGY

4.1 Introduction

The development of Intelligent Transportation System (ITS) has been a worldwide effort, with Japan and European nations leading the way and the United States and Canada now joining the charge. The focus of ITS is the maximization of both passenger travel and freight transportation systems through the use of computer communications and sensors. This field has been divided into five categories, in which investigation of specific sections of transportation is being performed.

They include Advanced Traffic Management Systems (ATMS), Advanced Traveller Information Systems (ATIS), Advanced Mobile Support Systems (AMSS), Advanced Vehicle Control Systems (AVCS) and Advanced Fleet Management Systems (AFMS). Of these categories, the most important to the courier industry are ATMS, ATIS and AFMS.

4.2 Advanced Traffic Management Systems

Combining the existing and new traffic management technology to optimize the traffic flow in an entire city, and not only a freeway or arterial corridor, is the idea behind Advanced Traffic Management Systems (ATMS). Such systems will integrate freeway, arterial and

collector traffic control systems to create an area-wide management system. It will also monitor the progress of ITS equipped vehicles to increase the accuracy of traffic data. These systems will eventually also be able to automatically collect tolls and manage parking facilities.

The city of Los Angeles is currently being used as a demonstration site for the Santa Monica Smart Corridor Freeway System, which incorporates the freeway and the parallel arterials to create the most sophisticated transportation corridor in North America. Using inductive loop detectors, closed circuit TVs and changeable message signs, the system monitors the traffic patterns in the corridor and optimizes signal times and ramp metering systems to maximize vehicle throughput. A typical setup is illustrated in Figure 4-1.

A subsidiary of Philips Traffic Systems, Peek Traffic, has developed a parking guidance system which informs drivers of empty parking spaces through the use of signs located along the roadside. The company recently installed such systems in Espoo, Finland and Malmo, Sweden. The success of these parking guidance systems can be measured by the reduction in time and energy spent finding suitable parking spots and the increased revenue realized by parking garages.

There are also concepts being investigated, such as the Vehicle Identification and Transaction Aid (VITA) developed in Europe. It would place an electronic tag upon each vehicle and install devices along the road to automatically charge the account for each vehicle upon passage of these detectors. This would eliminate the need for toll booth stations along the road system and thus reduce the associated backups.

Figure 4-1 Typical ATMS Installation

Source: Houston Department of Transportation

4.3 Advanced Traveller Information Systems

The provision of information to travellers, either before trip departure or en-route is the second category of ITS and is known as Advanced Traveller Information Systems (ATIS). The development of some ATIS components has already begun to surface in FTM systems. These are the changeable message signs, the highway advisory radio stations, and lane control systems. Other equipment, such as on-board display and voice navigational systems and home computer terminal links are only now being tested.

On-board systems use global positioning satellites and local transportation network maps to provide graphical and/or voice assistance to guide drivers to their destinations. Such systems are currently being tested in Chicago, Europe and Japan. Motorists simply input the desired address of their destination and the computer will lead the way, informing the driver when and where to turn. This technology has now begun to use real time data to determine the minimum travel path.

Peek Traffic has developed the **Trafficmaster**, a traffic information system which provides up to date road conditions to the driver in England. Through the use of infra-red traffic sensors installed on bridges approximately 3 kilometres apart, drivers are informed of traffic speed and the extent of congestion by a portable radio paging network linked to the **Trafficmaster**. The system can therefore be removed from the vehicle and continuously inform the driver of traffic conditions within a 40 kilometre radius of London (Peek Traffic, 1992a). This system, like the Travelguide program developed by the Ministry of Transportation of Ontario and others developed elsewhere, will allow for the reduction in travel time and energy spent. These systems are shown in Figures 4-2 and 4-3.

Figure 4-2 Travelguide Concept

Source: Heti (1994) pg 9 Figure 1

▲ Sony Electronics' NVX-F160 mobile navigation system utilizes the global positioning system

▲ The Bosch-Blaupunkt vehicle navigation system from Germany prompts the driver with a turn signal and a bar graph that gets steadily shorter as the vehicle approaches a desired turn. A voice prompter tells the driver when the turn is near.

▲ Oldsmobile's Guidestar navigation system is mounted in the dashboard but is removable

Figure 4-3 Examples of Operational ATIS packages

Source: Jurgen (1995) pg 39 Figure 3.

4.4 Advanced Fleet Management Systems

The implementation of Advanced Fleet Management Systems (AFMS) are presently being considered for use in North America, in view of the tremendous reliance on transport trucks to carry the continent's goods. Also known as Commercial Vehicle Operations (CVO), this system can also be used to monitor the operation of private and public transportation vehicles, so that information concerning delays can be more accurately given to the general public. The implementation of such systems will also improve the safety and efficiency of fleets.

A system, again developed by Peek Traffic, is under use in Frankfurt, Germany. Public buses which are equipped with a route guidance system are being used to maintain a precise schedule. The operator simply inputs the route number into the laptop computer and the computer will do the rest. By counting axle revolutions and receiving information from roadside beacons, the computer can determine the distance travelled and the upcoming bus stop. After consulting the bus schedule, the computer will inform the driver the deviance from the schedule and allows the driver to make the necessary steps to resume the proper schedule.

There are two systems under development in North America which will place electronic tags on commercial transport vehicles. These systems, one on Interstate 75 from Ontario to Florida and the other from British Columbia to Texas, will allow trucks to enter weigh stations only once, thereby reducing the travel costs of shipping goods. These projects however deal with technology used mainly for intercity goods movement.

Most important to the courier operation is the success of a combined ATMS and

ATIS facility for the management of vehicles. The combination of these two groups provides the ability for vehicles to receive information regarding delays on roads nearby or network wide. These systems would also then provide the opportunity for dynamic route guidance programs to be used which would allow for incident avoidance and route optimization based on current traffic conditions. This would allow for increased operational efficiency and reduced costs.

Optimization of fleet operations is one of the areas targeted by the trucking industry for improvement and can be accomplished by increased efficiency in determining vehicle locations and providing up to date information to drivers concerning new routes and pick-ups. During the past few years, the use of Advanced Vehicle Location (AVL) and Mobile Communication (MC) systems have grown exponentially in the United States with interest in Europe and Japan now beginning. Current fleet procedures require the driver to call the dispatcher and report location and progress approximately every four hours which results in increased delays and operating costs.

4.4.1 Automatic Vehicle Location Systems

The development of Advanced Vehicle Location systems has greatly enhanced the productivity of the trucking industry by enabling dispatchers to determine the location of every vehicle within a 30 to 50m range. This allows dispatchers to select the vehicle which has the capacity and is in close proximity to pick-up a new shipment. Naturally, the benefits will vary between fleets depending on whether they operate as a private carrier or a for-hire carrier. A private carrier will generally have standard pick-up and delivery times on certain

given routes while for-hire carriers are required to alter schedules and vehicle routings to best serve the customer

This trend towards increased customer service has been propelled by the availability of technology to perform these tasks which has in turn fed the research and development of new and more efficient technology. Terrestrial radio navigation systems have been used in the past by marine traffic for navigational purposes and more recently by the trucking industry along the eastern coast of the United States and western coast of Europe. Vehicle location can be determined by measuring the difference in synchronized radio signals from two radio stations separated by approximately 1500 km. One of the latest development in vehicle location technology has been geared around the use of satellite-based Global Positioning System (GPS).

Initially for United States military purposes, the GPS satellites and in-vehicle receiver are able to determine two or three dimensional positioning using either three or four satellites respectively. With capabilities to locate an object within 15m, modification by the US military may reduce accuracy to within 100m. However, through secondary processing, the accuracy can be improved to within 1m. Therefore, GPS provides reliable information to dispatchers regarding the operation of their fleet in a rural setting but may cause difficulties for courier operations in urban areas.

Canadian developed software packages cost approximately \$3500 US and are capable of alleviating emergencies due to break-downs on the road and provide coordination of receiving and pick-up of shipments. By monitoring vehicle travel routes, the dispatcher is able to verify that the driver is taking the most efficient route. With digitized road map

databases and the use of real-time traffic information from installations of freeway and area traffic management systems, road freight vehicles are capable of avoiding both recurring and non-recurring congestion by selecting a new route which will optimize their travel time

Demonstration projects are being tested in the United States with ADVANCE in the Chicago area and PATHFINDER in the Los Angeles area, as well as the TRAFFICMASTER, ALI-SCOUT and AUTOGUIDE projects in European cities. With goods being transported between and through major urban areas, optimization of travel time will ensure that companies are able to deliver transported goods in time.

4.4.2 Automatic Vehicle Identification Systems

There are a number of approaches which have been developed over the years and include inductive loop systems, radio frequency and microwave systems. All three approaches can be divided into active, semi-active and passive systems which are descriptive of their power source. Active systems generate power from the vehicle on which it is mounted and will either transmit an identification code continuously or can be triggered by a remote signal. Passive systems are sealed units which have no external power supply and are energized by remote receiver. These units are less vulnerable than active systems to interference and damage whether accidental or deliberate. Semi-active systems are also sealed units which use an internal battery to provide power to the unit for identification transmission when triggered by a remote receiver.

Regardless of the system implemented, standardization of data type and configuration is the most important issue regarding information technologies to ensure that systems can be

integrated with one another. Once standardized, the use for these systems are unlimited. Carriers travelling on interstates must report mileage by state for fuel tax, registration and in some instances for weight-distance taxes. Costs for carriers is estimated at \$2 billion annually and about \$5 billion in State costs for related paperwork of the taxes and registration (Convergence, 1992).

The use of roadside transponders at interchanges for interstates will allow governmental agencies to record the time, date and odometer reading for commercial vehicles using the interstates and reduce costly paperwork. While the courier industry will stand to benefit from these innovations on the intercity portion of delivery service, there is not a significant amount of intercity highway travel in the North American industry

The use of AVI also has tremendous potential in improving the "just-in-time", courier and customer service sectors in the trucking industry within urban areas. With the ability to inform customers of the exact location of their goods and provide an estimated time of arrival, businesses requiring prompt and up to date information for logistic purposes will be more inclined to conduct business with those who can provide such information. AVI also allows companies and managers to identify vehicles on the network, determine their current status based on other information and then use all the gathered information to make decisions regarding the fleet operation

4.4.3 Mobile Communications

Communication between driver and dispatcher is one of the most important factor in fleet management, since reduced operating and communication costs can lead to more

profitable businesses. Through the use of cellular technology or global satellites, increased distances can be covered to ensure quality mobile communications. The OmniTRACS Mobile Communication (MC) System has been introduced in Canada, the United States and Europe to provide one of the largest two-way satellite communication system available.

Equipped vehicles are able to send vehicle diagnostic information, trip reporting, driver paging and password messages among other options. Cellular technology has grown in popularity in public communication markets, however, their use in the trucking industry has not been as significant because savings in travel time from reduced call-in stops are lost in high long distance cellular costs. The use of MC allows for communication between dispatcher and driver to be initiated at the discretion of both parties as opposed to current practice which requires the driver to stop every 3 to 4 hours and telephone the dispatcher.

The benefits of en-route communications with cost effective systems include reduction in empty vehicle kilometres, waiting times, communication costs, real-time deliveries which increase customer service potential, real-time routing and more efficient matching of loads and available equipment, all of which lead to increased productivity and profitability for the company. The costs of this equipment can range from \$2000 to \$4000 per vehicle plus a monthly or per message charge, which can pay for themselves in less than one year.

Estimates provided by technology producers and road freight carriers illustrate that the number of empty vehicle kilometres can be reduced by 0.5 to 8.0 percent and one US firm reports that a reduction of this magnitude could increase profits by \$1.25 million annually from its 370 million kilometres of freight transport. Another US motor carrier reported that

the use of an AVL and MC system has reduced communication costs by 60 percent, or \$2 million per year. Savings in reduced idle time for driver 'call-ins' could range between one to three hours daily which could result in more shipments and increased profits (OECD, 1992).

Along with Advanced Vehicle Information systems, Electronic Data Interchange (EDI) will provide a reduction in the handling of tiresome paperwork requirements in the trucking industry. In providing a standard communication language, the ability of shippers and trucking firms to interchange documents and conduct standard business operations will increase the economic efficiency of their company and attract more customers. Danfoss A/S is a production company which produces heating controls, compressor and other equipment in 7 countries and has distributors in over 100 countries. The distributors have been requested by Danfoss A/S to implement a selected computer inventory system which, by use of a direct on-line computer link, will help to reduce fluctuations in demand thereby reducing transporting and distribution costs (OECD, 1992)

Similar attempts have been made by companies in Japan and other European nations in an attempt to reduce transportation costs for their goods, some with more success than others. Realizing that future global economic stability and growth will depend on the development of coordinated standards, the United Nations economic Commission for Europe has developed the international standard EDIFACT. This will ensure that standards for syntax rules in messages, a directory of standard messages and codes for international deliveries, countries, modes of transport and currencies transpire to allow the EDI field to expand globally and not continentally.

4.5 Summary

The use of EDI, AVI and AVL technology has been very useful in the development of proven and reliable customer service in the express delivery services such as Federal Express Corp. In 1973, Federal Express turned overnight parcel delivery into a science and has since been copied by smaller express delivery services. Within the United States, all parcels are sent by plane to Memphis, Tennessee which acts as the hub of the companies operation. When packages are requested for pick-up, the closest courier is sent to the customer by an on-board computer terminal. Once the package has been picked up, the courier uses a hand-held scanner to scan the bar code assigned to the package and transmits this information to the local Federal Express station which transmits the information to the customer service centre in Memphis.

When the package is brought to the local airport, the package is once again scanned to record the progress of the package. After arrival in Memphis, sorting and subsequent placement on the airplane headed for the given destination, the package is scanned and the information is conveyed to the customer service centre. Finally, once arrived in the city of destination, the package is scanned and given to the appropriate courier for delivery. By continuous scanning of the package, the customer service centre is capable of providing the location of the customer's package to within 30 minutes.

With this sort of information capable of being provided to the customer, Federal Express has been able to maintain valuable customers and gain more. With efficiency in reading bar codes at over 99 percent, the location of the 1.5 million packages which are delivered daily are always known. With similar use of the available technology, the location

of goods and vehicles within the trucking industry can be well established to provide reliable service to customers (OECD, 1992) A very similar process is followed by UPS, a major competitor of Federal Express, with their operation also using barcodes and scanners to maintain continuous tracking of packages

However, the largest gains can be made by the courier industry with the use of information obtained through ATMS and the transmission of information through ATIS. With respect to ATMS, implementation of infrastructure is still required by any municipalities and cities both in North America and abroad, but once installed the potential gains will be exceptional. When combined, ATMS and ATIS will provide the means for drivers to avoid the tremendous congestion on our roadways using real-time information and will allow both drivers and managers to optimize routes at either the vehicle or fleet levels.

CHAPTER 5

THEORY OF BENEFITS OF THE INTELLIGENT TRANSPORTATION SYSTEMS

5.1 Introduction

The theory behind the benefits which can be derived from Intelligent Transportation Systems (ITS) are all based upon the fundamental equations of transportation. A vehicle's distance travelled still remains a function of the velocity and time during travel and the service flow of a roadway is a function of the road geometry and the volume to capacity ratio. What ITS yields is a change in the operational characteristics of the transportation network, by means of real-time traffic information, route optimization and guidance techniques and vehicle location information. How large are the achievable benefits and who shall receive these benefits is a burning question.

The major key to solving this problem, is to determine to whom the real-time traffic information will be provided and how will it be used. There still remains much indecision as to whether provision of this information to individual drivers who have access to route guidance and route optimization facilities will actually result in a reduction in travel time and travel costs. Sometimes referred to as dynamic route guidance, the opinion is that if each

vehicle continuously searches for the instantaneous minimum travel time or travel cost path, it is possible that repeated re-routing would result in an overall decrease in efficiency and not a minimum time or cost.

The argument then leads to having the information retained by the local operating agency, which uses the information simply for maximizing operational efficiency of signal timing plans on the network. By relaying congestion locations through message signs and advisory radio station and without providing the detailed information to individuals and companies, there will then be a derived benefit by all users of the network.

Others suggest that providing routing information will yield a benefit to the overall network in several ways. If the actual routing information is provided by the operating agency to each vehicle, the system operational efficiency can be maximized by pre-selecting the path of the vehicles. However, if a detailed information package is relayed to each vehicle, the on-board computer system can determine the optimal path for each vehicle. The difference between these two systems is then the hardware and software requirements to perform the necessary task and whether the local operating agency or the individual driver absorbs the costs of the technology.

For the courier industry, there are certain benefits which would be derived from either system. Overall network efficiency gains would yield a reduction in congestion and thus operating costs. If each vehicle was provided information, courier vehicles could optimize their schedule and route based upon the current traffic information and therefore observe a reduction in delay due to incident and recurring congestion. Therefore, examination of the theoretical basis for courier operations, vehicle location and dispatching, route optimization

and route guidance will be performed

5.2 Theory of Courier Operations

Courier operations differ significantly from travel patterns of other goods movement organizations and commuter travel, however it is modelled remarkably well by the Travelling Sales Person problem. Both activities involve the need for a single vehicle or person to make several stops during the course of their daily schedule and requires a certain defined period of time for servicing each stop. Therefore, much of the logic used in the courier industry has been derived from examination of the travelling sales person problem.

5.2.1 Travelling Sales Person Problem

Optimization of the Travelling Sales Person (TSP) problem is based upon "finding an optimal route between a series of locations or stops, under the condition that each stop is visited once and only once and a return is made to the point of origin" (Mullner, 1972). The problem is further categorized by whether it is symmetric or asymmetric. A symmetric case would be examined if the costs (for example measured in travel time, travel costs or travel distance) are the same for routes between two points regardless of the direction travelled, while an asymmetric problem would have different routes between two points depending upon the direction (i.e. one-way streets) (Mullner, 1972).

When computing the possible routes between a set of points, the number of combinations becomes enormous. The equation for computing the number of route possibilities for a single direction of travel is $(1/2) N!$, which, for a twelve stop, symmetric

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case, would yield almost 240 million routes. To determine the optimum route from this size of options would be tremendously time consuming and therefore, algorithms have been developed over the years to try and simplify the process (Mullner, 1972)

Methods such as dynamic programming, integer programming, linear programming, branch-and-bound, tour-to-tour approximation and the Gilmore-Gomory method are all computerized and would require significant time to complete by hand. There have also been a few matrix and graphical solutions developed which do not require use of computers, nor computational time such as the Heinritz-Hsiao method, the Cascade algorithm and the Lockset method of sequential programming (Mullner, 1972)

5.2.2 Vehicle Routing Problem

Over the years, this type of analysis has further developed into the vehicle routing problem (VRP), which is the examination of more than a single route. For urban goods movement applications, VRP is important in the operation of distribution of the goods, whereby different pickup and delivery routing schemes can be examined. Operational procedures can be divided into several categories, as follows.

1. All deliveries are made before any pick-ups are started,
2. Pick-ups are made during the course of deliveries such that minimization of travel distance is achieved and vehicle capacity is not exceeded,
3. Pick-ups are made while en-route to first delivery such that vehicle capacity is not reached.

Of these, the courier industry is designed around the first option. Using overnight

transcontinental and international travel for delivery to other cities and the commitment to deliver packages by 10 00am the next day, it is necessary for the courier industry to complete all deliveries before beginning to pick up packages. Thus, the use of the other procedures would add uncertainty and risk into their goals and objectives of timely delivery and customer satisfaction.

The courier industry has one main constraint placed upon it, which somewhat limits the capability of minimizing travel costs through VRP. This constraint is that while deliveries to be made to the same destination, such as an office building with several organizations being located there, the TSP rule regarding single visits can not be guaranteed. Due to the nature of the courier industry, it becomes evident that, in the event of pick-ups, there exists the possibility that repeat visits to a location or general area will be required.

This stems from the dynamic nature of the service, whereby customers call the dispatch centre at all periods of the day, when a shipment is ready to leave that same day and therefore no advanced planning of routing is possible. It is here where a dynamic routing system with route optimization capabilities would provide an invaluable service to the courier industry. When a new service location is assigned to a specific vehicle by dispatch, either an on-board computer system could determine the "revised schedule of pick-ups" or that information be determined at the dispatch centre and then relayed.

5.3 Service Area and Orientation

There are two major travel components to goods transportation in urban areas. The first is that of the stem travel distance, the distance between the depot and the first delivery

location, and the second is the actual distance travelled for completion of the courier activities within the assigned service area. In many respects, both components are highly influenced by the transportation infrastructure available and the city form.

A majority of firms involved in the goods movement industry, courier companies included, locate their depots within easy access to freeways and major arterials to minimize the impact and costs of stem travel times. For courier companies and other industries which rely heavily on air freight movements for intercity transportation, efficient access to the airport is also essential.

Since the trips performed to the airport are typically completed during off-peak hours, the impact of delay caused by other vehicles is quite small and the effect of traffic incidents is also minor. However, as previously stated in Section 2.2 and 3.3, it is the distribution and collection of the packages by the courier vehicles which require the most attention due to their operation during peak travel hours.

One of the more important aspects of developing sound operational procedures is that of determining service areas that are efficient in both size and required travel distance. In small communities, the use of a single vehicle for all service requirements may be sufficient. However, as the city grows in size, there becomes an important decision with regards to the method in which the city is divided into service areas.

If the vehicle is carrying a full load of packages for delivery, Daganzo (1984) proposed that rectangular shaped zones be used and conform to Equation 5.1. The purpose of dividing the area into two halves, Daganzo explains is to allow for deliveries to be made in one half on the outbound journey and on the inbound trip for the other (Daganzo, 1984).

While this methodology provides slightly larger travel distance results than by empirical formulas, the courier industry must also contend with the pick-up phase of their operation, of which this procedure does not account for

$$C = 2wL\delta \quad (\text{Eq 5 1})$$

where C = vehicle capacity or number of stops

w = one-half of the width of service area

L = length of service area

δ = spatial density of delivery points.

In attempting to minimize the average overall travel distance of each vehicle, the effects of the stem and local service area travel distance must be incorporated. Substantial work has been done in this area by Daganzo, Newell and Hall at the University of California, Berkeley. In work completed during the mid 1980's and the 1990's, investigation into the effects of the number of items to be delivered, the size and configuration of the service areas and the number of vehicles used to service the region have been performed ((Newell, 1986c), (Newell and Daganzo, 1986a & b), (Daganzo and Hall, 1993), (Hall et al., 1994))

Initial work illustrated that the use of equi-travel-time contour lines may be beneficial in determining the orientation of the service areas (Newell and Daganzo, 1986a & b). The zones are usually rectangular with the longitudinal axis in the radial direction in circumstances where the transportation network utilizes a ring-radial configuration, while for networks with

a general metric, the orientation would not be so pronounced. Examples of these situations are illustrated in Figure 5-1 and Figure 5-2 respectively.

Figure 5-1 Possible Zoning for Ring-Radial Metric

Figure 5-2 Equi-travel-time Contours and Geometry For Idealized Networks

Source: Newell & Daganzo (1986a) Fig 1

Adding further complication to the problem is that of high-speed roadways which would create significantly complex contour lines. After investigating the effects of orientating the service areas at an angle to the road geometry, it was found that in a general network, typified by most cities, there would be no significant effect of service area orientation on the overall travel distance (Newell and Daganzo, 1986a & b)

A line-haul route is usually chosen which minimizes travel time and with line-haul distances in major cities being a substantial part of the overall travel distance, the use of freeways which are assumed to be faster and cheaper than other routes, yields service areas being often oriented perpendicular to the freeways. The research work determined that the stem or line-haul travel distance was simply twice the average distance between the depot and all the delivery sites for each zone, independent of the roadway configuration or available infrastructure. The location of delivery points were assumed to be randomly distributed over the service area and thus, the average distance would occur at approximately the zone centre. This was done so that the computed local travel distance would not be affected by the width and orientation of the zones (Newell and Daganzo, 1986b)

Most algorithms and techniques for determining routings of vehicles are based upon the use of a central depot from which deliveries are to be started from. Therefore, to minimize and simplify the computations needed for determining the local travel distance of a single delivery vehicle in any service area configuration, the line-haul distance was not used as the distance to the delivery point nearest to the depot. In this thesis, the examination of line-haul distance effects on the courier industry will not be performed so that concentration on the local delivery process can be undertaken.

5.4 Automatic Vehicle Location

In order to understand the potential benefits of Intelligent Transportation Systems for the purposes of vehicle location, some general explanation of the methods of use are required. In Section 5.2, a brief discussion indicated that for each service area, it was assumed that delivery locations were randomly distributed within the area and that each vehicle would service the entire area. The investigation of pick-ups yields a different servicing possibility.

With the location and number of deliveries known, the distribution segment of the courier operation requires simply the selection of an efficient route. As was mentioned in Section 5.1.1, the general methodology for solving the travelling sales person problem is used to determine the minimum travel distance or cost in the vehicle routing problem and is based on a fixed location and number of points. However, the collection segment of the courier operation does not provide the opportunity to predetermine a route or the number of pick-ups required.

One of the major questions to consider in the collection phase is whether courier vehicles should be restricted to operations within their designated zone, or is it feasible to allow some overlapping of collection zones to allow for increased servicing of pick-up requests by a vehicle closer but in the adjacent zone (Skomal, 1981). The availability of Automatic Vehicle Location (AVL) systems provide the opportunity to dispatchers to assign pick-ups to the nearest courier vehicle, as opposed to the vehicle which has been dedicated to that zone.

5.4.1 Response Time

The response time of an entire fleet is composed of the dispatcher time or delay and the average vehicle response time, of which the latter is further broken down into the vehicle travel time and the average service time. While automation of certain dispatch functions can reduce that portion of delay in fleet response, focus will be restricted to the vehicle response time gains available. With the use of an AVL system, the average travel time $[t_T]$, derived by Skomal (1981) and given by Equation 5.2, uses a summation of the product of the maximum travel time (t_m^*) for a vehicle m and the probability of the dispatcher assigning a service call ($p_{m,1}$) to that vehicle from the entire fleet.

$$[t_T] = \sum_{m=1}^{\bar{m}} p_{m,1} t_m^* \quad (\text{Eq. 5.2})$$

The average unit response time is calculated by factoring the probability that a vehicle is available for a service call and the average travel time. To this is added the average vehicle service time (t_s) multiplied by the probability that a vehicle was not available (ie. all vehicles are currently servicing calls) and given by Equation 5.3. (Skomal, 1981)

$$[t_R]_{AVL} = P_A(\rho)[t_T] + (1 - P_A(\rho))[t_s] \quad (\text{Eq. 5.3})$$

For a fleet not using an AVL system, the average unit response time is also made up of two components. Due to the dispatch not having the ability to locate vehicles, each vehicle only operates within its assigned area. Equation 5.4 demonstrates that using the average

distance to a service call, the size of the zone, the average vehicle speed, the number of vehicles assigned to the area and the vehicle utilization rate, the average fleet response time can be calculated (Skomal, 1981)

$$[t_R]_{NAVIL} = \frac{2(1-\rho)}{3[S]} \sqrt{\frac{A}{N}} + \rho[t_{sv}] \quad (\text{Eq 5.4})$$

where [S] = Average vehicle speed (km/hr)

A = service area (km²)

N = number of vehicles assigned to area

ρ = vehicle utilization rate

By subtracting Equation 5.3 from Equation 5.4, we can then determine the savings accrued from use of an AVL system. Based upon these equations, the decrease in average response time for between 10 and 30 vehicles operating in a 25 square mile area, with a service time of 16 minutes and an average travel speed of 15 miles per hour is shown in Figure 5-3. The figure also demonstrates the effect of an increasing utilization rate, which is the rate that the vehicle is servicing a call, for a constant 10 vehicles.

For a high number of vehicles servicing a region, as well as for a fleet of vehicles busy servicing calls, benefits can be accrued from the use of AVL technology. Current AVL systems still operate with a certain level of error in the estimation of location. Depending

upon the size of the standard deviation of this error, the average response time savings could total up to 6 minutes (Skomal, 1981). For the courier industry, who operate with an average service time between 3 and 5 minutes, such savings are impossible.

Figure 5-3 Response Time Reduction Accruing With Use of AVL System

Source: Skomal (1981) pg 49 Figure 2.12

5.5 Dynamic Vehicle Routing and Guidance

In previous sections, we have taken a cursory look at the vehicle routing problem, examined the methods used for determining the size of service area for vehicles and the development of methodology for calculating benefits from use of an AVL system. Combining

the knowledge of these items now allows for further investigation into dynamic vehicle routing and guidance

Courier companies are capable of pre-planning distribution routes for vehicles based upon the location of known destinations and assigning collection service calls to the nearest available vehicle, yet these actions are based on static or historical information regarding the road network and the associated traffic. The variability and randomness of collection service calls does not allow for pre-planning of routes and therefore there is no ability to determine a minimum travel cost route.

By having current traffic information provided through a traffic operations centre using ATMS technology, further increases in the potential savings for the courier industry are possible. In daily operations, courier vehicles encounter delay caused by either traffic incidents or increased travel demand. Traffic management technology has progressed substantially in recent years and is now able to provide instantaneous information such as traffic volumes, current operating speeds and locate areas of traffic congestion through video or other types of sensors.

This information is then capable of being used by the courier industry to route vehicles in a manner to circumvent the areas of delay by "dynamically" re-routing them to either new collection and distribution locations or by means of new routes to the current service call. With the traffic information capable of being provided at very small time intervals, one concern of engineers is to determine at what level of time savings will a vehicle be re-routed.

For example, a dynamic vehicle routing system determines at a given point in time that a savings of 30 seconds in overall travel time could be incurred with a change in route. What

is then the probability that, at the next evaluation 30 seconds later, the routing system would determine that the original route would result in a time savings due to new congestion areas. Then the overall (total) travel time of the vehicle could actually be greater than if the dynamic vehicle routing system had not re-routed the vehicle initially from the original route.

There are several possible costing factors which could be used to investigate the potential benefits of dynamic vehicle routing and guidance systems, including travel time, travel distance, operating costs and total costs. While there has not been much literature published which investigated the reasons for a driver's route choice, one study found that approximately 70 percent of business travellers, commercial vehicles and people on the journey to work select the quickest route with 10 percent selecting a route as a result of them not knowing any alternative routes (Outram and Thompson, 1978; cited by Wootton and Ness, 1989). This information would suggest that the most important factor considered by the public and businesses would be the accrued travel time for trips.

Some of the earliest work in the area of route guidance systems was conducted by Kobayashi (1979), in which a feasibility study of the use of a route guidance system in connection with the Comprehensive Automobile Traffic Control (CAC) Project for the Tokyo area was undertaken. Results showed that a reduction of 6 percent in the average travel time, 5 percent in fuel consumption and slightly over 6 percent in both carbon monoxide and hydrocarbon emissions could be obtained with the use of a route guidance system.

Other research, including that by Smith and Russam (1989), Koutsopoulos and Lotan (1989) and Breheret et al. (1990) (cited from Van Vuren and Van Vliet, 1992) found similar savings in both hypothetical and case studies. Using the TRANSYT-7F program for the Los

Angeles Smart Corridor project, a comparison of the shortest route travel time to the actually used route found that a savings of 12 percent by route guidance under recurring congestion could be obtained. The findings illustrated that less than 3 minutes could be saved for an average trip length of 25 minutes (Al-Deek et al., 1989).

The potential benefits which can be obtained are also dependent on the level of utilization of vehicle route guidance systems. It has been found that the greatest benefits for users of route guidance is attained at lower levels of route guidance use and the benefits change inversely proportional to the rate of use (Rakha et al., 1989, Smith and Russam, 1989, Kuhne, 1995).

Meanwhile, the societal benefits of dynamic route guidance usage for non-users increases proportionally to use. This result is intuitive since the purpose of a vehicle route guidance system is to minimize travel time or costs and therefore as a greater number of vehicles use the system for optimization, the travel path of more vehicles is optimized, travel demand is dispersed to other routes and the overall system benefits increase.

The results from simulations by Rakha et al. (1989) yielded three additional pieces of valuable information, as shown in Tables 5-1, 5-2 and 5-3. First, that as the duration of an incident increases for both freeways and arterials, the benefits of using a dynamic vehicle routing system increases. Secondly, when compared to a base case with no incidents, all scenarios result in an average travel time of approximately 80 percent of the base case. Finally, the largest incremental percentage of savings in average travel time, approximately 15 percent, occurs with a vehicle route guidance use between zero and 20 percent, after which further use has a decreasing impact on travel time savings.

If the system is initially used by courier companies and other commercial vehicles, the largest possible savings could be obtained. This is due to the higher associated costs with goods movement and the detrimental effect of commercial vehicle interaction on the general traffic stream. Thus, a re-routing of commercial vehicles to routes of less traffic would provide a benefit to both the trucking company as well as to the travelling public.

**Table 5-1 Decreases in Average Trip Time Relative to Base Case
(re-routing but no signal optimization)**

Percent Usage of Route Guidance						
Scenario	0%	20%	40%	60%	80%	100%
No Incident	100%	82%	79%	79%	79%	79%
5 min - freeway	101%	83%	81%	80%	79%	79%
10 min - freeway	103%	91%	84%	82%	81%	80%
15 min - freeway	109%	103%	92%	85%	83%	82%
5 min - arterial	102%	83%	80%	79%	79%	79%
10 min - arterial	105%	85%	81%	80%	79%	79%
15 min - arterial	109%	88%	82%	81%	79%	79%

Source: Rahka et al (1989) pg 301 Figure 7(a)

5.6 Advanced Traffic Management Systems

Although the use of Advanced Traffic Management Systems (ATMS) does not solely affect the urban goods movement community, the effects of ATMS on urban traffic conditions

**Table 5-2 Decreases in Average Trip Time Relative to Base Case
(re-routing and on-line signal optimization)**

Percent Usage of Route Guidance						
Scenario	0%	20%	40%	60%	80%	100%
No Incident	96%	81%	79%	79%	79%	79%
5 min - freeway	97%	82%	80%	79%	79%	79%
10 min - freeway	101%	87%	83%	81%	80%	80%
15 min - freeway	107%	98%	90%	85%	83%	81%
5 min - arterial	96%	82%	82%	80%	80%	80%
10 min - arterial	98%	87%	82%	82%	80%	79%
15 min - arterial	100%	89%	83%	81%	81%	79%

Source: Rahka et al (1989) pg 301 Figure 7(b)

**Table 5-3 Incremental Decrease in Average Trip Time Relative to Base Case
(no signal optimization)**

Incremental Increase in Usage of Route Guidance					
Scenario	0-20%	20-40%	40-60%	60-80%	80-100%
No Incident	18%	2%	0%	0%	0%
5 min - freeway	18%	3%	1%	0%	0%
10 min - freeway	13%	6%	3%	1%	1%
15 min - freeway	7%	11%	6%	3%	1%
5 min - arterial	19%	3%	1%	0%	0%
10 min - arterial	20%	4%	1%	0%	0%
15 min - arterial	21%	5%	2%	1%	0%

Source: Rahka et al (1989) pg 301 Figure 7(c)

is that such systems are capable of reducing the impact of both incident and recurring congestion. The same speed-flow-density relationships and capacity equations are still applicable when using ATMS, however, there are some changes in the range and dynamics of traffic flow due its use.

For example, the Ministry of Transportation of Ontario has found through data collection by their freeway traffic management system on Highway 401 in Toronto, COMPASS, that the lane capacity of an urban freeway is closer to the 2200 vehicles per hour per lane than the 2000 vehicles stated in the 1985 Highway Capacity Manual. It has also been found that 5 minute traffic volumes can reach 2400 vehicles per hour per lane during peak periods.

At the urban traffic network level, there have been substantial developments over the years at modifying traffic signal operations to increase intersection capacities. This includes the development of semi-actuated, actuated and real-time traffic controllers, the optimization of signal timing plans and the use of phase sequences to better reflect traffic demand patterns. Real-time traffic controllers provide the best opportunity for gains.

In research conducted by Rakha et al. (1989) which investigated the effects of route guidance on travel time, additional components of the research examined the impact of on-line signal optimization and the combining of route guidance with on-line signal optimization on the traffic network. For various scenarios comparing incident durations of a base case with no signal optimization to those with that feature, it was found that for incidents on the freeway, the difference in travel time decreases with incident duration. However, as shown in Table 5-4, there is an increase in the difference in travel time between the signal and non-

signal optimization scenarios as the duration of incident increases for incidents occurring on arterials.

**Table 5-4 Impact of Signal Optimization on Delay for Arterial Incident Durations
(no route guidance)**

Incident Duration (min)				
No Signal Optimization	0	5	10	15
Avg. Trip Time (min)	8.34	8.47	8.74	9.06
Avg. Trip Time (%)	100%	102%	105%	109%
Avg. Speed (km/hr)	59	58	56	54
Avg. Trip Length (km)	8.22	8.22	8.22	8.22
Signal Optimization				
Avg. Trip Time (min)	7.99	8.03	8.14	8.38
Avg. Trip Time (%)	96%	96%	98%	100%
Avg. Speed (km/hr)	62	61	61	59
Avg. Trip Length (km)	8.22	8.22	8.22	8.22

Source: Rahka et al (1989) pg 299 Figure 5

While it has been found that on-line or real-time traffic signal optimization yields an decrease in the observed travel time, this thesis will not investigate the impact of its use on the courier industry. There are several reasons for this decision. First, the use of real-time signal optimization results in a benefit to the overall traffic network and therefore it would not exclusively benefit the courier industry. Secondly, this thesis is investigating a range of

hypothetical situations which will demonstrate the effects of different volume to capacity ratios on potential benefits. Finally, it is beyond the capabilities of the available software to simulate such scenarios as a dynamic signal optimization based upon current traffic conditions and therefore would be impossible to properly complete.

CHAPTER 6

SIMULATION SET-UP AND PROCEDURE

6.1 Introduction

When conducting research, data are usually collected by means of experimental testing and observations. Also, computer simulation modelling can be used to generate information. There are several reasons for selecting the investigative technique of computer simulation over that of field studies in the case of courier operations. First, in order to collect a sufficient amount of field data, as would be required for analysis, a substantial amount of resources would be required along with the co-operation of any one of the many courier companies. As mentioned earlier, the major organizations which include UPS, Federal Express and Purolator Courier were contacted and requested for assistance.

The information desired comprised of either a log of an individual courier vehicle during a single day of operation, averaged totals for number of pick-ups and deliveries, information concerning the number new 'calls' received while a vehicle was en-route and the average service time per package for both downtown and suburban locations.

All requests were denied by the three organizations, who stated that due to the highly competitive nature of the industry, such information could be used as a competitive advantage by any competitor or that the resources needed to gather such information would not be available.

Secondly, a computer simulation with the use of well-accepted models allows for a greater diversity of scenarios which affect the industry, such as roadway configurations, traffic levels and operational characteristics. At present, only some of the main focal points of this thesis research have begun to be adopted by the industry into their operations, which include mobile communications and primitive vehicle scheduling/routing systems, while still many others are but in their developmental stages.

6.2 Selection of Models

In order to properly simulate an urban environment, the selection of a well-accepted traffic simulation program is important. Likewise, when using a hypothetical network it is necessary to use a signal timing program to effectively simulate a real-life urban network. There are many traffic and signal simulation programs and packages available such as TRAF-NETSIM, HCM and HCS which are the commonly used traffic simulation programs while TRANSYT-7F, PASSER II-90, TEAPAC, SOAP and SIGNAL85 are those packages regularly used for signal timing optimization.

While all these packages are effective and produce the necessary outputs after simulation, the TRAF-NETSIM and PASSER II-90 programs were selected for several reasons. Primarily, the issue of accessibility was considered. The Department of Civil and Environmental Engineering already possesses the TRAF-NETSIM package for use by students.

The package also allows for both a macroscopic and microscopic analysis using either the NETSIM or NETFLO programs. In Section 6.2.1, the beneficial reasons for this option

will be further explained. In addition, since the TRAF-NETSIM package was capable of delivering the necessary traffic outputs, also known as the Measures of Effectiveness (MOE), it was deemed to be an unnecessary expense to acquire any additional traffic simulation packages.

In the case of the signal timing program selection, the PASSER II-90 program was selected again on the basis of availability. The Regional Municipality of Ottawa-Carleton (RMOC) currently uses the PASSER II-90 program for their own traffic signal operation purposes. The RMOC graciously provided the necessary documentation to develop the required data inputs for the hypothetical networks as well as the computer time to complete the simulations. While other programs could have been utilized for this research, again the added expense of purchasing a traffic signal optimization program when one which provided all the required outputs was available and is used by traffic operation centres was deemed unnecessary.

Finally, in choosing to use a hypothetical simulation approach, a degree of randomness of traffic stream characteristics was used to further create a possible real-life situation. Again, there are many statistical packages available which are capable of generating random numbers in either a poisson, normal, uniform or any other distribution. The Carleton University computer system contains several packages, including SPSS and S-Plus. After consulting the Carleton University Statistical Consulting Centre, the S-Plus package was determined capable of generating the required numerical data.

6.2.1 TRAF-NETSIM Package

The TRAF-NETSIM package originally began as two separate programs which were later integrated to take advantage of each program's strengths. The package contains both a microscopic traffic network simulator, NETSIM, and two macroscopic simulators, NETFLO1 and NETFLO2, which provide less detailed output but allow for a greater number of roadways and vehicles to be evaluated. Along with these three programs are a macro and micro-simulator available for the evaluation of freeways.

In this research, only the NETFLO2 portion of the package was used due, in part, to the limited capabilities of NETSIM and NETFLO1 in handling the significant volumes in the larger hypothetical networks. In addition, the latter two packages were found to require nearly 3 hours of computer operating time to simulate a single hour worth of traffic time, compared to 4 minutes for the NETFLO2 package, and provided results which closely matched the NETFLO2 values.

NETSIM utilizes a fixed-interval methodology where each vehicle is treated as a distinct object and are moved individually every second. Different operating and performance characteristics are generated for each vehicle and each vehicle classification, as well as the behaviour of each driver. Each time a vehicle is moved, the program recalculates its position, speed and other traffic characteristics and all are done according to car following logic, response to traffic control devices and other demands such as lane switching and queue discharge. (FHA, 1993)

Due to the high computational needs of the NETSIM program, network volume is constrained to 3500 vehicles and a total of 500 links and 250 nodes (FHA, 1993). Like many

other models for arterial networks, NETSIM does not use a specific route for individual vehicles. Instead, all vehicles travel along a given link and once it reaches the downstream intersection, based on the assigned turn percentages for that intersection, the vehicle follows either the turn or through movement as required (McGurrin and Wang, 1992).

While the NETFLO packages do use many of the same techniques as NETSIM, the level of detail in operation and thus results are dramatically different. It is divided into two subprograms, NETFLO1 and NETFLO2. Using an event based simulation, NETFLO1 only moves vehicles when an event occurs and at that time moves the vehicle as far downstream as possible (FHA, 1993).

Unlike NETSIM, there is no use of car following logic in NETFLO1 which eliminates the provision of vehicle trajectories. However, due to the lower requirement of data and computer resources the NETFLO1 program is capable of handling 10,000 vehicles along with 700 links and 500 nodes. This provides the opportunity to investigate measures which must be applied to a larger network.

NETFLO2 was adapted from the TRANSYT (Traffic Network Study Tool) flow model and uses a combination of 5 histograms to describe the operations of the traffic stream. The program is capable of handling time varying flow and multiple cycle lengths (FHA, 1993). Apart from output such as aggregated link and bus-station measures, both the NETSIM and NETFLO packages produce similar information. The outputs generated can be found in Table 6-1 for NETSIM and Table 6-2 for NETFLO and are cited from the TRAF User Reference Guide Tables 15-7 and 15-14.

Table 6-1 Link Specific Measures for NETSIM Package

Measure	Units
Travel	Vehicle miles (Vehicle kms) Person miles(Person kms) Vehicle trips Person trips
Bus travel	Bus trips
Bus passenger travel	Person trips
Total travel time Delay time	Vehicle minutes, Person minutes
Bus travel time Bus delay Bus moving time	Minutes
Moving time	Vehicle minutes
Efficiency: Bus efficiency	Ratio: move time/total time
Mean travel time per vehicle mile Mean delay per vehicle-mile	Minutes/vehicle-mile (minutes/vehicle-km)
Mean travel time per vehicle Mean delay per vehicle Mean time in queue Mean Stopped time	Seconds/vehicle
Mean speed Bus speed	Miles/hour (Km/hour)
Vehicle stops Mean link Storage Area consumed	Percent
Bus stops	Number of stops
Cycle Failure	Number of phase failures
Mean content Average queue (by lane) Maximum queue (by lane)	Vehicles
Fuel consumed	Gallons (Liters)
Fuel economy	Vehicle-miles/gallon (Vehicle-kms/liter)
CO emissions HC emissions NOx Emissions	Kilograms/mile-hour (kilograms/km-hour)

Table 6-2 Cumulative Link-Specific Measures for NETFLO Package

<u>Measure</u>	<u>Units</u>	NETFLO 1	NETFLO 2
Travel	Vehicle miles (Vehicle km)	✓	✓
	Person miles (Person km)	✓	✓
	Vehicle trips person trips	✓	✓
Total travel time	Vehicle minutes, Person minutes	✓	✓
Delay time		✓	✓
Moving time	Vehicle minutes	✓	✓
Mean travel time/vehicle mile	Min/veh-mile (Min/veh-km)	✓	✓
Mean delay /vehicle mile		✓	✓
Mean travel time per vehicle	Seconds/vehicle	✓	✓
Mean delay per vehicle		✓	✓
Efficiency	Ratio moving time/total travel time)	✓	✓
Bus efficiency:		✓	✓
Mean speed	Miles/hour (km/hour)	✓	✓
Vehicle stops	Percent	✓	✓
Mean content	Vehicles	✓	
Mean link storage area consumed	Percent	✓	
Bus travel	Bus trips	✓	✓
Bus passenger travel	Person trips	✓	✓
Bus travel time	Minutes	✓	
Bus moving time		✓	✓
Bus delay time		✓	✓
Bus stops	Number of stops	✓	✓
Fuel economy	Vehicle-miles/gallon (Vehicle-km/litre)	✓	✓
	Person-miles/gallon (person-km/litre)	✓	✓
Fuel consumed	Gallons	✓	✓
CO emissions	Kg	✓	✓
	Grams/vehicle mile (Gram/km)	✓	✓
HC Emissions	Kg	✓	✓
	Grams/vehicle mile (Grams/km)	✓	✓

6.2.2 PASSER II-90 Package

PASSER II-90 is a computer program designed to determine a signal timing optimization for arterials. Standing for Progression Analysis and Signal System Evaluation Routine, PASSER II-90 is the most recent version of the package which can be used to evaluate current signal timing plans and to optimize the phase sequence, signal timing and signal offset for arterials. The program allows for a range of cycle lengths to be evaluated and then selects that which maximizes the progression efficiency (Courage and Wallace, 1991).

Input data requirements for the PASSER II-90 program can easily be obtained through field observations and traffic counts. Information required for the left, through and right turn movements include the volume, saturation flow and the geometric characteristics while generalized data such as percentage of heavy vehicles, number of buses per hour and the hourly parking volumes are also needed, as shown in Figure 6-1. Once the information is obtained, PASSER II-90 can be used to evaluate an existing timing plan or to generate the optimal signal phasing and timing solution, while providing various MOEs for the given arterial and each intersection.

The first set of MOEs demonstrate the general or overall effectiveness of the arterial signalization as shown in Table 6-3. Figure 6-2 illustrates the summary report generated which provides a more detailed breakdown of the signal effectiveness on a per intersection basis and the optimized signal timing plan is found in Figure 6-3.

STREET NAME Mockingbird NEMA VEHICLE MOVEMENT INTERSECTION 1

VOLUMES 4 7(5)
SAT FLO 368 43
MIN PHS 16 1700 10

VOLUMES 88
SAT FLO 1710
MIN PHS 10

5(5)

VOLUMES 431
SAT FLO 3266
MIN PHS 21

2

VOLUMES 240 1580
SAT FLO 1700 5250
MIN PHS 10 16

3(5)

VOLUMES 1114
SAT FLO 3500
MIN PHS 21 6

ARTERIAL NAME
Skillman Avenue

VOLUMES 51 1(5)
SAT FLO 1700
MIN PHS 10

TRAFFIC VOLUME CALCULATION	
LEFT TURN: LT BAY, "PROTECTED PHASE"	
THROUGH TRAFFIC (VPM)	= 400
RIGHT TURN TRAFFIC (VPM)	= 31
TOTAL TRAFFIC (VPM)	= 431
PEAK HOUR FACTOR	= 1.00
TRAFFIC VOLUME (VPM)	= 431
PLEASE PRESS ANY KEY TO CONTINUE.	

SATURATION FLOW RATE CALCULATION	
IDEAL SAT. FLOW (VPMGPL)	= 1800
NUMBER OF LANES (1 TO 3)	= 2
LANE UTILIZATION FACTOR	= 0.95
AVG. LANE WIDTH	= 12
% GRADE	= 0.0
% HEAVY VEHICLES	= 10.0
% PARKING MANEUVERS	= 0
% BUSES STOPPING	= 0
RIGHT TURN FACTOR	= 1.00
LEFT TURN FACTOR	= 1.00
AREA TYPE IS NOT CBD.	
AREA TYPE FACTOR	= 1.00
SATURATION FLOW (VPMG)	= 3200
PLEASE PRESS ANY KEY TO CONTINUE.	

MINIMUM PHASE TIME CALCULATION	
PEDESTRIAN "WALK" TIME (SEC)	= 4
PEDESTRIAN WALK SPEED (FPS)	= 4.00
PEDESTRIAN WALK DISTANCE (FT)	= 80
LESS HALF LANE WIDTH (FT)	= 8.00
MINIMUM PHASE TIME (SEC)	= 16
PLEASE PRESS ANY KEY TO CONTINUE.	

Figure 6-1 Data Input Screen from PASSER II

Source: Courage and Wallace (1991) pg 5-24, Figure 5 2

Table 6-3 Measures of Effectiveness Summary for PASSER II

MOE	DESCRIPTION	UNITS OF MEASURE	SOURCE OF ESTIMATE	COMMENT
CYCLE	The best cycle length	seconds	Optimization	
BAND	Bandwidth in the directions indicated	seconds	Optimization	
EFFICIENCY	Percentage of cycle in through bands	percent	Eq. (7.1)	
ATTAINABILITY	Percentage of green in the through band	percent	Eq. (7.2)	
PROGRESSION SPEED	Average speed in the two directions	mph ¹	Weighted average	
V/C RATIO	Degree of saturation	percent	Eq. (7.3)	Total value is the maximum
LOS	Levels of Service	N/A	See table 7.2	
TOTAL DELAY	Total delay	veh-hr	Average times volume	Adjusted for progression
AVERAGE DELAY	Average delay per vehicle	sec/veh	NCHRP method Eqs. (4.8-10)	Adjusted for progression
QUEUE LENGTH	Maximum queue length	vph	Figure 4.2.	
STOPS	Total and percentage of stops	vph and percent	Estimated by % red arrivals Eq. (4.14)	Accounted for progression
TOTAL GALS	Total fuel consumption	gallons ¹	TRANSYT-7F fuel model Eq. (4.14)	Only reported by intersection ² and system wide

Notes:

¹ PASSER II only deals in U.S. customary units.

² only in the native PASSER II format. This is not reported by intersection in the AAP-type output.

Source: Courage and Wallace (1991) pg 7-9, Table 7.1

(BEST.SOLN)

**** BEST SOLUTION.... NEMA PHASE DESIGNATION ****
 *** INT. 1 .0 SEC OFFSET ART ST PHASE SEQ IS LT 5 LEADS (2+5)
 Mockingbird .0 % OFFSET CROSS ST PHASE SEQ IS LT 3 LEADS (3+8)

	ARTERIAL STREET				CROSS STREET			
CONCURRENT PHASES	2+5	2+6	1+6	TOTAL	3+8	4+8	4+7	TOTAL
PHASE TIME (SECS)	10.1	27.5	10.8	48.4	25.7	10.9	10.0	46.6
PHASE TIME (%)	10.6	28.9	11.4	50.9	27.1	11.5	10.5	49.1

	MEASURES OF EFFECTIVENESS							
PHASE (NEMA)	5[5]	6	1[5]	2	3[5]	4	7[5]	8
PHASE DIRECTION	EBLTPR	WBTHRU	WBLTPR	EBTHRU	NBLTPR	SBTHRU	SBLTPR	NBTHRU
PHASE TIME (SEC)	10.1	38.3	10.8	37.6	25.7	20.9	10.0	36.6
V/C-RATIO	.81	.88	.42	.45	.62	.61	.40	.87
LEVEL OF SERVICE	D	E	A	A	B	B	A	E
DELAY (SECS/VEH)	73.5	33.4	44.0	23.9	35.6	37.1	44.5	33.6
LEVEL OF SERVICE	E	D	D	C	D	D	D	D
QUEUE (VEH/LANE)	3.6	10.8	1.3	4.7	5.3	4.1	1.1	10.1
STOPS (STOPS/HR)	109.	1028.	46.	391.	205.	521.	40.	1479.
TOTAL INTERSECTION DELAY	34.22 SECS/VEH				FUEL CONSUMPTION		MINIMUM DELAY CYCLE	
					83.73 GAL/HR		97 SECS	

A. PASSER II Format

(BEST.SOLN)

**** INTERSECTION 1 Mockingbird OFFSET= .0 SECONDS, .0 %
 ARTERIAL PHASE SEQUENCE IS LT 5 LEADS (2+5)
 CROSS STREET PHASE SEQUENCE IS LT 3 LEADS (3+8)

	ARTERIAL				CROSS STREET			
CONCURRENT PHASES	2+5	2+6	1+6	TOTAL	3+8	4+8	4+7	TOTAL
PHASE TIME (SECS)	10.1	27.5	10.8	48.4	25.7	10.9	10.0	46.6
PHASE TIME (%)	10.6	28.9	11.4	50.9	27.1	11.5	10.5	49.1

		MEASURES OF EFFECTIVENESS			
MOVEMENT/	V/C	TOTAL	AVERAGE	PROB. QUEUE	
NODE NOS.	RATIO (LOS)	DELAY	DELAY	CLEAR. (LOS)	STOPS
	(%)	(VEH-HR)	(SEC/VEH)	(%)	(VEH/HR) (%)
NB THRU :	87 (E)	14.54	33.6 (D)	81 (C)	1479. (95)
LEFT :	62 (B)	2.38	35.6 (D)	96 (B)	205. (85)
SB THRU :	61 (B)	5.85	37.1 (D)	99 (B)	521. (92)
LEFT :	40 (A)	.53	44.5 (D)	98 (B)	40. (92)
EB THRU :	45 (A)	2.86	23.9 (C)	100 (A)	391. (91)
LEFT :	81 (D)	1.80	73.5 (E)	47 (E)	109. (124)
WB THRU :	88 (E)	10.35	33.4 (D)	70 (D)	1028. (92)
LEFT :	42 (A)	.62	44.0 (D)	98 (B)	46. (91)
NODE 1 :	88 (MAX)	38.92	34.2	47 (MIN)	3817. (93)

B. AAP Format

Figure 6-2 PASSER II Best Solution Report, Artery Summary

Source: Courage and Wallace (1991) pg 7-12, Figure 7.4

(PIN.SET)

**** SUMMARY OF PASSER II-90 BEST SIGNAL TIMING SOLUTION ****
 Dallas Skillman Avenue DISTRICT # mm/dd/yy RUN NO. n

CYCLE = 95. SECONDS SPLIT = 1 2 3. OFFSET = 1 2 3.

DEFAULT(1) : SAME MASTER & SYS INT, OFFSET TO BEGINNING OF MAIN STREET GREEN
 MAST INT = 1 SYS INT = 1 SYS OFFSET = .0 REF MOVMT = 0 REF PNT = BEGIN

INTRSC 1 : Mockingbird COORD PHASE : 0 OFFSET : .0 SEC : .0%
 *- [MASTER INTERSECTION]

DUAL-RING PHASE #	5	6	1	2	3	4	7	8
PHASE SPLIT (SEC)	10.1	38.3	10.8	37.6	25.7	20.9	10.0	36.6
PHASE SPLIT (%)	11.1%	40.1%	11.1%	40.1%	27.1%	22.1%	11.1%	39.1%
PHASE REVERSAL	--	--	2	1	--	--	8	7
LEFT TURN	LEAD	--	LAG	--	LEAD	--	LAG	--

CONCURRENT PHASES	2+5	2+6	1+6	3+8	4+8	4+7	MAIN	CROSS
DURATION (SEC)	10.1	27.5	10.8	25.7	10.9	10.0	48.4	46.6
CYCLE COUNT (SEC)	.0	10.1	37.6	48.4	74.1	85.0	.0	48.4
CYCLE COUNT (%)	0.1%	11.1%	40.1%	51.1%	78.1%	89.1%	0.1%	51.1%

(PIN.SET)

**** SUMMARY OF PASSER II-90 BEST SIGNAL TIMING SOLUTION ****
 Dallas Skillman Avenue DISTRICT # mm/dd/yy RUN NO. n

CYCLE = 95. SECONDS SPLIT = 1 2 3. OFFSET = 1 2 3.

DEFAULT(1) : SAME MASTER & SYS INT, OFFSET TO BEGINNING OF MAIN STREET GREEN
 MAST INT = 1 SYS INT = 1 SYS OFFSET = .0 REF MOVMT = 0 REF PNT = BEGIN

INTRSC 2 : University COORD PHASE : 0 OFFSET : 29.9 SEC : 31.5%

DUAL-RING PHASE #	5	6	1	2	3	4	7	8
PHASE SPLIT (SEC)	10.0	63.9	10.0	63.9	.1	21.0	.1	21.0
PHASE SPLIT (%)	11.1%	67.1%	11.1%	67.1%	0.1%	22.1%	0.1%	22.1%
PHASE REVERSAL	--	--	--	--	4	3	8	7
LEFT TURN	LEAD	--	LEAD	--	LAG	--	LAG	--

CONCURRENT PHASES	1+5	1+6	2+6	4+8	3+8	3+7	MAIN	CROSS
DURATION (SEC)	10.1	.0	63.9	21.0	.0	.0	74.0	21.0
CYCLE COUNT (SEC)	29.9	40.0	40.0	8.9	29.9	29.9	29.9	0.9
CYCLE COUNT (%)	31.1%	42.1%	42.1%	9.1%	31.1%	31.1%	31.1%	9.1%

Figure 6-3 PASSER II Signal Timing Plan

Source: Courage and Wallace (1991) pg 7-20, Figure 7.9

Data input is also possible through the use of the Arterial Analysis Package EXective (AAPEX) which uses a simplified input procedure and then allows for data to be converted to either the PASSER-II or TRANSYT-7F setup. The user is requested to select a forward direction for the traffic stream. The program will then optimize traffic signal splits to minimize delay at each intersection based upon the provided approach volumes.

This is followed by the optimization of the phase sequence and signal offsets to maximize bandwidth efficiency and thus progression efficiency in the forward direction. The program then evaluates whether minor changes to the timing plans would further reduce delay in the reverse direction (Courage and Wallace, 1991).

The significant benefit in the use of the AAPEX program over the standard PASSER II-90 program is the ability to select a desired range of cycle lengths which should be investigated. Using the PASSER II-90 program requires each cycle length to be run independently and then the user must compare the bandwidth efficiency and total arterial delay between all cycle lengths to determine the optimum cycle length. However, in the AAPEX program, all these steps are inserted into the program instructions and completed automatically. This results in a lower user time requirement and an automation of the cycle length selection process.

6.2.3 S-Plus Statistical Package

The use of statistical packages in creating a hypothetical model provides the opportunity to remove any bias or influence on the results by the user. In the case of the S-Plus package, several random number generators can create distributions such as a normal,

binomial, uniform and poisson distribution. In transportation, these distributions can be used for various traffic stream characteristics. For example, the travel speed variation is well exemplified by the use of a normal distribution while the poisson distribution models the random arrival of vehicles to queues.

In the case of this research, a set of randomly generated numbers with a normal distribution were used to model the right and left turn movements for all arterials. Based on turn percentages obtained from the Regional Municipality of Ottawa-Carleton traffic counts conducted within the CBD, it was found that the mean turn percentage was approximately 17 percent, with a range between 2 and 33 percent.

Using these values for generating turn percentages within the hypothetical network, the S-Plus package produced values with a mean of 17 percent and within 7 standard deviations of the mean. The normal distribution was selected due to the equal possibility of the turn percentage deviating above or below the mean value.

The S-Plus package was also used to generate courier vehicle pick-up and delivery schedules by means of the uniform distribution model. Each link was assigned a number at mid-block to simulate a potential pick-up or delivery site and then the range of values were used as limits for the generation of routing schedules for the courier vehicle. The uniform distribution was chosen since each and every mid-block location would have the same probability of generating a service call.

6.3 Development of Hypothetical Network Models

For both the courier operators and firms involved in the distribution of other goods

and services, the need to model different arterial network configurations stems from the various geographic locations of operation. In studying the impacts of ITS on the courier industry, several notable characteristics were observed regarding operational concerns and modelling needs. Based upon a review of cities throughout the United States and Canada, it was found that a majority of cities have an arterial network in the CBD based upon a grid pattern and that this pattern typically involves a mixture of one and two-way streets.

When a larger metropolitan view is taken, again a grid-like pattern is typically found with two-way arterials being used and often with a freeway encircling an expanded CBD area. These arterials divide the city into zones of low and high residential development, commercial buildings and industrial and manufacturing areas. Cities such as Toronto, Calgary, Ottawa, Los Angeles, Chicago, New York and Phoenix can all be modelled using this blueprint.

Therefore, it was determined that through the use of a metropolitan based network and a CBD based network, it would be possible to simulate a majority of urban centres in North America. Figure 6-4 illustrates the grid pattern found in a typical CBD through the use of Ottawa as an example. The grid pattern found in the Metro Toronto area is shown in Figure 6-5.

Using hypothetical models to simulate realistic metropolitan conditions for research purposes, several key guidelines should be observed. These are as follows (MTO, 1975):

1. Network size -- should be sufficient in size to properly test potential
2. Network structure -- form a closed grid with intersecting major arterials

Figure 6-5 Metro Toronto Major Arterial Network

3. Network Boundary -- minimal traffic interaction with remainder of network signal system
4. Network Homogeneity -- homogeneity in traffic conditions, operational characteristics, land use and roadside activities
5. System Considerations -- signal parameters such as cycle length should be maintained
- 6 Representative Features -- make applicable to other areas.

In the research undertaken here, all these factors have been examined and are discussed in the following sections

6.3.1 Model Characteristics

Using various cities as examples, a metropolitan network consisting of a 9 by 11 arterial grid was developed and is shown in Figure 6-6. The arterials are mainly four-lane thoroughfares with two lanes per direction and turning bays are not provided. The perimeter arterials, along with a single east-west and one north-south arterial comprise of three lanes per direction with left-turn bays provided. The use of such a network satisfies the guidelines for the network structure. One characteristic which must be taken into account in this type of modelling process is that of arterial spacing.

At the macroscopic or metropolitan level, distances between arterials are expected to play a significant role in the impact of ITS on courier operations. For this reason, link lengths will range from 100 to 700 metres at 200 metres intervals. Due to the also limited

Figure 6-6 Hypothetical Network Model

capability of the NETFLO2, it was found that a maximum of 700 metres can be used for simulation purposes without overloading the program.

Major routes within the downtown core of cities are much more closely spaced, and can often be uni-directional. The reasons for one-way street use is the minimization of conflict between vehicles travelling in opposite directions and the elimination of conflict for left-turn movements. Vehicle progression is typically much smoother, however, these one-way streets can often be a hinderance to delivery vehicles without proper route planning. Additional travel time and distance is often incurred simply due to the circuitous route which must be taken by drivers.

Distances between roadways, or roadway lengths, within CBDs vary greatly. For example, in Ottawa, link lengths range between 25 and 61 metres for the downtown core while cities such as Dallas, Chicago and Manhattan range between 70 and 150 metres. These values were obtained through scaled maps of different cities. Therefore, the hypothetical models will use link lengths of 25, 50, 75 and 100 metres. With the range of link lengths taken and the large network modelled, the network size appears adequate.

Secondly, it is important to ensure that all levels of traffic are examined. Urban traffic conditions, as stated in Section 3.2, is one of the largest obstacles to operational efficiency for courier operations within an urban area. Therefore, the research conducted must recognize the possibility of a large range of traffic conditions.

Reports and studies from North America and abroad indicate that the maximum vehicle throughput of a roadway, with urban commuters being the main source of drivers, would convert into figures approximately 1.1 to 1.2 times the stated theoretical capacity of

the roadway. In order to ensure that most conditions are encompassed, it was decided that volume to capacity ratios of 0.8, 1.0 and 1.2 would be examined. Through the use of different traffic levels, both the network homogeneity and representative features for model characteristics are incorporated.

6.3.2 Operational Characteristics

6.3.2.1 Signal Timing Plan

To ensure a valid scenario, the operational characteristics of both the network and the courier vehicle must be accounted for. With regards to the network, the main factor which will affect the reliability of the results is the traffic signal timing plan and coordination chosen. To alleviate this problem, a first run of TRAF-NETSIM with a 90 second cycle length and a 50/50 signal split was conducted to provide traffic volumes for the PASSER II-90 program. Based upon work by Helali (1991), it was found that the Metropolitan of Toronto and Regional Municipality of Ottawa-Carleton operate traffic signals with this general cycle length and thus 90 seconds was chosen as a preliminary value.

Using the optimization features of PASSER II-90, a cycle length, signal split, phase sequence and offset were computed which minimized delay for each arterial. After five different arterials produced an optimum cycle length of 90 seconds, for the metropolitan case studies, it was determined that the cycle length for all arterials should be assigned a 90 second period, if the PASSER II-90 program resulted in a optimum cycle length which was approximately similar in bandwidth efficiency and total arterial delay to that calculated for the 90 second cycle length option.

The same initial signal conditions of 90 seconds and a 50/50 split were used for both the one-way and two-way street configurations of the CBD cases. In these simulations, the V/C ratio of 1.0 was again used as the basis for developing the signal timing plan. The results provided by the PASSER II-90 program ranged in cycle length between 50 and 60 seconds, with the exception of one or two arterials over the 25 to 100 metres range. For simplification of future work and calculations, a signal timing plan with cycle length of 50 seconds was chosen. Again, these signal timing plans were reassigned to TRAF-NETSIM for a second iteration

This procedure enabled the hypothetical models to closely simulate conditions found in many cities. Even with new technological improvements such as fully actuated and demand responsive signal timing systems being introduced, the majority of traffic signals are still not capable of responding to changing demand. Even with the use of traffic counts, there still remains significant delay at intersections due to these variations in demand.

The signal timing plan has been optimized for a volume to capacity ratio of 1.0 and will be used for all the simulation runs, including a V/C ratio of 1.2. Local governments conduct traffic counts around their regions periodically to determine if there is either a shift in the traffic patterns or substantial changes to travel demand or when deficiencies in operation are observed. However, these studies are usually conducted on a per site basis, as opposed to being conducted at an arterial or network level.

Since the percentages of left, right and through volumes are remaining constant, the PASSER II-90 program results in a signal timing plan which is relatively similar at the 1.2 V/C ratio as at the 1.0 ratio. The signal timing plan obtained from the analysis of all arterials

was then used to reprogram the TRAF-NETSIM package for evaluation of traffic performance characteristics.

It should also be noted that the output from the PASSER II-90 program did not provide information on the yellow or "caution" interval of the signal plan. Thus, in the metropolitan case the 90 second time plan was used but with 5 seconds removed from the green time allotted to each direction and the PASSER II-90 optimum cycle length of 50 seconds used with 5 seconds allotted to each direction for the CBD cases

These 5 seconds were themselves assigned with 3 seconds being used for the "cautionary" or change interval between phases of cross-directional traffic and 2 seconds for those phase changes involving traffic of the same direction. Figure 6-7 demonstrates the typical conversion or alteration of the PASSER II-90 optimum cycle length output to that used in this simulation.

6.3.2.2 Output Time Period

The TRAF-NETSIM package provides the capability of producing both intermediate and cumulative statistics at the conclusion of each simulation time period. With upto 19 time periods per TRAF-NETSIM run, a significant number of options for time period length were available. Based upon a suggestion in the TRAF-NETSIM manual, it was assumed that a single time interval length consistent with a signal cycle length would be most appropriate and that data be therefore output at 2 cycle intervals. The suggestion was that the most common signal length be used to determine the time interval which is used for the selection of a time period (FHA, 1993).

Figure 6-7 Phase Splits Used in Simulation

The conformity to this suggestion was used for the one-way and two-way CBD cases, as indicated in Section 6.2.2, but was determined to be inappropriate for the metropolitan case for the two simple reasons that it would possibly adversely affect the comparative nature of the research and that secondly, in the case of courier operations, the typical service time is between 3 and 5 minutes per site. In the modelling procedure developed, the selection of a 3 minute time period would generate a 3 to 6 minute service time while a 2 minute time period would produce a 3 to 5 minute service time as shown in Figure 6-8.

6.3.2.3 Courier Operations

The two most significant operational characteristics for couriers which must be examined are the availability of a route optimization and a route guidance device. The sequence in which pick-ups are serviced would be influenced by the use of a route schedule optimization program. It is this program which will determine, based upon current traffic conditions and pick-up locations, the order in which locations are to be serviced so as to minimize travel time, travel costs or incurred delay. Currently, no computer programs are available for use in this research and therefore will require a manual analysis of the possible route combinations and the subsequent decision based upon minimizing travel time.

The use of a route guidance system must also be studied. At the present time, operating conditions for courier companies leave the route decision making process to the driver. Usually, this decision is made based upon driver experience, however the inability of drivers to foresee congestion areas leads to the possible savings which could be obtained from a route guidance system. Again, while there are currently operational systems being

Figure 6-8 Effect of Time Period on Service Time

tested and used, a manual analysis of the output data from TRAF-NETSIM will be required to simulate the use of a route guidance system.

6.4 Selected Hypothetical Cases

For each of the hypothetical networks, one metropolitan (all two-way roads) and one CBD model (combination of one and two-way roads), there will be a significant number of variables which will be analyzed. Each of the following factors will be examined for their complete range as follows:

1. Traffic Volume to Capacity ratio : 0.8, 1.0 and 1.2
2. Arterial link length : Metropolitan 100 to 700 metres,
in 200 metre intervals and
25, 50, 75 and 100 metres
CBD 25, 50, 75 and 100 metres
3. Route optimization / No route optimization

As previously indicated, each of these factors plays a significant role in the potential benefits which can be derived from ITS technologies. The ratio of volume to capacity is related to the level of congestion found on the transportation network and thus, the amount of delay incurred by the courier industry. The spacing between arterials will also have an adverse effect on the operation of courier vehicles due to more circuitous routes being required, especially when one-way streets are encountered.

Since route and schedule optimization are desirable for improving courier operations,

the benefits from avoiding congestion, re-routing vehicles before the passing of widely spaced arterials and changing from a first in/first served methodology to one which minimizes travel time, distance or costs is necessary. In addition to these factors, each of the networks will be used for 12 different simulation cases, for which there are three base cases.

1. 6 pick-up/delivery (P&D) operations
2. 6 P&D operations with 2 unscheduled pick-ups
3. 6 P&D operations with 6 unscheduled pick-ups

These base cases will provide a good range of possible operating conditions for a single courier vehicle. While the number of pick-ups will only provide an operational time anywhere between 1.5 and 3 hours, depending upon the volume to capacity ratio and the arterial spacing modelled, this period length will be sufficient in illustrating the possible gains which can be achieved by a single vehicle. The timing of when the courier driver will be informed of an unscheduled pick-up will be evenly distributed during the time period examined.

The average service time within the courier industry is between 3 and 5 minutes. The intermediate outputs from TRAF-NETSIM will be provided in 2 minute intervals. Therefore, after each service location is reached, a service time will be used which falls into the 3 to 5 minute range and each service stop will be assumed to have been completed by the end of the next nearest time interval which provides a departure time using the next intermediate output for ease of computations.

6.5 Development of Route Optimization Program

In order to computerize the search for the optimum travel path between two points, the Simulation Optimum Route Determining System (SORDS) computer program was developed. Using the Turbo Pascal 7.0 programming language, the program reduces the output file from the TRAF-NETSIM program and selects only the required information for determining an optimum route between two nodes. The program was written specifically for the hypothetical network utilized in this research, but can be easily modified to accept any network of any size. Further modification would allow for the program to determine optimum routes based upon minimizing fuel consumption, move time, delay time, total travel time or even vehicle emissions.

6.5.1 Program Functions

Currently, the SORDS program allows for the selection of a single or multi-time period data output file, labelled as a "Static" and "Dynamic" output file respectively, from the TRAF-NETSIM model to be analyzed. Once this has been chosen, the user is asked whether the results of the route optimization search should be written to a file, in addition to being displayed on the screen and if so, is prompted for a file name. The next stage in the process is to reduce and eliminate all unnecessary output from the TRAF-NETSIM file.

The program asks the user if there are any existing data reduced files to be examined. If the user answers no, then the program takes a few moments to read the TRAF-NETSIM output file, eliminate all unnecessary information and store the pertinent requested data in a file named "j:\temp\temp.txt", otherwise, a file of the same name is read.

Once completed, the program is ready to begin its search for all possible route combinations between two nodes (intersections) on the network. The user is prompted, if a "Dynamic" output file was chosen, to specify the desired beginning time period. Having completed this, the origin and destination's X and Y coordinates are then requested.

Using the coordinate system shown below in Figure 6-9, the computer then undertakes five different search patterns to investigate all the possible route combinations and displays the results of each search on the screen and writes the same information to a text file, if this had been requested. At the end of the search, the average travel time is displayed. Given the entire list of route combinations, the user is then capable of determining the optimum route by selecting that which results in the lowest travel time.

The computer program, at this time, does not identify any single route as the best or optimum route for several reasons. First, the data file produced by TRAF-NETSIM is on a link travel time basis while a node to node procedure was chosen as the search method to reduce computations and minimize computer time for this program. However, this leads to some complications. When an origin or destination node is chosen, it is not possible under the current framework of the SORDS program to specify a particular link to be travelled upon, thus a vehicle can attain its destination without passing by the service location.

There are two methods which can be used to alleviate this problem. The user may specify the node at the beginning of the destination link as the destination node and then undertake a secondary search of the travel time on the destination link itself. The user could otherwise specify the end node of the destination link as the destination node and then only examine those route combinations which utilize the given end link. While both methods

Figure 6-9 Coordinate System of Network Used in the SORDS Program

would be somewhat crude and inefficient for a commercial application, for research purposes, these options proved effective in ensuring the proper data were generated.

Another difficulty arose in the selection process of specific data sets and the orientation or direction of travel. For search purposes, a constant downward and towards the right pattern was found to be most easily modelled. As such, the SORDS program has been developed to arrange the data of the TRAF-NETSIM output file into an array of a checkerboard pattern, as required, to ensure that only the data for a particular route and a particular direction are read. Source code for the SORDS program, a logic diagram and additional information are provided in Appendix B.

6.5.2 TRAF-NETSIM Data Setup

In order for the SORDS program to properly read the information from the TRAF-NETSIM output data file, the corresponding input data file requires some standardization. While there is a very structured arrangement of input data for the TRAF-NETSIM package, the user has some flexibility in the selection and order within the input data file. First, the numbering scheme of nodes is essential to proper operation of the SORDS program. All dummy nodes that are used in the program, i.e. those used along the perimeter similar to cordon count locations, require a '1xx' number configuration. Any link which contains a dummy node is not examined in the SORDS program.

Secondly, the network used must be of a 9 by 12 arterial network. This is due to the procedures currently used to place the data files into the above mentioned arrays. To circumvent this problem, mid-block nodes can be used along with the creation of imaginary

links whereby no traffic is assigned to those roadways and no signalization codes or signal time are allotted. The arterials must also be entered from left to right, in the forward (down) and back (up) direction, followed then by arterials from top to bottom in the forward (right) and back (left) direction. This again is to account for the methods used to place the data into arrays. Finally, the last link to be read from the TRAF-NETSIM output file must be the link comprises of nodes # 518 to # 508. These key nodes are used as flags so as to notify the program that the final link for that time period has been read.

6.6 Research Conditions and Input Data

The procedure used for the investigation of the impact of ITS on the courier industry within an urban context was quite straightforward. As previously mentioned, the selection of case studies yielded a large array of scenarios to investigate which were preliminarily completed through the iterative process between the TRAF-NETSIM and PASSER II-90 programs and detailed in Sections 6.3.2.1 and 6.3.2.2. Once final output files were generated from TRAF-NETSIM, these output data files were examined and inputted into the SORDS program for specific route information results.

The next stage was to determine the schedule to be followed by the courier vehicle through the generation of a set of random numbers by the S-Plus statistical program. Each link was assigned a number, in order, between 1 and 195 and then the S-Plus package was asked to generate 12 random numbers of uniform distribution. Service locations were assumed to be located at mid-block of the selected links. These 12 links were thus used as the basis for the three operational conditions of a 6 P&D, 6 + 2 P&D and 6 + 6 P&D

scenario, where the latter two cases involve the reception of new service calls after the vehicle has begun its daily activities. The links were generated in the following order:

1. Link #112 - node 551 to node 561	2. Link # 63 - node 633 to node 533
3. Link #151 - node 576 to node 586	4. Link # 149 - node 574 to node 584
5. Link #21 - node 513 to node 514	6. Link # 76 - node 537 to node 538
7. Link # 189 - node 601 to node 602	8. Link #24 - node 516 to node 517
9. Link #166 - node 584 to node 594	10. Link # 112 - node 551 to node 561
11. Link #35 - node 520 to node 521	12. Link # 131 - node 563 to node 573

For all cases, the beginning and finishing node used was #500, which is located at the top left-hand corner of the network. As discussed in Chapter 5, the routing of the courier vehicle from the depot to the service area would, in general, result in the vehicle entering the zone at the first available opportunity.

Therefore, it can be hypothesised that the courier depot would be located in a northwesterly direction from node 500. From these three scenarios, additional areas of investigation were drawn. The first area is that of a "pick-up in order" (PUIO) scenario whereby there is found to be no mobile communication devices and no route schedule optimization system.

The information collected from this scenario was the maximum and minimum travel time necessary to complete the service calls for the particular route. This provided an insight into the possible gains which could be achieved by the courier vehicle from simply being informed of the most favourable or efficient route available. The information was collected

on a dynamic basis, meaning that the travel times recorded were those computed for the time period immediately following the departure from the last completed service call.

Availability of historical or average travel time for the network was the focus for the second area of additional investigation. The "static" case, as referred to from now on, was expected to provide an overview of the effect of having some information of the typical traffic conditions that would be exhibited on the network. This would be accomplished in conjunction with the use of a mobile communication and a route schedule optimization system. In using a route optimization system, the service locations did not change, however two conditions needed to be checked.

As stated in Section 5.2.1, Mullner identified that an asymmetric problem would be when conditions such as travel time, distance or cost vary between any two points in an optimization problem. Thus, the route was investigated for both a clockwise and counter-clockwise service pattern to find if there was significant difference in the required total travel time. This asymmetric route concept was expected to prove even more significant in the one-way CBD scenarios.

Secondly, an optimized pattern of pick-up was determined using the same call locations as listed above. The optimization objective at this research stage was to minimize the overall travel distance by selecting an appropriate schedule. The minimum travel distance schedule would then be used for determining the minimum travel time among the potential routes. The schedule optimization was based upon the assumption that new calls would be received equally spaced, in order, among current service locations and not service times.

Thus, after the completion of the second service call, the courier operator would

receive information indicating that a new pick-up location had been assigned and instructions as to the most appropriate route to reach the newly given destination assigned. This would occur again after completion of the fourth service call, and so forth, and result in the route schedule therefore being as follows for the two-way road scenarios:

For 6 P&D

Clockwise	Counter-Clockwise
1 Link #112 - node 551 to node 561	1. Link # 21 - node 513 to node 514
2 Link #149 - node 574 to node 584	2. Link # 63 - node 633 to node 533
3 Link #151 - node 576 to node 586	3. Link # 76 - node 537 to node 538
4 Link # 76 - node 537 to node 538	4. Link #151 - node 576 to node 586
5. Link # 63 - node 633 to node 533	5. Link #149 - node 574 to node 584
6 Link # 21 - node 513 to node 514	6 Link #112 - node 551 to node 561

For 6 + 2 P&D

Clockwise	Counter-Clockwise
1 Link #112 - node 551 to node 561	1. Link # 21 - node 513 to node 514
2. Link #149 - node 574 to node 584	2. Link # 63 - node 633 to node 533
3. Link #189 - node 601 to node 602	3. Link # 76 - node 537 to node 538
4. Link #151 - node 576 to node 586	4. Link #151 - node 576 to node 586
5. Link # 76 - node 537 to node 538	5. Link #149 - node 574 to node 584
6 Link # 24 - node 516 to node 517	6. Link #189 - node 601 to node 602
7. Link # 21 - node 513 to node 514	7. Link #112 - node 551 to node 561
8 Link # 63 - node 633 to node 533	8. Link # 24 - node 516 to node 517

For 6 + 6 P&D**Clockwise**

1. Link #112 - node 551 to node 561
2. Link #149 - node 574 to node 584
3. Link #189 - node 601 to node 602
4. Link #151 - node 576 to node 586
5. Link # 76 - node 537 to node 538
- 6 Link # 24 - node 516 to node 517
7. Link # 21 - node 513 to node 514
8. Link # 63 - node 633 to node 533
- 9 Link #112 - node 551 to node 561
- 10 Link #166 - node 584 to node 594
- 11 Link #131 - node 563 to node 573
- 12 Link # 35 - node 520 to node 521

Counter-Clockwise

- 1 Link # 21 - node 513 to node 514
2. Link # 63 - node 633 to node 533
3. Link # 76 - node 537 to node 538
4. Link # 24 - node 516 to node 517
- 5 Link #151 - node 576 to node 586
6. Link #149 - node 574 to node 584
- 7 Link #166 - node 584 to node 594
- 8 Link #189 - node 601 to node 602
9. Link #112 - node 551 to node 561
- 10 Link #112 - node 551 to node 561
- 11 Link # 35 - node 520 to node 521
- 12 Link #131 - node 563 to node 573

The same schedules were used in the one-way case studies as well. One reason for this was to maintain a consistent schedule for comparison purposes between the achievable benefits in a one-way and two-way system. Using the same route schedule, the difference in travel distance in addition to travel time will therefore be noted. Further details as to the methodology used for reaching these route schedules can be found in Appendix C.

The final area of investigation was concerning the effects of having real-time traffic information, in addition to having mobile communication capabilities, a route and schedule

optimization system. Hereafter referred to as the "dynamic" case, it was expected to provide a lower travel time between two locations of service calls by accounting for variations in traffic conditions and thus minimizing interference from areas of traffic congestion.

Using the data provided from the TRAF-NETSIM program, new traffic information was provided every 2 minutes, which was assumed to be a reasonable rate of updating from a traffic management centre. Currently, freeway traffic management centres, such as the COMPASS system operated by the Ministry of Transportation of Ontario gathers new freeway traffic information every 20 seconds. The updated information provides the ability to re-evaluate which route from the present location to the point of service results in the minimum travel time.

6.6.1 Courier Logistical Considerations

In providing updated traffic information every 2 minutes, the route guidance system has the capability of determining the minimum travel time route in a near real-time basis. However, there are some logistical problems due to the simulation program limitations, in addition to the environment to be simulated. For instance, if the courier vehicle is en-route along a particular link when the route guidance system receives the new information, is it logical to assume that the vehicle would stop and return in the opposite direction to take a "new" minimum route.

In both theory and real applications, this would not be a feasible alternative, therefore the new information would only be engaged from the next intersection encountered by the vehicle. In other words, the courier vehicle would complete its travel upon a given link

regardless of whether the route guidance system would suggest a faster travel time along another route beginning from the previous intersection. Upon completion of travel on that link, the courier vehicle would be informed of the new, and faster travel path to be taken. Secondly, there would be the potential for greater travel distances to be incurred, which is a main factor in operational costs for couriers.

6.7 Input Data

In producing the hypothetical networks and subsequently the traffic volumes, signal timing plans and other traffic related information, the development of input data was required. In many cases, assumptions were made regarding values for some information which was deemed to be either insignificant to the traffic impact on the network or would too closely simulate a particular city, area or situation. In developing the input data, several areas of focus were needed. These included the factors which affect the roadway capacity, traffic signals and traffic volumes.

6.7.1 Roadway Capacity

The first and most important group of factors to investigate was those involved in the theoretical capacity of the roadways. The Highway Capacity Manual (1985) is generally viewed as the main source of information in the transportation field and divided into 14 chapters, of which Chapter 9 and Chapter 11 are of the most important in this research. Traffic flow can be segmented into interrupted and non-interrupted flow, as well as freeway and arterial traffic. This research focuses on interrupted arterial traffic flow. Interrupted

traffic flow is that which, as indicated, is interrupted by objects including traffic signals and stop signs.

To analyze any traffic network or particular roadway, several key components such as capacity, traffic conditions, roadway conditions and signalization conditions must be investigated. When signalized intersections are involved, the analysis becomes more complicated and the direct relationship between capacity and level of service is lost. The analysis is based upon an ideal condition free-flow saturation rate which is the flow of vehicles that could pass through the intersection if allotted a full green phase.

This initial saturation flow (S_o) has been empirically derived to be 1800 vehicles per hour per lane and is subsequently factored down for various impacts. Using this value and the known number of lanes for each link, the maximum capacity of the given roadway under ideal conditions can be found. The equation used in determining the factored saturation flow is taken from the Highway Capacity Manual (1985) Equation 9-8 and is shown in Equation 6-1.

$$s = s_o N f_w f_{HV} f_g f_p f_{bb} f_a f_{RT} f_{LT} \quad (\text{Eq 6.1})$$

where N = number of lanes on link

s_o = ideal saturation flow rate per lane, 1800 passenger cars per hour per lane

f_w = lane width adjustment factor

f_{HV} = heavy vehicle adjustment factor

f_g = approach grade adjustment factor

- f_p = parking lane and parking activity adjustment factor
- f_{bb} = bus blockage factor
- f_a = area type adjustment factor
- f_{RT} = right turn adjustment factor
- f_{LT} = left turn adjustment factor.

For the hypothetical networks used in this research, the above factors were computed from Tables 9-5 through 9-12 of the Highway Capacity Manual. The values taken are as follows:

- f_w = 1.00 for use of 12 foot (3.65 metres) lanes
- f_{HV} = 0.98 for a 5 percent mix of heavy vehicles in traffic stream
- f_g = 1.00 for level terrain
- f_p = 0.92 for 10 parking manoeuvres per hour for two lane group
- f_{bb} = 0.99 for less than 10 buses stopping per hour
- f_a = 0.90 for area being of central business district type
- f_{RT} = 0.95 for shared right turn with permitted phasing, moderate pedestrian conflict and average 20 percent turn percentage
- f_{LT} = 0.95 for exclusive left turn with protected phasing, moderate pedestrian conflict and average 20 percent turn percentage (3 lane arterial).

With the exception of the values for f_a and f_{LT} , these factors remain constant for all cases studied. The values chosen for these two factors were kept the same, despite the

differences in hypothetical cases for several reasons. The area type adjustment factor would normally be set at 1.00 for all cases not involving the CBD and thus for the metropolitan case studies in this research. However, comparative analysis of the case studies were expected to be performed on a inflow traffic volume and therefore the factor was not adjusted.

The left turn adjustment factor underwent similar consideration for change on the two lane arterials, where the value would have been 0.99 due to the shared left turn lane with protected phasing. Once again, it was decided to not adjust this factor since the difference generated, approximately 50 vehicles, would have a significant effect on the results and that, in using the 0.95 factor, the saturation flow rate would then be of a consistent value between all studied hypotheticals

Using the adjustment factors given, the resultant adjusted saturation flow was found to be equal to

$$s = 1305 * N \quad (\text{Eq. 6-2})$$

or 2610 vehicles per hour for a two lane arterial and 3915 vehicles per hour for a three lane arterial. With these values, the capacity of the arterial can be calculated. Equation 9-1 of the Highway Capacity Manual shows that the capacity of the intersection is simply a function of the saturation flow rate and the green-to-cycle length ratio.

$$c_i = s * (g / C) \quad (\text{Eq. 6-3})$$

In this research, the initial cycle split was chosen as 50/50 for both the 60 and 90 second cycle length, with 10 seconds from each cycle being allotted to the change interval. Therefore, the applicable (g / C) ratios are 0.40 and 0.45 respectively and hence yielded the following results:

For 60 second cycle Capacity of 2 lane arterial = 1044 vehicles per hour

Capacity of 3 lane arterial = 1566 vehicles per hour

For 90 second cycle Capacity of 2 lane arterial = 1175 vehicles per hour

Capacity of 3 lane arterial = 1762 vehicles per hour

6.7.2 Traffic Signals

In using the PASSER II-90 model, some general information was required for the analysis of each intersection. Generally, the default values available were satisfactory for use and were based upon values and tables from the Highway Capacity Manual. For example, the ideal saturation flow rate was selected as 1800 vehicles per hour per lane (vphpl), lane widths were 3.65m, vehicle occupancy equal to 1.0 and free flow speeds of 50 kph. Other factors such as a moderate level of pedestrians and 5 percent heavy vehicles were used to coincide with the input information for TRAF-NETSIM.

In addition to this preliminary information when requesting a signal optimization process, PASSER II-90 requires that an initial signal timing plan be entered as well as a minimum phase time for through and left turn operations, number of lanes, location of turning bays and approach volumes for the left, through and right turn movements. After discussion

with the RMOC traffic staff, a protected left turn phase and a separate through phase was selected with a minimum phase time of 5 and 15 seconds respectively.

Output from the PASSER II-90 program provided the optimum phase sequence, phase times, signal offsets and the cycle length for each arterial on the network. It was found from this output that a 50/50 cycle split was in general quite an accurate estimation of the optimum traffic signal timing plan. Under the PASSER II-90 package, the phase sequences are numbered as shown in Figure 6-10 and typical outputs provided by the PASSER II-90 program produced signal timing plans as illustrated in Table 6-4.

Figure 6-10 Phase Sequence Schematics for PASSER II

Source : Courage and Wallace (1991)

From these timing plans, a modified timing plan was assumed which rounded the phase times to the nearest 5 second interval. This generally provided a constant phase time for all intersections and phases. It was only the phase sequence which was maintained as output by PASSER II-90 for programming the TRAF-NETSIM data, since it would provide

an indication as to whether a leading or lagging left-turn green would be most appropriate.

Table 6-4 Timing Plan Results from PASSER II for Two-way Hypothetical Network

Phase Splits for Various Nodes Using PASSER II Notation							
60 Second Timing Plan	1+5	2+5	1+6	2+6	4+8	3+8	3+7
Node 500	-	10 sec	8 sec	8 sec	8 sec	8 sec	8 sec
Node 556	-	7 sec	7 sec	11 sec	10 sec	8 sec	7 sec
Node 558	-	11 sec	-	10 sec	20 sec	9 sec	-
Node 604	9 sec	-	-	16 sec	13 sec	-	12 sec
Node 507	-	7 sec	-	19 sec	16 sec	-	8 sec
90 Second Timing Plan							
Node 500	11 sec	5 sec	-	29 sec	29 sec	5 sec	11 sec
Node 556	12 sec	-	-	28 sec	30 sec	5 sec	15 sec
Node 558	-	27 sec	-	-	44 sec	-	19 sec
Node 604	-	20 sec	-	36 sec	-	34 sec	-
Node 507	-	14 sec	-	39 sec	-	37 sec	-

6.7.3 Traffic Volumes

While the theoretical capacity affects or limits the operations of a signalized intersection, there are other factors which can equally have a devastating effect on the level of delay incurred on an entire network. Factors such as the actual volume, quality of progression, length of green phases, cycle lengths, roadway lengths and others can cause significant delay to incur even though the intersection is operating at a low v/c ratio and vice versa (HCM, 1985).

The enormous impact of these other parameters were discovered during all phases of this research and primarily in the "dynamic" simulation of the metropolitan case studies. The initial case examined was that of the 700m arterial spacing with a 90 second cycle length and continued until the 100m case. It was here that link travel time for certain links were computed by TRAF-NETSIM to be either greater than one hour or zero. The condition of data became even more severe for the 75m case. Neither of these two calculated travel times would allow for a continuation of the simulation process and therefore a reexamination of the traffic volumes and signal timing plans used in this research was started.

The "static" case studies had all indications that the TRAF-NETSIM program was computing travel times without any erroneous, large or inexplicable results and therefore the resulting travel times in the 3600 second range were unexpected. While nothing unusual was discovered from reviewing the "static" case outputs, upon further examination of the output data file from the "dynamic" cases, an explanation to the results was discovered. The TRAF-NETSIM output demonstrated a distinct rise in travel time over each two minute simulation period until such time that there was a significant increase in the total. After this point, the number of trips and the travel time would suddenly become zero, which would indicate no travel volume.

After reviewing the methodology of TRAF-NETSIM in computing travel time, it was determined that the actual travel time should not become zero, as provided, but should actually have indicated infinity. The reason behind this is as follows. The TRAF-NETSIM package details travel time as the time required for a particular vehicle to complete travel over a given link and the total time is computed once the vehicle passes the stop line. Therefore,

if the given link and the downstream links have become so congested that no vehicle can leave a particular link, the programs assume that no vehicle is currently using that particular link and hence the average travel time on that link is zero.

This discovery caused a significant reorganization in the research to be conducted. It was decided that since the volumes used for the 90 second cycle length metropolitan cases were causing such enormous results, thus not allowing for further simulation under the 100m arterial spacing level, that a second set of lower inflow volumes be used for the network. The question still remained, what factors could be changed without affecting the comparison analysis between simulations.

The signal cycle length of 60 seconds, the saturation flow rate nor the number of lanes could be altered, as they would affect the ability to compare between scenarios. Altering the capacity of the arterials, according to Equation 6-1, could not be done without affecting the saturation flow rate or the green-to-cycle length. Yet, it was the green-to-cycle length which provided the greatest opportunity to factor down the existing values for use in the remaining simulations.

The signal time plan for the 60 second cycle length cases consisted of a 10 second protected left-turn phase for both the N-S and E-W directional traffic as well as a 15 second through phase. Therefore, the new inflow volumes would be assigned based upon a g/C of 0.25 or an equivalent phase of 15 seconds. In order to minimize the same results from occurring, several preliminary iterations were undertaken with these values. It was once again found that the erroneous output occurred early into the 50m cases and consequently the volumes were tested again at a g/C of 0.20, at which time the output files from TRAF-

NETSIM produced sufficient results to continue. The inflow traffic volumes for the simulation process were therefore as shown in Table 6-5.

Table 6-5 Inflow Volumes for Hypothetical Models

	Arterial Type	
Metropolitan Network	2 Lane Arterial	3 Lane Arterial
V/C = 0.8	940	1410
V/C = 1.0	1175	1762
V/C = 1.2	1410	2114
CBD Network	2 Lane Arterial	3 Lane Arterial
V/C = 0.8	434	652
V/C = 1.0	544	815
V/C = 1.2	653	980

CHAPTER 7

RESULTS AND OBSERVATIONS

7.1 Introduction

In conducting the research for investigating the impact of ITS technology on the courier industry in an urban environment, significant time and resources were devoted towards the development of hypothetical models, the generation of output data from these models and the subsequent analysis of the information. In total, 344 simulations of TRAF-NETSIM were required, each representing 30 minutes of simulated travel time, for the two-way metropolitan scenarios and 43 simulations were required for the one-way CBD scenarios.

These simulations resulted in the creation of the three case studies.

- 1) Pick-up in Order
- 2) Static Traffic Information
- 3) Dynamic Traffic Information

Within each of these three case studies, there were three pick-up and delivery (P&D) scenarios produced and three volume to capacity ratio categories. Subsequently, there were a total of twelve different combinations of arterial length and condition for each of these cases. Therefore, a total of 324 scenarios were developed for comparison in this thesis.

7.2 Case Study Results

7.2.1 Static Case Study

The use of static traffic information has been viewed by some as the most efficient means of providing route guidance information to the travelling public due to the very low requirement for data transmission. In this way, only a few packets of information are required to be stored for use to cover the morning and afternoon peak periods as well as the off-peak hours. Therefore in this research, traffic information was gathered for a range of traffic volumes, corresponding to three ratios of volume to capacity whereby travel times were computed for an average hour.

This was also done for two different network configurations, one of one-way streets and the second of two-way streets for a range of arterial spacings each. The results presented in Table 7-1 illustrate the effect that increasing volume has on the total delay incurred for a specific journey. Delay is defined as the difference between the incurred travel time and the travel time which would be incurred under free-flow conditions. As expected, the greater volume causes increased congestion on the network and hence a longer travel time is required for journey completion. The full set of data is provided for reference in Appendix D. In addition, the effect of the arterial spacing is dependent upon the range considered.

As shown in Figure 7-1, the two-way arterial CBD simulations demonstrate that with an increasing spacing, there is a reduction in the minimum travel time achievable. This is due to the lesser effect of progression efficiency and cycle length among other factors on the traffic operations as the distance between intersections increases. In research conducted by Helali (1991), this effect was observed and given the term signal spacing factor in the

developed equations. It is also apparent from the CBD simulations that the minimum point on each curve is located at a different arterial spacing. As the V/C ratio increases, the arterial spacing where the minimum point occurs increases. This trend is also found in the metropolitan cases where the minimum point upon the V/C equals 1.2 curve is located at 300m, while the minimum point for the remaining two curves has not yet been attained.

However, the metropolitan simulations yielded a trend that differs from that found in the CBD cases. It was found that as the arterial spacing increased from 100 metres to 700 metres, the delay time typically increased. This observed increase is dependent upon the actual location of the minimum point of each curve. From Figure 7-1, it is demonstrated that the minimum point for the curves of 0.8 and 1.0 V/C occur at some spacing less than 100m. The CBD curves illustrate that the minimum points could be at 100m for a V/C ratio of 1.0 and at 75m for a 0.8 V/C ratio.

Table 7-1 Total Delay for Static Travel Time Paths

Total Delay For Static Travel Time Paths (sec)									
P&D Operations	V/C Ratio	Arterial Length							
		25m	50m	75m	100m	100m	300m	500m	700m
6	0.8	1307.5	834.0	549.3	579.5	698.8	800.3	840.7	1000.4
	1.0	1632.3	1645.5	1039.1	718.6	709.5	846.7	916.7	1079.3
	1.2	1840.3	2104.2	1652.8	1013.5	753.5	921.3	1078.5	1315.1
8	0.8	1699.6	808.6	764.6	803.8	1109.5	1202.9	1266.6	1435.3
	1.0	2127.8	1366.8	884.9	849.2	1247.8	1295.4	1443.4	1610.4
	1.2	2421.7	1749.1	1353.2	959.7	1592.0	1388.4	1700.4	1983.2
12	0.8	2296.8	1142.6	1056.2	1086.4	1609.0	1676.2	1603.1	1846.9
	1.0	2930.6	2057.0	1396.0	1224.0	1845.3	1910.1	1969.4	2124.6
	1.2	3028.5	3028.5	2097.2	1514.9	2166.4	2061.1	2289.3	2552.9

Figure 7-1 (a) Total Travel Time for Static Clockwise Simulation with 6+2 P&D Operations

Figure 7-1(b) Total Travel Time for Static Clockwise Simulation with 6+2 P&D Operations

Throughout this discussion, travel time and delay time is used in many situations as interchangeable terminology. This occurs since total delay time is the difference between total travel time and free-flow travel time, where the number of links remains constant for the static and dynamic cases. It would normally be assumed that by increasing the distance between intersections under the same traffic volume that more or greater free-flow conditions would be achieved and would result in a reduction in total delay time. The greater distances increase the ratio of move to stop time, thereby reducing the impact of intersection delay. However, with free-flow conditions not being usually achieved due to heavy traffic volume, it is found that moving time delay is increased and therefore results in the larger total delay.

7.2.2 Dynamic Case Study

Various levels of government around the world have begun collecting traffic data by different technological methods. These technologies allow for the dissemination of this information to the travelling public. The concept behind dynamic route guidance systems is that the provision of traffic information in a real-time manner will allow the driver to make a more informed decision as to a selected path to attain their destination. To simulate this growing phenomenon, the TRAF-NETSIM package was used to produce traffic information at two minute intervals. Again, this was performed for all the cases and scenarios investigated in this research.

A summary of the results obtained is provided in Table 7-2 and illustrated in Figure 7-2. These demonstrate a similar set of trends as was found for the static case studies. There is a noticeable initial decrease in travel time as the arterial spacing increases, however, as was

found with the metropolitan static cases, the travel time begins to increase as the spacing increases for both the dynamic CBD and metropolitan case studies.

Table 7-2 Total Delay for Dynamic Travel Time Paths

Total Delay For Dynamic Travel Time Paths (sec)									
P&D Operations	V/C Ratio	Arterial Length							
		25m	50m	75m	100m	100m	300m	500m	700m
6	0.8	1160.1	550.9	557.1	591.6	1901.4	809.0	848.6	977.0
	1.0	1648.0	716.6	569.3	604.8	3983.6	807.8	857.3	1032.8
	1.2	N/A	1246.7	889.9	641.5	5944.2	885.0	955.0	1079.8
8	0.8	1965.4	777.6	766.0	805.4	9269.9	1176.6	1280.9	1559.7
	1.0	2116.4	1027.7	910.7	849.5	14266.4	1229.9	1616.1	1693.2
	1.2	N/A	1498.2	1136.5	1280.2	19774.3	1350.0	1671.0	1952.9
12	0.8	N/A	1201.2	1109.4	1108.7	N/A	2502.7	2392.9	2588.3
	1.0	N/A	5615.4	2099.1	1562.9	N/A	2755.5	3237.1	3149.1
	1.2	N/A	N/A	9630.2	3166.5	N/A	3486.6	3906.5	3656.0

The difference in these trends, when compared to those of the static cases, is that the dynamic case studies use data which more realistically portray the actual traffic patterns. As the arterial spacing increases, the journey travel time increases. Since the static cases averaged the observed travel time, as congestion increases further into the simulation, the dynamic case study results on travel time become larger than those of the static cases.

It is for this reason that the observed travel times at the 100m spacing metropolitan scenarios are significantly larger than those found in the static cases. The high traffic volumes, small spacing and signal progression factors all affect the efficiency of the traffic

**Figure 7-2 Total Travel Time for Dynamic Simulation
with 6+2 P&D Operations**

network, thereby resulting in large travel times. For the scenarios with shorter journey travel times, the impact of the dynamic versus static simulation procedure is essentially masked by the small time horizon examined.

Beyond the 300m spacing, the dynamic simulations very closely match the patterns of the static simulations. In comparing the data from Table 7-2 with those of Table 7-1, we find that for the 0.8 and 1.0 V/C ratios, the results are very close in magnitude and at the V/C ratio of 1.2, the data reflect a greater difference between static and dynamic travel times. There is also a greater observable difference between the two cases as the number of P&D activities increases

7.2.3 Pick-up In Order Case Study

The third set of data simulated was that for cases whereby no route scheduling information was available. This case was examined for the purpose of determining whether there could be substantial benefits derived from optimizing the courier route so as to minimize travel distance by comparing it to the dynamic case studies. Another reason for examining this set of scenarios was to investigate what level of benefit could be achieved by having a semi-dynamic route guidance system available.

By receiving traffic information prior to departure from a service stop, selecting a given route and following this route without adjustments for traffic fluctuations, a semi-dynamic route guidance system is considered a hybrid of the dynamic route guidance system. For each scenario in this case study, the minimum and maximum travel times were recorded for the pre-selected route schedule. This produced the data shown in Table 7-3. Again, the

general trends observed in both the static and dynamic cases are found in the data for the pick-up in order case studies.

Table 7-3 Total Delay of Minimum and Maximum Travel Time Paths

Summary for Total Delay Of Minimum and Maximum Travel Time Paths (sec)									
P&D Operations	V/C Ratio	Minimum Travel Time Path							
		Arterial Length							
		25m	50m	75m	100m	100m	300m	500m	700m
6	0.8	1560.6	811.7	829.6	866.3	1722.3	1242.7	1293.1	1133.3
	1.0	N/A	856.7	854.2	866.2	4175.1	1372.1	1376.5	1566.4
	1.2	N/A	1114.4	994.4	921.5	N/A	1584.8	1590.2	1946.8
8	0.8	N/A	1142.1	1157.8	1232.6	2016.6	2161.3	2113.4	1960.8
	1.0	N/A	1443.1	1284.0	1233.5	N/A	2311.1	2437.1	2877.9
	1.2	N/A	2851.4	1691.1	1496.8	N/A	2875.9	3186.8	3735.8
12	0.8	N/A	1651.4	1543.1	1632.1	N/A	2914.7	3205.9	3257.4
	1.0	N/A	5095.4	2299.1	1935.6	N/A	3520.6	4020.4	4197.5
	1.2	N/A	N/A	3158.0	3869.9	N/A	3960.2	4329.7	4523.2
		Maximum Travel Time Path							
6	0.8	8304.3	1094.1	1247.8	1529.8	3046.4	2081.8	2132.5	2060.5
	1.0	N/A	1592.4	2699.8	4069.9	13740.8	2458.5	3014.2	3014.2
	1.2	N/A	2478.9	3357.2	12882.2	N/A	2735.2	3518.1	4149.1
8	0.8	N/A	1494.8	1394.2	1477.0	2797.5	3797.7	4300.4	4502.0
	1.0	N/A	4078.1	2809.8	1733.0	N/A	6540.7	5257.1	8180.9
	1.2	N/A	8551.8	3589.3	2771.6	N/A	7835.6	8748.8	10812.6
12	0.8	N/A	3378.1	2095.4	4760.1	N/A	6373.2	7168.4	9366.0
	1.0	N/A	N/A	9911.8	10081.7	N/A	10993.4	10466.4	12229.1
	1.2	N/A	N/A	17825.7	12347.7	N/A	14033.3	16669.5	15235.2

The effects of increased traffic volume, herein referred to as the volume to capacity ratio, clearly demonstrate that an increase in volume has a significant impact on the level of travel time and therefore incurred delay. The impact however is also dependent upon the arterial spacing found on the network. The CBD cases can be found to have a graduating

increase in both travel time and delay as spacing increases while the converse appears to occur for the metropolitan cases

Also in the CBD scenarios, the travel time initially decreases and in a few cases begins to increase as the arterial length is enlarged. In the metropolitan scenarios, the continued increase in travel time is observed as the arterial lengths are increased. Figure 7-3 demonstrates these observed trends in graphical terms

7.2.4 One-way CBD Case Studies

A separate examination must be made for the static, dynamic and pick-up in order cases examined under the one-way street configuration scheme. While the patterns and trends observed from the data are very similar, the one-way traffic network does induce several additional considerations. For example, in the selection of route schedules, there is greater restrictions placed on the available routes which still maintain the minimum travel distance criterion

This naturally reduces the number of possible routes to be considered and which are available. As a result, there are fewer chances of diverting from a route of high congestion to one of lesser congestion. Therefore, the availability of a route guidance system, whether it be a static, dynamic or a hybrid version would be expected to yield dramatic savings in travel and incurred delay time due to the ability to determine traffic conditions downstream.

One trend which is more distinct in the one-way data of the dynamic and pick-up in order cases is the effect of traffic volume, or volume to capacity ratio, and its relationship to arterial spacing. It is observed by the one-way data in Table 7-4 that at the 0.8 V/C ratio the

**Figure 7-3 Total Travel Time for Pick Up In Order
Simulation with 6+2 P&D Operations**

delay time for the entire range of service calls examined does not demonstrate the minimum point found in the two-way cases. This indicates that the minimum point is located at a spacing smaller than 50m. For the other two V/C ratios, minimum points are found in the 50m to 75m range.

Table 7-4 Total Delay for Dynamic Travel Time Paths of One-Way Cases

One-way System -- Total Delay For Dynamic Travel Time Paths (sec)									
P&D Operations	V/C Ratio	Arterial Length							
		Minimum Time				Maximum Time			
		25m	50m	75m	100m	25m	50m	75m	100m
6	0.8	N/A	806.8	819.9	873.2	N/A	733.1	750.3	806.9
	1.0	N/A	1132.3	995.8	1136.1	N/A	1049.1	798.6	889.1
	1.2	N/A	N/A	1148.7	1263.8	N/A	N/A	1031.3	1155.6
8	0.8	N/A	1153.9	1174.9	1304.5	N/A	1113.2	1136.4	1262.9
	1.0	N/A	1428.9	1362.8	1391.8	N/A	N/A	1224.0	1388.7
	1.2	N/A	N/A	N/A	2080.7	N/A	N/A	N/A	2918.1
12	0.8	N/A	1500.1	1524.5	1696.1	N/A	1363.3	1386.1	1565.2
	1.0	N/A	N/A	3350.9	1924.6	N/A	N/A	1543.6	1755.6
	1.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Since it would be expected that at a lower traffic level there would be no excessive congestion encountered at the intersections, it would be reasonable to deduce that a greater proportion of the delay would be as a result of reduced travel speed. Demonstrated in Figures 7-4 (a) and 7-4(b), in graphical terms, are the observed relationships between delay, traffic volume and arterial spacing using two different formats for 6 P&D operations.

At a V/C of 1.2, the pattern observed in the two-way network configuration is maintained. There is a significant increase in the total incurred delay at or below the 50

Figure 7-4 (a) Total Delay Time For Pick-Up In Order Simulation with 6 P&D Operations For One-Way Case

Figure 7-4 (b) Total Delay Time For Static Case Simulation with 6 P&D Operations For One-Way Case

metre arterial spacing for the V/C ratio of 1.2 and as the arterial spacing is increased, the rise in total delay is less dramatic. Similarly, the effect of volume on the incurred delay for a given arterial spacing increases at an increasing rate. For all volume levels of the static cases, the two-way network trends are followed, unlike that found for the dynamic cases.

Another important factor involved in the examination of travel on one-way traffic networks is the impact on distanced travelled. Due to the additional restrictions placed on the vehicles, a more circuitous route is generally required and thus increases the operational costs of courier and other similar goods delivery operators. The significance of route scheduling systems which can function on a dynamic basis is therefore extremely high. By reducing the number of links travelled for either a single vehicle or an entire fleet, the use of a dynamic route scheduling program can increase productivity, reduce fuel consumption and eliminate unnecessary travel kilometres.

There were several conditions placed upon the one-way traffic network simulations to ensure a possibility to compare results. In order to accommodate this requirement, it was decided to not alter the geometric conditions of the roadway, nor would it be prudent to change the inflow traffic volume. PASSER II-90 was however used to develop a traffic signal plan which would be optimum under the one-way traffic network system.

As a result of the conditions set, significant delay occurred and congestion developed at a faster rate than it did using the two-way street network. To alleviate the resulting impacts, it was possible to add an extra lane to each arterial or reduce the inflow traffic volume. However, significant changes to the arterial capacity or the inflow volume were deemed to induce changes in traffic operations and influence comparative results.

7.3 Scenario Comparisons

To fully investigate the potential benefits of ITS use for courier operations in an urban environment, all eligible scenarios and factors chosen for this research were compared. These comparisons were expected to demonstrate the effect of arterial length, vehicle loading and the number of P&D operations on route travel time. These factors are important in the investigation of broader issues and areas such as the benefits of advanced traffic management systems and advanced traveller information systems along with the subareas of schedule optimization systems, mobile communications systems and route guidance systems.

Of these systems, advanced traveller information systems and advanced traffic management systems play instrumental roles, for without information regarding traffic conditions and not having a means of communicating quickly and easily with the courier vehicles, the remaining systems lose their effectiveness. The benefits of advanced traffic management systems and advanced traveller information systems are found in every facet of ITS research. This is due in large part to the need within the ITS infrastructure to gather and disseminate traffic information. Therefore the study of their subareas are of greater interest in this research.

In the comparison of the maximum and minimum travel time for the "pick-up in order" case study, knowing the quickest route to a destination should result in a significant increase in productivity. In addition, the dynamic case comparisons would demonstrate the benefits of knowing the schedule of service calls which would minimize travel distance and time. The comparisons between the static and dynamic case studies would indicate the level of variation that would occur if the traffic information provided was of a more dynamic nature, where only

the detail and currency of the traffic information is of difference between the two case studies.

It should be noted that the dynamic case study is more representative of the traffic conditions on the hypothetical network than the data obtained through the static case. As such, the difference observed between the two case studies does not actually indicate the gains that can be obtained by the use of one information packet over the other, but rather how close the static information packet can portray the highly dynamic actual conditions. This result will provide a basis for the development of route guidance systems and an investigation as to whether a dynamic route guidance system which provides information for all links constantly is truly necessary, or whether a static information base with updates as to the location of "unusual" congestion areas are satisfactory.

7.4 Simulation Results

7.4.1 Two-Way Metropolitan Cases

The cases examined for the metropolitan scenario included arterial lengths of 25, 50, 75 and 100 metres with a signal cycle length of 60 seconds and lengths of 100, 300, 500 and 700 metres with a signal cycle length of 90 seconds. These cases were performed for volume to capacity ratios of 0.8, 1.0 and 1.2, and for the three pick up and delivery scenarios illustrated in Section 6.4. In addition, an examination of the effects of a clockwise and counter-clockwise pick-up schedule was performed. The results obtained for the static case of 50 metres are found in Table 7-5 and the tables corresponding to the remaining scenarios can be found in Appendix D.

7.4.1.1 Route Scheduling Systems

One of the first, and most noticeable differences between scenarios is that of the number of links required to complete the P&D operations. It is here where some of the positive effects of route scheduling and more specifically dynamic route scheduling can be found. There were three scenarios examined in this thesis, including the pick-up in order scenario which used no route scheduling whatsoever, the clockwise dynamic route scheduling scenario and finally the counter-clockwise dynamic route scheduling scenario. The latter two scenarios were examined to determine whether there would be any benefit towards choosing one route direction for collection over another

The results of these investigations proved quite fruitful as can be seen in Table 7-6. The difference in total links travelled can be quite substantial between the use of a route scheduling program and the absence of one. For the base case of 6 P&D operations without any new service calls received there was a total of 18 additional links traversed for completion of the tasks with the absence of route scheduling. On networks with small spacings between arterials, the savings can be as little as 450m, however on the larger scale metropolitan cases examined in this thesis research, a 12.6 kilometre reduction in travel distance can have an enormous effect on fuel consumption, vehicle emissions and other operational costs for an entire fleet of vehicles over a year period.

The potential benefits become even greater when the use of a dynamic route scheduling system is implemented. It is here where the decision of a clockwise (CW) or counter-clockwise (CCW) route pattern also plays a role. As the number of unscheduled service calls increases to 2 and then 6, the savings in total links travelled increases to 24 and

Table 7-5 Travel Time Data for 50 Metre Static Case

Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	159.4	186.7	195.3	0 → 21	93.5	95.4	119.6
112 → 149	106.9	207.2	248.2	21 → 63	91.6	156.8	200.0
149 → 151	61.5	62.0	67.7	63 → 76	80.4	80.4	98.7
151 → 76	114.3	163.2	291.2	76 → 151	132.1	171.2	313.6
76 → 63	384.0	1017.8	1278.1	151 → 149	65.2	189.3	264.5
63 → 21	52.9	53.1	67.4	149 → 112	125.9	334.9	494.1
21 → 0	84.6	85.1	85.9	112 → 0	142.1	156.3	186.3
TOTAL	963.6	1775.1	2233.8	TOTAL	730.8	1184.3	1676.8
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	159.4	186.7	195.3	0 → 21	93.5	95.4	119.6
112 → 149	106.9	207.2	248.2	21 → 63	91.6	156.8	200.0
149 → 189	99.8	262.3	336.4	63 → 76	80.4	80.4	98.7
189 → 151	156.8	232.5	300.7	76 → 151	132.1	171.2	313.6
151 → 76	114.3	163.2	291.2	151 → 149	65.2	189.3	264.5
76 → 24	101.2	106.4	109.3	149 → 189	110.5	287.7	387.2
24 → 21	59.1	73.6	78.2	189 → 112	103.5	176.2	446.5
21 → 63	73.0	192.1	249.3	112 → 24	226.5	242.0	355.3
63 → 0	118.1	122.8	120.5	24 → 0	150.1	168.4	183.2
TOTAL	988.6	1546.8	1929.1	TOTAL	1053.4	1567.4	2368.6
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	159.4	186.7	195.3	0 → 21	93.5	95.4	119.6
112 → 149	106.9	207.2	248.2	21 → 63	91.6	156.8	200.0
149 → 189	99.8	262.3	336.4	63 → 76	80.4	80.4	98.7
189 → 151	156.8	232.5	300.7	76 → 24	132.1	106.4	111.0
151 → 76	114.3	163.2	291.2	76 → 151	180.1	333.4	485.1
76 → 24	101.2	106.4	109.3	151 → 149	65.2	189.3	264.5
24 → 21	59.1	73.6	78.2	149 → 166	38.8	85.0	122.4
21 → 63	73.0	192.1	249.3	149 → 189	78.1	229.7	317.3
63 → 112	105.5	181.8	247.7	189 → 112	103.5	176.2	446.5
112 → 166	128.6	196.0	235.1	112 → 112	0.0	0.0	0.0
166 → 131	81.9	205.6	260.5	112 → 35	123.3	124.4	154.2
131 → 35	169.3	243.3	290.3	35 → 131	176.2	207.8	236.4
35 → 0	46.0	65.5	98.3	131 → 0	194.1	223.1	321.3
TOTAL	1401.8	2316.2	2940.5	TOTAL	1356.9	2007.9	2877

Table 7-6 Total Links Travelled for Two-Way Traffic Network

Total Links Travelled For Two-Way Traffic Network					
P&D Operations	Pick-Up In Order	Route Scheduling System		Savings	
		CW	CCW	CW	CCW
6	54	36	36	18	18
8	74	50	54	24	20
12	98	72	66	26	32

26 links respectively for the CW travel path. However, the CCW direction routings were influenced to a larger extent than that of the CW direction.

In this case, the CCW route selection resulted in 54 and 66 total links travelled, corresponding to a 20 and 32 link savings in travel over the pick-up in order scenario and greater than the CW route for the 6 unscheduled service call scenario. Again, the reduction in links travelled proves to be a substantial savings in larger networks, but more importantly it demonstrates the effect of delaying servicing a location to such point that two service calls are made from the same stop

It was only because two stop deliveries were made at location #112 that the CCW route resulted in a greater savings in links travelled. Since the additional service calls and their locations are random in nature, it is impossible to predict whether the CW or CCW direction is most suitable before these unscheduled calls arrive. However, it is equally important to examine the potential savings in travel time since a shorter travel distance on more congested links would actually prove detrimental to any benefits

To illustrate the travel time benefits of a route scheduling system, the results for 6 P&D operations and the results of 8 and 12 P&D operations for a dynamic route scheduling system must be studied. Table 7-7 is a comparison between a total travel time for a non-optimized route schedule with route guidance information and that with an optimized route schedule and a route guidance system. The data illustrated in Table 7-7 represents the reduction in travel time which can be achieved from use of a combine route guidance and scheduling system. The negative sign indicates a reduction or savings in travel time.

Of the 54 scenarios where data were obtained, only two resulted in a lower total travel time by not using the route scheduling system. These two scenarios are the 50 metres case at V/C ratio of 1.2 and the 100 metres case at V/C of 0.8 for 6 P&D operations. A lower total travel time of approximately one minute resulted from the analysis from not using the route scheduling system, as compared to savings from use of the route scheduling system of between 4 and 50 minutes in total travel time for the remaining scenarios.

The potential benefits of combined system use on a fleet basis become clearly obvious. Naturally, a greater savings in travel time can be achieved on the metropolitan network where the total savings ranged upwards from 14 minutes. This was an expected result as each link requires a substantial travel time even at free-flow conditions and thus a reduction in the distance travelled would correspondingly reduce the total travel time.

Similar results are found when the total delay times are compared between the same scenarios and are found in Table 7-8. Noticeably, the savings are lower than the total travel time due to the difference in the number of links compared between the two cases. However, it remains clear that through optimization of the route schedule to a minimum distance route,

substantial gains can be made by a single courier vehicle.

**Table 7-7 Effect of Route Scheduling System on Total Travel Time
(Savings attributable to ITS)**

Effect of Route Scheduling System on Total Travel Time (sec)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	-432.9	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	-325.6	-204.9	67.5	-450.9	-501.8	-1439.6	-543.8	N/A	N/A
75	-369.7	-382.1	-201.7	-521.4	-502.9	-684.2	-574.1	-340.4	N/A
100	-404.3	-391.0	-409.6	-600.0	-556.8	-389.4	-710.6	-559.9	-890.6
METRO									
100	49.5	-321.1	N/A	N/A	N/A	N/A	N/A	N/A	N/A
300	-822.5	-953.1	-1088.6	-1503.1	-2199.6	-2044.3	-973.6	-1326.7	-1035.2
500	-1092.5	-1167.2	-1283.2	-1696.5	-1685.3	-1879.8	-1749.0	-1719.3	-1359.2
700	-1063.5	-1440.9	-1774.4	-1610.7	-2394.3	-2992.5	-1979.5	-2358.8	-2177.6

**Table 7-8 Effect of Route Scheduling System on Total Delay Time
(Savings attributable to ITS)**

Effect of Route Scheduling System on Total Delay Time (sec)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	-400.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	-260.8	-140.1	132.3	-364.5	-415.4	-1353.2	-450.2	N/A	N/A
75	-272.5	-284.9	-104.5	-391.8	-373.3	-554.6	-433.7	-200.0	N/A
100	-274.7	-261.4	-280.0	-427.2	-384.0	-216.6	-523.4	-372.7	-703.4
METRO									
100	179.1	-191.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A
300	-433.7	-564.3	-699.8	-984.7	-1081.2	-1525.9	-412.0	-765.1	-473.6
500	-444.5	-519.2	-635.2	-832.5	-821.0	-1515.8	-813.0	-783.3	-423.2
700	-156.3	-533.6	-867.0	-401.1	-1184.7	-1782.9	-669.1	-1048.4	-867.2

7.4.1.2 Route Guidance Systems

Several effects of route guidance systems are examined in this thesis, including the benefits of its use and the impact of using static or historical traffic information compared to dynamic or real-time traffic information. Route guidance systems allow for a courier vehicle to select the travel path between two service locations which minimizes the travel time. In the case of this research, the travel path was limited to one of minimum travel distance as well. It is possible for a route which involves a slightly greater distance travelled to yield a lower travel time. However, this scenario was not investigated.

Comparison for the benefits of a route guidance system were performed using the "pick-up in order" case studies between the minimum and maximum travel time data computed. As shown in Table 7-9, savings of delay time are found to be at least 4 minutes and can reach a total of 4 hours based upon the available data. Even greater benefits could be possible, however limitations of the TRAF-NETSIM package discussed in Chapter 6 restricted the available data. The data also indicated that there is a substantial increase in the achievable savings as the volume increases on the network. The maximum travel path would be that path whereby the driver takes the worst possible route and, while it is unlikely that this path would often be taken, it demonstrates that there are substantial benefits which could be achieved from route guidance systems.

There is another trend which is observed when further examination of the data is undertaken. While there are many factors which will affect the results and trends found, including link length and signal progression among others, a plot of the data shows a gradual decrease in savings of total incurred delay followed by a sudden increase in the potential

benefits which can be achieved as the arterial spacing decreases. A typical plot is found in Figure 7-5.

**Table 7-9 Difference in Total Delay Between Minimum and Maximum Travel Time Path
(Savings attributable to ITS)**

Difference in Total Delay Between Minimum and Maximum Travel Time Path (sec)									
P&D Operations	V/C Ratio	Arterial Length							
		25m	50m	75m	100m	100m	300m	500m	700m
6	0.8	6743.7	282.4	418.2	663.5	1324.1	839.1	839.4	927.2
	1.0	N/A	735.7	1845.6	3203.7	9565.7	1086.4	1637.7	1888.8
	1.2	N/A	1364.5	2362.8	11960.7	N/A	1150.4	1927.9	2202.3
8	0.8	N/A	352.7	236.4	244.4	780.9	1636.4	2187.0	2541.2
	1.0	N/A	2635.0	1525.8	499.5	N/A	4229.6	2820.0	5303.0
	1.2	N/A	5700.4	1898.2	1274.8	N/A	4959.7	5562.0	7076.8
12	0.8	N/A	1726.7	552.3	3128.0	N/A	3958.5	3962.5	6108.6
	1.0	N/A	N/A	7612.7	8146.1	N/A	7472.8	6446.0	8031.6
	1.2	N/A	N/A	14667.7	8477.8	N/A	10073.1	12339.8	10712.0

It should be recalled that several factors remained unchanged between scenarios, including the cycle length, signal timing plan and progression efficiency. The combination of these factors along with the effects of arterial spacing on the potential benefits of route guidance systems becomes quite complicated. The plot of the data demonstrates that increasing travel distance (i.e. arterial spacing) has a steadily increasing impact on the benefits of route guidance when combined with other factors. Figure 7-5 demonstrates that as the arterial spacing is decreased beyond a given point, there is a large increase in the level of savings which can be achieved through use of a route guidance system. This point is dependent upon several factors and can be explained in part by the fact that as arterial

Figure 7-5 Difference in Total Incurred Delay Between Minimum and Maximum Travel Time Path For 8 P&D Operations

spacing decreases, the impact of traffic signals increases and the ratio of travel to intersection stop time is decreased.

Much like the impact of interchanges on freeway capacity and performance, traffic signals have a similar impact on arterial traffic operations. As such, a greater distance between arterials reduces the number of intersections per kilometre, which is used indirectly as a factor in Chapter 11 of the Highway Capacity Manual for arterial performance. Hence, with a greater number of intersections per kilometre the effects of cycle length, signal timing plans and progression efficiency become far more pronounced.

Another important comparison that was undertaken in this research is the difference between having real-time traffic information for route guidance systems and simply having an averaged, static or historic travel information. It should be understood that this comparison will not indicate the level of savings that can be achieved from having static information as compared to having dynamic traffic information but rather the level of accuracy between the provision of static traffic information and real-time data.

The data provided by the TRAF-NETSIM program for the static and dynamic cases differ substantially in both the detail and the accuracy in realistically portraying the actual traffic conditions. The dynamic cases were computed in two minute intervals under a constant traffic volume in which congestion demonstrated a continual increase in intensity and therefore resulted in an increasing travel time. Conversely, the static cases were performed with a single time period of one hour in length, thus presenting travel times of an averaged hour. As a result, the comparisons shown in Table 7-10 of the static travel times subtracted by the dynamic travel times substantiate these observations.

**Table 7-10 Difference in Total Delay Between Static and Dynamic
Travel Time Paths
(Savings attributable to ITS)**

Difference in Total Delay Between Static and Dynamic Travel Time Paths (sec)									
P&D Operations	V/C Ratio	Arterial Length							
		25m	50m	75m	100m	100m	300m	500m	700m
6	0.8	147.4	283.1	-7.8	-12.1	-1202.6	-8.7	-7.9	23.4
	1.0	-15.7	928.9	469.8	113.8	-3274.1	38.9	59.4	46.5
	1.2	N/A	857.5	762.9	372.0	-5190.7	36.3	123.5	235.3
8	0.8	-265.8	31.0	-1.4	-1.6	-8160.4	26.3	-14.3	-124.4
	1.0	11.4	339.1	-25.8	-0.3	-13018.6	65.5	-172.7	-82.8
	1.2	N/A	250.9	216.7	-320.5	-18182.3	38.4	29.4	30.3
12	0.8	N/A	-58.6	-53.2	-22.3	N/A	-826.5	-789.8	-741.4
	1.0	N/A	-3558.4	-703.1	-338.9	N/A	-845.4	-1267.7	-1024.5
	1.2	N/A	N/A	-7533.0	-1651.6	N/A	-1425.5	-1617.2	-1103.1

In examining the data for the 300 metre to 700 metre range, several general observations can be made. Primarily, it must be realized that as the number of P&D operations increase, there is a corresponding increase in journey time for completion of the courier tasks. This fact leads to a justification of the previous statements. For the 6 P&D scenarios, there is a difference in the static and dynamic travel times of between +4 minutes and -9 seconds. At the 8 P&D operation level this range changes to +1 minute to -3 minutes and finally for the 12 P&D scenarios the difference increase to between -12 and -27 minutes.

This demonstrates that the static cases overestimate the travel time for the shorter 6 P&D operation scenario followed by an increasing underestimation for the 8 and 12 P&D cases. A reasonable explanation for this trend is simply that at the beginning of the simulations, the level of congestion has not grown to large enough proportions to affect traffic operations and that as the simulation continues, the impact increases. This trend is not

captured by the static case which simply averages the fluctuations in traffic delay.

Another observable trend is the effects of traffic volume, listed as the volume to capacity ratio for entry links, on the benefits of real-time route guidance information. Examination of the 6 P&D scenarios illustrate that as the level of entry traffic volume increases, the overestimation in travel time by the static case increases while the level of underestimation by the static case for the 12 P&D scenarios similarly increases as the volume increases.

This is due to the averaging effect which is performed for the development of the static cases. However, the same trend cannot be found in the comparison of the 8 P&D scenarios. There are several explanations for the 8 P&D scenario not following the trend. The results would tend to indicate that in this range of journey time there is some fluctuation in the dynamic data which results in a disturbance in the observed trends.

It is also likely that as the approximate journey time corresponds to the point in time where the dynamic analysis crosses the averaged static travel times. This area is further examined in Section 7.5.3. The metropolitan dynamic case studies used a 90 second cycle time while the data were collected at two minute intervals, as indicated in Section 7.2.2. This did cause some significant variation in results for the following reasons

In having the data gathered at a rate which differed from the cycle length, it was found that some intervals contained data with parts of two stoppage periods while others contained only one and is illustrated in Figure 7-6. With travel time measured as the length of time to travel a given link, including stop times, some periods were found to have a significantly higher travel time compared to those periods which only observed a single red phase. This

demonstrates the importance of computing travel time information on arterials using the most common cycle length as the basis for time periods.

In addition, the results for the 100m cases at first glance seem quite large and contrary to the trends of the remaining arterial spacings. Once again it must be recalled that at the lower arterial spacings, with all other factors kept constant, the effects of progression efficiency, cycle length and others play a significant role in traffic operations. Therefore, over an hour these impacts become quite substantial and thus the travel time for the dynamic case is quite large while the averaged values for the static case will not be as severely impacted. This yields the tremendous understatement of travel time by the static case as compared to the results of the dynamic case.

7.4.1.3 Combined System

The greatest benefits can be achieved through a combination of the dynamic route guidance system and a route scheduling system. The combined effect allows for a minimum travel distance to be selected by the scheduling system and then minimize the impact of traffic conditions by selecting the minimum travel distance route which provides the minimum travel time. As shown in Table 7-11, the savings are quite substantial. At the CBD level, savings were computed to range between 10 minutes and 200 minutes. Naturally, this level of savings is based upon the assumption that the worst case scenario is chosen by the driver.

Therefore, the longest time path is chosen for the non-optimized pick-up schedule. When compared to a travel distance and travel time minimized route, the gains are obviously

Figure 7-6 Effect of Time Period and Cycle Length Selection

**Table 7-11 Effect of Route Scheduling and Route Guidance on Total Travel Time
(Savings attributed to ITS)**

Effect of Route Scheduling System and Route Guidance System on Total Travel Time (sec)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	-7176.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	-608.0	-940.6	-1297.0	-789.2	-3122.4	-7125.6	-2270.5	N/A	N/A
75	-787.9	-2227.7	-2564.5	-736.2	-2007.1	-2560.8	-1126.4	-7953.1	N/A
100	-1067.8	-3594.7	-12370.3	-815.6	-1027.5	-11635.4	-3838.6	-8706.0	-9368.4
METRO									
100	-1274.6	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
300	-1661.6	-2039.5	-2239.0	-3139.5	-5829.2	-7004.0	-4932.1	-8799.5	-11108.3
500	-1931.9	-2804.9	-3211.1	-3883.5	-4505.3	-7941.8	-5711.5	-8165.3	-13699.0
700	-1990.7	-3329.6	-3976.7	-4151.9	-7697.3	-10069.3	-8088.1	-10390.4	-12889.6

substantial. The 10 minute savings occurs on a route which, under the worst condition would consume 21 minutes of travel. If only some portion of this potential savings could be achieved for a full day's worth of operation for an entire fleet, the reduction in operational costs could be very significant. It should be noted that the 50 metre arterial spacing combined with a volume to capacity ratio of 0.8 conditions could easily be found for a good part of the day in many of the major city business districts in North America and around the world.

For the metropolitan cases examined in this research, the savings in travel time from a combined route guidance and scheduling system is equally impressive. The smallest saving occurs at the 100 metre and 0.8 V/C ratio scenario and totals nearly 22 minutes, while the greatest travel time savings is found at the 500 metre and maximum volume to capacity ratio. This level of savings equals over 228 minutes. Again, under the worst case scenario, these two cases would require 56 and 333 minutes to complete.

While it is necessary to realize that the worst case scenario is not the most likely choice for route selection, the use of the worst case provides an ability to observe the ultimate time savings which could be achieved by a courier vehicle equipped with the required equipment to receive route scheduling and dynamic route guidance information. The savings found can possibly reduce the travel time for a route as simulated by nearly 50 percent over the worst case. Such potential is obviously quite dramatic and provides a potential for substantial operational efficiency improvement for courier vehicles.

7.4.2 One-Way CBD Cases

To effectively model the majority of central business districts around the world using one-way arterials, hypothetical models having arterial lengths of 25, 50, 75 and 100 metres with a signal cycle length of 60 seconds were constructed. The 9x11 network of arterials comprised of three laned bi-directional arterials along the perimeter and in addition contained a single north-south and a single east-west two-way arterial of 3 lanes per direction. The remaining arterials were two laned one-way arterials as shown in Figure 7-7.

7.4.2.1 Route Scheduling Systems

As was noted for the metropolitan cases in Section 7.4.1.1, one of the greatest benefits of a route scheduling system is the significant reduction in travel distance when a minimum travel distance is selected as a route decision criterion. While it is considered to be more efficient for dealing with the highly directional traffic patterns during morning and evening rush hours, one-way street systems are detrimental to vehicle operations within the

3

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

PRECISIONSM RESOLUTION TARGETS

Figure 7.7 One-Way Hypothetical Arterial Network

CBD Typically, the use of one-way street systems results in more circuitous routes being required. In addition, the number of route possibilities is reduced due to limitations placed on means of reaching the desired destination.

A summary of the number of links travelled to complete the service calls of the courier vehicle is shown in Table 7-12. It is observed that, as in the two-way metropolitan cases, the "pick-up in order" cases needed a greater number of links. For the route scheduling process of 6 P&D cases, there was a 18 link difference as compared to both the clockwise and counter-clockwise routing scheme. As the number of service calls increased, the benefits of a dynamic route scheduling system does not demonstrate the same impact in reducing the number of links travelled as what was observed in the two-way scenarios.

Table 7-12 Total Links Travelled for One-Way Traffic Network

Total Links Travelled For One-Way Traffic Network					
P&D Operations	Pick-Up In Order	Route Scheduling System		Savings	
		CW	CCW	CW	CCW
6	62	44	44	18	18
8	84	66	65	18	19
12	108	86	82	22	26

When the 8 P&D scenario is examined, there is only an additional saving of a single link in the counter-clockwise direction. At the 12 P&D scenarios, an observed savings of 22

and 26 links are recorded. Such savings are far more significant when the arterial spacing is larger since the distance travelled would correspondingly be larger. However, to the courier industry the potential savings in travel time from use of a route scheduling system would be viewed as most important.

Since the industry is so highly focused upon timely delivery of goods between locations, the ability to reduce travel time between service stops is unquestionably essential. The industry employs hand-held computer devices for package information recording and tracking for the exclusive purposes of reducing service time and increasing service reliability. Vehicle travel time is the natural progression of operational improvements to the courier industry.

In order to determine the potential savings of a route scheduling system from the simulations conducted in this thesis, comparison between the "pick-up in order" case results and that of the dynamic traffic information case are needed. As illustrated in Table 7-13, there is a limited amount of available data to use for analysis of the one-way scenarios. Travel time savings range approximately between one and 7 minutes for the 6 P&D cases, 5 to 45 minutes for the 8 P&D cases and 6 to 11 minutes for the 12 P&D cases.

These savings are possible for the total travel times ranging between 21 minutes and 165 minutes. Based upon these figures, the data appear to be inconsistent with those recorded for the two-way street configuration and do not provide significant results. However, a few trends can still be distinguished. Noticeably, there is an increase in travel time for a given V/C ratio corresponding to an increase in arterial spacing.

One exception occurs at the V/C ratio of 1.0 for the 8 P&D scenario at the 50 metre

arterial spacing. This is due to the fact that traffic link information was available to complete the simulation of the pick-up in order case, but only as congestion significantly increased. However, the data still demonstrate that there is an increase in the travel time beyond the 50 metre mark. It should be recalled that this trend was found for many of the scenarios previously examined.

**Table 7-13 Effect of Route Scheduling System on Total Travel Time
(Savings attributed to ITS)**

Effect of Route Scheduling System on Total Travel Time (sec)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	-276.4	-46.9	N/A	-308.9	-2686.2	N/A	-368.4	N/A	N/A
75	-311.9	-215.4	-201.9	-344.1	-287.2	N/A	-425.2	N/A	N/A
100	-392.9	-217.9	-298.8	-366.0	-549.2	-2440.7	-451.5	-622.7	N/A

The effects of volume on the travel time savings between scheduled and non-scheduled routes demonstrates substantive trends as shown in Figure 7-8. At low volumes, the effect of delay incurred at intersections is not significant, thus move time delay (i.e. delay incurred because the arterial is not operating at free flow conditions) is of greater weight. Therefore, the combination of fewer links and fewer congested links travelled is demonstrated in the graph by larger arterial spacing simulations resulting in greater travel time savings from route scheduling.

As the volume to capacity ratio increases to 1.0, several explanations arise from the drop in savings. The difference in paths between the scheduled and non-scheduled routes provides the best explanation for the observed trend. Since the two paths utilize different

Figure 7-8 Difference in Total Travel Time Between Route Scheduling and Non-Scheduled Route For 6 P&D Operations (One-Way Case)

links, the stochastic nature of travel yields the ability for one route to be more heavily affected by increases in traffic volume and more specifically as the inflow volume to the network approaches capacity

It must again be noted that a V/C ratio of 1.0 does not implicitly imply all links are loaded at a 1.0 V/C ratio. As such, the difference between the two simulations compared in this analysis yielded a reduction in the total travel time which could be saved from use of a route scheduling system. The raw data provided in Appendix D illustrates that there are greater increases in travel time for some segments of the route for the dynamic route scheduled cases as compared to the unscheduled "pick-up in order" cases.

Even more significant is that this increase in travel time rises as the arterial spacing increases. This observation is reflected in Figure 7-8 by the convergence of the 75m and 100m curves at the volume to capacity ratio equal to 1.0 level. The increasing travel time of the dynamic route scheduled cases has a negating effect on the savings achieved from travelling fewer routes. In this thesis, the increase in travel time is significant enough to result in nearly no difference between the 75m and 100m cases.

When the V/C ratio is increased to 1.2, these two curves demonstrate a diverging pattern, or is perhaps better explained separately as a continued decrease in travel time savings at the 75m arterial spacing and an increase in savings at the 100m spacing. The decrease found is less dramatic after the 1.0 V/C ratio for the 75m case and can be attributed to the fact that more links are operating at conditions of V/C of 1.0 or worse. Due to this occurring, the fewer routes required for travel begins to play a larger role in the potential travel time savings from use of a route scheduling system.

Since the routes are more likely to be equal in the number of links operating at capacity, the number of links used in the scheduled and non-scheduled route affects the potential savings. In addition, the combination of a smaller arterial spacing with an increasing inflow traffic volume has a negative effect on the operational efficiency of the network, as discussed in Section 7.2. As recalled, there is an increase in travel time incurred as the arterial spacing is decreased for a given V/C ratio. This increase is a geometric increase and is therefore reflected in the variation of trends found between the 1.0 and 1.2 V/C ratios.

For the 100m curve, the decline occurring for the 0.8 to 1.0 V/C range is found to demonstrate an increase for the V/C ratio in the 1.0 to 1.2 range and this observation can be quite easily explained. As was indicated for the V/C ratio of 1.0 discussion, the difference in routes travelled has a tremendous impact on travel time and thus the scheduled and non-scheduled routes will have different levels of impacts from an increase in the V/C ratio. However, as the V/C ratio is increased to 1.2, the majority of routes would now be expected to be operating at or above capacity. Therefore, there is significantly less chance of one route path observing very different operating conditions.

As a result, the potential benefits of a route scheduling system are more truly reflected in Figure 7-8 at the V/C ratio of 1.2 than at the 1.0 V/C level and are demonstrated by the increase in travel time savings. The majority of the savings are incurred from the reduction in the number of links travelled at the 1.2 V/C ratio, as was the case at the 0.8 V/C ratio. Clearly, the level of inflow volume into the network significantly effects the potential savings observed. More importantly, the links travelled by each route compared in this thesis have a dramatic impact on the potential savings, especially when the volume approaches capacity.

7.4.2.2 Route Guidance Systems

The use of a route guidance system is an important component in the effort to increase operational efficiency of both the general traffic stream and in particular the courier industry. With the downtown of most cities consisting of a series of one way arterials in combination with some two-way arterials, the examination of the usefulness of such a system is necessary. The substantial level of operation of courier vehicles within the CBD makes the study essential for determining the possible benefits which could be achieved by the industry

As was explained in the previous section, the geometric and operational criterion for the one-way case were taken and maintained from the two-way case in order to ensure that factors remained similar for comparative purposes. This resulted in significant congestion occurring and eliminating the opportunity for generating a full set of data. However, the data produced from the computer simulations partially illustrate several patterns and are shown in Table 7-14

**Table 7-14 Total Savings in Delay for PUJO Travel Time Paths
(Savings attributed to ITS)**

Total Savings in Delay For PUJO Travel Time Paths (sec)					
P&D Operations	V/C Ratio	Arterial Length			
		25m	50m	75m	100m
6	0.8	0.0	85.7	82.8	134.0
	1.0	0.0	1033.8	630.9	624.5
	1.2	0.0	5230.2	2941.9	1976.4
8	0.8	0.0	107.4	98.7	191.1
	1.0	0.0	0.0	335.6	301.2
	1.2	0.0	0.0	0.0	0.0
12	0.8	0.0	138.6	112.2	223.9
	1.0	0.0	0.0	0.0	359.7
	1.2	0.0	0.0	0.0	0.0

Similar to the trends observed for the two-way cases, the increase in volume generates an increasing savings in travel time. This is an expected result since the difference between the minimum travel time route and the maximum time route for a network loaded to less than capacity should not be significantly different. However, as the network is further loaded, some travel paths will suffer a larger growth in traffic volume than others depending upon certain considerations. Travel destinations, signal progression, traffic restrictions and other network factors will affect the route decision-making process of the public and therefore result in some routes receiving a greater proportion of the additional traffic.

Since there are a limited number of observations available for comparison, the range of savings was found to be between 82 seconds and 87 minutes, although this range is primarily for the 50 metre case. The combined effect of high volumes and short arterials yields significant operational problems for the traffic network and therefore results in the enormous potential savings. The range of potential gains for most cases would be in the 82 seconds to 30 minute range for this investigation.

In addition to the effect of increasing volume on the journey travel time, the arterial spacing also appears to have a significant impact on the potential savings. At both the 0.8 and 1.0 volume to capacity ratios, the travel time decreases initially for the range of arterial lengths examined, followed by an increase in the travel time beyond the 75 metre distance. This is similar to the observations made from the two way arterials. The only series of data available for the 1.2 V/C ratio is that at the 6 P&D scenario, thus not providing any trends to be identified.

The data demonstrated a trend of decreasing travel time for an increasing arterial

in several scenarios. Explanations for this possible trend are plentiful and include the effects of arterial lengths, signal progression, timing plans or the shift in importance of delay components from intersection delay to move delay which causes a minimum delay point.

Of greater concern is the trends demonstrated for a change in the volume to capacity ratio. In the dynamic cases, the increase in V/C ratio results in an increase in the potential savings in travel time. If the static and PUJO cases are examined, the travel time benefits increase, decrease or appear to plateau for the data available. It would therefore appear that the effects of changing V/C ratios and arterial spacing from the "pick-up in order" and the static cases do not provide for a good comparison between the additional operations costs for courier vehicles to operate in a one-way street network.

While it can be seen from the data that there is a potential gain from operating in a two-way traffic network, the conditions which were placed upon the simulations for certain comparative purposes caused negative impacts for other comparisons. It should be noted that traffic cordon count data from the Regional Municipality of Ottawa-Carleton were consulted for the purposes of ensuring that the assigned traffic loads were of a reasonable magnitude. With this information, the one-way case study was performed and the traffic levels of the two-way arterial cases maintained.

7.5 Summary of Potential Benefits

The analyses performed in Sections 7.3 and 7.4 discussed the impact of traffic volume, arterial spacing, operational conditions such as the number of service stops, route scheduling devices and route guidance systems. The main focus of this research was to determine the

**Table 7-15 Effect of Route Scheduling System on Total Travel Time
With No Route Guidance Information
(Savings attributable to ITS)**

Effect of Route Scheduling System on Total Travel Time (sec) No Route Guidance Information									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	-362.1	-1080.7	N/A	-416.3	N/A	N/A	-507.0	N/A	N/A
75	-394.7	-846.3	-3143.8	-442.8	-622.8	N/A	-537.4	N/A	N/A
100	-526.9	-842.4	-2275.2	-557.1	-850.4	N/A	-675.4	-982.4	N/A

These savings demonstrate that by having a driver choose the minimum travel time path as opposed to the maximum time path with no schedule optimization, a potential 22 and 75 minute journey can be reduced to a 16 and 23 minute trip respectively. It is also important to note from the data that greater savings can be achieved as the number of courier activities increase. However, due to the limitation in available data, it is not possible to determine how significant the potential savings truly are.

The provided data do illustrate several trends which were also found in previous sections. At the 0.8 V/C ratio, the savings in travel time increase for both an increasing arterial spacing and an increasing number of service calls. With capacity not being exceeded, the results obtained would be explained by the increase in travel distance at some level below the free-flow traffic level. However, the remaining data does not fully support this trend.

The 6 P&D scenarios with volume to capacity ratios of 1.0 and 1.2 demonstrate a decrease in the travel time savings which can be achieved as the arterial spacing is increased.

In these circumstances, the change in intersection spacing reduces the impact of intersection related delay, thereby reducing the severity of delay incurred by a given vehicle. Although the longer arterial lengths increase the move time delay, the delay suffered by vehicles at intersections are typically far greater in magnitude

The remaining set of data which were examined were at the 8 service call and 1.0 volume to capacity ratio. It would appear from the data that this data set, like the data at the 0.8 V/C level, that the potential savings are increased as the arterial length is increased. Several explanations are available. The most obvious reason is that the route selected for completion of the 8 service calls is one in which many of the links are operating with the volume below capacity.

While the network is loaded at one of the three predetermined case levels, it does not signify that each of the arterials within the network is operating at the given volume to capacity ratio. This is naturally due to the turn movement percentages assigned to each intersection. With turn percentages varying between intersections, some routes are more heavily used than others and therefore result in different traffic conditions.

The final observation is the effect that the level of traffic has upon the potential savings for a given arterial length. As was found in previous comparisons, there is a noticeable increase in the difference in travel time between the best and worst travel time paths. The data illustrate that there is a substantial potential for savings under conditions which would be typical of peak periods in a CBD and that during off-peak hours, the benefits are not as substantial.

7.4.3 CBD Case Comparisons

An important comparison which should be made is the effect of a one-way system on the travel time, travel distance and potential travel time savings from use of route guidance and scheduling systems. Some of the reasons used for the selection of a one-way traffic network over a two-way network are the reduction in traffic conflicts, the increase in arterial progression and the reduction in travel time. However, for vehicles requiring to operate within this environment there are a significant number of hinderances and restrictions which will increase operating costs.

Of first note, the increase in travel distance for completion of the journey is an important factor and is shown in Table 7-16. For the journeys requiring 6 service calls, there is an 8 link increase for the same route on the one-way network and this increases to between 10 and 16 links for the 12 service call stage. It is important to note that the added travel distance is accumulated by a single vehicle over an operating time of not more than approximately two hours. Hence, if a full day's worth of operations for an entire fleet is considered, a substantial reduction in vehicle-kilometres travelled can be obtained.

Comparison of the simulated data for the dynamic, static and pick-up in order cases also provides a reasonable method for detailing the effects of a one-way traffic network on courier operations. From Tables 7-17, 7-18 and 7-19, the general observation made is that a one-way street system could increase travel times anywhere between 4 minutes and 130 minutes for the minimum travel path.

Specifically, the dynamic traffic information scenarios provide a more realistic portrayal of actual traffic conditions and in doing so yield more dependable results. This is

caused by the averaging effect that the static cases utilized. thereby masking the increasing impact of congestion. These results indicate that savings would fall into the 250 to 800 second range for upto 8 service calls. Also, as the arterial spacing or volume to capacity ratio increases, there is a corresponding increase in the achievable travel time savings.

Table 7-16 Additional Links Travelled for One-Way Traffic Network Versus Two-Way

Additional Links Travelled For One-Way Traffic Network versus Two-Way									
P&D Operations	Pick-Up In Order		Route Scheduling System				Additional Links Required		
			One-Way		Two-Way				
	1-Way	2-Way	CW	CCW	CW	CCW	PUIO	CW	CCW
6	62	54	44	44	36	36	8	8	8
8	84	74	66	65	50	54	10	16	11
12	108	98	86	82	72	66	10	14	16

Table 7-17 Effect of Network Configuration on Total Travel Time

Static Traffic Information

Effect of Network Configuration on Total Travel Time (sec) Static Traffic Information (1-way Minus 2-way)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	3248.0	4188.5	5727.7	4060.8	5687.3	7898.3	5841.7	7518.4	9956.6
50	-37.6	-139.9	1268.7	334.0	667.1	2711.6	333.3	682.7	3268.6
75	355.3	-19.5	-164.1	382.6	424.0	784.5	427.1	312.0	633.6
100	251.4	314.5	363.2	406.7	482.5	1125.9	515.9	578.1	1183.5

Table 7-18 Effect of Network Configuration on Total Travel Time**Pick-Up in Order Methodology**

Effect of Network Configuration on Total Travel Time (sec) Pick-up in Order (1-way Minus 2-way)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	206.7	257.7	3338.6	255.9	2607.2	N/A	137.9	N/A	N/A
75	205.0	259.8	259.0	264.0	268.8	N/A	287.8	N/A	N/A
100	270.2	358.2	511.5	308.3	577.9	2895.0	357.1	453.3	N/A

Table 7-19 Effect of Network Configuration on Total Travel Time**Dynamic Traffic Information**

Effect of Network Configuration on Total Travel Time (sec) Dynamic Traffic Information (1-way Minus 2-way)									
	6 P&D			8 P&D			12 P&D		
CBD	0.8	1.0	1.2	0.8	1.0	1.2	0.8	1.0	1.2
25	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
50	255.9	415.7	N/A	376.3	401.2	N/A	298.9	N/A	N/A
75	262.8	426.5	258.8	408.9	452.1	N/A	415.1	1251.8	N/A
100	281.6	531.3	622.3	499.1	542.3	800.5	587.4	361.7	N/A

Under the static or "pick-up in order" scenarios, there is not as definite a trend as found with the dynamic cases. The trends demonstrate, in general, an increase in the travel time saved for an increasing arterial spacing. However, there is a noticeable initial decrease

in several scenarios. Explanations for this possible trend are plentiful and include the effects of arterial lengths, signal progression, timing plans or the shift in importance of delay components from intersection delay to move delay which causes a minimum delay point.

Of greater concern is the trends demonstrated for a change in the volume to capacity ratio. In the dynamic cases, the increase in V/C ratio results in an increase in the potential savings in travel time. If the static and PUJO cases are examined, the travel time benefits increase, decrease or appear to plateau for the data available. It would therefore appear that the effects of changing V/C ratios and arterial spacing from the "pick-up in order" and the static cases do not provide for a good comparison between the additional operations costs for courier vehicles to operate in a one-way street network.

While it can be seen from the data that there is a potential gain from operating in a two-way traffic network, the conditions which were placed upon the simulations for certain comparative purposes caused negative impacts for other comparisons. It should be noted that traffic cordon count data from the Regional Municipality of Ottawa-Carleton were consulted for the purposes of ensuring that the assigned traffic loads were of a reasonable magnitude. With this information, the one-way case study was performed and the traffic levels of the two-way arterial cases maintained

7.5 Summary of Potential Benefits

The analyses performed in Sections 7.3 and 7.4 discussed the impact of traffic volume, arterial spacing, operational conditions such as the number of service stops, route scheduling devices and route guidance systems. The main focus of this research was to determine the

level of travel time savings which could be achieved by the courier industry through use of route scheduling, route guidance or a combined system

While there are other operational benefits from reduced travel time, which include fuel consumption, maintenance costs and operational efficiency that would prove to be quite substantial for an entire fleet operating over a full year, the examination of these benefits was not however a part of this thesis. Accordingly, the following sections summarize the trends observed only from the data generated for the hypothetical networks developed for this thesis.

7.5.1 Effects of Volume and Arterial Spacing

The impact of traffic volume was one of the major factors which was examined for this thesis. Since traffic volume can fluctuate significantly over the course of a day, the research was performed for a range of volume to capacity ratios from 0.8 to 1.2. It was hypothesized that the greatest benefit from use of ITS technology would occur during peak period traffic conditions and therefore the given range was selected.

As the data demonstrate, there is a significantly smaller benefit from route guidance systems with a decrease in the traffic volume. Following general traffic theory, as the volume decreases, travel speed increases towards the free-flow arterial speed. This results in a lower rate of move time delay, which is the difference between the current travel time and that which would be observed under free-flow conditions. Conversely, as traffic level increased over the entire network, there was a corresponding increase in the magnitude of savings.

This relationship, and the associated rate of increase, appears to be dependent upon the arterial spacing on the network. Equations in the Highway Capacity Manual for the

analysis of arterial performance use a factor which requires the average distance between intersections. The data illustrate that with an increase in the arterial spacing, the impact of a change in volume becomes less significant. With a greater spacing between intersections, delay incurred at the intersections decreases in relative magnitude to the move time delay. Figures 7-9 (a), (b) and (c) illustrate the combination effect of intersection and move delay.

This trend is not maintained for the entire range examined. When the larger, metropolitan network is considered, it becomes evident that there is a point at which the rate of change of intersection delay is no longer greater than the growth in delay from move or approach delay. It is here where the data demonstrate an increase in the potential benefits of route guidance and scheduling systems.

7.5.2 Effects of Unscheduled Pick-Ups

Many of the courier and goods delivery organizations do not operate with fixed schedules for pick-up or delivery of goods. Due to the dynamic nature of demand for their services, new service calls are constantly being received by the dispatch centres and these service locations are forwarded to an appropriate courier vehicle. Therefore, while much of the delivery portion of the operation can be performed without dynamic scheduling, the pick-up operations cannot.

Decisions as to which courier vehicle to forward the service call to and when the pick-up should be made is of significant importance to improving the operational efficiency of both the individual vehicle and the entire fleet. Unscheduled pick-ups eliminate any possibility for generating an optimum travel route to minimize travel distance or other factors before the

Figure 7-9 (a) Plot of Typical Intersection Delay Incurred

Figure 7-9 (b) Plot of Typical Move Time Delay Incurred

Figure 7-9 (c) Plot of Total Delay Time Incurred

route is begun. As such, a review of the impact of a dynamic route scheduling device was undertaken.

Results showed that there was no direct causal link between the number of new service calls and the number of additional links which must be travelled. The addition of 2 service calls placed evenly in mid-route increased the number of links travelled by 14 to 20 links, depending upon the use of a route scheduling device and a non-scheduled route. When 6 service calls were added at the rate of one after every two service call completions, it was found that between 36 and 44 additional links were required.

Based on the data from this analysis, it is evident that the most important factor in determining the effectiveness of a route scheduling system is dependent upon when the additional calls are received. If a great proportion of the unscheduled pick-ups are gathered while there are still service calls to be completed, the effect of these unscheduled pick-ups are less significant. If the new calls are obtained on an individual basis where each is fully serviced before the next is received there is no benefit from a dynamic scheduling system.

In the cases where 2 additional service calls are simulated an additional 6 links are saved through the use of a route scheduling system. For the scenario with 6 additional service stops, the savings in travelled links was only a total of 8. This clearly indicates that frequency, location and timing play a significant role in the potential savings for a dynamic route scheduling system.

A combination between these two cases is observed in the 6+6 P&D scenario where a majority of the service calls are received after the initial 6 locations are completed. This leads to a minimum opportunity to optimize the schedule to reduce unnecessary travel.

distance. The 6+2 P&D scenarios were not subjected to this constraint since both unscheduled service calls were received before completion of the initial six service calls.

7.5.3 Effects of Route Optimization

The ability to determine the path of least resistance and therefore of the shortest travel time is a very important benefit which can be used by both the general public and courier operators to reduce travel times. This thesis examined the potential of using either a static or dynamic traffic information base for route guidance purposes. While both systems have merit from logistical, computational and economical viewpoints, a true and fully dynamic route guidance system is currently only a future possibility.

The enormous cost of dynamic traffic information collection within the urban arterial network dramatically hinders the implementation of such a system. A static traffic information database could possibly prove to be quite beneficial towards reducing travel time. The resulting savings would however be dependent upon the length of the time period selected.

The static traffic information system would essentially use an average travel time for a given period of time while the dynamic system could update traffic conditions as frequently as every one to two minutes. The comparison of these two cases under the scope of this thesis demonstrated that over the initial or tail-end of a peak period, or at a volume to capacity below 1.0, a static case could estimate the actual travel time quite accurately.

For the 6 P&D case, the static traffic information overestimated the travel time by no more than 4 minutes and at the 8 P&D case it underestimated the time by 3 minutes. As the

length of the journey further increased, the travel time was underestimated by between 12 and 27 minutes. This is for the most part due to the ever increasing congestion which was observed upon the network. Since the static system averages the travel time, it would be logical to see that as the congestion increases, the difference between the average travel time and the actual travel time would increase and is illustrated in Figure 7-9

Therefore, for effective use of static traffic information it is essential to segment the peak hour period into adequate divisions to account for the significant peaking characteristics found. There is merit in using static traffic information during the off-peak periods, since fluctuations in traffic volume are quite small. However, the ultimate system would be the use of a dynamic route guidance system so that any and all changes in travel patterns and travel time can be considered when courier vehicles select a route towards the next destination.

One factor which was not considered in this research was the impact of traffic delays caused by vehicle breakdowns or incidents. Unfortunately, the NETFLO program in the TRAF-NETSIM package did not provide the opportunity to allocate incidents as required for this research. However, the ability of the route guidance system to detect areas of heavy congestion, represented by larger travel times, would allow for the presumption that it could detect heavy congestion with a traffic incident as the root cause.

7.6 Observations and Discussion

At the centre of many discussions regarding ITS implementation is how detailed the traffic information should be, how often can or must it be disseminated and to whom should the data be distributed. There is considerable discussion among engineers, planners and

Figure 7-10 Example of Static and Dynamic Travel Time Results Over Time

government officials as to how the traffic information should be disseminated to users. Some argue that if the infrastructure is funded through public funds that all people who desire the traffic information be eligible to receive it while others believe that the information be only used for internal purposes such as the real-time coordination of traffic signals. These questions are of the utmost importance to courier companies and their decision making process for investment into ITS technologies

Essential to courier companies is the determination of how the information is to be used. If each vehicle uses the information for a dynamic route guidance system on an individual basis, the entire network would be continuously diverted to a path of minimum travel time which would become heavily congested and the route guidance system would then divert the traffic. A system of this nature would most likely result in little or no gain in travel time while often increasing travel distance.

The other option would be to have a route guidance system operated by a central computer system which could maintain a record of the number of vehicles diverted and optimize the overall transportation system's operation. While this would benefit the entire travelling public, it is unsure whether the courier industry would see sufficient reductions in travel time to justify the expenses for ITS investment.

Regardless of the configuration and state of an implemented ITS operated network, the courier industry can realize improvements in their operations. The benefits of implementing either a route scheduling system, a route guidance system or a system combining both technologies are numerous, but are not limited to the travel time savings detailed in this thesis. Added to the time savings is the reduction in fuel consumption, vehicle

wear, maintenance costs as well as the potential increase in productivity. However at the present time, use of a dynamic route guidance system is quite restricted.

While many cities are implementing freeway traffic management systems, thereby providing an ability to disseminate freeway traffic information, arterial networks still lag behind in receiving dynamic traffic systems. Most arterials are controlled by pre-timed or semi-actuated traffic signal systems. Therefore, until fully adaptive traffic signal systems are installed or traffic information is gathered on a dynamic basis, route guidance systems are limited to the static systems.

During the course of this thesis research, it was found that there are several operational considerations which must be made for effective use of traffic information in an ITS application. In the simulation process, it was realized that one of the most important factors in the performance and effectiveness of a dynamic route guidance system is to have the traffic data provided such that the most common traffic signal cycle length is an integer multiple of the data collection time period.

Unlike freeway traffic data collection, the presence of traffic signals results in an additional constraint on the ability to analyze periods not equal to a cycle length. With collection periods not equalling the cycle length, the data and travel time reported will be influenced by the number of stop periods encountered during the data collection period. The data collected during a period of a single stop phase will be significantly lower than those which contains more than a single phase. As a result of this inflated travel time, the route guidance system may inappropriately direct the vehicle to a route which is more heavily congested.

In addition to the data collection factor, it is important to investigate the methodology used for determining the selected minimum travel time route under a dynamic route guidance system and exactly how "dynamic" the system is. In this research, the dynamic route guidance system selected the travel path which resulted in the minimum travel time from the vehicle's current location to the location of the destination.

With traffic information provided at two minute intervals, the dynamic route guidance system determined a new "most appropriate route" upon the completion of travel on the current link using the most recent traffic information available. Therefore, if the traffic data were received while the vehicle was at mid-link, travel along the link would be completed at which time the optimum route would be re-evaluated.

Although it was not investigated in this thesis, it remains to be answered whether the route selected proved to be actually the minimum travel time route. Since traffic is dynamic, and the data provided reflects the current situation on the network, what is an appropriate time horizon for the dynamic route guidance system to use for determining the best path?

For example, two route travel times are represented in Table 7-20 and indicate that using the current dynamic traffic information the travel path which results in the minimum travel time is Route A. Of note, the travel time for the first three links of Route B are lower than that of Route A, however, the second three links are significantly inflated. At the next set of traffic data provided two minutes later, it is found that if the vehicle had chosen Route B initially, the vehicle would have reached the destination earlier than by taking Route A.

It is a scenario of this type which prompts the questioning of what criteria should be chosen for the selection of the minimum travel path. Should the dynamic route guidance

system chose the route which results in the instantaneous overall minimum travel time, the route which minimizes travel until the next available traffic data set or that which maximizes travel distance while the current data set is valid. The remaining option is to have the selection be based upon some combination of the instantaneous overall minimum and the minimum travel time based upon the current data interval results.

If so, what percentage or time difference would be appropriate to justify the selection of the longer travel path. For the above example, if the total travel time of Route B was approximately 10 percent greater than that for Route A, yet the initial time period would allow for a greater number of links to be travelled, does the driver select Route B. The dynamic nature of traffic does not allow for presuming of conditions remaining constant.

As such, the occurrence of non-recurring congestion from a traffic incident would significantly alter the decision of a travel path. If this incident occurs at or after the initial selection of a travel path, the congestion which would develop due to this incident would not influence route choice possibly until it is too late to alter the vehicle's travel path. These two operational factors warrant further investigation and analysis.

Another observation which was made during the simulation process was the effect of small arterial spacings on traffic operations. One of the major problems with short distances between arterials is the lack of storage. For example, with an average vehicular length of 5 metres, including distance headways, it is only possible to store 5 vehicles per lane for a 25 metre arterial spacing. Therefore, regardless of the progression efficiency available, there are constantly vehicles stored in a queue. When vehicle start-up losses are considered, congestion can very quickly reach catastrophic levels.

Table 7-20 Example of Route Selection Process for Two Different Routes

Time Period 1 -- Data Provided for Two Minute Interval		
	Route A	Route B
Link 1	44 seconds	40 seconds
Link 2	50 seconds	40 seconds
Link 3	39 seconds	40 seconds
Link 4	40 seconds	55 seconds
Link 5	37 seconds	63 seconds
Link 6	42 seconds	60 seconds
Total Travel Time	252 seconds	290 seconds
Travel Time Before 2nd Time Period	133 seconds	120 seconds
Time Period 2 -- Data Provided for Two Minute Interval		
Link 4	55 seconds	41 seconds
Link 5	60 seconds	37 seconds
Link 6	55 seconds	42 seconds
Total Travel Time	170 seconds	120 seconds
Overall Trip Travel Time	303 seconds	240 seconds

By increasing the spacing between intersections, the storage capabilities of the network significantly increases. This allows for vehicles to pass through the intersection at the time of the phase change, as opposed to being forced to await for an available space. When the arterial configurations for major metropolitans were re-examined, a trend was found. A great majority of the cities are designed with a rectangular block format where the longer arterial spacing is oriented towards the areas of high demand.

This thesis focused upon a transportation network with street blocks of a square configuration. While this may not be typical of many cities, it had been decided to eliminate any bias of the results through the use of a square block pattern. Depending upon the location of the service stops, the potential savings in travel time could have varied significantly. Therefore, investigation into a rectangular network should be undertaken for determination of the impact on the potential savings of route guidance and scheduling systems.

Finally, one of the most interesting and troubling observations occurred not from the actual study of ITS benefits, but rather the simulation results from the NETFLO2 program of the TRAF-NETSIM package. As has been previously mentioned, there were two cases of route guidance systems examined for this thesis. The static case utilized a one hour simulation period and generated a set of cumulative or average travel time statistics, while the dynamic case comprised of traffic information being provided at two minute intervals with only the data for that specific time interval being examined

The static case provided a travel time estimate for all links to be used. However, as time progressed for the dynamic case, links began to indicate a travel time of zero seconds and that no vehicles had completed trips along that link. Since the TRAF-NETSIM package computes travel statistics only when a vehicle passes the stop line at the end of the link, as congestion increased towards gridlock conditions, the package provided zero values. This does not reflect the actual conditions which are being simulated.

It then becomes of concern as to the accuracy of the static traffic data. If congestion is so severe as to result in gridlock, do the data provided account for the travel time incurred

while the vehicle is stuck in traffic. Or do the zero values yield a lower average travel time than what is actually encountered. With the TRAF-NETSIM package having been used in industry and research for many years, it is disconcerting to believe that any study which simulated the traffic conditions over a single one hour period could possibly have underestimated the overall impact of geometric or traffic volume modifications.

In addition, the methodology used for simulation purposes is of question. Brought about by the inability to gather traffic information for the 25 metre CBD scenario of the one-way street configuration, the order in which traffic data are located in the TRAF-NETSIM input file is important to investigate. The reason for such a review is to determine whether the TRAF-NETSIM package uses a push or pull type method for vehicle progression on the network.

The use of either system would justify the need to order input data in a specific sequence. Based upon the results obtained, it is believed that the program moves vehicles onto the network using a push methodology. Therefore, if the downstream link is the next to be analyzed and is already congested, the link currently being modelled would not be capable of moving vehicles off the link and a shockwave of congestion would occur.

In this thesis, the input data were listed in order from upstream to downstream link. This sequencing may have, in part, accelerated the congestion which developed on the network. Hence, it would be of interest to investigate whether reordering of the link sequence would result in a reduction of the congestion and travel times computed.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Summary

Intelligent Transportation Systems has become a key area of investigation for the transportation industry over the past decade. Initially begun strictly for military purposes, many of the new technologies are now being used in ITS installations. Developments have brought forth many innovations, including freeway traffic management systems, mobile communication systems, global positioning systems and vehicle location and tracking systems. These technologies have found their way into transportation systems such as freeway operations, intercity goods transportation operations and computerized bus schedules.

The courier industry has focused many of their efforts of operational improvements away from transportation factors. The industry employs hand-held computer devices for package information recording and tracking for the exclusive purposes of reducing service time and increasing service reliability. Computer automation of the courier industry has led to more efficient servicing operations.

Since the industry is so highly focused upon timely delivery of goods between locations, the ability to reduce travel time between service stops is unquestionably essential. Vehicle travel time is the natural progression of operational improvements to the courier

industry. UPS had attempted a joint venture with the New York Ports Authority for dissemination of congestion and incident related delay information, however it was found that the courier vehicles most often were the first to encounter these congested areas.

It was for this reason that the investigation into the potential benefits of ITS implementation for use in the courier industry was initiated. The use of route scheduling systems and route guidance systems were investigated for a hypothetical network whereby factors such as arterial spacing, traffic volume and unscheduled pick-ups were varied.

8.2 Conclusions

Examination of the significant range of observations provided the opportunity from which several key conclusions are drawn:

- Route scheduling demonstrates significant benefits when a fixed number of pick-up and deliveries are required. When additional service calls are necessary, the benefits derived from a dynamic route scheduling system are extremely dependent upon the frequency, timing and location of the additional calls. Travel time savings can range from one to 50 minutes for a CBD area and greater than 14 minutes for a metropolitan network.
- Route guidance systems provide significant possibilities for savings of anywhere between 87 seconds and 4 hours depending upon volume, arterial spacing and the number of service calls. Savings of this proportion indicate that there is a significant potential benefit from use of a route guidance system.
- It was determined that route scheduling and route guidance systems can be very

beneficial to the operational efficiency of the courier industry, even at the limited pick-up and delivery schedules examined in this thesis. Naturally, as the number of service requirements increases, there will be a corresponding increase in the level of benefits which can be achieved on a daily basis. When the total savings are investigated for an entire fleet, the savings should demonstrate that tremendous savings are possible.

- The combination of these two systems even further increase the potential savings in travel time and other associated operational costs. In some cases, reductions of almost 50 percent are possible over the longest travel time route for a non-optimized route of maximum travel distance.
- The effects of certain traffic criteria such as arterial spacing, traffic volume and the number of unscheduled pick-ups on the benefits of route guidance and route scheduling systems were examined and found to have, in some cases, a dramatic impact on the potential savings.
- The negative effects of a one-way traffic network on courier operations was documented by demonstrating that a more circuitous route was required which resulted in greater travel times.
- Comparison between a static and dynamic route guidance system demonstrated that the accuracy of the results of a static system is affected by the time period analyzed, the traffic volume assigned and the operational efficiency of the network under study. The results are called into question due to the inability of a static system to reflect the real-time traffic conditions. For an hour simulation, a static system was found to slightly overestimate the required travel time initially and significantly underestimate

the travel time at the end. With dynamic route guidance systems still in its infant stages, static route guidance systems must use sufficiently small time intervals to avoid masking the large fluctuations which occur during peak periods.

- The use of a combined route guidance and route scheduling system illustrated that there is a complementary nature between the two systems which yielded savings of at least 10 minutes and to a high of 228 minutes in travel time. These savings represent approximately a 50 percent reduction in travel time over the worst case scenarios and therefore demonstrate the potential of combining components.
- It was also found that intersection delay has a greater effect on total travel time than does move time delay. In addition, the effects of arterial spacing results in an inverse relationship between these two travel time components while the effects of volume creates a proportional relationship. As such, intersection delay decreases with an increased arterial spacing while the move delay increases. Meanwhile, an increase in volume yields an increase in both the intersection and move time delay.
- When these combined systems are examined for their potential travel time savings, it is found that both volume and arterial spacing increases result in a potential saving of travel time.
- The impact on travel time and potential savings from use of either a one-way and two-way traffic network was also undertaken. It was discovered that for the one-way traffic network, there is an increase in the number of links required for completion of routes as well as an increase in travel time to the magnitude of between 4 and 130 minutes. Again, the effect of arterial spacing and volume only magnify the negative

impact of the additional travel distance required for a one-way system.

- Another area investigated was the effect of choosing one route direction over another. In this thesis, it was found that there can be significant differences between travel times for each direction. While direction has an impact for routes with a fixed number of service calls, when unscheduled service locations are incorporated into the route, it becomes impossible to determine which route is the most beneficial route until the end of the service day.

8.3 Recommendations

As is sometimes the case with research projects, new questions and areas of investigation can be quite numerous as are the conclusions found. This thesis is no different. On the basis of the conclusions, the following recommendations on areas of future work are made:

- With route scheduling and route guidance systems individually demonstrating substantial benefits to the operational efficiency of the courier industry, even at the limited pick-up and delivery schedules examined in this thesis, further research should be conducted to determine the potential benefits which could be accrued from a full day's worth of courier operations for a single vehicle.
- The combination of these two systems even further increase the potential savings in travel time and other associated operational costs. Continuation of research into the potential gains should be undertaken using new routing and network configurations to investigate the validity of the results found in this thesis research.

- Examination of the effects of certain traffic criteria such as arterial spacing, traffic volume and the number of unscheduled pick-ups on the benefits of route guidance and route scheduling systems should be continued using new routes and network configurations.
- There is a need to use more recent and sophisticated traffic models to verify the results found from the TRAF-NETSIM simulations. The NETFLO2 program provides a reasonable basis for recommending the use of route guidance and route scheduling systems. However, the limitations of the model restricted the level of detail in the output from the simulation process as well as the flexibility of the hypothetical network
- It can be recommended that for any dynamic route guidance system implemented, that the most common cycle length be used as the basis for collection and dissemination of real-time travel time information.
- This thesis investigated the impacts of ITS on a square arterial grid. With many cities having a rectangular configuration, it is recommended that further investigation be undertaken to study this scenario.
- The dramatic impact that traffic incidents have on traffic performance and operations is another significant area which requires further study to evaluate the effectiveness of route guidance and scheduling systems.
- Further study is required into the methodologies used by a "dynamic" route guidance system. Investigation into how and what criteria is used for selection of the optimum travel time route and whether the route selection should be based on the overall travel

time to the destination or if the greatest distance travelled for the time period be used. The difference in overall travel times between two routes may provide reason to examine both possible routes if they are within a predefined time or percentage deviation.

- In addition, further study should be performed to determine at what time intervals can a static route guidance system use arterial traffic information without having the peaking effect of rush hour traffic masked or over-detailing the off-peak periods while still maintaining a near-static methodology.
- Some of the more interesting research should be conducted into the effects of arterial spacing, volume and the order of input data on the simulation performance of the TRAF-NETSIM package. As previously mentioned, severe congestion resulted in zero values being produced instead of high travel times. It is believed that the order of links in the input data file may be partially responsible for the severity of the incurred delay.

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- 18 *ITS Journal : R&D, Operational Testing and Development of Intelligent Transportation Systems*. Editor-in-Chief Chelsea C. White III, University of Michigan, Gordon & Breach Publishers. ITS America, Volume 3, No 1, pp 1-84. 1996

APPENDIX A

Correspondance With Courier Companies

- A.1 Reply From UPS Further To Request For Information**
- A 2 Reply From Purolator Courier Ltd Further To Request For Information**

From: Dave Bailey <dbailey@is.ups.com>
 Subject: Reply to your inquiry
 To: "ochoudhr@ccs.carleton.ca" <ochoudhr@ccs.carleton.ca>
 Date: Wed, 15 Nov 95 11:58:27 -0500

-- [From: Dave Bailey * EMC.Ver #2.5.02] --

Thank you for your inquiry. However, as a private company, UPS can not give this information for competitive reasons.

John Flick
 Public Relations
 United Parcel Service

----- FORWARD, Original message follows -----

> Date: Friday, 10-Nov-95 10:12 AM

>
 > From: Omar Hussain Choudhry \ Internet: (ochoudhr@ccs.carleton.ca)
 > To: UPS Customer Service \ Internet: (customer.service@ups.com)
 > Subject: Info for M.Eng Thesis

> Dear Sir or Madam,

> I am a Master's of Engineering student at Carleton University
 > in Ottawa, Canada. I originally wrote to you on Sept.21/95,
 > requesting some information regarding your operations for my
 > thesis. It's focus is on the achievable benefits of Intelligent
 > Transportation Systems (ITS) on urban courier services. As such,
 > I am in need of certain information on average metropolitan rates.
 > This information includes.

- > 1. Number of Pick ups per vehicle -- downtown vehicle
- > -- suburb vehicle
- > 2. Number of deliveries per vehicle -- downtown & suburbs
- > 3. Average deployment area (eg. blocks) -- downtown & suburbs
- > 4. Average service time per package -- downtown & suburbs
- > 5. The ROADNET program currently operating

> I would greatly appreciate any response and help in obtaining
 > information for conducting my thesis. Thank-you kindly.

>
 > Yours Sincerely,
 > Omar Choudhry
 > Carleton University
 > Dept. of Civil and Enviro Engineering
 > Mackenzie Building, Room 3432
 > Ottawa, Ontario
 > K1S 5B6 Canada

> email: ochoudhr@ccs.carleton.ca

> ----- FORWARD, End of original message -----

Aug 22 15:45 1996 standard input Page 1

From tjarvis@idirect.com Thu Nov 16 18:05:03 1995
 Date: Thu, 16 Nov 1995 18:04:51 -0500
 X-Sender: tjarvis@idirect.com
 X-Mailer: Windows Eudora Light Version 1.5.2
 Mime-Version: 1.0
 Content-Type: text/plain; charset="us-ascii"
 To: ochoudhr@ccs.carleton.ca (Omar Hussain Choudhry)
 From: Terrie Jarvis <tjarvis@idirect.com>
 Subject: Re: Info for Master's Thesis
 Content-Length: 1616

Hi Omar

We forwarded your request to our Industrial Engineering department. They indicated that as much as they would like to assist you in your research, your request requires resources which they are extremely short of at the moment - people and time! If you would like to follow up by telephone, call 1-800-326-4963 and ask for Mr. Sam Manfredi, Director, Industrial Engineering on ext. 6714. Perhaps personal contact with him might be more effective.

Good luck.

Terrie Jarvis
 Marketing Co-ordinator
 Purolator Courier Ltd.

At 10:29 AM 11/10/95 EST, you wrote:

> Dear Sir or Madam,
 > I am a Master's of Engineering student at Carleton University
 > in Ottawa, Canada. I originally wrote to you on Sept.21/95,
 > requesting some information regarding your operations for my
 > thesis. It's focus is on the achievable benefits of Intelligent
 > Transportation Systems (ITS) on urban courier services. As such,
 > I am in need of certain information on average metropolitan rates.
 > This information includes:
 > 1. Number of Pick ups per vehicle -- downtown vehicle
 > -- suburb vehicle
 > 2. Number of deliveries per vehicle -- downtown & suburbs
 > 3. Average deployment area (eg. blocks) -- downtown & suburbs
 > 4. Average service time per package -- downtown & suburbs
 >
 > I would greatly appreciate any response and help in obtaining
 > information for conducting my thesis. Thank-you kindly.
 >
 > Yours Sincerely,
 > Omar Choudhry
 > Carleton University
 > Dept. of Civil and Enviro Engineering
 > Mackenzie Building, Room 3432
 > Ottawa, Ontario
 > K1S 5B6 Canada
 >
 > email: ochoudhr@ccs.carleton.ca

APPENDIX B

SORDS Route Determining Program

- B.1 Description Of SORDS (Simulation Optimum Route Determining System)**
- B.2 SORDS Route Determining Source Code**

Appendix B.1

The Simulation Optimum Route Determining System (SORDS) program was developed for the purpose of computerizing the search procedures for selecting the minimum travel time route. The program was written specifically for the hypothetical network in this thesis, but can be easily modified to accept networks of any size. SORDS has been designed to investigate TRAF-NETSIM output data files for both single and multiple time period simulation, named "Static" and "Dynamic" respectively.

Once the selected data output file has been reduced, the user is prompted for the coordinates of the origin and destination nodes between which route combinations are to be examined. Using a series of search procedures, all combinations are investigated and the route travel times are subsequently given to the user by the means of screen display and, if requested, by a computer data file.

Since this program was specifically developed for use in this thesis, there are currently some limitations to its use. Primarily, the modelled network must consist of a 9x12 node configuration. The program therefore requires that TRAF-NETSIM simulations be structured to accomodate this feature by means of a specifically ordered data input file. Once the output data file has been selected by the user, the program prompts the user for the time period to be analysed, if the "dynamic" option was chosen, as well as the coordinates for the origin and destination node between which travel times are to be computed.

All combinations are illustrated to the user on-screen for analysis and the user can then select the route which meets their specific requirements and needs. This process has been left

to the user at this stage of the program. Future modifications may be made to have the computer select the appropriate use after a series of questions are posed to the user concerning their route choice selection criteria.

Appendix B.2

```

Program Thesis;
uses CRT;
label mark;
type String2 = string[2];
    Output = array[0..16, 0..22] of Real;
    String3 = string[3];
    String4 = string[4];
    String6 = string[6];
    String8 = string[8];
    StringA = string[66];
    StringB = string[20];
    StringC = string[11];
var Confirm, Answer, pause, Asks, Answer2, Slcfile : char;
    A, B, C, D, E, F, G, H, I, J, K, L, M, N, O : String3;
    Iterate, X1, X2, Y1, Y2, Num, X1p, TP, X2p, Y1p, Y2p : integer;
    kounter : integer;
    Average, Overall : real;
    Name : String8;
    Infile, Database : text;
    Junk, Dtabas : Output;

Procedure Intro;
var Outfile : text;
begin
    ClrScr;
    writeln('  SSSS   000   RRRR   DDDD   SSSS   Simulation Optimum ');
    writeln(' S      O   O   R   R   D   D   S      Route Determination ');
    writeln('  SSS   O   O   RRRR   D   D   SSS      System ');
    writeln('    S   O   O   R   R   D   D   S      ');
    writeln('  SSSS   000   R   R   DDDD   SSSS   By Omar Choudhry');
    writeln;
    writeln(' You are currently using the data location program for');
    writeln('route travel time determination from TRAF-NETSIM output');
    writeln('This program will allow you to gather selected information');
    writeln('such as travel time and will eventually include fuel consumption');
    writeln('Developed by Omar Choudhry for M.Eng. degree');
    writeln('NOTE : The data file to be searched must be located in');
    writeln('        the drive labelled drive F:\...\ ');
    writeln('Would you like the selected data to also be placed in a file');
    write(' named Yes(Y) or No(N) : ');
    readln(Confirm);
    if (Confirm = 'Y') OR (Confirm = 'y') then begin
        write('Please enter an 8 letter name w/ ext. : ');
        readln(Name);
        Assign( Outfile, Name);
        Rewrite( Outfile );
    end;
end;

Procedure Introduction(var Slcfile :char );
label Goback;
var Verify : char;
begin
    ClrScr;
    writeln;
    writeln(' Select name of the database to be used (1 or 2) ');
    writeln('          1. DYNAMIC.OUT (Dynamic model)');
    writeln('          2. STATIC.OUT (Static model)');
    writeln;
Goback:  Verify := '0';
    while Verify = '0' do begin
        write(' Please make a selection (enter (1) or (2)) : ');
        readln(Slcfile);
        writeln;
    end;
end;

```



```

Case Slkfile of
  '1' : write('You have selected PART A. Yes(1) or No(0) : ');
  '2' : write('You have selected PART B. Yes(1) or No(0) : ');
  else begin writeln('Incorrect entry. Try Again. ');
        goto Goback;
      end;
    end;
  readln( Verify );
  writeln;
end;
end;

Procedure Nodes;
Label Skip, Skip1, Skip2, Skip3;
begin
Skip:   write('Enter the origin node X-coordinate: ');
      readln(X1);
      if X1 > 8 then goto Skip;
Skip1:  write('Enter the origin node Y-coordinate: ');
      readln(Y1);
      if Y1 > 11 then goto Skip1;
Skip2:  write('Enter the destination node X-coordinate: ');
      readln(X2);
      if X2 > 8 then goto Skip2;
Skip3:  write('Enter the destination node Y-coordinate: ');
      readln(Y2);
      if Y2 > 11 then goto Skip3;
      writeln;
end;

Procedure Writting(Newpg:char;Dum:String2; Node1:String3;Dum2:String2;Node2: String3;
                  Dummy:StringB;Dummy4:StringC;Dum3: StringA);
var Outfile : text;
begin
  if (Confirm = 'Y') OR (Confirm = 'y') then begin
    Assign( Outfile , Name);
    Append( Outfile );
    writeln(Outfile,Newpg,Dum,Node1,Dum2,Node2,Dummy,Dummy4,Dum3);
    Close( Outfile );
  end;
end;

Procedure Redinfo( Slkfile :char );
var Dbase, Outfile : text;
    Dum : string[60];
    Dume : string[47];
    Yup : string[3];
    Dum2, Dum4 : string[8];
    Dum1, Dum3 : string[9];
    Foor, PH : string[2];
    counter,Flag : integer;
    Newpg, Newph, blank1, blank2, blank3: char;
begin
  writeln;
  writeln('Reading through file. Please wait. ');
  if Slkfile = '1' then Assign( Dbase , 'j:\temp\dynamic.out' )
    else Assign( Dbase , 'j:\temp\static.out' );
  Reset( Dbase );
  Assign( Outfile , 'j:\temp\tempb.txt');
  Rewrite( Outfile );
  Flag := 0;
  counter:=0;
  readln( Dbase, Yup, Newpg, Foor, blank1, blank2, Newph,PH, blank3,Dume,
Dum1,Dum2,Dum3,Dum4,Dum);
  repeat
    if Yup = ' ( ' then
      if (Flag <> 1) then begin
        if (Newpg <> '1') then
          if (Newph <> '1') then begin
            Append( Outfile );

```

```

        counter:=counter+1;
        writeln(Outfile,Newpg,foor,blank2,Newph,PH,Dum1,Dum2,' ',Dum3,'
',Dum4,Dum);
        Close( Outfile );
    end;
end;
if (Newpg = '5') then
    if (Foor = '18') then
        if (Newph = '5') then
            if (PH='08') then if (Flag = 1) then Flag := 0
                               else Flag := 1;
            readln( Dbase, Yup, Newpg, Foor, blank1, blank2, Newph,PH,blank3,Dume, Dum);
        until (Yup = 'OLA');
    end;
end;

```

```

Procedure Question( Asks : char);
begin
    write('Do you have existing "temp1.txt" file to use? ');
    readln(Asks);
    if Asks = 'n' then Redinfo(Slcfile);
    if Asks = 'N' then Redinfo(Slcfile);
end;

```

```

Procedure Putaray;
var R1,R2,R3 : real;
    Looper,Looper2,Zerol,Zero,Loop, Loop2, I1,I2 : integer;
begin
    write('.');
    For Zerol:= 0 to 16 do
        For Zero := 0 to 22 do begin Dtabas[Zerol,Zero] := 0;
                                    Junk[Zerol,Zero] := 0;
                                end;

    For Loop := 0 to 11
        do begin
            Looper:=11-Loop;           ( X values )
            For Loop2 := 1 to 8
                do Readln( Infile,I1,I2,R1,R2, Dtabas[Loop2*2-1,Loop*2]);
            For Loop2 := 1 to 8
                do begin
                    Looper2 := 8- Loop2;
                    Readln( Infile, I1,I2,R1,R2, Junk[Loop2*2-1,Looper*2]);
                end;
            end;

    For Loop2 := 0 to 8
        do begin
            ( Y values )
            For Loop := 0 to 10
                do Readln( Infile, I1,I2,R1,R2, Dtabas[Loop2*2,Loop*2+1]);
            For Loop := 0 to 10
                do begin
                    Looper:=10-Loop;           (er)
                    Readln( Infile, I1,I2,R1,R2,Junk[Loop2*2,Loop*2+1] );
                end;
                write('.');
            end;
        end;
end;

```

```

Procedure Putaray2;
var R1,R2,R3 : real;
    Looper,Looper2,Zerol,Zero,Loop, Loop2, I1,I2 : integer;
begin
    write('.');
    For Zerol:= 0 to 16 do
        For Zero := 0 to 22 do begin Dtabas[Zerol,Zero] := 0;
                                    Junk[Zerol,Zero] := 0;
                                end;

    For Loop := 0 to 11
        do begin
            Looper:=11-Loop;           ( X values )
            For Loop2 := 1 to 8
                do begin

```

```

        Readln( Infile, I1, I2, R1, R2, Dtabas[Loop2*2-1, Looper*2]);
    end;
    For Loop2 := 1 to 8
    do Readln( Infile, I1, I2, R1, R2, Junk[Loop2*2-1, Loop*2]);
    end;
    For Loop2 := 0 to 8
    do begin
        Looper2:= 8-Loop2;
        For Loop := 0 to 10
        do Readln( Infile, I1, I2, R1, R2, Junk[Loop2*2, Loop*2+1]);
        For Loop := 0 to 10
        do Readln( Infile, I1, I2, R1, R2, Dtabas[Loop2*2, Loop*2+1] );
        write(' ');
        end;
    end;

    end;

    Procedure Putaray3;
    var R1, R2, R3 : real;
    Looper, Looper2, Zerol, Zero, Loop, Loop2, I1, I2 : integer;
    begin
        write(' ');
        For Zerol:= 0 to 16 do
        For Zero := 0 to 22 do begin Dtabas[Zerol, Zero] := 0;
                                Junk[Zerol, Zero] := 0;
                                end;
        For Loop := 0 to 11
        do begin
            Looper := 11-Loop;
            For Loop2 := 1 to 8
            do Readln( Infile, I1, I2, R1, R2, Junk[Loop2*2-1, Loop*2]);
            For Loop2 := 1 to 8
            do Readln( Infile, I1, I2, R1, R2, Dtabas[Loop2*2-1, Looper*2]);
            end;
        For Loop2 := 0 to 8
        do begin
            Looper2:= 8-Loop2;
            For Loop := 0 to 10
            do Readln( Infile, I1, I2, R1, R2, Junk[Loop2*2, Loop*2+1]);
            For Loop := 0 to 10
            do begin
                Looper := 10-Loop;
                Readln( Infile, I1, I2, R1, R2, Dtabas[Looper2*2, Loop*2+1] );
                end;
            write(' ');
            end;
        end;

    end;

    Procedure Putaray4;
    var R1, R2, R3 : real;
    Looper, Looper2, Zerol, Zero, Loop, Loop2, I1, I2 : integer;
    begin
        write(' ');
        For Zerol:= 0 to 16 do
        For Zero := 0 to 22 do begin Dtabas[Zerol, Zero] := 0;
                                Junk[Zerol, Zero] := 0;
                                end;
        For Loop := 0 to 11
        do begin
            Looper:=11-Loop;
            For Loop2 := 1 to 8
            do Readln( Infile, I1, I2, R1, R2, Junk[Loop2*2-1, Looper*2]);
            For Loop2 := 1 to 8
            do Readln( Infile, I1, I2, R1, R2, Dtabas[Loop2*2-1, Loop*2]);
            end;
        For Loop2 := 0 to 8
        do begin
            Looper2:= 8-Loop2;
            For Loop := 0 to 10
            do Readln( Infile, I1, I2, R1, R2, Dtabas[Looper2*2, Loop*2+1]);
            For Loop := 0 to 10

```

```

        do Readln( Infile, I1,I2,R1,R2,Junk[Loop2*2,Loop*2+1] );
        write(' ');
    end;
end;

Procedure Getinfo2;
var Value, tottm : real;
    Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h : integer;
begin
    tottm := 0;
    Xcoor1 := X1*2;
    Ycoor1 := Y1*2;
    Xcoor2 := X2*2;
    Ycoor2 := Y2*2;
    For i := Xcoor1 to Xcoor2
    DO begin
        if ((i mod 2) = 1) then Delay(1)
        else For k := Ycoor1 to Ycoor2
            Do begin tottm := tottm + Dtabas[i,k]; (reads across)
                if (Dtabas[i,k]<>0) then write(i,k,' ',Dtabas[i,k]:4:1,' ');
                if k = Ycoor2 then
                    For j := i to Xcoor2 (reads remain down)
                    Do begin tottm := tottm + Dtabas[j,k];
                        if (Dtabas[j,k]<>0) then write(j,k,' ',Dtabas[j,k]:4:1,' ');
                        end;
                    if (k=Ycoor1) and (i<>Xcoor1) then
                        For h := Xcoor1 to (i) ( adds start to 1st horiz )
                        Do begin tottm := tottm + Dtabas[h,k];
                            if (Dtabas[h,k]<>0) then write(h,k,' ',Dtabas[h,k]:4:1,' ');
                            end;
                        end;
                if ((i mod 2) <> 1) then begin writeln('==> Time = ',tottm:5:1);
                    Overall := tottm + Overall;
                    kounter := kounter + 1;
                    end;
                tottm:=0;
            end;
    end;
end;

Procedure Getinfo3;
var Value, tottm : real;
    Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h : integer;
begin
    tottm := 0;
    Xcoor1 := X1*2;
    Ycoor1 := Y1*2;
    Xcoor2 := X2*2;
    Ycoor2 := Y2*2;
    For i := Ycoor1 to Ycoor2
    DO begin
        if ((i mod 2) = 1) then Delay(1)
        else For k := Xcoor1 to Xcoor2
            Do begin tottm := tottm + Dtabas[k,i]; (reads down)
                if (Dtabas[k,i]<>0) then write(k,i,' ',Dtabas[k,i]:4:1,' ');
                if k = Xcoor2 then
                    For j := i to Ycoor2 (reads remain across)
                    Do begin tottm := tottm + Dtabas[k,j];
                        if (Dtabas[k,j]<>0) then write(k,j,' ',Dtabas[k,j]:4:1,' ');
                        end;
                    if (k=Xcoor1) and (i<>Ycoor1) then
                        For h := Ycoor1 to (i-1) ( adds from start to 1st vert )
                        do begin
                            tottm := tottm + Dtabas[k,h];
                            if (Dtabas[k,h]<>0) then write(k,h,' ',Dtabas[k,h]:4:1,' ');
                            end;
                        end;
                if ((i mod 2) <> 1) then begin writeln('==> Time = ',tottm:5:1);
                    Overall := tottm + Overall;
                end;
            end;
    end;
end;

```

```

        kounter := kounter + 1;
    end;
    tottm:=0;
end;
end;

Procedure Getinfo4;
var Value, tottm : real;
    Steps,Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h,ipp,next,kpp,ip,kp,Step,Z,loopi,loopk: integer;
begin
    tottm := 0;
    Xcoor1 := X1*2;
    Ycoor1 := Y1*2;
    Xcoor2 := X2*2;
    Ycoor2 := Y2*2;
    if Abs(X1-X2) < Abs(Y1-Y2) then Z:= Abs(X1-X2)
    else Z:= Abs(Y1-Y2);
For Step:= 1 to Z
do begin
    ip:=Xcoor1;
    kp:=Ycoor1;
    Steps:=Step*2;
    tottm := tottm + Dtabas[ip,kp];
    if (Dtabas[ip,kp]<>0) then write(ip,kp,' ',Dtabas[ip,kp]:4:1,' ');
    while (kp<Ycoor2) and (ip<Xcoor2) do begin
        For next := 1 to Steps do begin
            if ((ip=Xcoor2) or (kp=Ycoor2)) then next := Steps
            else begin tottm:= tottm + Dtabas[(ip+1),kp];
                if (Dtabas[(ip+1),kp]<>0)
                    then write((ip+1),kp,' ',Dtabas[(ip+1),kp]:4:1,' ');
                ip := ip + 1;
            end;
        end;
        For next := 1 to Steps do begin
            if ((kp=Ycoor2) and (ip=Xcoor2)) then next := Steps
            else begin tottm := tottm + Dtabas[ip,(kp+1)];
                if (Dtabas[ip,(kp+1)]<>0)
                    then write(ip,(kp+1),' ',Dtabas[ip,(kp+1)]:4:1,' ');
                kp := kp + 1;
            end;
        end;
        while (ip < Xcoor2) do begin
            tottm:= tottm + Dtabas[(ip+1),kp];
            if (Dtabas[(ip),kp]<>0)
                then write((ip),kp,' ',Dtabas[(ip),kp]:4:1,' ');
            ip := ip + 1;
        end;
        while (kp < Ycoor2) do begin
            tottm:= tottm + Dtabas[ip,(kp)];
            if (Dtabas[ip,(kp)]<>0)
                then write((ip),(kp),' ',Dtabas[ip,(kp)]:4:1,' ');
            kp := kp + 1;
        end;
    end;
    writeln('==> Time = ',tottm:5:1);
    Overall := tottm + Overall;
    kounter := kounter + 1;
    tottm:=0;
end;
end;

Procedure Getinfo5;
var Value, tottm : real;
    Steps,Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h,ipp,next,kpp,ip,kp,Step,Z,loopi,loopk: integer;
begin
    tottm := 0;
    Xcoor1 := X1*2;
    Ycoor1 := Y1*2;

```

```

Xcoor2 := X2*2;
Ycoor2 := Y2*2;
if Abs(X1-X2) < Abs(Y1-Y2) then Z:= Abs(X1-X2)
else Z:= Abs(Y1-Y2);
For Step:= 1 to Z
do begin
  ip:=Xcoor1;
  kp:=Ycoor1;
  Steps:=Step*2;
  tottm := tottm + Dtabas[ip,kp];
  if (Dtabas[ip,kp]<>0) then write(ip,kp,' ',Dtabas[ip,kp]:4:1,' ');
  while (kp<Ycoor2) and (ip<Xcoor2) do begin
    For next := 1 to Steps do begin
      if ((kp=Ycoor2) or (ip=Xcoor2)) then next := Steps
      else begin tottm := tottm + Dtabas[ip,(kp)];
        if (Dtabas[ip,(kp)]<>0) then
          write(ip,(kp),' ',Dtabas[ip,(kp)]:4:1,' ');
        kp := kp + 1;
      end;
    end;
    For next := 1 to Steps do begin
      if ((ip=Xcoor2) and (kp=Ycoor2)) then next := Steps
      else begin tottm:= tottm + Dtabas[(ip),kp];
        if (Dtabas[(ip),kp]<>0) then
          write((ip),kp,' ',Dtabas[(ip),kp]:4:1,' ');
        ip := ip + 1;
      end;
    end;
    while (kp < Ycoor2) do begin
      tottm := tottm + Dtabas[ip,(kp)];
      if (Dtabas[ip,(kp)]<>0) then
        write(ip,(kp),' ',Dtabas[ip,(kp)]:4:1,' ');
      kp := kp + 1;
    end;
    while (ip < Xcoor2) do begin
      tottm:= tottm + Dtabas[(ip),kp];
      if (Dtabas[(ip),kp]<>0) then
        write((ip),kp,' ',Dtabas[(ip),kp]:4:1,' ');
      ip := ip + 1;
    end;
  end;
  writeln('==> Time = ',tottm:5:1);
  Overall := tottm + Overall;
  kounter := kounter + 1;
  tottm:=0;
end;
end;

Procedure Getinfo6;
var Value, tottm : real;
    times, Incr,Steps,Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h,ipp,next,kpp,ip,kp,Step,Z,Incr, W,loopi,loopk: integer;
    pauses : char;
begin
  tottm := 0;
  times:=0;
  Xcoor1 := X1*2;
  Ycoor1 := Y1*2;
  Xcoor2 := X2*2;
  Ycoor2 := Y2*2;
  if Abs(X1-X2) < Abs(Y1-Y2) then begin Z:= Abs(X1-X2);
    W:= Abs(Y1-Y2);
  end
  else begin Z:= Abs(Y1-Y2);
    W:= Abs(X1-X2);
  end;
  end;
  For Incr := 1 to W do begin
    Incr:= Incr*2;
  For Step:= 1 to Z
    do begin

```

```

ip:=Xcoor1;
kp:=Ycoor1;
Steps:=Step*2;
tottm := tottm + Dtabas[ip,kp];
if (Dtabas[ip,kp]<>0) then write(ip,kp,' ',Dtabas[ip,kp]:4:1,' ');
while ((kp<Ycoor2) and (ip<Xcoor2)) do begin
  For next := 1 to Steps do begin
    if ((ip=Xcoor2) or (kp=Ycoor2)) then next := Steps
    else begin tottm:= tottm + Dtabas[(ip+1),kp];
      if (Dtabas[(ip+1),kp]<>0) then
        write((ip+1),kp,' ',Dtabas[(ip+1),kp]:4:1,' ');
      ip := ip + 1;
    end;
  end;
  For next := 1 to Incre do begin
    if ((kp=Ycoor2) ) then next := Incre
    else begin tottm := tottm + Dtabas[ip,(kp+1)];
      if (Dtabas[ip,(kp+1)]<>0) then
        write(ip,(kp+1),' ',Dtabas[ip,(kp+1)]:4:1,' ');
      kp := kp + 1;
    end;
  end;
end;
while (ip < Xcoor2) do begin
  tottm:= tottm + Dtabas[(ip+1),kp];
  if (Dtabas[(ip),kp]<>0) then
    write((ip),kp,' ',Dtabas[(ip),kp]:4:1,' ');
  ip := ip + 1;
end;
while (kp < Ycoor2) do begin
  tottm:= tottm + Dtabas[(ip),kp];
  if (Dtabas[(ip),(kp)]<>0) then
    write((ip),(kp),' ',Dtabas[(ip),(kp)]:4:1,' ');
  kp := kp + 1;
end;
writeln('==> Time = ',tottm:5:1);
times := times+1;
if times= 10 then begin readln(pauses);
  times:=0;
  end;
Overall := tottm + Overall;
kounter := kounter + 1;
tottm:=0;
end;
end;
end;

Procedure Getinfo7;
var Value, tottm : real;
    times, Incr, Steps,Xcoor1,Xcoor2,Ycoor1,Ycoor2:integer;
    i,j,k,h,ipp,next,kpp,ip,kp,Step,Incre,W,Z,loopi,loopk: integer;
    pauses : char;
begin
  tottm := 0;
  times := 0;
  Xcoor1 := X1*2;
  Ycoor1 := Y1*2;
  Xcoor2 := X2*2;
  Ycoor2 := Y2*2;
  if Abs(X1-X2) < Abs(Y1-Y2) then begin Z:= Abs(X1-X2);
    W:= Abs(Y1-Y2);
  end
  else begin Z:= Abs(Y1-Y2);
    W:= Abs(X1-X2);
  end;
  For Incr:= 1 to W do begin
    Incre:= Incr*2;
    For Step:= 1 to Z
      do begin
        ip:=Xcoor1;

```

```

kp:=Ycoor1;
Steps:=Step*2;
tottm := tottm + Dtabas[ip,kp];
if (Dtabas[ip,kp]<>0) then write(ip,kp,'',Dtabas[ip,kp]:4:1,' ');
while (kp<Ycoor2) and (ip<Xcoor2) do begin
  For next := 1 to Steps do begin
    if ((kp=Ycoor2) or (ip=Xcoor2)) then next := Steps
    else begin tottm := tottm + Dtabas[ip,(kp)];
      if (Dtabas[ip,(kp)]<>0) then
        write(ip,(kp),'',Dtabas[ip,(kp)]:4:1,' ');
      kp := kp + 1;
    end;
  end;
  For next := 1 to Incre do begin
    if ((ip=Xcoor2) ) then next := Incre
    else begin tottm:= tottm + Dtabas[(ip),kp];
      if (Dtabas[(ip),kp]<>0) then
        write((ip),kp,'',Dtabas[(ip),kp]:4:1,' ');
      ip := ip + 1;
    end;
  end;
end;
while (kp < Ycoor2) do begin
  tottm := tottm + Dtabas[ip,(kp)];
  if (Dtabas[ip,(kp)]<>0) then write(ip,(kp),'',Dtabas[ip,(kp)]:4:1,' ');
  kp := kp + 1;
end;
while (ip < Xcoor2) do begin
  tottm:= tottm + Dtabas[(ip),kp];
  if (Dtabas[(ip),kp]<>0) then write((ip),kp,'',Dtabas[(ip),kp]:4:1,' ');
  ip := ip + 1;
end;
writeln('==> Time = ',tottm:5:1);
times := times+1;
if times= 10 then begin readln(pauses);
  times:=0;
end;
Overall := tottm + Overall;
kounter := kounter + 1;
tottm:=0;

end;
end;
end;

```

```

Procedure Conclusion;
var Outfile : text;
begin
  ClrScr;
  if (Confirm = 'Y') OR (Confirm = 'y') then begin
    Assign( Outfile , Name);
    Append( Outfile );
    Writeln( Outfile );
  end;
end;

```

```

Procedure Decision;
label Skipper;
var Flag, Zerol,Zero : integer;
begin
  Flag := 0;
  Skipper: while (Flag <> 1) do begin
    if ( X1p = X2p ) then if (Y1p > Y2p) then begin
      Putaray2;
      Flag:=1;
      goto Skipper;
    end;
    if ( Y1p = Y2p ) then if (X1p > X2p) then begin
      Putaray4;
      Flag:=1;
    end;
  end;
end;

```



```

                                goto Skipper;
                                end;
If (X1p > X2p) then if (Y1p > Y2p) then begin
                                Putaray3;
                                Flag:=1;      ( Dbbase )
                                goto Skipper;
                                end
                                ( X1>X2 & Y2>Y1 ) else begin
                                Putaray4;
                                Flag := 1;      ( Dabase )
                                goto Skipper;
                                end
                                else if (Y1p > Y2p) then begin
                                Putaray2;
                                Flag := 1;      ( Dtbase )
                                goto Skipper;
                                end;
                                If ((X1p <= X2p) and (Y1p <= Y2p)) then Putaray;
                                Flag := 1,
end;
end;

Procedure Switcher;
label Skippy;
var Flag,temp1,temp2:integer;
begin
    Flag := 0;
    X1p:=X1;
    X2p:=X2;
    Y1p:=Y1;
    Y2p:=Y2;
Skippy: While (Flag<>1) do begin
    if ( X1 = X2 ) then if ( Y1 > Y2 ) then begin
                                Y1 := 11-Y1;
                                Y2 := 11-Y2;
                                Flag:=1;
                                goto Skippy;
                                end
                                else begin
                                Flag:=1;
                                goto Skippy;
                                end;
    if ( Y1 = Y2 ) then if ( X1 > X2 ) then begin
                                X1 := 8-X1;
                                X2 := 8-X2;
                                Flag:=1;
                                goto Skippy;
                                end
                                else begin
                                Flag:=1;
                                goto Skippy;
                                end;
    If ( X1 > X2 ) then if ( Y1 > Y2 ) then begin
                                X1 := 8-X1;
                                Y1 := 11-Y1;
                                X2 := 8-X2;
                                Y2 := 11-Y2;
                                Flag:=1;
                                goto Skippy;
                                end
                                ( X1>X2 & Y2>Y1 ) else begin
                                X1 := 8-X1;
                                X2 := 8-X2;
                                Flag:=1;
                                goto Skippy;
                                end
                                else if ( Y1 > Y2 ) then begin ( X2 > X1 & Y1 > Y2 )
                                Y1 := 11-Y1;
                                Y2 := 11-Y2;
                                Flag := 1;

```

```

                                goto Skippy;
                                end;
    If ((X1 < X2) and (Y1 < Y2)) then Delay(1);
    Flag:=1;
  end;
end;

begin
  Answer:= '1';
  Answer2:= '1';
  Repeat
    Intro;
    Introduction( Slcfile );
    Question(Asks);
    if Asks = 'N' then
      Redinfo( Slcfile );      { Puts TRAF-NETSIM outfile into temp.txt file }
    Repeat
      Overall := 0;
      kounter := 0;
      if (Slcfile = '2') then TP := 1;
      if (Slcfile = '1') then
        begin
          writeln('You have selected a file with several time periods. ');
          write('Please select the time period to analyse : ');
          readln( TP );
        end;
        Nodes;                { Asks for nodes to be examined }
        Switcher;              { Switches node # for orientation }
        writeln('X1 = ',X1,' Y1 = ',Y1,' X2 = ',X2,' Y2 = ',Y2);
        Assign( Infile , 'j:\temp\tempb.txt');
        Reset( Infile );
        For Iterate := 1 to TP do Decision; { Selects the proper array }
        Close(Infile);
        writeln;
      mark:  Getinfo2;
            readln(pause);
            Getinfo3;                { Begins collection of route travel times }
            readln(pause);
            Getinfo4;                { for various possible route combinations }
            readln(pause);
            Getinfo5;                { between the selected nodes }
            readln(pause);
            Getinfo6;
            readln(pause);
            Getinfo7;
            Average := Overall / kounter;
            writeln(' Average Travel time is ', Average:5:1);
            writeln('Repeat time period ',TP,' ? ('Y' for yes)');
            readln(pause);
            if pause='Y' then goto mark;
            writeln('Would you like to continue with this file but');
            write('with the use of different nodes? Yes(Default) or No(N) : ');
            readln(Answer);
            until (Answer = 'N');
            writeln;
            write('Would you like to continue with program? Yes(Default) or No(N) : ');
            readln(Answer2);
            until (Answer2 = 'N');
            Conclusion;
    end.

```

APPENDIX C

Methodology For Selecting Route Schedule

- C.1 Description Of Route Scheduling Process**
- C.2 Graphical Example Of Methodology Used**

Appendix C.1

The process of scheduling pick-up and deliveries for courier operations is invaluable in the minimization of route travel distance. For courier companies, there are two important and distinct operating characteristics. The first is the delivery segment which involves the routing of vehicles to a predetermined number of delivery points, based upon vehicle capacity, with the location of these points known. Thus, the optimization of a delivery path can be referred to as a "static optimization" and will simply invoke the determination of the order of deliveries such that the minimum distance is travelled.

The second segment of the courier operation is the pick-up phase. In this case, the location and number of points is not known prior to commencement of the vehicle's operation. This can be referred to as a "dynamic optimization", where the route is continually re-optimized to minimize the travel distance which remains from the current position to the depot or journey end.

In this thesis, both a "static" and "dynamic" route scheduling system was used. The 6 P&D operations were subjected to no new service calls and therefore examined the possible benefits for a "static optimization", while the 8 P&D and 12 P&D operation received 2 and 6 additional service calls following the start of the operation and therefore examined the "dynamic optimization".

In both cases, there was found to be significant savings which could be accrued by use of either system. The savings however did not increase proportionally with the number of additional calls. Other factors such as the time frame which additional calls are

received, the location of the service calls and the frequency are important in determining the potential benefits which can be achieved.

The methodology used in this thesis research was that the additional service calls would be received and allocated to vehicles, not at given time intervals, but rather at equal spacing among the route schedule. As such, the 8 P&D operations would receive the first additional service call after completion of the second and fourth service calls. The 12 P&D operation scenarios would receive the service calls after the second, fourth, sixth, eighth, tenth service calls and as the final service call. Appendix C.2 further illustrates the methodology used in graphical format.

Home
112
149
151
76
21
63
Home

Step 1

Home
112
149
151
76
21
63
Home

Insert Now
← 189

Step 3

Home
112
149
189
151
76
24
21
63
Home

Delay
Delay
← 166 Insert

Step 5

Home
112
149
189
151
76
24
21
63
112
166
Home

Insert Now
← 35

New Calls
Order
189
24
166
112
35
131

Step 2

Home
112
149
189
151
76
21
63
Home

Delay
← 24 Insert

Step 4

Home
112
149
189
151
76
24
21
63
166
Home

Insert Now
← 112

Step 6

Home
112
149
189
151
76
24
21
63
112
166
35
Home

Insert Now
← 131

APPENDIX D

Simulation Data Results

- D.1 One-Way Static Cases**
- D.2 One-Way Dynamic Cases**
- D.3 One-Way Pick-up In Order Cases**
- D.4 Two-Way Static Cases**
- D.5 Two-Way Dynamic Cases**
- D.6 Two-Way Pick-up In Order Cases**

Appendix D.1

25 Metre Static Case for One-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	1290.2	1884.7	2385.5	0 → 21	236.8	423.0	531.6
112 → 149	678.2	758.0	805.7	21 → 63	541.3	778.0	835.3
149 → 151	545.4	397.5	506.1	63 → 76	349.4	1024.9	1254.9
151 → 76	663.9	944.7	1203.6	76 → 151	801.5	688.3	830.1
76 → 63	1023.2	1331.7	2054.5	151 → 149	912.1	883.0	1056.7
63 → 21	76.8	158.2	185.9	149 → 112	1113.8	1443.7	1689.9
21 → 0	357.0	425.2	505.9	112 → 0	198.0	211.8	252.5
TOTAL	4634.7	5900	7647.2	TOTAL	4152.9	5452.7	6451
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	1290.2	1884.7	2385.5	0 → 21	236.8	423.0	531.6
112 → 149	678.9	758.0	805.7	21 → 63	541.3	778.0	835.3
149 → 189	1252.8	1388.1	2392.3	63 → 76	349.4	1024.9	1254.9
189 → 151	228.4	420.2	363.3	76 → 151	801.5	688.3	830.1
151 → 76	663.9	944.7	1203.6	151 → 149	912.1	883.0	1056.7
76 → 24	440.9	558.9	927.7	149 → 189	1252.8	1388.1	2392.3
24 → 21	569.5	948.5	1264.8	189 → 112	2378.0	3338.9	4169.1
21 → 63	541.3	778.0	835.3	112 → 24	402.0	579.2	744.0
63 → 0	213.3	252.8	260.6	24 → 0	604.6	732.3	951.5
TOTAL	5879.2	7933.9	10438.8	TOTAL	7478.5	9835.7	12765.5
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	1290.2	1884.7	2385.5	0 → 21	236.8	423.0	531.6
112 → 149	678.9	758.0	805.7	21 → 63	541.3	778.0	835.3
149 → 189	1252.8	1388.1	2392.3	63 → 76	349.4	1024.9	1254.9
189 → 151	228.4	420.2	363.3	76 → 24	440.9	558.9	927.7
151 → 76	663.9	944.7	1203.6	24 → 151	1227.7	1332.3	1845.0
76 → 24	440.9	558.9	927.7	151 → 149	912.1	883.0	1056.7
24 → 21	569.5	948.5	1264.8	149 → 166	578.2	731.5	820.9
21 → 63	541.3	778.0	835.3	166 → 189	1102.1	1118.2	1818.6
63 → 112	1382.4	1488.1	1461.4	189 → 112	2378.0	3338.9	4169.1
112 → 166	639.0	722.3	728.8	112 → 112	0.0	0.0	0.0
166 → 131	303.0	381.6	422.9	112 → 35	576.2	862.5	824.6
131 → 35	212.3	253.0	273.6	35 → 131	660.6	810.8	897.1
35 → 0	90.7	77.7	75.0	131 → 0	269.0	423.5	410.7
TOTAL	8293.3	10603.8	13139.9	TOTAL	9272.3	12285.5	15392.2

50 Metre Static Case for One-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	182.0	378.9	986.9	0 → 21	68.4	97.5	235.8
112 → 149	164.3	358.7	643.1	21 → 63	128.9	180.8	523.5
149 → 151	123.6	136.9	285.5	63 → 76	135.4	203.5	374.1
151 → 76	155.3	219.7	378.5	76 → 151	131.0	368.2	739.6
76 → 63	132.1	301.9	757.9	151 → 149	135.2	271.3	618.3
63 → 21	61.7	65.7	87.3	149 → 112	119.5	329.0	821.0
21 → 0	135.8	202.2	392.1	112 → 0	171.9	186.9	264.3
TOTAL	954.8	1664	3531.3	TOTAL	890.3	1637.2	3576.6
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	182.0	378.9	986.9	0 → 21	68.4	97.5	235.8
112 → 149	164.3	358.7	643.1	21 → 63	128.9	180.8	523.5
149 → 189	144.7	395.8	843.6	63 → 76	135.4	203.5	374.1
189 → 151	142.6	156.8	183.6	76 → 151	131.0	368.2	739.6
151 → 76	155.3	219.7	378.5	151 → 149	135.2	271.3	618.3
76 → 24	131.2	181.7	343.6	149 → 189	136.9	395.8	843.6
24 → 21	160.7	213.3	556.2	189 → 112	123.4	582.2	1451.5
21 → 63	128.9	180.8	523.5	112 → 24	232.4	302.1	491.5
63 → 0	170.5	185.8	239.3	24 → 0	244.2	294.3	591.6
TOTAL	1380.2	2271.5	4698.3	TOTAL	1335.8	2695.7	5869.5
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	182.0	378.9	986.9	0 → 21	68.4	97.5	235.8
112 → 149	164.3	358.7	643.1	21 → 63	128.9	180.8	523.5
149 → 189	144.7	395.8	843.6	63 → 76	135.4	203.5	374.1
189 → 151	142.6	156.8	183.6	76 → 24	131.2	181.7	343.6
151 → 76	155.3	219.7	378.5	24 → 151	179.7	506.0	1084.4
76 → 24	131.2	181.7	343.6	151 → 149	135.2	271.3	618.3
24 → 21	160.7	213.3	556.2	149 → 166	120.9	283.6	499.9
21 → 63	128.9	180.8	436.4	166 → 189	94.6	347.5	679.9
63 → 112	116.5	272.4	735.9	189 → 112	123.4	582.2	1451.5
112 → 166	135.7	278.6	521.6	112 → 112	0.0	0.0	0.0
166 → 131	72.9	123.0	235.5	112 → 35	123.8	329.2	528.8
131 → 35	197.0	235.8	326.6	35 → 131	134.1	237.3	646.5
35 → 0	53.7	53.8	68.0	131 → 0	263.9	300.7	405.7
TOTAL	1785.5	3049.3	6259.5	TOTAL	1639.5	3521.3	7392

75 Metre Static Case for One-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	203.5	214.8	298.4	0 → 21	78.3	84.9	106.5
112 → 149	181.9	254.9	423.6	21 → 63	131.3	145.7	241.7
149 → 151	135.6	142.8	149.3	63 → 76	151.0	176.9	307.7
151 → 76	168.9	174.3	271.2	76 → 151	144.4	208.7	581.8
76 → 63	141.5	149.4	230.0	151 → 149	147.1	173.1	326.1
63 → 21	67.6	71.6	89.7	149 → 112	129.1	161.4	230.6
21 → 0	243.2	249.4	264.1	112 → 0	185.1	185.7	186.3
TOTAL	1142.2	1257.2	1726.3	TOTAL	966.3	1136.4	1980.7
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	203.5	214.8	298.4	0 → 21	78.3	84.9	106.5
112 → 149	181.9	254.9	423.6	21 → 63	131.3	145.7	241.7
149 → 189	152.2	189.7	251.8	63 → 76	151.0	176.9	307.7
189 → 151	158.3	161.5	202.0	76 → 151	144.4	208.7	581.8
151 → 76	168.9	174.3	271.2	151 → 149	147.1	173.1	326.1
76 → 24	141.1	151.7	211.1	149 → 189	152.9	189.7	251.8
24 → 21	173.7	182.9	402.0	189 → 112	133.5	146.9	391.1
21 → 63	140.4	145.7	241.7	112 → 24	254.8	263.8	391.4
63 → 0	183.6	189.8	192.3	24 → 0	263.7	271.0	384.6
TOTAL	1503.6	1665.3	2494.1	TOTAL	1457.01	1660.7	2982.7
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	203.5	214.8	298.4	0 → 21	78.3	84.9	106.5
112 → 149	181.9	254.9	423.6	21 → 63	131.3	145.7	241.7
149 → 189	152.2	189.7	251.7	63 → 76	151.0	176.9	307.7
189 → 151	158.3	161.5	202.0	76 → 24	141.0	151.7	211.1
151 → 76	168.9	174.3	271.2	24 → 151	199.0	267.0	929.1
76 → 24	141.1	151.7	211.1	151 → 149	147.1	173.1	326.1
24 → 21	173.7	182.9	402.0	149 → 166	134.6	210.7	384.8
21 → 63	140.4	145.1	241.7	166 → 189	104.0	113.6	173.4
63 → 112	128.4	136.7	144.6	189 → 112	133.5	146.9	391.1
112 → 166	151.3	204.3	310.4	112 → 112	0.0	0.0	0.0
166 → 131	78.6	81.0	108.2	112 → 35	133.5	136.6	191.2
131 → 35	211.8	218.3	273.1	35 → 131	151.9	158.6	167.2
35 → 0	57.6	57.2	57.2	131 → 0	286.1	287.4	288.3
TOTAL	1947.7	2172.4	3195.2	TOTAL	1791.3	2053.1	3718.2

100 Metre Static Case for One-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	246.7	254.9	311.5	0 → 21	94.2	97.8	101.8
112 → 149	172.4	206.3	359.1	21 → 63	149.7	172.5	302.3
149 → 151	154.1	163.1	166.9	63 → 76	154.1	175.8	286.7
151 → 76	171.8	177.0	251.3	76 → 151	166.6	197.0	440.7
76 → 63	169.9	181.3	211.1	151 → 149	171.4	183.3	231.3
63 → 21	70.7	73.4	75.7	149 → 112	151.8	164.6	215.4
21 → 0	162.1	293.9	317.9	112 → 0	189.7	198.1	205.6
TOTAL	1147.7	1349.9	1693.5	TOTAL	1077.5	1189.1	1783.8
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	246.7	254.9	311.5	0 → 21	94.2	97.8	101.8
112 → 149	172.9	206.3	359.1	21 → 63	149.7	172.5	302.3
149 → 189	181.2	188.4	255.8	63 → 76	154.1	175.8	286.7
189 → 151	174.4	180.0	188.1	76 → 151	166.6	197.0	440.7
151 → 76	171.8	177.0	251.3	151 → 149	171.4	183.3	231.3
76 → 24	183.1	194.1	202.2	149 → 189	181.2	188.4	233.2
24 → 21	209.8	228.2	480.5	189 → 112	165.7	178.5	363.3
21 → 63	149.7	172.5	303.6	112 → 24	274.9	283.4	293.5
63 → 0	196.1	205.5	208.7	24 → 0	315.2	330.3	429.9
TOTAL	1685.7	1806.9	2560.8	TOTAL	1673	1807	2682.7
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	246.7	254.9	311.5	0 → 21	94.2	97.8	101.8
112 → 149	172.9	206.3	359.1	21 → 63	149.7	172.5	302.3
149 → 189	181.2	188.4	255.7	63 → 76	154.1	175.8	286.7
189 → 151	174.4	180.0	188.1	76 → 24	183.1	194.1	202.2
151 → 76	171.8	177.0	251.3	24 → 151	237.4	269.6	691.7
76 → 24	183.1	194.1	202.2	151 → 149	171.4	183.3	231.3
24 → 21	209.8	228.2	480.5	149 → 166	199.9	215.6	320.8
21 → 63	149.7	172.5	303.6	166 → 189	121.3	126.3	146.5
63 → 112	161.4	167.6	174.4	189 → 112	165.7	178.5	363.6
112 → 166	180.4	231.7	287.9	112 → 112	0.0	0.0	0.0
166 → 131	91.9	100.4	108.7	112 → 35	162.6	178.5	257.5
131 → 35	241.8	263.7	336.8	35 → 131	184.1	185.7	187.7
35 → 0	56.4	56.5	57.8	131 → 0	302.8	318.4	328.0
TOTAL	2221.5	2421.3	3317.6	TOTAL	2126.3	2296.1	3420.1

Appendix D.2

50 Metre Dynamic One-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	179.6	192.7	202.0	0 --> 21	67.1	70.9	77.0
112 --> 149	168.0	205.4	228.4	21 --> 63	120.6	148.1	178.2
149 --> 151	126.2	134.0	138.4	63 --> 76	138.7	147.0	292.6
151 --> 76	157.8	291.3	315.9	76 --> 151	133.4	180.3	390.5
76 --> 63	133.5	197.5	2572.8	151 --> 149	136.9	142.4	22031.6
63 --> 21	62.3	63.3		149 --> 112	121.5	347.5	
21 --> 0	137.8	206.5		112 --> 0	173.3	171.3	
TOTAL	965.2	1290.7	3457.5	TOTAL	891.5	1207.5	22969.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	179.6	192.7	202.0	0 --> 21	67.1	70.9	77.0
112 --> 149	168.0	205.4	228.4	21 --> 63	120.6	148.1	178.2
149 --> 189	139.3	153.6	228.0	63 --> 76	138.7	147.0	292.6
189 --> 151	145.2	147.6	144.0	76 --> 151	133.4	180.3	390.5
151 --> 76	157.7	209.6	200.9	151 --> 149	136.9	142.4	22031.6
76 --> 24	132.4	147.3	680.5	149 --> 189	139.8	362.7	
24 --> 21	162.4	203.7		189 --> 112	125.2	1210.0	
21 --> 63	131.2	157.4		112 --> 24	237.9	1491.3	
63 --> 0	175.7	249.2		24 --> 0	247.6		
TOTAL	1391.5	1666.5	1683.8	TOTAL	1347.2	3752.7	22969.9
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	179.6	192.7	202.0	0 --> 21	67.1	70.9	77.0
112 --> 149	168.0	205.4	228.4	21 --> 63	120.6	148.1	178.2
149 --> 189	139.3	153.6	228.0	63 --> 76	138.7	147.0	292.6
189 --> 151	145.2	147.6	144.0	76 --> 24	132.5	326.3	329.5
151 --> 76	157.7	209.6	200.9	24 --> 151	184.9	286.0	860.4
76 --> 24	132.4	147.3	680.5	151 --> 149	137.0	524.6	
24 --> 21	162.4	203.7		149 --> 166	124.6	939.8	
21 --> 63	131.2	157.4		166 --> 189	96.4		
63 --> 112	119.0	2104.0		189 --> 112	124.8		
112 --> 166	140.8			112 --> 112	0.0		
166 --> 131	74.2			112 --> 35	126.0		
131 --> 35	205.7			35 --> 131	138.1		
35 --> 0	54.2			131 --> 0	267.8		
TOTAL	1809.7	3521.3	1683.8	TOTAL	1658.5	2442.7	1737.7

75 Metre Dynamic One-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	202.6	212.6	228.7	0 → 21	77.0	81.1	86.8
112 → 149	186.3	206.0	233.7	21 → 63	142.3	146.5	152.2
149 → 151	138.1	146.7	150.0	63 → 76	154.6	162.8	204.6
151 → 76	171.4	176.4	245.7	76 → 151	147.2	166.7	298.7
76 → 63	143.2	147.5	191.4	151 → 149	148.7	153.3	154.8
63 → 21	68.5	70.3	71.8	149 → 112	131.1	138.1	183.8
21 → 0	147.4	273.9	265.0	112 → 0	187.0	187.7	188.0
TOTAL	1057.5	1233.4	1386.3	TOTAL	987.9	1036.2	1268.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	202.6	212.6	228.7	0 → 21	77.0	81.1	86.8
112 → 149	186.3	206.0	233.7	21 → 63	142.3	146.5	152.2
149 → 189	168.7	169.7	169.7	63 → 76	154.6	162.8	204.6
189 → 151	160.4	163.6	168.5	76 → 151	147.2	166.7	298.7
151 → 76	171.5	176.7	242.8	151 → 149	148.7	153.3	154.8
76 → 24	142.8	155.3	162.0	149 → 189	155.4	168.4	249.8
24 → 21	176.3	194.8		189 → 112	135.2	149.5	549.3
21 → 63	134.0	248.3		112 → 24	259.9	271.2	
63 → 0	188.7	192.2		24 → 0	267.1	275.5	
TOTAL	1531.3	1719.2	1205.4	TOTAL	1487.4	1575	1696.2
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	202.6	212.6	228.7	0 → 21	77.0	81.1	86.8
112 → 149	186.3	206.0	233.7	21 → 63	142.3	146.5	152.2
149 → 189	168.7	169.7	169.7	63 → 76	154.6	162.8	204.6
189 → 151	160.4	163.6	168.5	76 → 24	142.4	155.5	167.8
151 → 76	171.5	176.7	242.8	24 → 151	204.3	228.2	679.0
76 → 24	142.8	155.3	162.0	151 → 149	148.5	153.4	1839.4
24 → 21	176.3	194.8		149 → 166	138.6	184.6	
21 → 63	134.0	248.3		166 → 189	106.2	115.9	
63 → 112	130.9	137.9		189 → 112	134.9	149.3	
112 → 166	156.8	1234.9		112 → 112	0.0	0.0	
166 → 131	79.9	633.2		112 → 35	135.6	138.3	
131 → 35	220.4	224.4		35 → 131	155.9	187.1	
35 → 0	58.3	57.9		131 → 0	288.6	283.7	
TOTAL	1988.9	3815.3	1205.4	TOTAL	1828.9	1986.4	3129.8

100 Metre Dynamic One-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	247.8	254.6	265.2	0 --> 21	92.1	94.2	97.7
112 --> 149	220.1	245.3	283.0	21 --> 63	167.2	175.2	184.3
149 --> 151	156.5	167.2	170.7	63 --> 76	172.0	179.3	233.2
151 --> 76	157.1	179.0	255.7	76 --> 151	169.6	198.0	377.6
76 --> 63	172.5	182.9	188.0	151 --> 149	175.0	187.1	193.9
63 --> 21	71.6	78.0	77.0	149 --> 112	155.7	169.6	175.0
21 --> 0	164.4	345.9	341.0	112 --> 0	192.1	202.5	210.7
TOTAL	1190	1452.9	1580.6	TOTAL	1123.7	1205.9	1472.4
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	247.8	254.6	265.2	0 --> 21	92.1	94.2	97.7
112 --> 149	220.1	245.3	283.0	21 --> 63	167.2	175.2	184.3
149 --> 189	185.0	194.5	197.0	63 --> 76	172.0	179.3	233.2
189 --> 151	177.1	183.1	191.4	76 --> 151	169.6	198.0	377.6
151 --> 76	189.8	175.1	164.7	151 --> 149	175.0	187.1	193.9
76 --> 24	186.4	198.0	174.1	149 --> 189	184.9	193.9	196.1
24 --> 21	218.1	229.5	667.6	189 --> 112	169.2	182.6	590.1
21 --> 63	152.9	179.8	405.8	112 --> 24	281.4	289.7	331.6
63 --> 0	202.5	207.1	207.1	24 --> 0	319.5	356.7	1181.6
TOTAL	1779.7	1867	2555.9	TOTAL	1730.9	1856.7	3386.1
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	247.8	254.6	265.2	0 --> 21	92.1	94.2	97.7
112 --> 149	220.1	245.3	283.0	21 --> 63	167.2	175.2	184.3
149 --> 189	185.0	194.5	197.0	63 --> 76	172.0	179.3	233.2
189 --> 151	177.1	183.1	191.4	76 --> 24	186.5	198.1	208.5
151 --> 76	173.5	178.1	164.7	24 --> 151	241.6	272.4	700.1
76 --> 24	186.4	198.0	174.1	151 --> 149	174.8	186.5	192.9
24 --> 21	218.1	229.5	667.9	149 --> 166	166.7	234.5	166.6
21 --> 63	152.9	179.8	405.8	166 --> 189	123.9	129.7	245.0
63 --> 112	164.6	171.0	166.8	189 --> 112	169.4	182.7	12875.0
112 --> 166	185.0	282.0	504.7	112 --> 112	0.0	0.0	0.0
166 --> 131	94.4	102.3		112 --> 35	168.5	184.0	
131 --> 35	252.9	268.2		35 --> 131	187.8	189.8	
35 --> 0	57.5	57.4		131 --> 0	305.1	319.6	
TOTAL	2315.3	2543.8	3020.6	TOTAL	2155.6	2346	14903.3

Appendix D.3

50 Metre Pick-Up In Order for One-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	179.6	192.7	202.0	0 --> 112	179.6	192.7	202.0
112 --> 63	115.1	118.3	118.1	112 --> 63	115.1	120.6	168.7
63 --> 151	212.5	218.0	223.3	63 --> 151	236.0	249.1	312.6
151 --> 149	137.1	143.0	144.8	151 --> 149	137.1	143.0	144.8
149 --> 21	185.9	189.4	229.2	149 --> 21	210.9	781.5	3267.3
21 --> 76	135.8	176.4	2005.7	21 --> 76	147.2	188.2	2136.9
76 --> 0	275.6	299.8	1753.1	76 --> 0	301.4	696.3	3674.1
TOTAL	1241.6	1337.6	4676.2	TOTAL	1327.3	2371.4	9906.4
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	179.6	192.7	202.0	0 --> 112	179.6	192.7	202.0
112 --> 63	115.1	118.3	118.1	112 --> 63	115.1	120.6	168.7
63 --> 151	212.5	218.0	223.3	63 --> 151	236.0	249.1	312.6
151 --> 149	137.1	143.0	144.8	151 --> 149	137.1	143.0	144.8
149 --> 21	185.9	189.4	229.2	149 --> 21	210.9	781.5	3267.3
21 --> 76	135.8	176.4	2005.7	21 --> 76	147.2	188.2	2136.9
76 --> 189	132.5	138.7	2657.8	76 --> 189	132.5	138.7	2657.8
189 --> 24	307.7	1846.3		189 --> 24	344.0	4749.0	
24 --> 0	294.2	1329.9		24 --> 0	305.4	4262.5	
TOTAL	1700.4	4352.7	5580.9	TOTAL	1807.8	10825.3	8890.1
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	179.6	192.7	202.0	0 --> 112	179.6	192.7	202.0
112 --> 63	115.1	118.3	118.1	112 --> 63	115.1	120.6	168.7
63 --> 151	212.5	218.0	223.3	63 --> 151	236.0	249.1	312.6
151 --> 149	137.1	143.0	144.8	151 --> 149	137.1	143.0	144.8
149 --> 21	185.9	189.4	229.2	149 --> 21	210.9	781.5	3267.3
21 --> 76	135.8	176.4	2005.7	21 --> 76	147.2	188.2	2136.9
76 --> 189	132.5	138.7	2657.8	76 --> 189	132.5	138.7	2657.8
189 --> 24	307.7	1846.3		189 --> 24	344.0	4749.0	
24 --> 166	94.8			24 --> 166	110.6		
166 --> 112	150.0			166 --> 112	152.2		
112 --> 35	126.0			112 --> 35	126.0		
35 --> 131	138.4			35 --> 131	144.5		
131 --> 0	262.7			131 --> 0	281.0		
TOTAL	2178.1	3022.8	5580.9	TOTAL	2316.7	6562.8	8890.1

75 Metre Pick-Up In Order for One-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	202.6	212.6	228.7	0 --> 112	202.6	212.6	228.7
112 --> 63	126.3	128.0	129.0	112 --> 63	128.4	130.3	133.5
63 --> 151	236.1	259.5	266.6	63 --> 151	259.6	273.4	312.1
151 --> 149	148.7	153.3	154.8	151 --> 149	148.7	153.3	154.8
149 --> 21	201.3	208.3	206.1	149 --> 21	226.1	233.0	1236.0
21 --> 76	152.5	161.0	251.2	21 --> 76	163.7	172.7	436.4
76 --> C	301.9	326.1	351.8	76 --> 0	323.1	904.4	2028.6
TOTAL	1369.4	1448.8	1588.2	TOTAL	1452.2	2079.7	4530.1
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	202.6	212.6	228.7	0 --> 112	202.6	212.6	228.7
112 --> 63	126.3	128.0	129.0	112 --> 63	128.4	130.3	133.5
63 --> 151	236.1	259.5	266.6	63 --> 151	259.6	273.4	312.1
151 --> 149	148.7	153.3	154.8	151 --> 149	148.7	153.3	154.8
149 --> 21	201.3	208.3	206.1	149 --> 21	226.1	233.0	1236.0
21 --> 76	152.5	161.0	251.2	21 --> 76	163.7	172.7	436.4
76 --> 189	142.8	154.3	436.9	76 --> 189	142.8	154.3	436.9
189 --> 24	353.8	414.7		189 --> 24	373.3	668.1	
24 --> 0	311.3	314.7		24 --> 0	328.9	344.3	
TOTAL	1875.4	2006.4	1673.3	TOTAL	1974.1	2342	2938.4
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	202.6	212.6	228.7	0 --> 112	202.6	212.6	228.7
112 --> 63	126.3	128.0	129.0	112 --> 63	128.4	130.3	133.5
63 --> 151	236.1	259.5	266.6	63 --> 151	259.6	273.4	312.1
151 --> 149	148.7	153.3	154.8	151 --> 149	148.7	153.3	154.8
149 --> 21	201.3	208.3	206.1	149 --> 21	226.1	233.0	1236.0
21 --> 76	152.5	161.0	251.2	21 --> 76	163.7	172.7	436.4
76 --> 189	142.8	154.3	436.9	76 --> 189	142.8	154.3	436.9
189 --> 24	353.8	414.7		189 --> 24	373.3	668.1	
24 --> 166	112.2	1187.6		24 --> 166	120.6	1393.9	
166 --> 112	161.8			166 --> 112	163.8		
112 --> 35	135.8			112 --> 35	135.8		
35 --> 131	156.3			35 --> 131	158.6		
131 --> 0	283.9			131 --> 0	302.3		
TOTAL	2414.1	2879.3	1673.3	TOTAL	2526.3	3391.6	2938.4

100 Metre Pick-Up In Order for One-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	247.8	254.6	265.2	0 --> 112	247.8	254.6	265.2
112 --> 63	131.0	135.7	141.3	112 --> 63	138.0	142.5	148.5
63 --> 151	277.6	283.3	306.1	63 --> 151	287.5	295.3	337.2
151 --> 149	174.5	187.4	194.3	151 --> 149	174.5	187.4	194.3
149 --> 21	214.6	252.0	259.2	149 --> 21	278.9	298.0	901.2
21 --> 76	191.4	197.4	300.3	21 --> 76	199.8	198.8	555.7
76 --> 0	346.0	360.4	413.0	76 --> 0	390.1	918.7	1453.7
TOTAL	1582.9	1670.8	1879.4	TOTAL	1716.9	2295.3	3855.8
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	247.8	254.6	265.2	0 --> 112	247.8	254.6	265.2
112 --> 63	131.0	135.7	141.3	112 --> 63	138.0	142.5	148.5
63 --> 151	277.6	283.3	306.1	63 --> 151	287.5	295.3	337.2
151 --> 149	174.5	187.4	194.3	151 --> 149	174.5	187.4	194.3
149 --> 21	214.6	252.0	259.2	149 --> 21	278.9	298.0	901.2
21 --> 76	191.4	197.4	300.3	21 --> 76	199.8	198.8	555.7
76 --> 189	186.6	198.1	202.8	76 --> 189	186.6	198.1	202.8
189 --> 24	369.9	535.9	2414.4	189 --> 24	416.1	702.4	3205.2
24 --> 0	352.3	371.8	913.0	24 --> 0	407.6	440.3	22222.8
TOTAL	2145.7	2416.2	4996.6	TOTAL	2336.8	2717.4	28032.9
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	247.8	254.6	265.2	0 --> 112	247.8	254.6	265.2
112 --> 63	131.0	135.7	141.3	112 --> 63	138.0	142.5	148.5
63 --> 151	277.6	283.3	306.1	63 --> 151	287.5	295.3	337.2
151 --> 149	174.5	187.4	194.3	151 --> 149	174.5	187.4	194.3
149 --> 21	214.6	252.0	259.2	149 --> 21	278.9	298.0	901.2
21 --> 76	191.4	197.4	300.3	21 --> 76	199.8	198.8	555.7
76 --> 189	186.6	198.1	202.8	76 --> 189	186.6	198.1	202.8
189 --> 24	369.9	535.9	2414.4	189 --> 24	416.1	702.4	3205.2
24 --> 166	120.0	212.7		24 --> 166	139.9	235.4	
166 --> 112	192.8	219.0		166 --> 112	202.8	257.9	
112 --> 35	168.4	181.6		112 --> 35	168.4	181.6	
35 --> 131	187.9	188.1		35 --> 131	195.9	198.1	
131 --> 0	304.3	320.7		131 --> 0	354.5	376.1	
TOTAL	2766.8	3166.5	4083.6	TOTAL	2990.7	3526.2	5810.1

Appendix D.4

25 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	276.3	263.8	399.8	0 --> 21	325.2	365.9	477.2
112 --> 149	112.1	239.4	204.1	21 --> 63	130.2	171.4	216.4
149 --> 151	64.8	75.3	78.9	63 --> 76	1043.3	1406.7	1479.0
151 --> 76	422.1	569.7	681.1	76 --> 151	167.8	218.0	177.5
76 --> 63	198.4	245.6	197.4	151 --> 149	186.4	412.8	304.9
63 --> 21	151.9	175.6	201.4	149 --> 112	355.7	389.1	327.2
21 --> 0	146.7	127.7	142.4	112 --> 0	380.3	370.3	371.7
TOTAL	1372.3	1697.1	1905.1	TOTAL	2588.9	3334.2	3353.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	276.3	263.8	399.8	0 --> 21	325.2	365.9	477.2
112 --> 149	112.1	239.4	204.1	21 --> 63	130.2	171.4	216.4
149 --> 189	159.8	324.6	347.4	63 --> 76	1043.3	1406.7	1479.0
189 --> 151	257.1	240.4	266.7	76 --> 151	167.8	218.0	177.5
151 --> 76	159.2	569.7	681.1	151 --> 149	186.4	412.8	304.9
76 --> 24	394.2	126.0	135.6	149 --> 189	180.7	263.1	213.3
24 --> 21	123.0	78.6	75.6	189 --> 112	450.1	293.7	286.6
21 --> 63	116.8	204.4	212.6	112 --> 24	648.3	752.9	919.8
63 --> 0	191.1	170.9	188.8	24 --> 0	285.2	237.6	236.4
TOTAL	1789.6	2217.8	2511.7	TOTAL	3417.2	4122.1	4311.1
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	276.3	263.8	399.8	0 --> 21	325.2	365.9	477.2
112 --> 149	112.1	239.4	204.1	21 --> 63	130.2	171.4	216.4
149 --> 189	159.8	324.6	347.4	63 --> 76	1043.3	1406.7	1479.0
189 --> 151	257.1	240.4	266.7	76 --> 24	122.2	126.7	135.6
151 --> 76	159.2	569.7	681.1	24 --> 151	169.6	276.9	243.0
76 --> 24	394.2	126.0	135.6	151 --> 149	186.4	412.8	304.9
24 --> 21	123.0	78.6	75.6	149 --> 166	38.5	138.0	133.9
21 --> 63	116.8	204.4	212.6	166 --> 189	142.2	281.0	299.3
63 --> 112	155.9	181.8	135.1	189 --> 112	450.1	293.7	286.6
112 --> 166	115.7	209.0	192.0	112 --> 112	0.0	0.0	0.0
166 --> 131	138.8	269.9	162.5	112 --> 35	323.0	303.8	313.3
131 --> 35	348.4	276.4	265.7	35 --> 131	297.5	403.8	347.7
35 --> 0	69.1	76.2	59.9	131 --> 0	431.0	339.0	372.9
TOTAL	2426.4	3060.2	3158.1	TOTAL	3659.2	4519.7	4609.8

50 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	159.4	186.7	195.3	0 --> 21	93.5	95.4	119.6
112 --> 149	106.9	207.2	248.2	21 --> 63	91.6	156.8	200.0
149 --> 151	61.5	62.0	67.7	63 --> 76	80.4	80.4	98.7
151 --> 76	114.3	163.2	291.2	76 --> 151	132.1	171.2	313.6
76 --> 63	384.0	1017.8	1278.1	151 --> 149	65.2	189.3	264.5
63 --> 21	52.9	53.1	67.4	149 --> 112	125.9	334.9	494.1
21 --> 0	84.6	85.1	85.9	112 --> 0	142.1	156.3	186.3
TOTAL	963.6	1775.1	2233.8	TOTAL	730.8	1184.3	1676.8
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	159.4	186.7	195.3	0 --> 21	93.5	95.4	119.6
112 --> 149	106.9	207.2	248.2	21 --> 63	91.6	156.8	200.0
149 --> 189	99.8	262.3	336.4	63 --> 76	80.4	80.4	98.7
189 --> 151	156.8	232.5	300.7	76 --> 151	132.1	171.2	313.6
151 --> 76	114.3	163.2	291.2	151 --> 149	65.2	189.3	264.5
76 --> 24	101.2	106.4	109.3	149 --> 189	110.5	287.7	387.2
24 --> 21	59.1	73.6	78.2	189 --> 112	103.5	176.2	446.5
21 --> 63	73.0	192.1	249.3	112 --> 24	226.5	242.0	355.3
63 --> 0	118.1	122.8	120.5	24 --> 0	150.1	168.4	183.2
TOTAL	988.6	1546.8	1929.1	TOTAL	1053.4	1567.4	2368.6
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	159.4	186.7	195.3	0 --> 21	93.5	95.4	119.6
112 --> 149	106.9	207.2	248.2	21 --> 63	91.6	156.8	200.0
149 --> 189	99.8	262.3	336.4	63 --> 76	80.4	80.4	98.7
189 --> 151	156.8	232.5	300.7	76 --> 24	132.1	106.4	111.0
151 --> 76	114.3	163.2	291.2	24 --> 151	180.1	333.4	485.1
76 --> 24	101.2	106.4	109.3	151 --> 149	65.2	189.3	264.5
24 --> 21	59.1	73.6	78.2	149 --> 166	38.8	85.0	122.4
21 --> 63	73.0	192.1	249.3	166 --> 189	78.1	229.7	317.3
63 --> 112	105.5	181.8	247.7	189 --> 112	103.5	176.2	446.5
112 --> 166	128.6	196.0	235.1	112 --> 112	0.0	0.0	0.0
166 --> 131	81.9	205.6	260.5	112 --> 35	123.3	124.4	154.2
131 --> 35	169.3	243.3	290.3	35 --> 131	176.2	207.8	236.4
35 --> 0	46.0	65.5	98.3	131 --> 0	194.1	223.1	321.3
TOTAL	1401.8	2316.2	2940.5	TOTAL	1356.9	2007.9	2877

75 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	171.7	185.0	226.4	0 → 21	103.4	106.6	110.2
112 → 149	103.4	120.7	174.4	21 → 63	80.2	145.4	212.2
149 → 151	67.7	69.1	70.2	63 → 76	90.3	91.2	92.3
151 → 76	123.2	127.6	153.6	76 → 151	139.6	149.8	221.4
76 → 63	125.2	577.1	1068.6	151 → 149	63.8	65.0	118.7
63 → 21	58.0	58.9	58.9	149 → 112	99.7	157.6	349.4
21 → 0	94.5	95.1	95.1	112 → 0	156.3	173.8	231.1
TOTAL	743.7	1233.5	1847.2	TOTAL	733.3	889.4	1335.3
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	171.7	185.0	226.4	0 → 21	103.4	106.6	110.2
112 → 149	103.4	120.7	174.4	21 → 63	80.2	145.4	212.2
149 → 189	102.2	107.4	161.7	63 → 76	90.3	91.2	92.3
189 → 151	166.7	176.7	238.8	76 → 151	139.6	149.8	221.4
151 → 76	123.2	127.6	153.6	151 → 149	63.8	65.0	118.7
76 → 24	110.4	111.7	113.2	149 → 189	111.3	117.2	189.9
24 → 21	64.9	65.4	67.2	189 → 112	107.2	138.5	316.2
21 → 63	59.8	128.4	274.3	112 → 24	214.5	253.2	327.2
63 → 0	132.3	132.0	213.6	24 → 0	166.0	167.2	169.3
TOTAL	1034.6	1154.9	1623.2	TOTAL	1076.3	1234.1	1757.4
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	171.7	185.0	226.4	0 → 21	103.4	106.6	110.2
112 → 149	103.4	120.7	174.4	21 → 63	80.2	145.4	212.2
149 → 189	102.2	107.4	161.7	63 → 76	90.3	91.2	92.3
189 → 151	166.7	176.7	238.8	76 → 24	110.4	111.7	113.2
151 → 76	123.2	127.6	153.6	24 → 151	181.9	204.8	276.5
76 → 24	110.4	111.7	113.2	151 → 149	63.8	65.0	118.7
24 → 21	64.9	65.4	67.2	149 → 166	40.6	41.0	52.7
21 → 63	59.8	128.4	274.3	166 → 189	79.1	83.3	137.2
63 → 112	100.7	186.0	263.2	189 → 112	107.2	138.5	316.2
112 → 166	127.2	144.8	186.7	112 → 112	0.0	0.0	0.0
166 → 131	85.2	87.1	151.4	112 → 35	133.2	137.0	194.7
131 → 35	179.8	252.3	343.6	35 → 131	194.3	198.4	207.0
35 → 0	49.8	91.7	131.5	131 → 0	213.9	270.8	417.6
TOTAL	1445	1784.8	2486	TOTAL	1398.3	1593.7	2248.5

100 Metre Static Case for Two-Way Case (CBD)							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	198.2	202.0	217.4	0 → 21	118.2	121.5	123.5
112 → 149	114.0	119.2	138.2	21 → 63	97.1	118.9	159.6
149 → 151	76.9	79.0	80.2	63 → 76	107.2	108.1	108.3
151 → 76	137.4	139.7	144.7	76 → 151	146.4	148.3	149.8
76 → 63	141.9	264.4	517.3	151 → 149	75.0	77.2	79.0
63 → 21	66.9	67.7	68.1	149 → 112	113.8	118.0	145.8
21 → 0	103.4	105.8	106.8	112 → 0	178.9	185.0	206.4
TOTAL	838.7	977.8	1272.7	TOTAL	836.6	877	972.4
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	198.2	202.0	217.4	0 → 21	118.2	121.5	123.5
112 → 149	114.0	119.2	138.2	21 → 63	97.1	118.9	159.6
149 → 189	110.3	112.8	114.1	63 → 76	107.2	108.1	108.3
189 → 151	199.1	205.0	210.7	76 → 151	146.4	148.3	149.3
151 → 76	137.4	139.7	144.7	151 → 149	75.0	77.2	79.0
76 → 24	110.1	111.2	112.2	149 → 189	128.9	131.9	133.5
24 → 21	68.8	69.0	69.4	189 → 112	138.0	141.9	154.8
21 → 63	73.8	95.7	158.1	112 → 24	249.5	276.4	300.1
63 → 0	152.1	154.6	154.9	24 → 0	172.4	175.2	176.7
TOTAL	1163.8	1209.2	1319.7	TOTAL	1232.7	1299.4	1384.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	198.2	202.0	217.4	0 → 21	118.2	121.5	123.5
112 → 149	114.0	119.2	138.2	21 → 63	97.1	118.9	159.6
149 → 189	110.3	112.8	114.1	63 → 76	107.2	108.1	108.3
189 → 151	199.1	205.0	210.7	76 → 24	110.1	111.2	112.2
151 → 76	137.4	139.7	144.7	24 → 151	183.1	188.5	200.6
76 → 24	110.1	111.2	112.2	151 → 149	75.0	77.2	79.0
24 → 21	68.8	69.0	69.4	149 → 166	45.7	47.8	48.7
21 → 63	73.8	95.7	158.1	166 → 189	83.2	84.1	84.8
63 → 112	105.2	151.9	206.0	189 → 112	138.0	141.9	154.8
112 → 166	141.1	144.7	164.2	112 → 112	0.0	0.0	0.0
166 → 131	105.0	107.0	108.8	112 → 35	138.4	141.6	162.0
131 → 35	194.0	220.4	284.6	35 → 131	210.0	216.5	222.5
35 → 0	47.8	63.8	104.9	131 → 0	251.4	279.7	328.3
TOTAL	1604.8	1742.4	2033.3	TOTAL	1557.4	1637	1784.3

100 Metre Static Case for Two-Way Case (Metro)							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	242.4	234.5	247.7	0 --> 21	117.0	119.8	120.3
112 --> 149	148.0	146.8	149.6	21 --> 63	99.3	102.7	102.7
149 --> 151	90.1	94.7	95.2	63 --> 76	233.3	221.8	236.3
151 --> 76	175.1	176.3	176.1	76 --> 151	171.2	165.3	165.6
76 --> 63	118.7	127.2	156.0	151 --> 149	79.1	79.8	78.5
63 --> 21	70.9	72.6	71.8	149 --> 112	310.7	342.9	350.1
21 --> 0	112.8	116.6	116.3	112 --> 0	330.2	339.3	330.1
TOTAL	958	968.7	1012.7	TOTAL	1340.8	1371.6	1383.6
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	242.4	234.5	247.7	0 --> 21	117.0	119.8	120.3
112 --> 149	148.0	146.8	149.6	21 --> 63	99.3	102.7	102.7
149 --> 189	173.8	186.0	186.0	63 --> 76	533.3	621.8	636.3
189 --> 151	304.8	370.0	651.1	76 --> 151	171.2	165.8	165.6
151 --> 76	175.1	176.3	176.1	151 --> 149	79.1	79.8	78.5
76 --> 24	111.2	175.8	219.5	149 --> 189	173.8	186.0	186.0
24 --> 21	70.5	71.1	70.7	189 --> 112	566.0	649.5	651.3
21 --> 63	79.5	79.5	83.8	112 --> 24	428.2	463.7	488.7
63 --> 0	164.2	167.8	167.5	24 --> 0	182.6	186.7	186.1
TOTAL	1469.5	1607.8	1952	TOTAL	2350.5	2575.8	2615.5
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 21	242.4	234.5	247.7	0 --> 21	117.0	119.8	120.3
21 --> 63	148.0	146.8	149.6	21 --> 63	99.3	102.7	102.7
63 --> 76	173.8	186.0	186.0	63 --> 76	533.3	621.8	636.3
76 --> 24	304.8	370.0	651.1	76 --> 24	111.2	111.4	116.3
24 --> 151	175.1	176.3	176.1	24 --> 151	226.4	224.1	223.2
151 --> 149	111.2	175.8	219.5	151 --> 149	79.1	79.8	78.5
149 --> 166	70.5	71.1	70.7	149 --> 166	53.5	53.6	53.3
166 --> 189	79.5	79.5	83.8	166 --> 189	123.1	135.1	135.2
189 --> 112	142.2	187.0	171.7	189 --> 112	566.0	649.5	651.3
112 --> 112	175.5	174.4	177.3	112 --> 112	0.0	0.0	0.0
112 --> 35	100.5	101.5	100.0	112 --> 35	281.6	290.1	280.7
35 --> 131	216.1	218.7	218.7	35 --> 131	240.1	250.5	249.3
131 --> 0	187.8	242.1	232.6	131 --> 0	397.7	435.3	437.0
TOTAL	2127.4	2363.7	2684.8	TOTAL	2828.3	3073.7	3084.1

300 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	359.4	389.8	439.7	0 --> 21	212.2	211.4	253.2
112 --> 149	218.4	219.7	220.1	21 --> 63	171.9	173.0	174.2
149 --> 151	136.3	139.4	144.3	63 --> 76	220.7	268.1	279.7
151 --> 76	304.6	306.3	320.7	76 --> 151	307.5	309.4	310.0
76 --> 63	204.9	206.1	206.5	151 --> 149	129.1	131.5	132.4
63 --> 21	127.1	127.7	127.8	149 --> 112	265.0	315.1	333.2
21 --> 0	227.2	235.3	239.8	112 --> 0	393.9	491.1	520.2
TOTAL	1577.9	1624.3	1698.9	TOTAL	1700.3	1899.6	2002.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	359.4	389.8	439.7	0 --> 21	212.2	211.4	253.2
112 --> 149	218.4	219.7	220.1	21 --> 63	171.9	173.0	174.2
149 --> 189	210.3	219.0	220.4	63 --> 76	220.7	268.1	279.7
189 --> 151	353.9	357.6	370.9	76 --> 151	307.5	309.4	310.0
151 --> 76	304.6	306.3	315.1	151 --> 149	129.1	131.5	132.4
76 --> 24	191.3	192.4	192.7	149 --> 189	210.3	274.9	276.5
24 --> 21	123.1	124.0	124.5	189 --> 112	302.3	389.7	429.4
21 --> 63	184.5	216.7	230.1	112 --> 24	473.7	482.9	486.9
63 --> 0	337.4	349.9	354.9	24 --> 0	354.9	363.7	368.7
TOTAL	2282.9	2375.4	2468.4	TOTAL	2382.6	2604.6	2711
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	359.4	389.8	439.7	0 --> 21	212.2	211.4	253.2
112 --> 149	218.4	219.7	220.1	21 --> 63	171.9	173.0	174.2
149 --> 189	210.3	219.0	220.4	63 --> 76	220.7	268.1	279.7
189 --> 151	353.9	357.6	370.9	76 --> 24	234.7	242.3	242.7
151 --> 76	304.6	306.3	315.1	24 --> 151	361.1	391.1	404.3
76 --> 24	191.3	192.4	192.7	151 --> 149	129.1	131.5	132.4
24 --> 21	123.1	124.0	124.5	149 --> 166	95.5	109.8	141.6
21 --> 63	184.5	216.7	230.1	166 --> 189	170.3	173.9	175.0
63 --> 112	199.0	199.6	200.3	189 --> 112	302.3	389.7	429.4
112 --> 166	258.4	273.6	305.6	112 --> 112	0.0	0.0	0.0
166 --> 131	316.2	374.4	391.1	112 --> 35	392.0	526.6	577.0
131 --> 35	347.9	351.7	352.9	35 --> 131	383.3	391.5	422.5
35 --> 0	164.4	240.5	252.9	131 --> 0	506.4	541.7	559.3
TOTAL	3231.4	3465.3	3616.3	TOTAL	3179.5	3550.6	3791.3

500 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	505.0	555.9	686.3	0 → 21	306.8	314.3	425.2
112 → 149	303.1	308.0	308.6	21 → 63	234.2	235.9	242.0
149 → 151	180.8	184.4	205.2	63 → 76	287.8	297.2	313.9
151 → 76	404.4	410.9	415.1	76 → 151	399.4	401.2	402.9
76 → 63	276.9	280.1	281.4	151 → 149	173.5	175.6	181.4
63 → 21	173.4	175.1	176.2	149 → 112	335.5	393.8	431.0
21 → 0	293.1	298.3	301.7	112 → 0	457.0	538.5	624.3
TOTAL	2136.7	2212.7	2374.5	TOTAL	2194.2	2356.5	2620.7
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	505.0	555.9	686.3	0 → 21	306.8	314.3	425.2
112 → 149	303.1	308.0	308.6	21 → 63	234.2	235.9	242.0
149 → 189	317.6	324.2	327.0	63 → 76	287.8	297.2	313.9
189 → 151	466.6	480.0	547.3	76 → 151	399.4	401.2	402.9
151 → 76	404.4	410.9	415.1	151 → 149	173.5	175.6	181.4
76 → 24	245.8	248.1	249.4	149 → 189	372.4	384.7	390.6
24 → 21	175.0	178.1	178.9	189 → 112	368.0	485.7	610.2
21 → 63	229.3	291.3	336.7	112 → 24	655.2	673.6	690.7
63 → 0	419.8	446.9	451.1	24 → 0	466.2	473.7	477.5
TOTAL	3066.6	3243.4	3500.4	TOTAL	3263.5	3441.9	3734.4
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	505.0	555.9	686.3	0 → 21	306.8	314.3	425.2
112 → 149	303.1	308.0	308.6	21 → 63	234.2	235.9	242.0
149 → 189	317.6	324.2	327.0	63 → 76	287.8	297.2	313.9
189 → 151	402.5	480.0	547.3	76 → 24	305.1	314.1	315.6
151 → 76	404.4	410.9	415.1	24 → 151	479.4	515.7	536.5
76 → 24	245.8	248.1	249.4	151 → 149	236.1	238.8	259.8
24 → 21	175.0	178.1	178.9	149 → 166	64.7	65.5	65.6
21 → 63	229.3	291.3	336.7	166 → 189	252.9	258.7	261.4
63 → 112	275.4	277.8	278.9	189 → 112	368.0	485.4	610.2
112 → 166	366.7	373.5	374.2	112 → 112	0.0	0.0	0.0
166 → 131	366.9	448.0	477.7	112 → 35	444.2	593.2	683.0
131 → 35	464.5	472.6	475.6	35 → 131	523.8	536.4	570.7
35 → 0	138.9	193.0	225.6	131 → 0	684.2	736.3	768.6
TOTAL	4195.1	4561.4	4881.3	TOTAL	4187.2	4591.5	5052.5

700 Metre Static Case for Two-Way Case							
Clockwise Route				Counter-Clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	660.5	712.4	908.5	0 → 21	410.3	418.3	587.9
112 → 149	394.2	395.9	396.4	21 → 63	292.5	296.4	307.7
149 → 151	245.5	252.9	272.7	63 → 76	378.4	387.3	409.5
151 → 76	525.2	532.3	539.8	76 → 151	663.0	723.8	767.0
76 → 63	377.8	379.7	381.0	151 → 149	241.8	240.6	241.6
63 → 21	321.4	325.2	331.0	149 → 112	421.1	477.8	517.8
21 → 0	290.2	295.3	300.1	112 → 0	574.3	628.2	704.6
TOTAL	2814.8	2893.7	3129.5	TOTAL	2981.4	3172.4	3536.1
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	660.5	712.4	908.5	0 → 21	410.3	418.3	587.9
112 → 149	394.2	395.9	396.4	21 → 63	292.5	296.4	308.3
149 → 189	399.3	413.3	412.3	63 → 76	378.4	387.3	409.5
189 → 151	625.5	641.8	736.9	76 → 151	521.2	525.9	529.5
151 → 76	522.6	528.6	539.8	151 → 149	311.6	315.4	334.1
76 → 24	318.1	322.3	325.3	149 → 189	399.3	407.7	412.3
24 → 21	237.6	238.3	238.9	189 → 112	443.0	549.4	699.7
21 → 63	254.9	317.3	379.4	112 → 24	880.3	893.9	952.3
63 → 0	542.6	560.5	565.7	24 → 0	597.2	603.2	608.9
TOTAL	3955.3	4130.4	4503.2	TOTAL	4233.8	4397.5	4842.5
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	660.5	712.4	908.5	0 → 21	410.3	418.3	587.9
112 → 149	394.2	395.9	396.4	21 → 63	292.5	296.4	308.3
149 → 189	399.3	413.3	412.3	63 → 76	378.4	387.3	409.5
189 → 151	625.5	641.8	736.9	76 → 24	388.0	392.9	396.8
151 → 76	522.6	459.4	539.8	24 → 151	610.6	641.1	665.7
76 → 24	318.1	392.9	325.3	151 → 149	311.6	315.4	316.2
24 → 21	237.6	238.3	238.9	149 → 166	77.8	79.1	79.9
21 → 63	254.9	317.3	379.4	166 → 189	318.0	328.6	332.4
63 → 112	387.8	390.7	391.1	189 → 112	443.0	549.4	699.7
112 → 166	469.0	475.0	476.3	112 → 112	0.0	0.0	0.0
166 → 131	421.9	496.4	525.1	112 → 35	500.4	635.5	721.2
131 → 35	623.5	630.0	633.6	35 → 131	691.9	706.0	723.5
35 → 0	160.8	190.0	218.1	131 → 0	891.8	928.5	962.7
TOTAL	5475.7	5753.4	6181.7	TOTAL	5314.3	5678.5	6203.8

Appendix D.5

25 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	125.6	126.3	151.3	0 → 21	82.2	79.2	104.4
112 → 149	91.1	92.2	92.6	21 → 63	58.0	58.2	58.4
149 → 151	57.9	58.7	58.6	63 → 76	292.3	505.3	1461.1
151 → 76	220.9	328.8	345.8	76 → 151	119.1	114.2	245.3
76 → 63	98.6	197.1	291.2	151 → 149	44.5	360.0	3745.9
63 → 21	234.4	383.9	1138.5	149 → 112	201.0	1908.7	-
21 → 0	396.4	525.8	-	112 → 0	775.5	984.2	-
TOTAL	1224.9	1712.8	2078	TOTAL	1572.6	4009.8	5615.1
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	125.6	126.3	151.3	0 → 21	82.2	79.2	104.4
112 → 149	91.1	92.2	92.6	21 → 63	58.0	58.2	58.4
149 → 189	79.3	80.7	80.6	63 → 76	292.3	505.3	1461.1
189 → 151	148.2	167.8	176.5	76 → 151	119.1	114.2	-
151 → 76	328.5	282.9	547.0	151 → 149	44.5	360.0	-
76 → 24	169.6	200.0	-	149 → 189	87.1	1228.6	-
24 → 21	181.6	166.9	-	189 → 112	958.0	-	-
21 → 63	348.0	575.3	-	112 → 24	-	-	-
63 → 0	583.5	514.3	-	24 → 0	-	-	-
TOTAL	2055.4	2206.4	1048	TOTAL	1641.2	2345.5	1623.9
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	125.6	126.3	151.3	0 → 21	82.2	79.2	104.4
112 → 149	91.1	92.2	92.6	21 → 63	58.0	58.2	58.4
149 → 189	79.3	80.7	80.6	63 → 76	292.3	505.3	1461.1
189 → 151	148.2	167.8	176.5	76 → 24	75.1	119.8	-
151 → 76	328.5	282.9	-	24 → 151	216.5	206.4	-
76 → 24	169.6	200.0	-	151 → 149	101.0	380.0	-
24 → 21	181.6	166.9	-	149 → 166	33.9	585.0	-
21 → 63	348.0	575.3	-	166 → 189	371.1	-	-
63 → 112	583.5	-	-	189 → 112	-	-	-
112 → 166	-	-	-	112 → 112	-	-	-
166 → 131	-	-	-	112 → 35	-	-	-
131 → 35	-	-	-	35 → 131	-	-	-
35 → 0	-	-	-	131 → 0	-	-	-
TOTAL	2055.4	1692.1	501	TOTAL	1230.1	1933.9	1623.9

50 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	155.9	161.0	167.1	0 --> 21	92.8	96.1	100.6
112 --> 149	94.6	95.5	96.2	21 --> 63	74.0	74.7	75.1
149 --> 151	62.6	65.3	66.9	63 --> 76	80.7	82.7	84.3
151 --> 76	113.2	115.4	117.3	76 --> 151	130.1	132.2	130.5
76 --> 63	113.7	270.1	800.0	151 --> 149	58.6	59.6	60.1
63 --> 21	54.0	53.4	48.3	149 --> 112	90.9	140.0	1873.3
21 --> 0	86.5	85.5	80.5	112 --> 0	159.2	159.8	284.5
TOTAL	680.5	846.2	1376.3	TOTAL	686.3	745.1	2608.4
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	155.9	161.0	167.1	0 --> 21	92.8	96.1	100.6
112 --> 149	94.6	95.5	96.2	21 --> 63	74.0	74.7	75.1
149 --> 189	94.1	97.0	97.4	63 --> 76	80.7	82.7	84.3
189 --> 151	152.9	161.8	172.3	76 --> 151	130.0	131.2	130.5
151 --> 76	113.4	115.2	115.3	151 --> 149	58.6	59.6	60.1
76 --> 24	101.1	102.1	102.6	149 --> 189	103.0	104.8	147.8
24 --> 21	60.0	62.1	66.4	189 --> 112	98.2	168.3	2502.9
21 --> 63	73.7	300.2	712.5	112 --> 24	230.8	232.5	1890.6
63 --> 0	111.9	112.8	148.4	24 --> 0	144.3	151.0	169.1
TOTAL	957.6	1207.7	1678.2	TOTAL	1012.4	1100.9	5161
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	155.9	161.0	167.1	0 --> 21	92.8	96.1	100.6
112 --> 149	94.6	95.5	96.2	21 --> 63	74.0	74.7	75.1
149 --> 189	94.1	97.0	97.4	63 --> 76	80.7	82.7	84.3
189 --> 151	152.9	161.8	172.3	76 --> 24	100.9	102.7	104.7
151 --> 76	113.4	115.2	115.3	24 --> 151	167.8	169.4	204.9
76 --> 24	101.1	102.1	102.6	151 --> 149	58.7	59.3	77.9
24 --> 21	60.0	62.1	66.4	149 --> 166	37.4	38.1	147.7
21 --> 63	73.7	300.2	712.5	166 --> 189	72.7	128.7	5600.0
63 --> 112	108.0	288.9	244.6	189 --> 112	98.0	1568.7	-
112 --> 166	117.3	204.7	599.1	112 --> 112	0.0	0.0	-
166 --> 131	150.5	4000.0	11709.3	112 --> 35	113.9	141.0	-
131 --> 35	193.9	190.8	-	35 --> 131	218.9	503.5	-
35 --> 0	45.0	95.3	-	131 --> 0	194.4	494.5	-
TOTAL	1460.4	5874.6	14082.8	TOTAL	1310.2	3459.4	6395.2

75 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	171.6	176.8	187.9	0 --> 21	102.2	106.0	110.4
112 --> 149	104.1	105.3	106.4	21 --> 63	82.0	83.0	83.9
149 --> 151	68.7	71.3	73.6	63 --> 76	90.5	92.5	94.5
151 --> 76	125.1	127.6	128.9	76 --> 151	141.6	144.1	144.7
76 --> 63	126.1	126.7	432.1	151 --> 149	65.6	66.2	66.9
63 --> 21	59.3	59.8	60.2	149 --> 112	101.4	102.7	126.7
21 --> 0	96.6	96.2	95.2	112 --> 0	157.6	176.8	296.5
TOTAL	751.5	763.7	1084.3	TOTAL	740.9	771.3	923.6
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	171.6	176.8	187.9	0 --> 21	102.2	106.0	110.4
112 --> 149	104.1	105.3	106.4	21 --> 63	82.0	83.0	83.9
149 --> 189	103.9	106.1	107.3	63 --> 76	90.5	92.5	94.5
189 --> 151	169.0	179.4	187.9	76 --> 151	141.6	144.1	144.7
151 --> 76	125.2	127.4	129.4	151 --> 149	64.5	66.2	66.9
76 --> 24	110.3	112.6	113.8	149 --> 189	115.3	117.3	107.0
24 --> 21	65.8	65.5	66.3	189 --> 112	108.8	114.2	228.6
21 --> 63	61.3	183.5	381.0	112 --> 24	217.1	253.3	533.3
63 --> 0	124.8	124.1	126.5	24 --> 0	159.8	161.5	303.5
TOTAL	1036	1180.7	1406.5	TOTAL	1081.8	1138.1	1672.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	171.6	176.8	187.9	0 --> 21	102.2	106.0	110.4
112 --> 149	104.1	105.3	106.4	21 --> 63	82.0	83.0	83.9
149 --> 189	103.9	106.1	107.3	63 --> 76	90.5	92.5	94.5
189 --> 151	169.0	179.4	187.9	76 --> 24	110.4	112.7	115.1
151 --> 76	125.2	127.4	129.4	24 --> 151	182.5	184.9	185.7
76 --> 24	110.3	112.6	113.8	151 --> 149	64.4	65.8	66.7
24 --> 21	65.8	65.5	66.3	149 --> 166	41.9	42.7	43.0
21 --> 63	61.3	183.5	381.0	166 --> 189	80.4	81.4	81.7
63 --> 112	100.5	356.7	3848.6	189 --> 112	108.5	126.3	2500.7
112 --> 166	129.3	258.6	885.4	112 --> 112	0.0	0.0	0.0
166 --> 131	86.2	337.5	3467.8	112 --> 35	126.6	128.6	328.0
131 --> 35	220.6	352.1	414.6	35 --> 131	208.1	243.0	844.4
35 --> 0	50.4	126.4	122.6	131 --> 0	229.2	286.9	401.1
TOTAL	1498.2	2487.9	10019	TOTAL	1426.7	1553.8	4855.2

100 Metre Dynamic Two-Way Case (CBD)							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	198.6	202.2	205.4	0 --> 21	117.0	119.4	121.3
112 --> 149	114.2	118.1	122.2	21 --> 63	98.1	100.3	102.1
149 --> 151	78.3	80.6	82.2	63 --> 76	106.8	109.3	110.8
151 --> 76	137.7	141.7	144.4	76 --> 151	147.9	150.7	154.2
76 --> 63	142.8	143.1	143.7	151 --> 149	76.4	78.7	81.1
63 --> 21	69.3	70.1	93.9	149 --> 112	114.7	116.0	117.7
21 --> 0	109.9	108.2	108.9	112 --> 0	181.0	190.4	193.0
TOTAL	850.8	864	900.7	TOTAL	841.9	864.8	880.2
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	198.6	202.2	205.4	0 --> 21	117.0	119.4	121.3
112 --> 149	114.2	118.1	122.2	21 --> 63	98.1	100.3	102.1
149 --> 189	111.8	114.8	117.1	63 --> 76	106.8	109.3	110.8
189 --> 151	200.9	211.8	210.6	76 --> 151	147.9	150.7	154.2
151 --> 76	137.9	141.3	143.5	151 --> 149	76.4	78.7	81.1
76 --> 24	110.7	112.5	113.9	149 --> 189	131.2	133.6	136.2
24 --> 21	69.2	69.1	69.5	189 --> 112	138.6	142.1	144.8
21 --> 63	75.0	90.9	331.2	112 --> 24	273.7	251.8	277.7
63 --> 0	147.1	148.8	326.8	24 --> 0	165.0	166.8	167.1
TOTAL	1165.4	1209.5	1640.2	TOTAL	1254.7	1252.7	1295.3
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	198.6	202.2	205.4	0 --> 21	117.0	119.4	121.3
112 --> 149	114.8	118.1	122.2	21 --> 63	98.1	100.3	102.1
149 --> 189	111.8	114.8	117.1	63 --> 76	106.8	109.3	110.8
189 --> 151	200.9	211.8	210.6	76 --> 24	110.8	112.6	114.3
151 --> 76	137.9	141.3	143.5	24 --> 151	184.1	190.4	195.8
76 --> 24	110.7	112.5	113.9	151 --> 149	76.4	78.8	80.8
24 --> 21	69.2	69.1	69.5	149 --> 166	47.0	48.9	50.1
21 --> 63	75.0	90.9	331.2	166 --> 189	83.8	85.1	85.6
63 --> 112	109.2	148.8	501.6	189 --> 112	138.4	141.6	149.1
112 --> 166	138.1	160.8	341.2	112 --> 112	0.0	0.0	0.0
166 --> 131	106.4	108.0	362.1	112 --> 35	132.1	133.0	345.1
131 --> 35	205.3	430.9	897.0	35 --> 131	219.9	222.4	215.4
35 --> 0	49.2	172.1	269.6	131 --> 0	237.0	349.2	1373.2
TOTAL	1627.1	2081.3	3684.9	TOTAL	1551.4	1691	2943.6

100 Metre Dynamic Two-Way Case (Metro)							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	285.3	293.6	320.3	0 --> 21	156.4	157.3	164.8
112 --> 149	154.6	155.0	161.9	21 --> 63	143.8	142.8	142.7
149 --> 151	113.0	112.6	99.8	63 --> 76	208.0	278.8	308.2
151 --> 76	319.9	371.2	640.3	76 --> 151	244.1	231.4	231.4
76 --> 63	205.6	233.6	203.4	151 --> 149	116.1	193.0	183.3
63 --> 21	82.2	76.8	82.7	149 --> 112	215.3	289.2	248.6
21 --> 0	1000.0	3000.0	4695.0	112 --> 0	795.8	1300.0	1934.4
TOTAL	2160.6	4242.8	6203.4	TOTAL	1879.5	2592.5	3213.4
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	285.3	293.6	320.3	0 --> 21	156.4	157.3	164.8
112 --> 149	154.6	155.0	161.9	21 --> 63	143.8	142.8	142.7
149 --> 189	146.5	145.4	143.8	63 --> 76	208.0	278.8	308.2
189 --> 151	241.1	252.1	237.3	76 --> 151	244.1	231.4	231.4
151 --> 76	647.5	485.8	547.0	151 --> 149	116.1	193.0	183.3
76 --> 24	155.3	164.9	156.5	149 --> 189	210.9	789.0	590.5
24 --> 21	809.6	1421.4	1779.2	189 --> 112	171.5	619.2	262.9
21 --> 63	190.0	708.2	1493.0	112 --> 24	1053.5	1349.2	2965.8
63 --> 0	7000.0	11000.0	15295.3	24 --> 0	10000.0	15000.0	20000.0
TOTAL	9629.9	14626.4	20134.3	TOTAL	12304.3	18760.7	24849.6
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	285.3	293.6	320.3	0 --> 21	156.4	157.3	164.8
112 --> 149	154.6	155.0	161.9	21 --> 63	143.8	142.8	142.7
149 --> 189	146.5	145.4	143.8	63 --> 76	208.0	278.8	308.2
189 --> 151	241.1	252.1	237.3	76 --> 24	159.7	156.0	151.8
151 --> 76	647.5	485.8	547.0	24 --> 151	329.5	326.8	329.1
76 --> 24	155.3	164.9	156.5	151 --> 149	178.2	199.2	193.9
24 --> 21	809.6	1421.4	1779.2	149 --> 166	1810.3	4206.1	-
21 --> 63	190.0	708.2	1034.0	166 --> 189	456.6	902.6	-
63 --> 112	178.8	190.8	237.4	189 --> 112	489.7	619.2	-
112 --> 166	11000.0	14873.7	-	112 --> 112	0.0	0.0	0.0
166 --> 131	-	-	-	112 --> 35	-	-	-
131 --> 35	-	-	-	35 --> 131	-	-	-
35 --> 0	-	-	-	131 --> 0	-	-	-
TOTAL	13808.7	18690.9	4617.4	TOTAL	3932.2	6988.8	1290.5

300 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	349.9	367.4	421.3	0 --> 21	228.4	231.9	275.0
112 --> 149	226.3	235.9	208.4	21 --> 63	176.7	180.3	181.2
149 --> 151	147.7	140.3	172.2	63 --> 76	208.3	215.8	235.6
151 --> 76	291.7	263.0	259.3	76 --> 151	318.0	307.5	355.6
76 --> 63	210.7	217.5	208.0	151 --> 149	123.6	143.1	143.4
63 --> 21	126.4	120.8	126.7	149 --> 112	301.4	364.3	422.0
21 --> 0	233.9	240.5	266.7	112 --> 0	532.7	731.4	744.5
TOTAL	1586.6	1585.4	1662.6	TOTAL	1889.1	2174.3	2357.3
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	349.9	367.4	421.3	0 --> 21	228.4	231.9	275.0
112 --> 149	226.3	235.9	208.3	21 --> 63	176.7	180.3	181.2
149 --> 189	240.8	224.1	232.8	63 --> 76	208.3	215.8	235.6
189 --> 151	352.0	355.3	396.7	76 --> 151	318.0	307.5	355.3
151 --> 76	311.0	297.0	312.0	151 --> 149	123.6	143.1	143.4
76 --> 24	139.2	181.4	203.6	149 --> 189	265.0	288.9	230.6
24 --> 21	127.5	126.9	120.7	189 --> 112	319.5	470.2	511.6
21 --> 63	195.3	196.9	210.5	112 --> 24	470.7	490.2	462.3
63 --> 0	314.6	325.0	324.1	24 --> 0	361.8	378.5	376.4
TOTAL	2256.6	2309.9	2430	TOTAL	2472	2706.4	2771.4
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	349.9	367.4	421.3	0 --> 21	228.4	231.9	275.0
112 --> 149	226.3	235.9	208.3	21 --> 63	176.7	180.3	181.2
149 --> 189	240.8	224.1	232.8	63 --> 76	208.3	215.8	235.6
189 --> 151	352.0	355.3	396.7	76 --> 24	226.4	229.9	255.7
151 --> 76	311.0	297.0	312.0	24 --> 151	371.3	296.2	315.9
76 --> 24	139.2	181.4	203.6	151 --> 149	141.9	132.9	126.2
24 --> 21	127.5	126.9	120.7	149 --> 166	104.8	101.0	104.9
21 --> 63	195.3	196.9	210.5	166 --> 189	124.7	159.8	161.6
63 --> 112	196.7	204.1	198.1	189 --> 112	363.1	452.1	540.4
112 --> 166	276.4	340.4	316.7	112 --> 112	0.0	0.0	0.0
166 --> 131	446.9	605.0	664.4	112 --> 35	310.2	431.1	477.0
131 --> 35	564.3	376.3	358.5	35 --> 131	332.6	330.8	340.9
35 --> 0	631.6	800.0	1398.2	131 --> 0	490.0	524.4	513.9
TOTAL	4057.9	4310.7	5041.8	TOTAL	3078.4	3286.2	3528.3

500 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	481.2	496.9	521.2	0 --> 21	284.8	297.4	316.1
112 --> 149	308.1	312.3	313.3	21 --> 63	236.7	239.0	240.6
149 --> 151	177.5	180.6	198.2	63 --> 76	289.1	310.4	312.1
151 --> 76	343.5	337.0	373.3	76 --> 151	393.8	405.9	431.6
76 --> 63	348.5	354.1	355.4	151 --> 149	169.9	183.6	185.3
63 --> 21	176.0	170.6	186.3	149 --> 112	382.8	410.3	450.7
21 --> 0	309.8	301.8	303.3	112 --> 0	497.1	776.2	902.5
TOTAL	2144.6	2153.3	2251	TOTAL	2254.2	2622.8	2838.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	481.2	496.9	521.2	0 --> 21	284.8	297.4	316.1
112 --> 149	308.1	312.3	313.3	21 --> 63	236.7	239.0	240.6
149 --> 189	327.1	342.4	347.9	63 --> 76	289.1	310.4	312.1
189 --> 151	472.9	485.8	638.6	76 --> 151	393.8	405.9	431.6
151 --> 76	343.9	339.5	367.5	151 --> 149	169.9	183.6	185.3
76 --> 24	261.1	326.5	306.3	149 --> 189	392.3	386.3	316.6
24 --> 21	175.0	230.8	182.9	189 --> 112	403.9	589.4	834.7
21 --> 63	298.3	466.6	376.3	112 --> 24	635.8	641.0	638.5
63 --> 0	413.3	415.3	417.0	24 --> 0	481.0	477.1	463.3
TOTAL	3080.9	3416.1	3471	TOTAL	3287.3	3530.1	3738.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	481.2	496.9	521.2	0 --> 21	284.8	297.4	316.1
112 --> 149	308.1	312.3	313.3	21 --> 63	236.7	239.0	240.6
149 --> 189	327.1	342.4	347.9	63 --> 76	289.1	310.4	312.1
189 --> 151	472.9	485.8	638.6	76 --> 24	393.4	326.3	329.1
151 --> 76	343.9	339.5	367.5	24 --> 151	478.8	526.7	583.1
76 --> 24	261.1	326.5	306.3	151 --> 149	174.8	182.8	173.1
24 --> 21	175.0	230.8	182.9	149 --> 166	129.8	124.1	130.0
21 --> 63	298.3	461.2	376.3	166 --> 189	271.9	258.8	271.4
63 --> 112	279.6	285.4	280.0	189 --> 112	414.2	658.3	866.5
112 --> 166	360.3	378.9	728.1	112 --> 112	0.0	0.0	0.0
166 --> 131	586.6	898.9	792.8	112 --> 35	630.7	1206.2	1664.8
131 --> 35	477.0	446.2	484.9	35 --> 131	537.3	537.0	524.8
35 --> 0	613.8	824.3	1158.7	131 --> 0	691.3	675.3	671.0
TOTAL	4984.9	5829.1	6498.5	TOTAL	4532.8	5342.3	6082.6

700 Metre Dynamic Two-Way Case							
Clockwise Route				Counter-clockwise Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 → 112	633.7	665.8	707.5	0 → 21	386.8	401.4	408.8
112 → 149	385.2	390.7	395.4	21 → 63	308.3	311.2	319.8
149 → 151	248.7	256.4	257.9	63 → 76	392.2	381.7	383.9
151 → 76	516.9	512.7	520.9	76 → 151	550.6	595.6	625.7
76 → 63	373.1	375.0	381.1	151 → 149	245.7	261.7	249.3
63 → 21	334.3	344.0	320.9	149 → 112	415.2	458.0	516.6
21 → 0	299.5	302.6	310.5	112 → 0	618.6	626.3	850.8
TOTAL	2791.4	2847.2	2894.2	TOTAL	2917.4	3045.9	3354.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 → 112	658.2	665.8	678.7	0 → 21	400.4	478.2	408.8
112 → 149	388.8	390.7	399.3	21 → 63	288.3	234.4	294.8
149 → 189	379.7	390.6	439.7	63 → 76	379.1	449.2	391.7
189 → 151	651.1	644.5	750.5	76 → 151	431.5	469.4	517.3
151 → 76	468.1	535.2	477.8	151 → 149	230.8	446.2	263.9
76 → 24	400.0	302.7	426.8	149 → 189	411.1	246.1	493.5
24 → 21	236.9	248.2	235.2	189 → 112	526.8	499.1	1096.3
21 → 63	345.6	392.9	516.5	112 → 24	872.6	794.2	583.4
63 → 0	551.3	642.6	548.4	24 → 0	617.4	808.2	604.1
TOTAL	4079.7	4213.2	4472.9	TOTAL	4158	4425	4653.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 → 112	658.2	643.5	678.7	0 → 21	400.4	392.0	408.8
112 → 149	388.8	393.8	399.3	21 → 63	288.3	291.0	294.8
149 → 189	379.7	392.3	439.7	63 → 76	379.1	386.2	391.7
189 → 151	651.1	652.5	750.5	76 → 24	396.9	410.2	382.8
151 → 76	468.1	608.9	477.8	24 → 151	627.9	661.2	725.9
76 → 24	351.2	319.9	426.8	151 → 149	231.1	246.0	235.0
24 → 21	236.9	241.5	235.2	149 → 166	149.7	161.7	162.8
21 → 63	345.6	486.2	516.5	166 → 189	345.8	481.9	350.1
63 → 112	388.8	384.0	382.7	189 → 112	505.1	863.5	1073.9
112 → 166	489.9	467.8	509.9	112 → 112	0.0	0.0	0.0
166 → 131	801.7	1083.6	1125.0	112 → 35	704.9	1074.4	1720.2
131 → 35	621.0	635.2	787.9	35 → 131	704.9	700.7	739.7
35 → 0	436.1	468.7	554.8	131 → 0	932.1	1035.1	1090.9
TOTAL	6217.1	6777.9	7284.8	TOTAL	5666.2	6703.9	7576.6

Appendix D.6

25 Metre Pick-Up In Order for Two-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	125.6	126.3	148.7	0 --> 112	163.9	189.8	194.0
112 --> 63	97.3	99.5	99.4	112 --> 63	127.9	162.2	182.0
63 --> 151	141.6	149.0	156.8	63 --> 151	405.4	753.1	1954.2
151 --> 149	44.7	45.3	45.3	151 --> 149	44.7	45.3	
149 --> 21	329.1	727.7	1546.2	149 --> 21	329.1	2649.3	
21 --> 76	669.8			21 --> 76	1141.8		
76 --> 0	249.7			76 --> 0	6188.7		
TOTAL	1657.8	1147.8	1996.4	TOTAL	8401.5	3799.7	2330.2
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	125.6	126.3	148.7	0 --> 112	163.9	189.8	194.0
112 --> 63	97.3	99.5	99.4	112 --> 63	127.9	162.2	182.0
63 --> 151	141.6	149.0	156.8	63 --> 151	405.4	753.1	1954.2
151 --> 149	44.7	45.3	45.3	151 --> 149	44.7	45.3	-
149 --> 21	329.1	727.7	1546.2	149 --> 21	329.1	2649.3	-
21 --> 76	669.8	-	-	21 --> 76	1141.8	-	-
76 --> 189	-	-	-	76 --> 189	-	-	-
189 --> 24	-	-	-	189 --> 24	-	-	-
24 --> 0	-	-	-	24 --> 0	-	-	-
TOTAL	1408.1	1147.8	1996.4	TOTAL	2212.8	3799.7	2330.2
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	125.6	126.3	148.7	0 --> 112	163.9	189.8	194.0
112 --> 63	97.3	99.5	99.4	112 --> 63	127.9	162.2	182.0
63 --> 151	141.6	149.0	156.8	63 --> 151	405.4	753.1	1954.2
151 --> 149	44.7	45.3	45.3	151 --> 149	44.7	45.3	-
149 --> 21	329.1	727.7	1546.2	149 --> 21	329.1	2649.3	-
21 --> 76	669.8	-	-	21 --> 76	1141.8	-	-
76 --> 189	-	-	-	76 --> 189	-	-	-
189 --> 24	-	-	-	189 --> 24	-	-	-
24 --> 166	-	-	-	24 --> 166	-	-	-
166 --> 112	-	-	-	166 --> 112	-	-	-
112 --> 35	-	-	-	112 --> 35	-	-	-
35 --> 131	-	-	-	35 --> 131	-	-	-
131 --> 0	-	-	-	131 --> 0	-	-	-
TOTAL	1408.1	1147.8	1996.4	TOTAL	2212.8	3799.7	2330.2

4 OF 4

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

50 Metre Pick-Up In Order for Two-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	155.9	161.0	167.1	0 --> 112	187.8	243.6	283.6
112 --> 63	106.8	108.8	111.4	112 --> 63	145.5	148.7	167.0
63 --> 151	160.8	163.4	168.6	63 --> 151	200.6	204.2	207.5
151 --> 149	58.6	59.9	60.2	151 --> 149	58.6	59.9	60.2
149 --> 21	168.4	177.6	231.0	149 --> 21	168.4	177.6	231.0
21 --> 76	135.9	151.5	290.3	21 --> 76	158.9	295.7	845.0
76 --> 0	219.7	228.9	280.2	76 --> 0	368.7	657.1	879.0
TOTAL	1006.1	1051.1	1308.8	TOTAL	1288.5	1786.8	2673.3
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	155.9	161.0	167.1	0 --> 112	187.8	243.6	283.6
112 --> 63	106.8	108.8	111.4	112 --> 63	145.5	148.7	167.0
63 --> 151	160.8	163.4	168.6	63 --> 151	200.6	204.2	207.5
151 --> 149	58.6	59.9	60.2	151 --> 149	58.6	59.9	60.2
149 --> 21	168.4	177.6	231.0	149 --> 21	168.4	177.6	231.0
21 --> 76	135.9	151.5	290.3	21 --> 76	158.9	295.7	845.0
76 --> 189	101.4	101.5	102.4	76 --> 189	108.9	192.4	466.2
189 --> 24	290.2	284.1	317.9	189 --> 24	433.6	2365.8	4874.4
24 --> 0	230.5	501.7	1668.9	24 --> 0	284.5	642.2	1668.9
TOTAL	1408.5	1709.5	3117.8	TOTAL	1746.8	4330.1	8803.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	155.9	161.0	167.1	0 --> 112	187.8	243.6	283.6
112 --> 63	106.8	108.8	111.4	112 --> 63	145.5	148.7	167.0
63 --> 151	160.8	163.4	168.6	63 --> 151	200.6	204.2	207.5
151 --> 149	58.6	59.9	60.2	151 --> 149	58.6	59.9	60.2
149 --> 21	168.4	177.6	231.0	149 --> 21	168.4	177.6	231.0
21 --> 76	135.9	151.5	290.3	21 --> 76	158.9	295.7	845.0
76 --> 189	101.4	101.5	102.4	76 --> 189	108.9	192.4	466.2
189 --> 24	290.2	284.1	317.9	189 --> 24	433.6	2365.8	4874.4
24 --> 166	90.3	700.0	6671.7	24 --> 166	104.9	1010.0	6671.7
166 --> 112	147.6	1937.7	-	166 --> 112	1096.6	3154.6	-
112 --> 35	113.9	123.5	-	112 --> 35	113.9	-	-
35 --> 131	278.9	688.9	-	35 --> 131	371.6	-	-
131 --> 0	195.5	790.3	-	131 --> 0	581.6	-	-
TOTAL	2004.2	5448.2	8120.6	TOTAL	3730.9	7852.5	13806.6

END

1 8-0 6-9 7

FIN

100 Metre Pick-Up In Order for Two-Way Case (CBD)							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	198.6	202.2	205.4	0 --> 112	228.0	273.3	333.0
112 --> 63	142.5	145.0	146.7	112 --> 63	165.5	168.4	173.3
63 --> 151	199.5	202.1	206.4	63 --> 151	243.3	242.9	256.7
151 --> 149	76.3	78.5	81.2	151 --> 149	76.3	78.5	81.2
149 --> 21	202.4	180.5	206.7	149 --> 21	202.4	180.5	206.7
21 --> 76	169.8	174.1	184.1	21 --> 76	203.4	206.7	246.3
76 --> 0	266.0	272.6	279.8	76 --> 0	799.7	3308.4	11973.8
TOTAL	1255.1	1255	1310.3	TOTAL	1918.6	4458.7	13271
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	198.6	202.2	205.4	0 --> 112	228.0	273.3	333.0
112 --> 63	142.5	145.0	146.7	112 --> 63	165.5	168.4	173.3
63 --> 151	199.5	202.1	206.4	63 --> 151	243.3	242.9	256.7
151 --> 149	76.3	78.5	81.2	151 --> 149	76.3	78.5	81.2
149 --> 21	202.4	180.5	206.7	149 --> 21	202.4	180.5	206.7
21 --> 76	169.8	174.1	184.1	21 --> 76	203.4	206.7	246.3
76 --> 189	110.8	112.6	117.2	76 --> 189	118.1	124.2	138.7
189 --> 24	336.0	338.9	339.2	189 --> 24	414.5	630.1	980.7
24 --> 0	329.5	332.4	542.7	24 --> 0	329.5	332.4	859.0
TOTAL	1765.4	1766.3	2029.6	TOTAL	1981	2237	3275.6
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	198.6	202.2	205.4	0 --> 112	228.0	273.3	333.0
112 --> 63	142.5	145.0	146.7	112 --> 63	165.5	168.4	173.3
63 --> 151	199.5	202.1	206.4	63 --> 151	243.3	242.9	256.7
151 --> 149	76.3	78.5	81.2	151 --> 149	76.3	78.5	81.2
149 --> 21	202.4	180.5	206.7	149 --> 21	202.4	180.5	206.7
21 --> 76	169.8	174.1	184.1	21 --> 76	203.4	206.7	246.3
76 --> 189	110.8	112.6	117.2	76 --> 189	118.1	124.2	138.7
189 --> 24	336.0	338.9	339.2	189 --> 24	414.5	630.1	980.7
24 --> 166	128.8	132.3	164.0	24 --> 166	151.4	158.2	493.9
166 --> 112	145.2	187.6	1192.2	166 --> 112	154.8	601.8	1310.7
112 --> 35	143.1	143.5	280.2	112 --> 35	143.1	143.5	280.2
35 --> 131	208.4	240.9	323.3	35 --> 131	262.0	3767.6	4648.0
131 --> 0	276.3	503.0	1128.9	131 --> 0	3102.9	4211.6	3903.9
TOTAL	2337.7	2641.2	4575.5	TOTAL	5465.7	10787.3	13053.3

100 Metre Pick-Up In Order for Two-Way Case (Metro)							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	285.3	293.6	320.3	0 --> 112	462.8	543.2	579.7
112 --> 63	211.1	207.4	206.0	112 --> 63	279.9	326.1	333.5
63 --> 151	331.4	293.9	292.9	63 --> 151	407.4	363.2	362.9
151 --> 149	116.1	132.4	124.5	151 --> 149	116.1	132.4	124.5
149 --> 21	278.4	299.4	299.3	149 --> 21	278.4	299.4	299.3
21 --> 76	644.3	2566.2	2650.9	21 --> 76	1007.3	5154.3	-
76 --> 0	244.5	771.0	0.0	76 --> 0	883.3	7311.0	NC
TOTAL	2111.1	4563.9	3893.9	TOTAL	3435.2	14129.6	1699.9
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	285.3	293.6	320.3	0 --> 112	462.8	543.2	597.7
112 --> 63	211.1	207.4	206.0	112 --> 63	279.9	326.1	333.5
63 --> 151	331.4	293.9	292.9	63 --> 151	407.4	363.2	362.9
151 --> 149	116.1	132.4	124.5	151 --> 149	116.1	132.4	124.5
149 --> 21	278.4	299.4	299.3	149 --> 21	173.5	299.4	299.3
21 --> 76	644.3	2566.2	2650.9	21 --> 76	372.4	5154.3	-
76 --> 189	110.1	1041.2	1402.2	76 --> 189	368.0	1744.6	-
189 --> 24	313.6	6752.3	-	189 --> 24	655.2	24961.1	-
24 --> 0	259.1	-	-	24 --> 0	466.2	-	-
TOTAL	2549.4	11586.4	5296.1	TOTAL	3301.5	33524.3	1717.9
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	285.3	293.6	320.3	0 --> 112	462.8	543.2	597.7
112 --> 63	211.1	207.4	206.0	112 --> 63	279.9	326.1	333.5
63 --> 151	331.4	293.9	292.9	63 --> 151	407.4	363.2	362.9
151 --> 149	116.1	132.4	124.5	151 --> 149	116.1	132.4	124.5
149 --> 21	278.4	299.4	299.3	149 --> 21	278.4	299.4	299.3
21 --> 76	644.3	2566.2	2650.9	21 --> 76	1007.3	5154.3	-
76 --> 189	110.1	1041.2	-	76 --> 189	117.8	1744.6	-
189 --> 24	313.6	6752.3	-	189 --> 24	373.3	24961.1	-
24 --> 166	100.2	-	-	24 --> 166	115.1	-	-
166 --> 112	127.4	-	-	166 --> 112	135.2	-	-
112 --> 35	-	-	-	112 --> 35	-	-	-
35 --> 131	-	-	-	35 --> 131	-	-	-
131 --> 0	-	-	-	131 --> 0	-	-	-
TOTAL	2517.9	11586.4	3893.9	TOTAL	3293.3	33524.3	1717.9

300 Metre Pick-Up In Order for Two-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	352.7	358.3	414.2	0 --> 112	497.9	544.0	506.5
112 --> 63	262.1	266.0	265.1	112 --> 63	313.5	369.3	417.0
63 --> 151	391.9	400.4	400.7	63 --> 151	457.4	518.1	565.0
151 --> 149	123.7	127.6	143.4	151 --> 149	123.7	127.6	143.4
149 --> 21	390.3	394.5	387.3	149 --> 21	390.3	394.6	387.3
21 --> 76	364.8	450.5	578.7	21 --> 76	416.1	609.0	776.4
76 --> 0	523.6	541.2	561.8	76 --> 0	1049.3	1062.3	1106.0
TOTAL	2409.1	2538.5	2751.2	TOTAL	3248.2	3624.9	3901.6
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	352.7	358.3	414.2	0 --> 112	497.9	544.0	506.5
112 --> 63	262.1	266.0	265.1	112 --> 63	313.5	369.3	417.0
63 --> 151	391.9	400.4	400.7	63 --> 151	457.4	518.1	565.0
151 --> 149	123.7	127.6	143.4	151 --> 149	123.7	127.6	143.4
149 --> 21	390.3	394.5	387.3	149 --> 21	390.3	394.6	387.3
21 --> 76	364.8	450.5	578.7	21 --> 76	416.1	609.0	776.4
76 --> 189	239.2	243.1	227.9	76 --> 189	256.6	252.9	246.4
189 --> 24	651.9	666.7	682.0	189 --> 24	1367.8	2494.6	3189.2
24 --> 0	983.1	1002.4	1375.0	24 --> 0	1572.8	2829.0	3202.8
TOTAL	3759.7	3909.5	4474.3	TOTAL	5396.1	8139.1	9434
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	352.7	358.3	414.2	0 --> 112	497.9	544.0	506.5
112 --> 63	262.1	266.0	265.1	112 --> 63	313.5	369.3	417.0
63 --> 151	391.9	400.4	400.7	63 --> 151	457.4	518.1	565.0
151 --> 149	123.7	127.6	143.4	151 --> 149	123.7	127.6	143.4
149 --> 21	390.3	394.5	387.3	149 --> 21	390.3	394.6	387.3
21 --> 76	364.8	450.5	578.7	21 --> 76	416.1	609.0	776.4
76 --> 189	239.2	243.1	227.9	76 --> 189	256.6	252.9	246.4
189 --> 24	651.9	666.7	682.0	189 --> 24	1367.8	2494.6	3189.2
24 --> 166	214.7	225.1	253.6	24 --> 166	778.5	852.4	286.0
166 --> 112	422.1	483.7	484.9	166 --> 112	434.2	502.7	504.6
112 --> 35	727.6	1124.9	1332.0	112 --> 35	727.6	1124.9	1332.0
35 --> 131	373.9	379.6	389.2	35 --> 131	1538.6	1945.9	2621.2
131 --> 0	516.6	517.0	518.0	131 --> 0	1687.8	3374.2	5175.1
TOTAL	5031.5	5637.4	6077	TOTAL	8990	13110.2	16150.1

500 Metre Pick-Up In Order for Two-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	468.2	479.9	501.0	0 --> 112	677.2	746.0	788.7
112 --> 63	343.9	343.4	356.9	112 --> 63	394.8	459.4	505.6
63 --> 151	531.6	550.3	566.6	63 --> 151	613.4	680.4	729.0
151 --> 149	175.2	183.6	185.3	151 --> 149	175.2	183.6	185.3
149 --> 21	524.7	535.8	627.4	149 --> 21	524.7	535.8	627.4
21 --> 76	460.7	464.6	477.8	21 --> 76	579.8	663.9	791.7
76 --> 0	732.8	762.9	819.2	76 --> 0	1111.4	1689.1	1834.4
TOTAL	3237.1	3320.5	3534.2	TOTAL	4076.5	4958.2	5462.1
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	468.2	479.9	501.0	0 --> 112	677.2	746.0	788.7
112 --> 63	343.9	343.4	356.9	112 --> 63	394.8	459.4	505.6
63 --> 151	531.6	550.3	566.6	63 --> 151	613.4	680.4	729.0
151 --> 149	175.2	183.6	185.3	151 --> 149	175.2	183.6	185.3
149 --> 21	524.7	535.8	627.4	149 --> 21	524.7	535.8	627.4
21 --> 76	460.7	464.6	477.8	21 --> 76	579.8	663.9	791.7
76 --> 189	306.8	323.7	314.4	76 --> 189	354.2	424.7	549.0
189 --> 24	975.6	923.2	956.1	189 --> 24	1554.2	1985.6	2999.8
24 --> 0	990.7	1296.6	1865.3	24 --> 0	2090.9	2241.7	4236.3
TOTAL	4777.4	5101.1	5850.8	TOTAL	6964.4	7921.1	11412.8
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	468.2	479.9	501.0	0 --> 112	677.2	746.0	788.7
112 --> 63	343.9	343.4	356.9	112 --> 63	394.8	459.4	505.6
63 --> 151	531.6	550.3	566.6	63 --> 151	613.4	680.4	729.0
151 --> 149	175.2	183.6	185.3	151 --> 149	175.2	183.6	185.3
149 --> 21	524.7	535.8	627.4	149 --> 21	524.7	535.8	627.4
21 --> 76	460.7	464.6	477.8	21 --> 76	579.8	663.9	791.7
76 --> 189	306.8	323.7	314.4	76 --> 189	354.2	424.7	549.0
189 --> 24	975.6	923.2	956.1	189 --> 24	1554.2	1985.6	2999.8
24 --> 166	308.2	283.4	309.7	24 --> 166	1051.8	1114.5	1531.0
166 --> 112	483.5	801.4	806.2	166 --> 112	502.0	820.3	880.0
112 --> 35	993.1	1484.0	1581.3	112 --> 35	993.1	1484.0	1581.3
35 --> 131	529.3	537.7	539.0	35 --> 131	1589.8	2128.0	3517.5
131 --> 0	633.1	637.4	636.0	131 --> 0	1686.2	2768.2	5511.2
TOTAL	6733.9	7548.4	7857.7	TOTAL	10696.4	13994.4	20197.5

700 Metre Pick-Up In Order for Two-Way Case							
Minimum Time Route				Maximum Time Route			
Node to Node	6 P&D Operations			Node to Node	6 P&D Operations		
	V/C = 0.8	V/C = 1.0	V/C = 1.2		V/C = 0.8	V/C = 1.0	V/C = 1.2
0 --> 112	545.0	595.0	612.0	0 --> 112	737.0	845.9	883.9
112 --> 63	378.0	457.8	478.0	112 --> 63	399.0	504.8	581.7
63 --> 151	672.1	711.5	702.8	63 --> 151	722.6	753.2	912.7
151 --> 149	242.0	232.5	233.4	151 --> 149	330.3	373.8	395.2
149 --> 21	541.0	647.9	731.4	149 --> 21	541.0	647.9	731.4
21 --> 76	526.8	631.0	736.0	21 --> 76	659.0	882.4	1042.3
76 --> 0	950.0	1012.3	1174.8	76 --> 0	1393.2	2168.8	2323.5
TOTAL	3854.0	4288	4668.4	TOTAL	4782.1	6176.8	6870.7
6 + 2 P&D Operations				6 + 2 P&D Operations			
0 --> 112	545.0	595.0	612.0	0 --> 112	737.0	845.9	883.9
112 --> 63	378.0	457.8	478.0	112 --> 63	399.0	504.8	581.7
63 --> 151	672.1	711.5	702.8	63 --> 151	722.6	753.2	912.7
151 --> 149	242.0	232.5	233.4	151 --> 149	330.3	373.8	395.2
149 --> 21	541.0	647.9	731.4	149 --> 21	541.0	647.9	731.4
21 --> 76	526.8	631.0	736.0	21 --> 76	659.0	882.4	1042.3
76 --> 189	383.4	388.2	414.0	76 --> 189	413.2	560.7	710.6
189 --> 24	1218.6	1238.8	1211.9	189 --> 24	2022.5	2710.4	2623.2
24 --> 0	1183.5	1704.8	2345.9	24 --> 0	2407.0	4631.4	6661.2
TOTAL	5690.4	6607.5	7465.4	TOTAL	8231.6	11910.5	14542.2
6 + 6 P&D Operations				6 + 6 P&D Operations			
0 --> 112	545.0	595.0	612.0	0 --> 112	737.0	845.9	883.9
112 --> 63	378.0	457.8	478.0	112 --> 63	399.0	504.8	581.7
63 --> 151	672.1	711.5	702.8	63 --> 151	722.6	753.2	912.7
151 --> 149	242.0	232.5	233.4	151 --> 149	330.3	373.8	395.2
149 --> 21	541.0	647.9	731.4	149 --> 21	541.0	647.9	731.4
21 --> 76	526.8	631.0	736.0	21 --> 76	659.0	882.4	1042.3
76 --> 189	383.4	388.2	414.0	76 --> 189	413.2	560.7	710.6
189 --> 24	1218.6	1238.8	1211.9	189 --> 24	2022.5	2710.4	2623.2
24 --> 166	381.7	386.3	379.6	24 --> 166	1018.7	846.2	869.1
166 --> 112	622.8	490.7	469.0	166 --> 112	677.3	1193.4	1281.3
112 --> 35	1133.9	1781.9	1901.9	112 --> 35	1133.9	1781.9	1901.9
35 --> 131	705.0	705.6	698.1	35 --> 131	2653.9	2468.4	2808.3
131 --> 0	846.3	869.5	894.3	131 --> 0	2996.8	3599.3	5432.8
TOTAL	8196.6	9136.7	9462.4	TOTAL	14305.2	17168.3	20174.4

APPENDIX E

Relevant On-Going Research Projects

- E 1 Commercial Fleet Management
 Center for Transportation Research
 Virginia Polytechnic Institute & State University

Project Abstract:

Title: Commercial Fleet Management
Principle Investigator: Roger Stough
 Elly Doyle
Start Date: Oct. 1, 1996
End Date: Sept. 30, 1997
ITS User Service Bundle: Commercial Vehicle Operations Initiatives

Abstract: In recent years, significant improvements have been made in the management of commercial fleet operations as companies have adopted and, in some cases such as UPS, developed a variety of ITS type technologies for proprietary use. Adoption of these technologies by smaller transportation companies has been relatively slow mostly because of costs. As software becomes less expensive and more user friendly more companies will get interested. But, the other factor influencing decisions by companies is the lack of information about the impact the utilization of any given technology will have on their profitability. This project will test one ITS technology, an electronic surveillance system, to determine what effect it will have on reliability and efficiency in a real commercial fleet operation with a view towards developing a methodology that can be applied to other CVO ITS technologies.

The proposed project is designed to determine how much, if any, different types of surveillance information can make in fleet operations and what the cost/benefit ratio will be. The private partner in this project is NOVA Group, Ltd., a diversified transportation company located in northern Virginia with operations in Maryland, the District of Columbia and Virginia.

When combined with mobile data terminals, surveillance information technology would be more effective than surveillance data alone. However, the costs of equipping a fleet of over 100 vehicles with terminals is quite high and NOVA, the company that will serve as the test operation, is not prepared to make such an investment without knowing what the incremental benefit could be. (However, such a test could be considered for a follow-on project should the RCS be interested.) The proposed alternative to mobile data terminals is for dispatchers to identify affected drivers and communicate the congestion information to them via their radios; an approach that will satisfy the evaluation requirements for this project.

NOVA anticipates that benefits from surveillance information will fall into the two categories mentioned in the RFP: reliability and efficiency. Presumably the pick up and delivery component of all components of NOVA's operation, courier, passenger and freight, should be more reliable, if drivers are able to avoid delays due to congestion. And it is possible their operating costs could be reduced as well, since congestion delays also increase gas consumption. More importantly the reliability factor that is so critical to a delivery business, especially where intermodal connections have to be made according to timetables, should improve. The question is, by how much and at what cost?

NOVA has been developing a sophisticated routing software package that can interface with surveillance technology, which makes the company a good candidate for testing and evaluating the effect that an additional technology can have on fleet operations. NOVA participated in the recently completed Capitol IVHS Operations Test/Wide Area Surveillance, better known as the Cell Tracker project, and thus is familiar with surveillance technology.

The project will also document the system requirements and standardization issues involved in integrating information from surveillance sources in the Washington metropolitan area, since it should be of value to other companies considering the use of this technology in their operations.

Todd Madeksza, a doctoral candidate in the Institute of Public Policy's Ph.D. program, will play a major role in executing this project. Todd worked as a graduate research assistant during his Masters' degree training on a major ITS research project focusing on institutional issues in ITS and in particular the roles of the private and public sectors. This earlier work coupled with his past year as an assistant supporting a similar project make him a good fit for this project. We anticipate that Todd will write a dissertation on ITS benefit assessment which is the base purpose of this project.

The Center for Transportation and Land Policy in the Institute of Public Policy at George Mason University in partnership with NOVA Group, Ltd. proposes:

to conduct a test of surveillance technology to determine the value that it can bring to the courier, freight and passenger transportation industry in terms of improvements in reliability and efficiency; and to analyze the cost effectiveness of utilizing this technology.

Objectives:

To determine to what extent surveillance technology can contribute to improvements in fleet management operations;

To analyze the costs in relation to changes in efficiency and reliability and the effect on a company's profitability.

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