Traffic Management in Urban Areas under Freight Regulatory Initiatives

Mohammad Fozlul Haque Bhuiyan

A Thesis

in

The Department

of

Concordia Institute for Information Systems Engineering

Presented in Partial Fulfillment of the Requirements
for the Degree of Master of Applied Sceince (Quality Systems Engineering) at
Concordia University
Montreal, Quebec, Canada

March 2011

CONCORDIA UNIVERSITY

School of Graduate Studies

This is to certify that the thesis pepared

By: **Mohammad Fozlul Haque Bhuiyan**

Entitled: **Traffic Management in Urban Areas under Freight Regulatory Iitiatives**

and submitted in partial fulfillment of the requirements for the degree of

Master of Applied Sceince (Quality Systems Engineering)

Complies with the regulations of the University and meets the acceptaed standards with respect to originality and quality.

Signed by the final examining committee:

………………………….. Dr. Amr Youssef (Chair)

……..... Dr. Onur Kuzgunkaya (External Examiner)

... Dr. Abdessamad Ben Hamza (Internal Examiner)

…………………... Dr. Anjali Awasthi (Supervisor)

……………………… Dr. Chun Wang (Supervisor)

Approved by

……………………………………………………………

Chair of Department or Graduate Program Director

………20…… ……………………………………………………………….

Dean of Faculty

ABSTRACT

Traffic Management in Urban Areas under Freight Regulatory Initiatives

Mohammad Fozlul Haque Bhuiyan

The increasing awareness of non-sustainable impacts of urban freight movements on city traffic congestion, environment, and economy has boosted the amount of research in this area in recent years. Implementation of freight regulatory initiatives (policies) such as access-timing-sizing restrictions has become very important to deal with the nuisances associated with freight transport in cities. There is a lack of holistic understanding of the implications of freight transport policies on traffic management and no specific methodology aimed at analyzing, planning, and implementing urban freight regulatory policies exists in literature. In this thesis, we address the problem of evaluating and implementing freight regulatory initiatives for better traffic management in cities. The first part of the thesis presents an integrated approach based on microscopic traffic simulation and design of experiments for evaluating and selecting freight restriction policies for a specific city. In the second part, a conceptual implementation model is proposed for implementing the selected freight restriction policies by addressing the decentralized urban freight management problem and socioeconomic values of freight from cities point of view.

ACKNOWLEDGMENTS

First I would like to express my profound gratitude to my supervisors Dr. Anjali Awasthi and Dr. Chun Wang for all the supervision, encouragement, guidance, tireless support and help they provided over the last two years; my recognition is not only limited to academic issues.

I would like to thank my family and also all my colleagues. It is beyond doubt that I would not have reached this level of education without their support and encouragement.

I am also thankful to the Government of Canada and Concordia University, for providing different kind of financial support that enabled me to concentrate on my work and successful preparation of this thesis.

Finally, I proudly dedicate this thesis to my recently born baby Faiza Zahra Bhuiyan.

Mohammad Fozlul Haque Bhuiyan
March 2011

Table of Contents

List of Figures

List of Tables

page

List of Acronyms

BESTUFS	– BEST Urban Freight Solutions, European Commission
BTS	– Bureau of Transportation Statistics, United States
CITM	– Le Comité Interrégional pour le Transport des Marchandises, Montreal
	– Interregional Committee for the Transportation of Goods, Montreal
CSPPSFT	– Committee for Study of Public Policy for Surface Freight Transport
ERTRAC	– European Road Transport Research Advisory Council
FHWA	– Federal Highway Administration, United States
HICOMP	– Highway Congestion Monitoring Program, California
OECD	– Organization for Economic Co-operation and Development
ACQ	– Quebec Trucking Association, Canada.
TAC	– Transportation Association of Canada
TRB	– Transportation Research Board, United States
UTTF	– Urban Transportation Task Force, Canada

Chapter 1

Introduction

1.1. Background (Urban Freight and Consequence)

Urban freight is the part of freight transportation most visible to the public. Freight Management in urban areas includes implementing various policies for increasing the efficiency of freight and commercial transport while reducing the congestion in urban areas. It is sometimes described as “the last kilometer problem” because it represents the final delivery of goods to retailers or consumers. However, it also includes the movement of raw materials and unfinished goods between factories and warehouses, and the movement of finished goods from producers to distribution centers. Urban freight, as considered in this study, includes only the most prominent urban freight mode, the Trucking.

Urbanization has been a clear trend in the past decades. Urban areas now constitute the living environment of over 72% of the population, and as urbanization continues the proportion residing in urban areas is expected to increase to 84% by 2050 (European Commission, 2009). This alteration in the pattern of distribution of people and the logistic systems to facilitate access and availability of goods and services will result in substantial growth in service activities and the numbers of vehicles in urban areas required to accommodate their demands. Urban productivity is highly dependent on the efficiency of these transport systems and the capacities of the infrastructure to respond to changing patterns of demand. To support the growth several cities are implementing policies intemperately focusing on physical infrastructure for accommodating freight movements efficiently.

Globalization has also put a tremendous strain on existing transport networks and freight transport issues have risen sharply on the critical agenda of most countries, especially in cities where population density is the highest. Effective freight transport services are one of the key success factors for cities seeking to compete in the globalized economy (Docherty, 2004). The benefits of goods transport in urban areas comes with negative impacts such as air pollution and congested roads. When the negative impacts of urban freight transport became more and more visible and noticeable, the interest of policy-making bodies for urban goods movement started to grow. The appearance of the concept of sustainable transport in policy reflections during the nineties also increased the policy-makers' interest for urban goods transport (Allen et al., 2000; Anderson et al., 2005). Most policy measures sound familiar; however there is a serious lack of detailed understanding of the impacts of many of these measures and their transferability to different contexts (May et al., 2003).

As congestion continues to build on roadways, it is becoming important to improve the operational strategies of the roadways. This is especially true in the urban areas. One of the strategies most often promoted as a means for increasing roadway capacity, hence reducing congestion, is the urban freight regulatory policies. Taking the negative and positive impacts of these policies into consideration in developing an efficient and environmentally-friendly urban transport system is essential for the economic health and the quality of life of cities. According to the experiences of different programs and the national and international pilot projects of R&D, there is no standard solution for resolving the problems due to an inappropriate organization of freight transport (Cybernetix, 2002). The increasing congestion and decreasing city accessibility make it quite difficult to achieve high levels of efficiency in urban freight transportation (Anderson et al., 2005). The growth in freight is a major contributor to congestion in urban areas and on intercity routes. Several surveys in different European cities show that urban freight transport accounts for about 10-15% of total urban traffic in terms of number of vehicles, and 20-25% in terms of car-equivalents vehicle-km (BESTUFS II, 2008).

The growth of road freight transport within and through cities has increased significantly in the past decades and prognoses indicate that this trend will continue in the future. Furthermore, as noted by Stantchev and Whiteing (2006), urban freight transport deals primarily with the distribution of goods at the end of the supply chain therefore many deliveries tend to be made in small loads and in frequent trips, resulting in several vehicle kilometers travelled. As a result urban areas suffer from constantly increasing number of trucks involved in freight transport operations. Large presence of trucks, both in rural and urban areas, degrades the speed, comfort, and convenience experienced by passenger car drivers. Trucks have slower braking and acceleration rates than passenger cars, which increases frustration of drivers in congested situations. The problem is severe in old and port cities which are the important players in the process of globalization.

Congestion can be reduced by either reducing traffic (travel demand), or by increasing road capacity (supply). Reduction of travel demand includes: Road pricing, Congestion pricing, Road space rationing, and Policy approaches (Incentives to use public transport, Online shopping promotion, etc). Increased road capacity includes: Adding more capacity at bottlenecks, Creating new routes, and Traffic management improvements. A major change in insights was the observation that putting down more roads and more road capacity cannot solve congestion problems on its own (Visser et al., 1999). So increasing the road capacity was bound to limits, with the result that less road capacity is available for freight transport (Banister, 2000). This also leads to the emphasis on other types of regulations to deal with urban freight transport. In this research we will focus on improving Traffic management which is the least expensive in terms of road capacity improvement. Most transportation researchers agree that some form of pricing would be the one of the best ways for reducing traffic congestion i.e. improvement of Traffic management (Taylor, 2002). But many public officials see congestion pricing, toll roads and parking charges as politically risky and unpopular, and insist that traffic congestion be mitigated by other effective means.

Cities are complex spatial structures having a high level of accumulation and concentration of economic activities supported by transport systems. Cities are reactive, rather than proactive, when faced to traffic issues and habituated to apply restriction policies on freight trucks on a trial and error basis or follow other cities' experience to alleviate the nuisance associated with freight transport in urban areas. Since all cities do not have the same geographical structure, built environment, economic conditions, municipal administration support, so their practices in freight transport and logistics activities cannot be directly adopted by one another. The effects of experiences are strongly related to the characteristics of the city. To achieve urban sustainability, new models for the management of freight movements within city limits are warranted (Lindholm and Behrends, 2010).

Despite the significance and the problems associated with selecting appropriate regulatory policies for urban freights in cities, city administrators have not yet come up with adequate techniques to deal with a specific set of regulatory policies for traffic management while simultaneously focusing on cities socioeconomic benefits. Some cities have implemented policies for limited vehicle access considering a number of objectives and implications such as financing of infrastructure, traffic management, reaching environmental targets (Quak and de Koster, 2006b). But none of the limited access policies put efforts on differentiating higher priority freights from the lower priority ones from socioeconomic point of view (for example how to differentiate freights loaded with perishable goods or emergency medical equipment from freights loaded with luxury furniture equipment or construction materials in case of limited access). For limited access policies, the challenge still ahead is whom to allow and whom not to when socioeconomic values are the main concern especially in case of freight transportation. The purpose of this research is twofold: first, to identify the most efficient freight restriction policies for a city, and second, to develop a well-balanced implementation model for the significant restriction policies by addressing the decentralized urban freight management problem. This research should be seen as a contribution to laying the groundwork for determining efficient freight regulatory policies for specific city as well as a well-balanced policy implementation framework to allow limited number of freight trucks with higher socioeconomic values to enter the city keeping into account the dynamic traffic conditions of the city.

1.2. Challenges for Cities

Efficient management of urban freight movement is essential to strengthen the economic structure of a city and to reduce nuisances associated with it. The literature search (Crainic et al., 2004) revealed that public authorities didn't pay much attention to urban freight transport issues and the overall goal of implementing different freight regulatory policies is to improve highway operations and level of safety. Few challenges associated with efficient freight traffic management from cities point of view are presented as follows.

Understanding the Real Demand

Freight transport in urban areas is still not well understood and there is no widespread methodology specifically aimed at the analysis and planning of such areas (Lindholm and Behrends, 2010). Insufficient awareness and understanding of freight industry needs has impeded the development of support for necessary improvements. To achieve urban sustainability, new models for the demand management of freight movements within city limits are warranted. Moreover, unavailability of relevant information data and communication gaps have led to ambivalence and even resistance on the part of government, public and other stakeholders to determine the actual demand. Historically, there has been very little sharing of critical data among industry stakeholders and governments. Governments have rarely supported the value of sharing information with industries. From an industry perspective, companies that compete with each other are often reluctant to share information for competitive reasons and/or competition laws. Inaccurate demand estimation results from lack of information sharing and lack of co-operations among stakeholders.

Lack of Urban Freight Data

Good information enables good decisions. Freight data can play an important role by demonstrating the existence of problems, aiding analysis to identify alternative solutions, and measuring results against established objectives. In most cities, city planning and traffic surveys are based only on passenger transport without adequate consideration of the needs of freight transport. Adequate interesting/important data about freight transport within cities is missing. Some initiatives exist to collect specific freight data from these projects at national level; however it is more difficult to extract city level information. To decide between different solutions in order to improve the congestion, pollution and varied problem concerning the road use in urban areas, a large survey realized within the framework of WP3 by BESTUFS (involving 78 experts in 11 different European countries) revealed the lack of urban freight data (BESTUFS II, 2008).

Limited Techniques for Policy Selection

Inconsistencies in freight-related data, knowledge and approaches among different levels of government and neighboring municipalities create challenges in determining significant policies for truck route regulations and network consistency. Regulations that limit the way goods can be delivered also limit opportunities for creative solutions. For example, time restrictions, access restrictions, vehicle sizing restrictions have significant impact on urban freight movement in the city. There may be opportunities to apply a regulatory policy and relax it on certain operating hours to diffuse freight demands over time and reduce competition for travel and delivery space in peak periods. Sometimes policies are not recommended to be implemented alone since they are naturally supportive of each other, and policy coordination greatly strengthens the chance for successful implementation, notably through reduced negative reactions from the private sector. A well established methodology is required for selecting a set of significant policies for a city.

Limited Techniques for Implementation of Significant Policies

Poorly coordinated public and private decision-making processes could impede the implementation of solutions. Government and industry stakeholders frequently speak different languages and do not understand each other's plans and make investment decisions. In addition, the public is not fully aware of the importance of efficient freight transportation to the city's socioeconomic health and quality of life. The freight restrictions are related to city's structure, environmental nuisances, economic activities, cultural values, and regulations on operating hours of a city. Since these constraints can be in conflict, inevitably city-specific optimization is needed. Moreover, several actors are directly or indirectly involved in urban freight transport. Therefore to find an optimal compromise between interests of the involved actors is a big challenge.

Limited use of Technology to Optimize and Manage Urban Freight

There is a massive scope to improve the efficiency of logistics operations through the greater use of information technology (Whiteing et al, 2003; Czerniak et al, 2000; Stantchev and Whiteing, 2006). Technology provides access to information about traffic conditions and route delays. There is an opportunity to use innovative technology and efficient methodologies which would increase the efficiency of freight movement by providing real-time travel information to optimize routing or finding ways to better manage goods movement. More consolidated information at the city level would also provide benefits in reducing traffic congestion and balancing socioeconomic values in freight management for city. Large majority of cities have not yet found adequate solutions to help optimize the urban movement of goods (Dablanc, 2007).

1.3.Freight Regulatory Initiatives (Policies) for Cities

Sustainability of urban freight transport largely depends on the local regulations in cities. Regulation seems to be the easiest way for the government sector to control the whole system; for example, by introducing weight restriction it is possible to prevent large vehicles from entering restricted zones, such as residential areas and city centers. Eco-zoning is a new trend that allows only low emission vehicles to enter the restricted zones. The restrictions can be flexible by time period, level of emissions, weight limit, and size of vehicle. Different case studies on city access restrictions show that in the last years, innovative schemes, new concepts and trials have been done in the field of environment related schemes and access charging schemes (BESTUFS II, 2006). In this thesis, we will focus on the following three regulatory policies.

Access Restrictions

Access restriction policy is defined as restricting certain roads or areas in cities for urban freight movement. This involves restricted movements of all trucks from traveling on certain routes or delivery zones. For example, in Boston, vehicles with commercial license plates are prohibited from using certain streets in downtown. Only certain companies such as U.S. Postal Service and newspapers are allowed to enter after 2:00 pm, while other companies who want to enter the restricted zone have to apply for a one day special permission (Seattle Urban Mobility Plan, 2008). Regional truck bans have been considered in a number of cities including London (Allen et al., 2004), Los Angeles (Ogden, 1992), Enschede-Netherlands (Rasch, 2006), and most recently Barcelona-Spain (Dablanc, 2007).

Figure 1 Access Restriction for Trucks

Timing Restrictions

In timing restriction policy, urban freight vehicles are allowed to perform movements inside the city centers only during specific hours of the day. One of the popular examples is “off-peak delivery” as the name implies, includes measures intending to shift deliveries to the off-peak period. Nighttime delivery programs have been implemented with much success in many European cities (Geroliminis and Daganzo, 2005). Analysis of the application of time restriction in Italian cities show that some cities prefer to restrict access late in the morning and early in the afternoon to favor tourism (Ferrara, Parma, Siena, Ravenna, Vicenza); others prefer to restrict access during the morning peak (Piacenza, Parma, Rimini); others distribute restrictions all day long (Bologna, Roma, Firenze, Lucca) (Cityports, 2005; Maggi, 2007). Daytime restrictions on freight trucks to enter the city are existent in many Asian cities since several years. Time restriction scheme has been introduced in Reims-France (Littiere, 2006) to implement time delivery windows for each delivery vehicle entering the inner-city area.

Source: Google image

Figure 2 Timing Restriction for Trucks

Vehicle Sizing Restrictions

Vehicle sizing restrictions involve the movements of certain types of vehicles with prescribed size, weight and loading factor dimensions in the city. A familiar name for these types of restrictions is the “Truck ban policy”. The focus of truck bans is generally on larger commercial vehicles. Here, truck ban refers to restrictions for a specific kind of truck, prohibited from the downtown during a certain period of time. A truck ban policy has been implemented in Liège-Belgium (van Isacker, 2006). Wisetjindawat (2006) studied the implementation of truck ban prohibiting trucks larger than 5 tons from entering downtown Tokyo during peak hours. In 1991, large truck ban policy was also applied in Los Angeles where large trucks were defined as commercial vehicles with three or more axles, including tractor-trailer combinations (Campbell, 1995).

Source: Google image

Figure 3 Vehicle sizing Restriction for Trucks

1.4. Problem Statement

Freight transport plays an important role in economic growth of cities and at the same time is a major contributor of negative impacts on road transportation and environment of urban areas. To reduce the nuisances associated with freight transportation, cities need regulatory policies and a well defined methodology to select and implement them so that maximum socioeconomic benefits can be achieved. The challenge is to find a set of freight regulatory policies that will be significant for the city.

Here in this research we will address two questions the first one is, how to select significant freight regulatory policies for cities, and the second one is, how to implement those regulatory policies in a decentralized environment while addressing cities socioeconomic benefits.

1.5. Thesis Contribution

In literature, there is no widespread methodology specifically aimed at the analysis of freight regulatory policies, their implementations and impacts on traffic flow in cities while considering the decentralized nature and socioeconomic benefits of freights. In this thesis in the first section, we target the problem of assessing the impact of three freight regulatory initiatives (access-timing-sizing regulations) on traffic management in urban areas. A three step approach based on urban traffic simulation, design of experiments (DOE) and optimization is proposed along with an application on City of Montreal.

In the second part of the thesis, a well-balanced policy implementation framework is developed to allow limited number of freight trucks with higher socioeconomic values to enter the city in certain time intervals keeping into account the decentralized nature of urban freight and the dynamic traffic conditions of the city. The model comprises an iterative bidding framework for freight transport access management in cities that require implementing periodic access limits on city highway entrances.

1.6.Thesis Outline and Publications

The thesis is carried out with an aim to develop a methodological framework for cities to evaluate and select significant freight regulatory policies for the city and develop a well-balanced implementation model considering the decentralized nature of the urban freight. The structure of the rest of the thesis is as follows. Chapter two presents the literature review. Chapter three describes the methodological framework of solution approach which divides the thesis into two main parts. The first part of the thesis (Chapter four) presents the methodology for selecting freight regulatory policies for cities. The second part (Chapter five) formulates the decentralized urban freight management problem and presents an agent based iterative bidding model. Chapter six summarizes the thesis with conclusions and future works.

The work carried out in this thesis resulted in following publications:

- M. F. H. Bhuiyan, A. Awasthi, C. Wang, “Decentralized Urban Freight Management through market based Mechanisms”, 2010 IEEE International Conference on Systems Man and Cybernetics (SMC), 10-13 Oct. 2010, Istanbul, pp. 1488 – 1494.
- M. F. H. Bhuiyan, A. Awasthi, C. Wang, “Investigating the Impact of Access-Timing-Sizing Regulations on Traffic Management in Urban Areas”, Submitted.
- M. F. H. Bhuiyan, A. Awasthi, C. Wang, “An iterative bidding framework for Decentralized Urban Freight Management”, Submitted.

Chapter 2

Literature Review

2.1.Urban Freight Policies and their Challenges

Regulatory policies towards urban goods movements can have a number of effects on city. For example, policies aimed at improving the efficiency of urban freight contribute to national or regional economic development as well as benefit other road users through, for instance, reduction in congestion levels. Policies can also be designed to help reduce the adverse impacts of freight transport on environment and increase highway safety. Traditionally, national governments and urban authorities have not had a good track record in involving urban freight transport actors in decision-making and have not sufficiently considered urban freight requirements within urban development strategies and plans. Participation in policy-making has been often kept to a limited consultation exercise. Most of them view freight transport as a problem rather than an essential activity, and have focused their attention on individual vehicle activity rather than thinking about the overall system. As noted by Quak and de Koster (2006, 2007), Browne et al. (2005), and Holguin-Veras (2007, 2008), very limited literature exists in this direction.

Initially, city authorities and municipalities tried to resolve the freight related problems by managing urban freight delivery operations with different measures. Litman (2003) and Gorman (2008) report that although freight vehicles represent only 10-20% of total vehicle mileage, they tend to impose large impact on traffic flows and reduction in freight traffic can significantly reduce congestion. Restricting freight trucks from entering the congested zones or during congested timings can cause an incredible reduction in congestion in cities. By now, many regulatory policies have been developed by authorities in different urban areas to improve the goods distribution process. Several types of restrictions that can be imposed on goods delivery vehicles to control congestion are summarized by Browne et al. (2005). These policies have been proposed to improve the existing urban good distribution system and can be categorized into: regulatory policies, fiscal measures, land-use and planning measures, technological innovations, investment and practice innovations (Visser et . al., 1999; Maggi, 2007). Munuzuri et al. (2005) provides a classification of urban freight transport policies for local authorities. They distinguish four groups of policies: (i) policies related to the public infrastructure (e.g. transfer point, modal shift); (ii) policies related to land use management (e.g. parking area planning, load/unload zones); (iii) policies related to access conditions (e.g. spatial restrictions, time restrictions); and (iv) policies related to traffic management (e.g. scope of regulations such as freight zone, street or carrier classification). BESTUFS II (2007) categorizes urban freight transport initiatives into five themes as listed below.

- *Policies focused on Operations* – to improve aspects of operational efficiency including speed and reliability of deliveries, reduction of costs, convenience and customer service, and operational safety.
- *Policies focused on Land use and infrastructure* – to reduce the demand for freight transport by thorough reorganization of the land use patterns in urban areas (retail, commercial, industrial, freight transport operations, residential).

- *Policies focused on Environment* – to reduce or minimize the environmental impacts of urban freight transport.
- *Regulatory policies* – to influence urban transport behavior and patterns through implementation of traffic and transport policies.
- *Policies focused on Technology* – to improve operational performance of equipment and facilities, or reduce environmental impact through application of technological initiatives.

Wisetjindawat (2010) summarizes the information on freight transport policies of several regions including Asia, Europe, and United States in the report "Review of good practices in urban freight transportation". The report also classifies policies into five different groups and discusses each of the categories based on their contribution to achieving the stated objectives. Particular points of concern with each policy are also presented in the report.

When attempting to implement urban freight regulatory policies, careful analysis and evaluation processes are required beforehand to ensure that the negative effects do not outweigh the positive ones (LEAN, 1999). The most important thing when dealing with freight movements is to find the best compromise among the varied interests of the different actors. Most freight experts emphasize the importance of creating win-win solutions when deciding freight restriction policies. May et al. (2006) identified barriers in planning urban freight policy and implementing urban transport measures. Quak and de Koster (2006, 2007) and Browne et al. (2005) focus on the effect of time-access regulations on different supply chains. The successes of freight regulatory policies are very dependent on cooperation from the private sector. Careless restriction policies will elicit negative responses from the private sector (Wisetjindawat, 2010).

The government authorities are still working on efficient ways of planning and implementing regulatory policies to least affect the efficiency of logistics operators and achieve continuous improvement in the economic, social and environmental performance of freight systems.

2.2. Policy Initiatives on Urban Freight Transport

2.2.1. European Context

Road traffic in many urban areas continues to grow at a faster rate than road capacity. Where this is occurring, congestion, delay and unreliability of the network is worsening. UK road network as the most congested in Europe, costs the economy £20 billion a year (Freight Transport Association, 1996). The significant share of these costs is generated by delayed road freight traffic in urban areas. In the last 30 years, freight transport in Great Britain has increased significantly. According to Summerfield and Babb (2003), movement of goods by road accounts for majority of this growth as road freight activity in the UK rose from 88 billion tone kilometers in 1972 to 157 billion tone kilometers in 2001.

Since the beginning, European cities such as France, Italy, Germany, Netherlands, etc. have been active in urban goods transport policy issues (Karrer et al., 2007). Active research into urban freight transport issues took place in the UK during the 1970s. Much of this was related to concerns about the safety of heavy goods vehicles in urban areas, and resulted in studies into transshipment centers and other vehicle restrictions (Battilana and Hawthorne, 1976; Hassell et al., 1978). Most of the policies aimed at reducing the impact of freight transport on cities are punitive to freight transport operation for example, vehicle weight and size regulations; access time regulations; permanent road closures; night deliveries; etc. Urban policies targeted on freight mobility appear to be quite inefficient (Dablanc, 2007). Access time restriction and vehicle restriction are increasingly used, especially in Western Europe, to improve social sustainability in urban areas. An increasing number of European cities are engaged in the design and implementation of demand management strategies based upon the concept of 'controlled access', for urban freights.

European research into urban freight transport has increased since the late 1990s (Ambrosini et.al., 2001; Meimbresse and Sonntag, 2000; Thompson and Taniguchi, 2001). More recently there has been growing interest in the logistics of collection and delivery services in town and city centers, in particular, both on the part of the government, researchers, companies and environmentalists. Many European cities have introduced access regulatory schemes. European Commission (2010) performed a systematic search on 417 European cities and only 78 of those cities had no access regulatory policy.

The urban freight transport and distribution considerations by local authorities in the European countries have taken place as a reaction to problems, usually arising from complaints made by residents and other road users. Most local authorities in urban areas have not developed coherent freight transport policies to the same extent that they have done with their public transport policies. However, local authorities are being encouraged by central Government to focus more on freight transport and include urban distribution and sustainability in their local transport plans. The European Commission funded "BEST Urban Freight Solutions" (BESTUFS) thematic network was formed in 2000. The main objective of BESTUFS is to identify, describe and disseminate best practices, success criteria and bottlenecks of urban freight transport solutions. Furthermore, BESTUFS aims to maintain and expand an open European network between urban freight experts, user groups, associations, ongoing projects, the relevant European Commission Directorates and representatives of national, regional and local transport administrations and transport operators. The project team organizes regular workshops and conferences all over Europe and reports about interesting urban commercial transport related developments, demonstrations and events on European, national, regional and local level. The initiative has received considerable attention from practitioners as well as from researchers and all information is publicly available on the web site (www.bestufs.net).

2.2.2. North American Context

Achieving sustainability is the greatest challenge facing the urban transportation community in Canada. It will not be easy, and it will not be done overnight. As noted by Transport Canada (2006), truck traffic has grown faster than private vehicle traffic during the last decade under the unprecedented stimuli of deregulation and a substantial amount of recurrent congestion has occurred due to Trucking. Same thing was also reported in United States by CSPPSFT (1996) for trucking. They noted that truck transport tends to impose the greatest congestion costs, although exact impacts depend on specific conditions, such as the route and travel time. In 2005, congestion caused Americans to consume an additional 2.9 billion gallons of fuel and spend an additional 4.2 billion hours in their vehicles, for a combined total economic cost of $78 billion (Schrank and Lomax, 2007). Traffic congestion in Canada's major urban areas costs Canadians a bare minimum of about $3 billion a year, according to a new study released by Transport Canada (2006). A major portion of the congestion results from the growth in freight transport in urban areas and on intercity routes.

The 1986 survey of state practices by the Federal Highway Administration (FHWA, 1986) identified the most common reasons given by the states for using truck restrictions which are: (i) to improve operations (14 states); (ii) to reduce accidents (8 states); (iii) for pavement structural considerations (7 states); and (iv) for restrictions in construction zones (5 states). Several studies have shown that when properly implemented, truck restrictions can increase the overall operational efficiency of freeways and lead to improved traffic safety. A decade later another study conducted by Wishart and Hoel (1996) reported that a variety of truck restriction policies have been implemented throughout the United States. The study also revealed that generally states restrict trucks by speed, lane, time, or route.

While the Europeans and Asians with their denser urban cores and narrower streets have had to face the challenge earlier with the freight policies, Canadian cities are just now beginning to see urban goods movement as an increasingly important part of urban land use planning and traffic planning. A recent study by Transport Canada, (2004) suggested a number of freight restriction policies (e.g. night-time and off-peak hour deliveries, restriction of trucking on certain roads during peak periods) beside the emergence of Freight Stakeholder Partnerships and other urban and regional efforts across Canada. One initiative is Urban Transportation Task Force (UTTF) in 2003 by Council of Deputy Ministers Responsible for Transportation and Highway Safety. The goal of UTTF is to explore urban transportation issues and sharing of information.

A good initiative by California Department of Transportation (2009) is the "Annual Data Compilation" (2008 HICOMP) program. The purpose of the program was to measure congestion occurring on urban-area freeways in California. The 2008 HICOMP presents congestion data on California urban freeway segments with a history of recurrent congestion although it does not include the congestion on local surface streets. The Greater Toronto and Hamilton Area (GTHA) are a significant generator of goods movement activities in Canada. To coordinate the relationship with the movement of people in order to maintain the competitiveness of the regional economy, a study was undertaken by Metrolinx as a first step to explore urban freight transportation in the region. This study considered the challenges and opportunities for improving urban freight effectiveness and efficiency in the GTHA (Metrolinx, 2011). The greater Montreal area is a hub for transportation of freight by roads to Ontario and other provinces and, above all, to American markets. The Ministry of Transports Quebec (2009) recently published a guideline titled "Policy on Road Freight Transport 2009-

2014" where they outlined their future initiatives toward urban freight policies and its improvement in the region.

2.2.3. Other Cities

The truck restriction policy in Metro Manila is one of the most well-known cases of large truck restrictions currently in effect (Ogden, 1992; Campbell, 1995). There are also examples of several other cities such as Beijing, Kualalumpur, etc that have implemented truck restrictions as a measure to mitigate traffic congestion. Truck regulation in Bangkok began with a time-restricted ban in the city center to alleviate traffic congestion. The truck restriction scheme underwent several changes before being implemented in its current stage (Castro and Kuse, 2005).

A study by Jenkins and Kennedy (2000) concludes the lack of information on existing transport demand and the situation is particularly serious for road freight transport in Asia. They also emphasize on the introduction of vehicle size and weight regulations on certain roads in Central Asia to make efficient use of large trucks and to minimize overall road transport costs.

To emphasize the research and development in City Logistics and urban freight transport, the Institute for City Logistics (ICL) was established in Kyoto, Japan in 1999. The Institute is a centre of excellence for bringing together academics and practitioners to exchange knowledge, experience and information through conferences and short courses. ICL carries out fundamental investigations and tests their applicability to the real society.

ICL also provides the platform for exchange of knowledge, experience, and information about City Logistics and urban freight transport (Taniguchi et al 2003). The Asian Development Bank (ADB) has assisted the countries of the Central Asian Region (Kazakhstan, the Kyrgyz Republic, China, Tajikistan and Uzbekistan) in identifying policy issues. The countries concerned now wish to institutionalize an institutional framework, including the establishment of a Ministerial-level Conference supported by a Transport Working Group (TWG) for improving transportation policy issues in the region (Jenkins and Kennedy, 2000).

2.3.Effectiveness of Regulatory Initiatives

There is not much research on the effectiveness of regulatory policies, freight transport operations and costs. Exceptions are Allen et al. (2003) who found that the effectiveness depends on the size of the fleet and the width of the serviced area. In a series of papers Holguin-Veras (2007, 2008) analyze the potential for night delivery as a way to decouple passenger traffic peaks from freight traffic peaks using stated preference data and discrete choice modeling. In case of vehicle sizing restriction, smaller trucks can have same or even more negative effects compared to few large trucks, as McKinnon (1998) demonstrated in the context of evaluation of transshipment option. The same argument is put forward by Holguin-Veras (2006). Quak and de Koster (2006b) find that the use of vehicle weight restriction results in decreased transport efficiency.

Restrictions by time-of-day are ostensibly instituted to prevent trucks from using a lane or a road during those times when traffic congestion is at its highest level. Studies of states by Mannering et al. (1993) and Wishart and Hoel (1996) found that time-of-day restrictions vary in application ranging from restriction during a defined peak hour to restriction only in 12 hours of daylight. Kearney (1975) argued that complete restriction of truck traffic on urban freeways could potentially increase average network speeds by about 10 mph during the peak hours.

Route restriction involves restricting all trucks, or trucks of specific size, weight, or axle classification, from traveling on certain routes. In some situations, trucks are prohibited from entering the central business district through designation of bypass and business routes. Another route restriction method is designed to guide trucks along specific roadways to downtown areas, industrial facilities, or major commercial areas. The literature search did not find any study quantifying the effectiveness of route restrictions.

The inefficiency in urban freight transport can result from variations in urban freight transport policy measures in different urban areas or different parts of a single urban area. For example, different access or loading time restrictions or vehicle emissions requirements within different parts of a city can be problematic to companies serving these locations with a single vehicle. It can result in the need for additional goods vehicles and goods vehicle trips. Such inefficiencies can have both financial and environmental impacts and are therefore best avoided from both the perspective of companies and the wider society. This suggests the need for collaboration between public policy makers with responsibility for freight transport regulations in urban areas as well as consideration of the benefits of harmonizing such regulations to avoid operational inefficiency.

Several researchers (Miller et al. 2001; Böhler and Reutter, 2006; Piecyk and McKinnon 2007) provide guidelines for increasing freight transport efficiency. A workshop entitled "Managing urban freight transport by companies and local authorities" was held on 21/22 September 2006 in Vienna. The workshop addressed the issues of the efficiency of urban freight transport operations. It considered the problems experienced by freight transport operators due to regulations and policy measures in towns and cities, initiatives taken by urban authorities to improve the working environment for the freight transport sector, and working relationships between urban authorities and freight transport operators. The main conclusions of the workshop were that more consideration of the impact of urban transport initiatives on freight transport was needed in European towns and cities.

2.4. Methodologies for evaluating Freight Regulatory Initiatives

Few studies exist in terms of analysis tools and assessment procedures for evaluating the feasibility of an intervention in the field of city logistics (Cityports, 2005). This methodology consists of three phases. During the first phase key information is collected on critical issues related to the delivery of goods in the urban context where an intervention is to be done is analyzed. In the second phase an integrated solution is identified, which takes into account all main aspects, such as technical/logistics aspects, political/administrative aspects and involvement of stakeholders. In the third phase a cost-benefit analysis is carried out to assess external costs and benefits and how stakeholders share them. Apparently, this research has not devised a new procedure, instead has developed a patchwork based on several relevant European experiences. In fact, the methodology aims specifically to build a common vision of the operating mechanisms of urban logistics, of the modeling criteria, and of the evaluation criteria; it also provides guidelines and tools for the study of the haulage of goods, determination of solutions coherent to the context, and the development of feasibility studies.

A study by European Commission (2010) summarizes the nature and functioning of all the existing access restrictions schemes (they consider all the regulatory policies discussed till now under this scheme) in 417 European cities, the study confirmed that the availability of data on the impacts of scheme implementation is extremely limited, and in general of episodic nature. The study concludes that many of the drivers, enablers, and barriers experienced by cities that decide to implement access restriction policies, are common to all types of schemes, irrespective of the specific features of the scheme itself. It also concludes that, cities deciding to implement access restriction policies effectively shall make adequate balance between policy issues and implementation challenges, jointly considering available resources and local environment.

According to Sonntag (1985), there are two main approaches for freight transport modeling: Operational Research (OR) models and statistical and probabilistic models (SP). Both are considered as macro-economic models, in order to calculate the global impacts of urban goods movement on congestion. BESTUFS II (2008) mention micro-simulation modeling as another promising approach beside these two. In this thesis we use both DOE and micro-simulation modeling.

2.5. Implementation of Freight Regulatory Initiatives

Although, a large number of cities in Europe have already implemented different regulatory policies for freight transport especially for trucking but none of them have used a formal methodology, most of them reported several drawbacks and modifications afterwards. They have used experiment based approaches like trial and error to cope with the problem. Most regulatory decisions concerning urban freight transport in European towns and cities have been taken by urban or regional authorities over the last few decades. Some of these authorities have been relatively active in terms of freight policy making but, until recently, did relatively little in terms of developing strategies and taking regulatory actions (BESTUFS II, 2007). Instead, most of the transport efforts of urban and regional authorities have been focused on passenger transport rather than freight. Wherever freight-related action has been taken by urban and regional authorities, most of it has been concerned with limiting the negative impacts of urban freight operations, rather than considering the economic and social importance of these activities and identifying methods by which to improve its efficiency.

An overview of recent development of freight transport management and traffic management using Intelligent Transport Systems (ITS) aimed to make optimum use of vehicles and infrastructure is given by Jorna and van Drunen (2002). They focus on integrated development approach incorporating the real time traffic demand information with a view on supply chain management perspective to deal with increasing congestion on the road networks and increasing competition in freight transport business. Different type of solutions or initiatives that can be implemented by local administrations in order to improve freight deliveries in urban environments are summarized by Muñuzuri et al. (2005). Awasthi and Proth (2006) present a systems based approach for city logistics decision making. van Dam et al. (2007) develop an integral model for intermodal freight hub location decisions using agents. A conceptual design with illustrative case study using an agent based model for planning the location of intermodal freight hubs was presented in their study. Song and Regan (2004) present an auction based carrier collaboration mechanism to facilitate economically efficient corporation among functionally equivalent small and medium sized trucking companies based on a post market exchange. They use global optimization to deliver economically efficient solutions to every participant in the network.

In recent years, we find some studies on application of agent based modeling approaches for urban traffic management in transportation literature. Lee et al. (2010) present a collaborative real-time traffic information generation and sharing framework for the intelligent transportation system. Doniec et al. (2008) present a behavioral multi-agent model for road traffic simulation. Logi and Ritchie (2002) present a multi-agent architecture for cooperative inter-jurisdictional traffic congestion management. Hernandez et al. (2002) present a multi-agent architecture for intelligent traffic management systems. Adler et al (2005) present a multi-agent approach to cooperative traffic management and route guidance. Davidsson et al. (2005) present an analysis of agent-based approaches to transport logistics. However, none of these studies have approached the urban traffic management problem under limited access restrictions from a decentralized point of view which is one of the policy implementation focus of our research.

In this study, we review all available sources of information, including general literature, websites, reports issued by cities, reports of EU funded projects etc, dealing with freight regulatory initiatives as well as grey literature available through direct contacts with the authors to develop our methodological framework for evaluation, selection and implementation of freight regulatory initiatives..

Chapter 3

Methodological Framework

3.1. Methodology

The methodological framework for evaluating, selecting and implementing regulatory policies for traffic management in cities is presented in Figure 4 below. There are two main sub problems addressed in the thesis, which are presented in detail as follows:

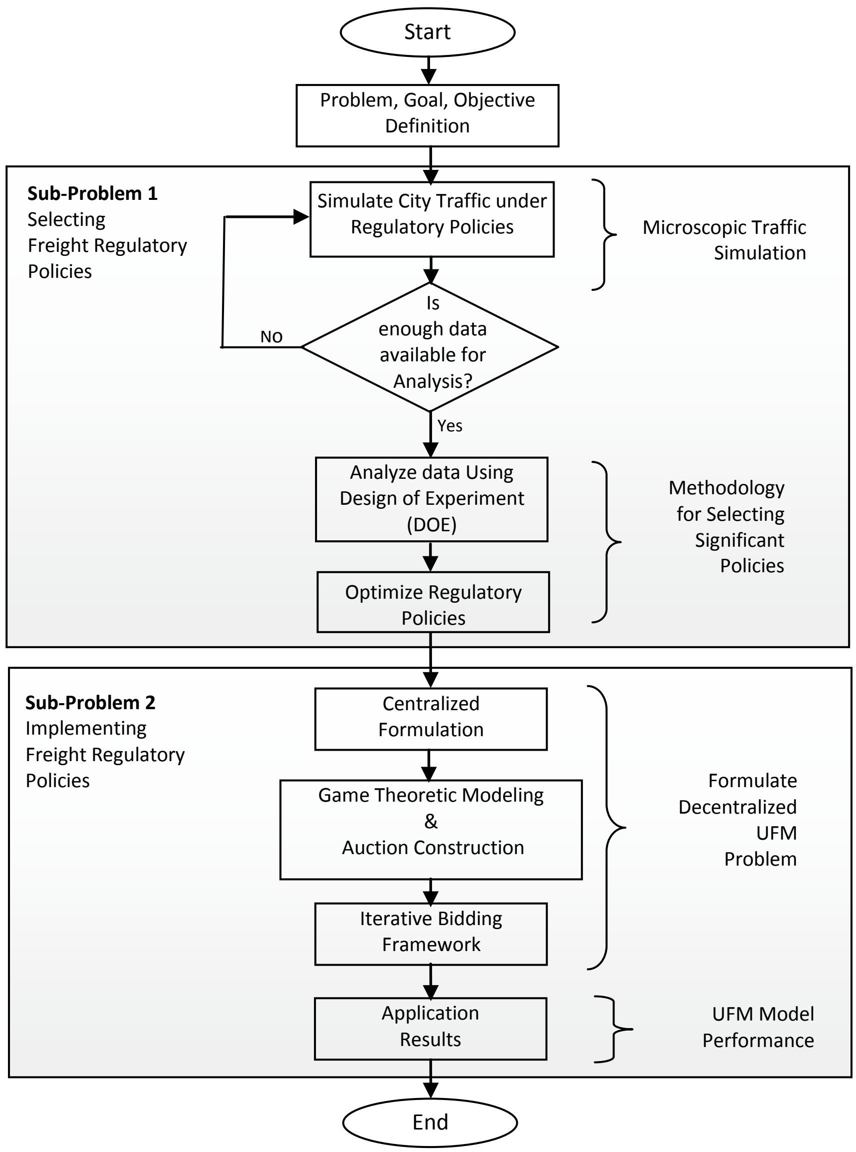


Figure 4 The general process map of the research

1. Selection of freight regulatory policies

In this part, we deal with the problem of evaluating and selecting freight regulatory policies for traffic management in urban areas. First of all, the city traffic (in our case for City of Montreal) is simulated for a set of regulatory policies (access-timing-sizing) under different scenarios. The simulation is run until enough data is collected for the DOE analysis. Finally, ANOVA is applied on the collected data to generate regression models for traffic management variables (average- speed, delay and trip time) which are further optimized to determine the best levels for significant freight regulatory policies chosen for the study.

2. Implementation of freight regulatory policies

The second part of the thesis presents a modeling framework for urban freight management under the regulatory policies obtained from previous step. A decentralized mathematical formulation using the game theoretic modeling and auction construction for the urban freight problem is presented and a solution approach with an iterative bidding architecture is proposed for the city.

3.2. Context of the Study: City of Montreal

Montreal is one of the largest commercial and transport hubs in North America, is the convergence point of the highway network of Quebec. It is served by the motorways: A-20: the center and east of Quebec, and the provinces of the Atlantic; A-40: the center and the north of Quebec; A-10: Cantons of the East and Maine; A-10/A-55: New England; Southern A-15: is and the south of the United States; Western A-40: the north of Ontario is the Canadian West; Western A-20: south of Ontario, Midwest and American West.

Like the Interstates, East-West motorways are assigned even numbers, and North-South motorways are assigned odd numbers in the region.

In this study, we consider two most densely populated area of greater Montreal which include the entire Island of Montreal and Laval as City of Montreal (Figure 5). Currently there are no restrictions on freight trucks, thereby causing huge congestion within the city and consequent delay in travel. Also city transport authority can't enforce restrictions on freight trucks due to their huge impact on local economic strength. As noted by Transport Quebec, "the greater Montreal area is a hub for the transportation of freights by roads to Ontario and the other provinces and, above all, to American markets" (Ministry of Transports Quebec, 2009). Nevertheless, the city of Montréal produced an elaborate Transportation Plan in 2007. The document mentions the need to limit and control freight trucks in the city, stating that "Montréal wants to control the weight and the size of trucks as well as delivery zones and schedules within certain predetermined perimeters including the city centre" (Page 127).

Figure 5 also highlights the annual amount of freight that moves from City of Montreal or towards Montreal from several destinations. These data on freight transport come primarily from a study based on data of 1993 and supplemented in 1996 on behalf of the ex Urban community of Montreal and the Ministry for Transport of Québec.

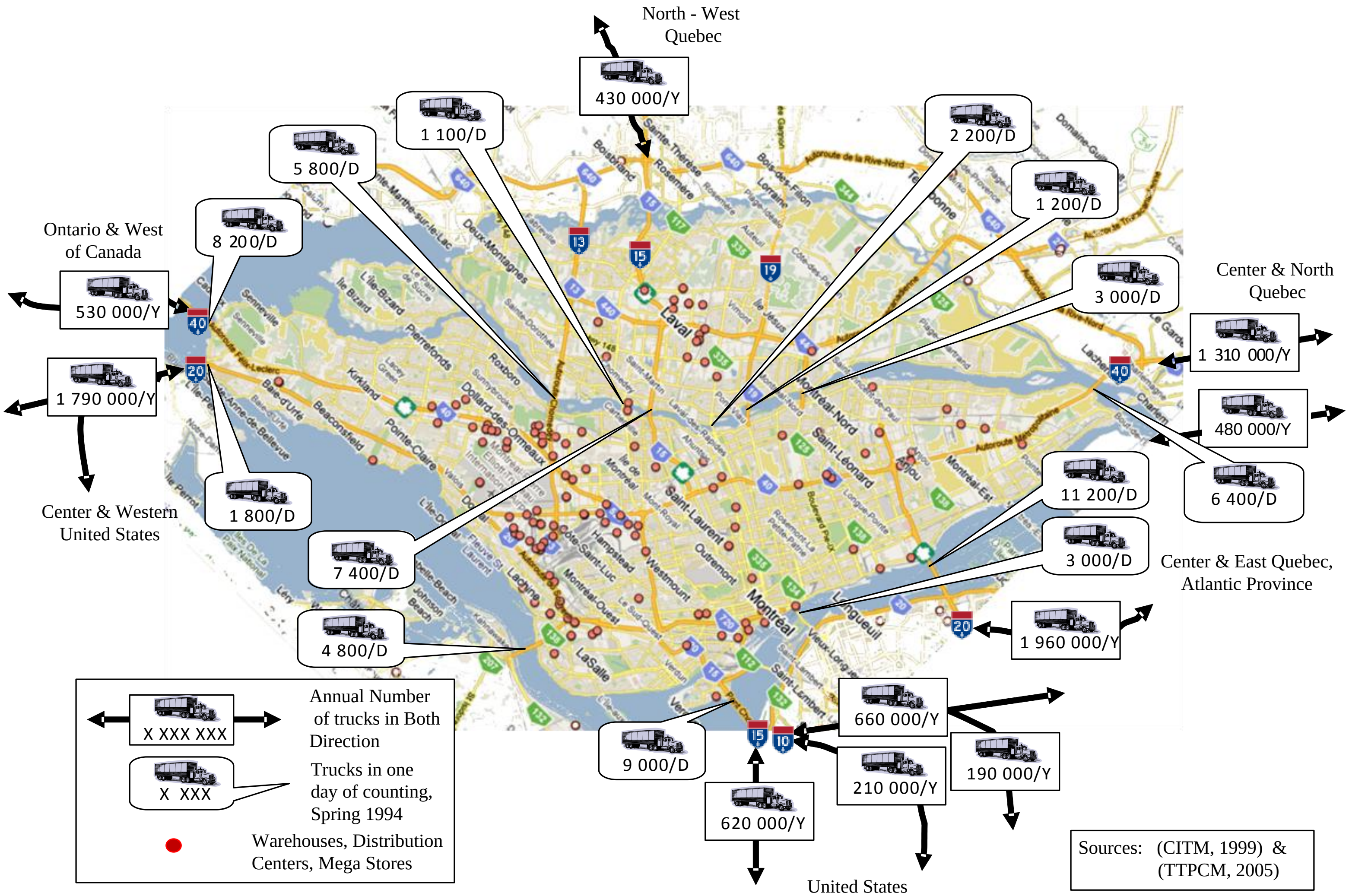


Figure 5 Freight (Trucking) Traffic in City of Montreal.

In 1993, the estimated number of movement of truck per day in the metropolitan region of Montreal was 110,000. This estimate excludes interurban freights, on average the trip time was 40 minute and the average distance of 29 kilometers. Another study by Ministry of Transports Quebec (2003), supplemented in 2003 starting from data collected in 1999, shows the interurban freights. This study shows that 152 000 heavy vehicles per week cross the limits of the metropolitan region. Among them each week 127 000, borrow the highway network of the island of Montreal. The figure also shows the amount of freight trucks that passes through different points of the city in one day, spring 1994, as explain by Le Comité Interrégional pour le Transport des Marchandises (CITM), (1999).

Chapter 4

Selection of Freight Regulatory Initiatives

4.1. Problem Definition

Cities are dominant centers of production and consumption which inevitably requires a freight transport system to support it (Ogden, 1992). Most transport, both passenger and freight, starts and ends in urban areas and often bypasses several urban areas on its way. To combat negative impacts of urban freight transport, local authorities are trying to control it as much as possible. Most of the large and mid size cities especially the old ones are implementing or have tried to implement measures such as freight regulatory policies to ease the congestion scenario. Although several studies (Dablanc, 2007) have been reported on freight restriction policies and their implications but there is lack of efficient methodologies to determine the restriction policies that will fit a specific city's scenario. The simplest way to find the most effective restriction policy for a specific city has often been the trial and error technique which involves applying a set of restriction policies for certain time, observing the impact and if no improvements are observed, then going for another set of restrictions for better implication. Another way to find the most effective restriction policies is to use a well defined structured methodology to come up with pinpointed workable solution of restriction policies for cities.

Literature shows there are several regulatory policies for freight trucks, many of these policies are mutually reinforcing, and a balanced overall package of regulatory policies can increase effectiveness of implementation and cooperation from the private sector. The implementation of a combination of the policies is highly recommended.

Despite several data collection efforts; no consistent source of comprehensive trucking data, for freight planning, developing transportation models, forecasting and assessing network performance, policies, or operations, is available. In general it can be stated that there is lack of appropriate information and data collection on city transportation especially on urban freight transport. The literature review also concludes that researches which focus exclusively on freight transport are rather seldom and the knowledge on the urban freight transport as one part of the whole traffic system of a city is rather incomplete. Therefore, in this part of the thesis we are treating the problem of investigating the impact of three regulatory policies (access-timing-sizing restrictions) on traffic management in urban areas. The goal is to assess the impact of these policies using traffic data generated from simulation. The simulated data will be further analyzed using data analysis techniques such as DOE to compare the performance of the three policies and select the policies significant for the city. These policies will be tested in the context of City of Montreal.

The challenges dealt in this thesis in selecting significant freight regulatory policies are summarized as follows:

Challenges-

- Development of a well defined methodology for evaluating policies.
- Data generation for analyzing policies and their implications.
- Defining levels of implementation of policies for efficient traffic management.

4.2. Solution Approach

Most of transport researchers conclude that freight restriction policies are mutually reinforcing and recommended a set of policies will be more effective for a city, we have decided to use Design of Experiment (DOE) analysis to analyze and determine the set of significant regulatory policies. Where there is a lack of data, a simulation study can evaluate the significance of different regulatory policies under certain conditions and DOE is the most effective analysis method when interest is on a set of policies and their interactions rather than a particular one. The proposed solution approach for selecting significant freight regulatory policies consists of three steps process. These steps are described in Figure 6.

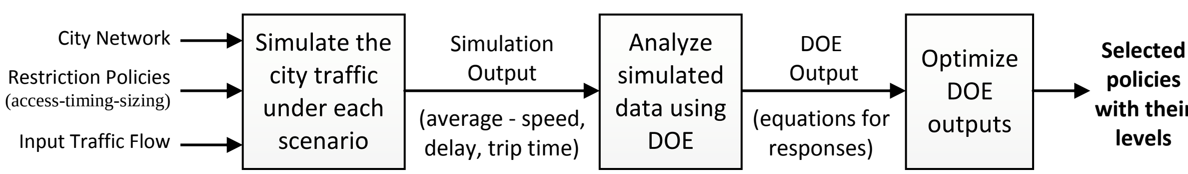


Figure 6 Three step approach for selecting freight regulatory policies for cities.

The first step involves conducting urban network traffic simulation to generate scenario data for evaluating the freight restriction policies for a specific city. In the second step, DOE is used to analyze the simulated traffic data for testing the effectiveness of the policies. In the third step, an optimization using desirability function approach, of the regulatory policies for all the responses, is performed to determine the exact level of regulatory policies for the city.

The traffic data for City of Montreal is obtained using the microscopic traffic simulation software, VISSIM. In this thesis, we focus on three regulatory policies namely access-timing-sizing restriction. The details of the three restriction policies considered in the simulation model are presented as follows.

Access Restriction (A_R)

Access restriction policy is defined as restricting certain roads or areas in cities for urban freight movement. In this study, this involves restricted movements of all trucks from traveling on certain routes, most congested 30% for mid level restriction and 50% for high level access restriction.

Timing Restriction (T_R)

In timing restriction policy, urban freight vehicles are allowed to perform movements inside the city centers only during specific hours of the day. For example, Off-peak delivery in this study means freight trucks are allowed from 10am to 3pm (noon off-peak) and 9pm to 6am (night off-peak).

Vehicle Sizing Restriction (V_R)

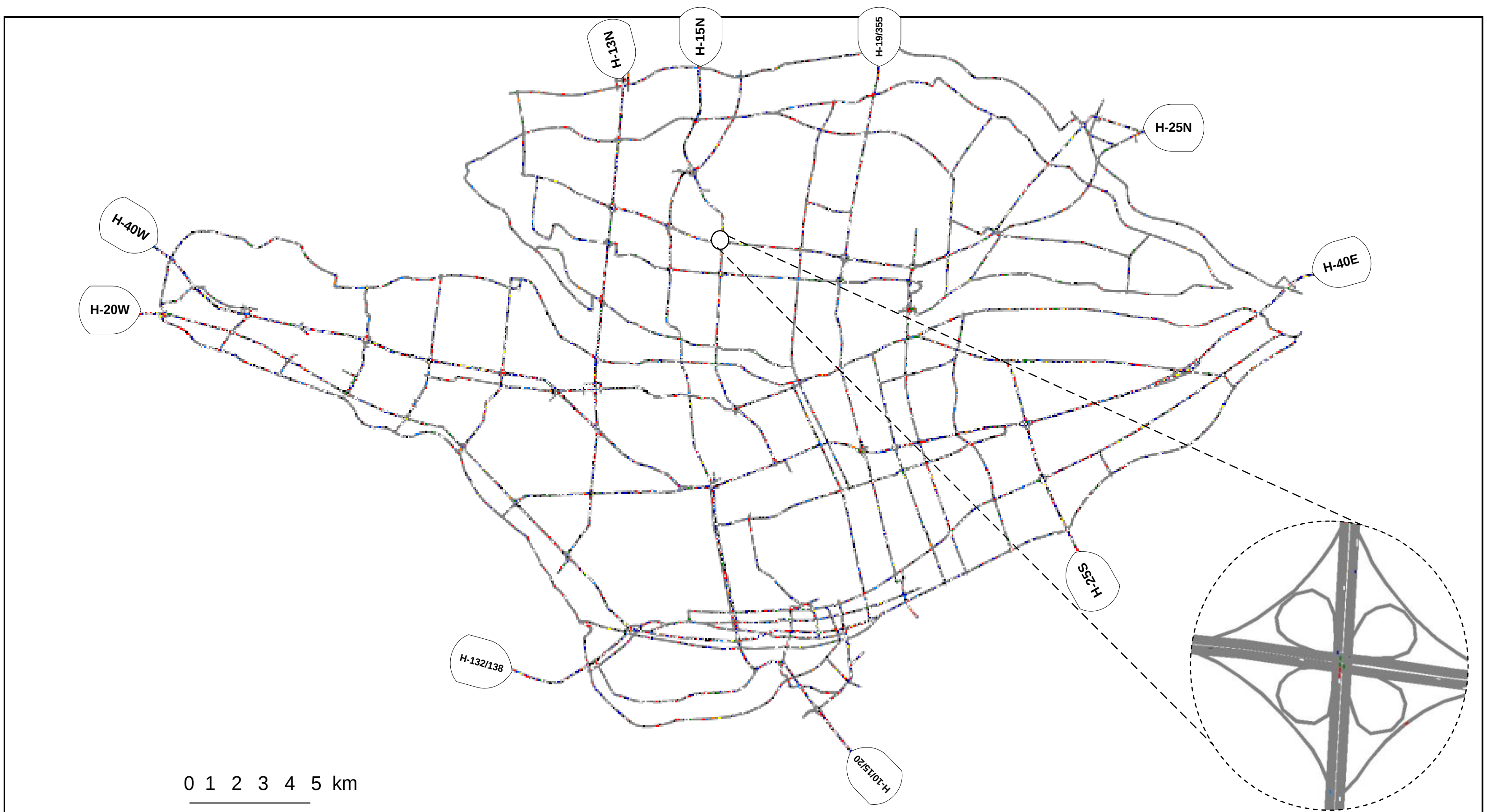
Vehicle sizing restrictions involve the movements of certain types of vehicles with prescribed size, weight and loading factor dimensions in the city. In our study, we have considered only the truck size as it is more related to traffic congestion whereas the weight restriction is mostly focus on the safety issues. Three different size classes for freight trucks; small (length 14.65m or under), medium (length over 14.65m but not exceeding 16.2m) and large (length 18.1m or above) are considered in this study.

We have considered “no restriction” for the three policies in the default scenario. In this study it is indicated as the low restriction for all policies. The different scenarios for restriction policies, explained in section 4.2.3, are applied on the highways (autoroutes) at their entrances as well as on other inner city roads (entrances) on freight trucks according to the experimental designs shown in Table 2 and Table 3. The performance of the three regulatory policies on traffic management in the city is measured in terms of Average speed (km/h), Average delay (min), and Average trip time (min).

4.2.1. Traffic Simulation

Traffic impacts can be accurately estimated using microscopic simulation models due to their ability to simulate individual vehicles and their interactions that can have a strong impact on various performance measures such as average speed, queue length, travel delays and trip time. These models generate exact trajectories of individual vehicles based on certain car-following and lane changing algorithms (PTV, 2008). In this study the microscopic multi-modal traffic flow simulation software VISSIM is used for simulating the City of Montreal. The city has in total ten medium and large entrances on motorways 40W, 20W, 132/138, 10/15/20, 25S, 40E, 25N, 19/335, 15N, 13N for larger external freights and six narrow entrances for small trucks to enter. We consider two most densely populated area of greater Montreal which includes the entire Island of Montreal and Laval as the city of Montreal.

In this study average speed, average delay and average trip time is used as the response parameter for the simulation output. A study by Mussa (2004) on determining the operational and safety impacts of the trucks restriction on Interstate 75 freeway in United States also uses average travel time (trip time) and average delay as the simulation responses. The road network of the City of Montreal including all the highways (auto routes) and most of the important roads were developed approximately on a real scale keeping eyes on Google map. The network of the City of Montreal used in the simulation study is shown in Figure 7. The figure also shows the positions of the main roadway entrances for the city where the access mechanisms can be implemented for controlling freight traffic in the city.



VISSIM montreal	Project:
File: montreal.inp	Scenario:
Simulation Time: 5164.4	Montreal Highway Simulation

Figure 7 Simulation network in VISSIM for the City of Montreal.

4.2.2. Traffic Scenarios

The traffic flow scenarios considered in our study are based on the report “Le Diagnostic sur la Congestion Routière et le Transport des Marchandises” (CITM, 1999). This report portrays the congestion situation in the City of Montreal and demonstrates its relation with the transport of goods. It also shows the number of trucks that pass through different points on city highways in one day (spring 1994) and the time wise distribution of circulation of traffic on city motorways. Another study, ordered by the Ministry for Transport of Quebec (MTQ), to quantify the annual socioeconomic cost of the road congestion in the great area of Montreal also helps to identify the congested roads of the city when applying regulatory policies. This study conducted by Gourvil and Joubert (2004) related to the road congestion of 1993 on the basis of data of the investigation origin-destination 1993, one congestion scenario in the city is depicted in Figure 8. The threshold for the congestion in this figure was defined as 60% from speed with free flow regardless of the roadway types in each area of the city. It is necessary however to mention that, in almost all the cases, only one of the two directions of a segment of road is congested. The majority of the segments of roads congested roads are on the island of Montreal, and more particularly in the city center.

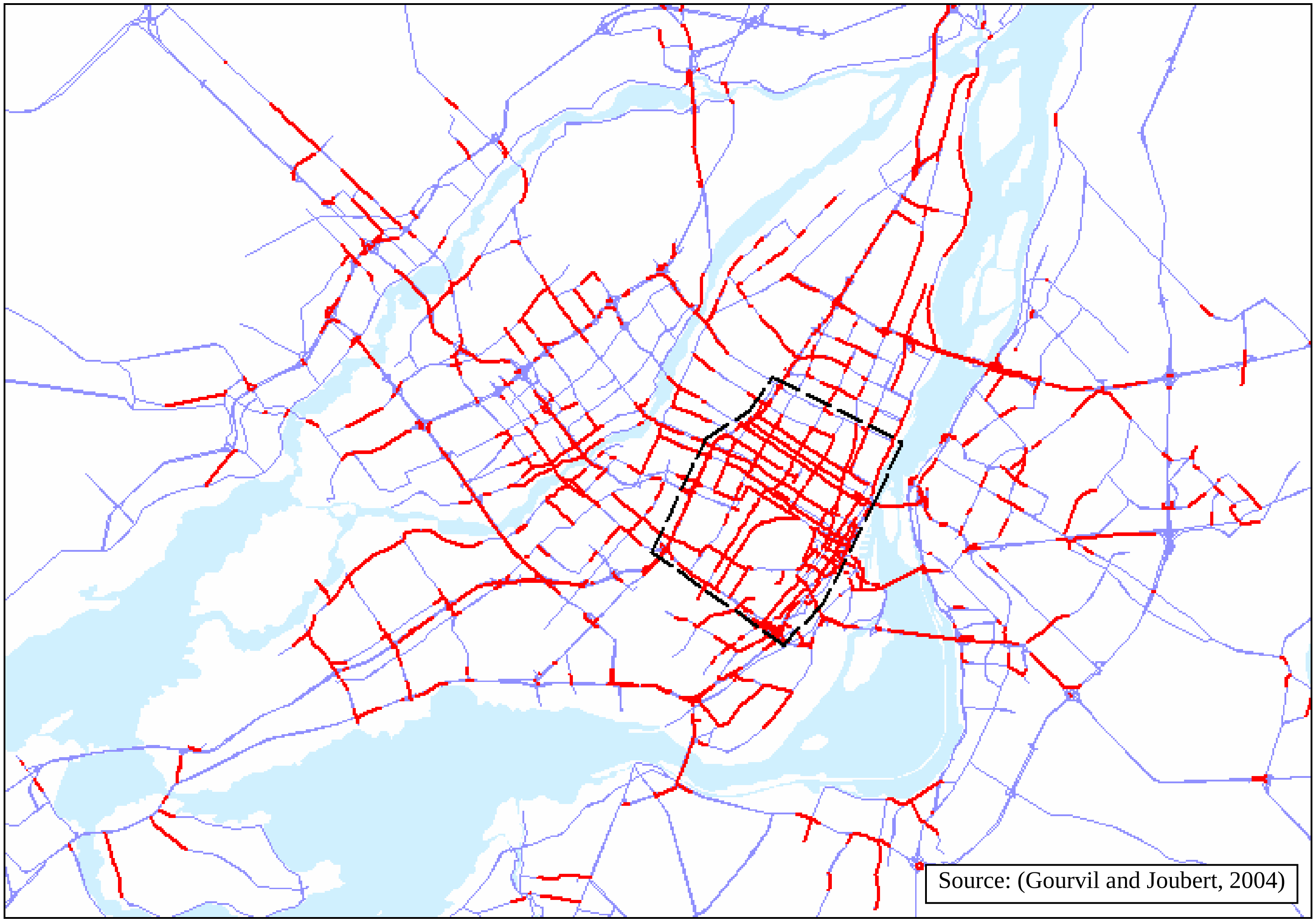


Figure 8 Motorways and arteries congested at the peak period (morning of the autumn 1998) in City of Montreal

We have simulated the traffic on the city for one day, considering 4 time periods (night off-peak 9pm to 6am, morning peak 6am to 10am, day off peak 10am to 3pm and evening peak 3pm to 9pm) input flow patterns comprising of different vehicles ratio considering roads type and the time periods as depicted in the report (CITM, 1999). Cars of 3 different sizes, vans, buses, trucks of 6 different sizes, and bikes are simulated on the city network. The speed limit on Montreal's autoroutes is generally 100 km/hr in rural areas and 70–90 km/hr with a minimum 60km/hr in urban areas. The desired speed on the highway in the simulation was set to minimum 60km/hr to maximum 100km/hr for cars and for trucks from 60km/hr to 80km/hr. The speed on the city local roads is varied from 30km/hr to 60km/hr for all vehicle classes. For the different freight regulatory policies, we tested different scenarios which simulated the number of trucks on highways in each time period. Other parameters for the simulation model were kept as default and the simulation was run for several iterations (54 iterations for full factorial design and 15 iterations for Box-Behnken design) for different traffic scenarios.

4.2.3. Design of Experiments

Optimizing a dynamic system model with classic experimental design technique in comparison with intuitive approaches shows more efficiency, effectiveness and accuracy in estimators of input effects (Kleijnen, 1995). DOE (Montgomery, 2007) helps to determine the factors, which are important for explaining process variation. DOE also helps to understand how the factors influence the system. Methods such as factorial design, response surface method (RSM), and Taguchi techniques can be used for planning the experiments. In this study, we use Design of Experiments to analyze the simulated data obtained from VISSIM.

Basic Definitions

Factor: Factors are the variables of interest, in our case they are the restriction policies, which influence the responses (outputs) of a system. For example, in our model Access restriction, Time restriction, and Vehicle-sizing restriction are the factors.

Level: Levels are specific values for the factors at which the experiment is performed. For example, two levels for factors can be classified as “low” and “high” whereas for three levels it could be “low”, “medium” and “high”. In our model, the factors have three levels.

Effect: Effect of a factor is defined as change in the response produced by a change in the level of the factor. For example, in our model we will measure the effect of factors such as Access restriction, Time restriction, and Vehicle-sizing restriction on effects such as travel time, average delay, average speed etc.

Factorial Design

Factorial designs allow for the simultaneous study of the effects that several factors may have on a response. A full factorial DOE is an experiment whose design consists of two or more factors, each with discrete possible values or "levels", and whose experimental units take on all possible combinations of these levels across all such factors. Such an experiment allows studying the effect of each factor on the response variable, as well as the effects of interactions between factors on the response variable. It should be noted however, that, while full factorial designs like 2^k and 3^k are very efficient, they are not necessarily orthogonal with respect to all main effects. The three level full factorial designs that are of interest in this research can be represented by a multidimensional regression equation describing both the main and the interaction effects of variables (factors) in general form:

$$Y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_1x_2 + b_5x_1x_3 + b_6x_2x_3 + b_7x_1^2 + b_8x_2^2 + b_9x_3^2 + b_{10}x_1^2x_2 + b_{11}x_1^2x_3 + b_{12}x_1x_2^2 + b_{13}x_2^2x_3 + b_{14}x_1x_3^2 + b_{15}x_2x_3^2 + b_{16}x_1^2x_2^2 + b_{17}x_1^2x_3^2 + b_{18}x_2^2x_3^2 + b_{19}x_1x_2x_3 + b_{20}x_1^2x_2x_3 + b_{21}x_1x_2^2x_3 + b_{22}x_1x_2x_3^2 + b_{23}x_1^2x_2^2x_3 + b_{24}x_1^2x_2x_3^2 + b_{25}x_1x_2^2x_3^2 + b_{25}x_1^2x_2^2x_3^2 + \mathcal{E} \quad (1)$$

where Y is the dependent variable; $x_1, x_2, \text{and } x_3$ are the factors or variable; b_0 is constant ; $b_1, b_2, \text{and } b_3$ are main effect; $b_7, b_8, \text{and } b_9$ are the quadratic main effects; rest of the b_i, i=4,5,6,10…..25 are the interactions for two and higher factors; and $\mathcal{E}$ is the error.

These designs require that the levels of all the factors are set at, for example, 2 or 3 levels. In many instances, such designs are not feasible, because, for example, some factor combinations are constrained in some way (e.g., factors x_2 and x_3 cannot be set at their high levels simultaneously). Also, for reasons related to efficiency, it is often desirable to explore the experimental region of interest at particular points. Moreover, the sparsity-of-effects principle states that a system is usually dominated by main effects and low-order interactions. Thus it is most likely that main (single factor) effects and two-factor interactions are the most significant responses (see factorial experiment). In other words, higher order interactions such as three-factor interactions are very rare. Formally, Wu and Hamada (2000, page 112) refer to this as the hierarchical ordering principle.

They state that the effect sparsity principle actually refers to the idea that only a few effects in a factorial experiment will be statistically significant.

Response Surface Method

Response surface methodology (Montgomery, 2007; Oktem et al., 2005) is a collection of mathematical and statistical techniques that are useful for modeling and analysis of problems in which a response of interest is influenced by several variables. RSM is widely used as an optimization, development, and improvement technique for processes based on the use of factorial designs —that is, those in which the response variable is measured for all the possible combinations of the levels chosen for the factors. The application of the RSM becomes indispensable when, after the significant factors affecting the response have been identified, it is considered necessary to explore the relationship between the factor and dependent variable within the experimental region and not only at the borders. Response surfaces are recommended for these types of factorial designs for their effectiveness and quick execution. This consists of correlating the *k* factors put into action through a second-degree polynomial expression of the following form:

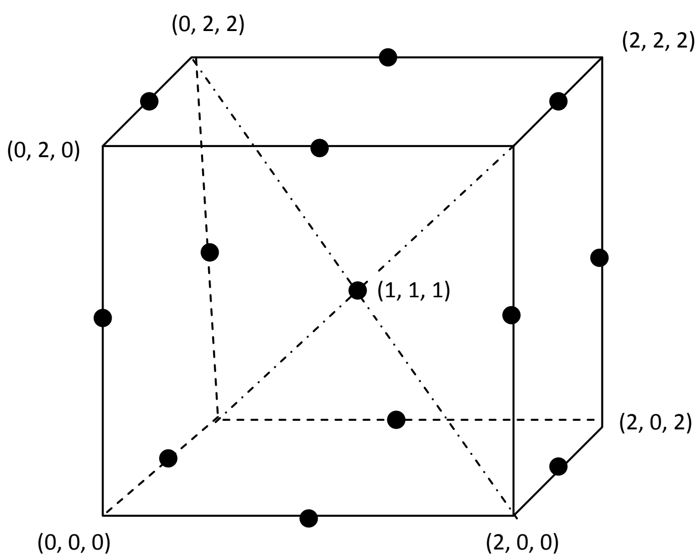
$$Y = \mathrm{b}_0 + \sum_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{b}_\mathrm{i}\mathrm{x}_\mathrm{i} + \sum_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{b}_{\mathrm{ii}}\mathrm{x}_\mathrm{i}^2 + \sum_{\mathrm{i}=1}^{\mathrm{k}-1} \cdot \sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{k}} \mathrm{b}_{\mathrm{ij}}\mathrm{x}_\mathrm{i}\mathrm{x}_\mathrm{j} \qquad (2)$$

and for 3 factors, it becomes

$$Y = \mathrm{b}_0 + \mathrm{b}_1\mathrm{x}_1 + \mathrm{b}_2\mathrm{x}_2 + \mathrm{b}_3\mathrm{x}_3 + \mathrm{b}_{11}\mathrm{x}_1^2 + \mathrm{b}_{22}\mathrm{x}_2^2 + \mathrm{b}_{33}\mathrm{x}_3^2 + \mathrm{b}_{12}\mathrm{x}_1\mathrm{x}_2 + \mathrm{b}_{13}\mathrm{x}_1\mathrm{x}_3 + \mathrm{b}_{23}\mathrm{x}_2\mathrm{x}_3 + \mathcal{E} \qquad (3)$$

where Y is the dependent variable and x_i is the factors or variables with which we wish to correlate it. The symbols b_0, b_i, and b_{ij} are the effects.

The RSM designs are classified into Central Composite Design (CCD) and Box-Behnken Design (BBD). BBD is more significant when the optimum response is not located at the extremes of the experimental region. The present work uses the BBD as in our consideration neither of the restriction policies are useful at the extremes from the cities point of view. BBD (Box and Behnken, 1960) introduced designs for three level factors that are widely used in response surface methods to fit second-order models to the response. The designs were developed by the combination of two level factorial designs with incomplete block designs. Figure 9 shows the BBD for three factors in coded form. The design is obtained by the combination of 2^2 designs with a balanced incomplete block design having three treatments and three blocks. The advantages of these designs include the fact that they are all spherical designs and require factors to be run at only three levels. Yet another advantage of these designs is that there are no runs where all factors are at either the highest value or lowest value levels.



Run	Factors		
	A_R	T_R	V_R
1	0	0	1
2	2	0	1
3	0	2	1
4	2	2	1
5	0	1	0
6	2	1	0
7	0	1	2
8	2	1	2
9	1	0	0
10	1	2	0
11	1	0	2
12	1	2	2
13	1	1	1
14	1	1	1
15	1	1	1

Figure 9 Box-Behnken Design (BBD).

Since DOE analysis needs data for all the responses for different combination of effects and there levels to provide better support for selecting regulatory policies, we use BBD to exclude policies like only small trucks allowed or night delivery only. Thus for more significant analysis and efficient implementation of freight regulatory policies we use BBD.

4.3. Numerical Application

In this section, we present the application of the proposed approach for City of Montreal. The freight restriction policies (factors) investigated are Access restriction, Timing restriction, and Vehicle-sizing restriction. Table 1 shows the three factors and along with their levels used in our study. For the simplicity of experimental design, only three levels namely low, medium and high are considered for each restriction policies. Here no restriction for each policy is considered as the low level, a certain level of restriction is considered as high level restriction and an approximate middle between these two levels is considered as medium level for that restriction.

Table 1: Factors and levels

		Levels		
Factors	Notation	Low (L or 0)	Medium (M or 1)	High (H or 2)
Access Restriction	A_R	All roads are open to Trucks*	30% roads are restricted to Trucks	50% roads are restricted to Trucks
Timing Restriction	T_R	Any Time Delivery*	Off peak Delivery (Early Morning & Night)	Night Delivery
Vehicle-sizing Restriction	V_R	All (Small, Medium & Large) Trucks Allowed*	Small & Medium Trucks Allowed	Only Small Trucks Allowed

*No Restriction

Table 2 depicts the design matrix for the full factorial design and replicates the effects (simulation outcomes or responses) like Average Speed, Average Delay, and Average Trip Time. In this study the averages are computed for all vehicles that completed their trip on the network in simulation time. As indicated in Table 2 some scenarios (runs marked [i]) of full factorial design is considered unreasonable or impractical in real environment but these are considered here due to the design. The impractical restriction scenarios can be avoided to have a better optimization of the simulation results for restriction policies with more significant DOE discussed earlier in response surface method.

Table 2: 3^3 Full factorial Design Matrix

Run	Access Restriction (A_R)	Timing Restriction (T_R)	Vehicle-sizing Restriction (V_R)	Congestion Parameters					
				Average Speed (km/hr)		Average Delay (min)		Average Trip Time (min)	
				Replica-1	Replica-2	Replica-1	Replica-2	Replica-1	Replica-2
1	L	L	L	54.893	55.370	6.477	6.050	28.475	27.842
2	L	L	M	56.043	57.287	5.956	5.643	28.212	27.760
3[i]	L	L	H	57.033	57.945	5.437	5.414	26.777	26.209
4	L	M	L	61.391	62.692	3.718	3.395	24.699	24.518
5	L	M	M	62.552	63.008	3.719	3.390	24.467	24.317
6	L	M	H	62.656	63.038	3.636	3.274	24.467	23.840
7[i]	L	H	L	62.614	64.216	3.642	3.522	24.362	24.025
8	L	H	M	62.758	63.624	3.639	3.610	24.249	24.050
9[i]	L	H	H	62.762	63.276	3.634	3.471	24.260	23.816
10	M	L	L	59.651	60.742	4.675	4.452	25.789	25.038
11	M	L	M	59.904	61.647	4.789	4.644	25.760	24.917
12	M	L	H	60.296	62.267	4.506	4.269	25.640	24.837
13	M	M	L	62.747	64.710	3.628	3.374	24.251	24.003
14	M	M	M	62.812	63.452	3.467	3.386	24.548	24.258
15	M	M	H	63.006	63.749	3.565	3.220	24.150	23.529
16	M	H	L	62.799	64.412	3.601	3.474	24.157	23.842
17	M	H	M	62.854	63.671	3.595	3.360	24.128	23.556
18	M	H	H	63.891	65.405	3.424	3.174	24.145	24.116
19[i]	H	L	L	56.719	56.787	5.960	5.467	27.393	27.286
20	H	L	M	58.834	59.063	4.871	4.485	26.019	25.199
21[i]	H	L	H	59.021	60.880	5.021	4.528	26.035	25.444
22	H	M	L	62.970	64.399	3.542	3.388	24.204	23.848
23	H	M	M	63.065	63.992	3.542	3.202	24.211	23.772
24	H	M	H	63.328	64.474	3.453	3.370	24.041	23.300
25[i]	H	H	L	62.992	64.932	3.544	3.417	24.170	23.333
26	H	H	M	62.920	65.097	3.573	3.370	24.124	23.257
27[i]	H	H	H	63.540	65.821	3.538	3.386	24.069	24.069

[i] Impractical Scenario

Table 3 shows the design matrix for Box–Behnken design, experimental design for response surface methodology devised by George E. P. Box and Donald Behnken. The three levels for restriction policies are indicated as 0 for “low”, 1 for “medium” and 2 for “high”.

Table 3: Design Matrix for Box-Behnken design

Access Restriction (A_R)	Timing Restriction (T_R)	Vehicle-sizing Restriction (V_R)	Congestion Parameters		
			Average Speed (km/hr)	Average Delay (min)	Average Trip Time (min)
0	0	1	56.043	5.956	28.212
2	0	1	58.834	4.871	26.019
0	2	1	62.758	3.639	24.249
2	2	1	62.920	3.573	24.124
0	1	0	61.391	3.718	24.699
2	1	0	62.970	3.542	24.204
0	1	2	62.656	3.636	24.467
2	1	2	63.328	3.453	24.041
1	0	0	59.651	4.675	25.789
1	2	0	62.799	3.601	24.157
1	0	2	60.296	4.506	25.640
1	2	2	63.891	3.424	24.145
1	1	1	62.812	3.467	24.548
1	1	1	62.875	3.474	24.622
1	1	1	63.011	3.498	24.696

4.4. Results

A factorial experiment can be analyzed using ANOVA or regression analysis. Other useful exploratory analysis tools for factorial experiments include main effects plots, interaction plots, and a normal probability plot of the estimated effects. ANOVA (Montgomery, 2007) gives a summary of the main effects and interactions, the regression coefficients, and the p-value. The p-value in the ANOVA analysis helps to determine which effects (factors and interactions) are statistically significant. The p-value represents the probability of making a type-I error or rejecting the null hypothesis when it is true. The smaller the p-value, the smaller is the probability that you would be making a mistake by rejecting the null hypothesis. The cutoff value often used is 0.05, i.e., reject the null hypothesis when the p-value is less than 0.05. It is common to declare a result significant if the p-value is less than 0.05.

In this study Minitab (Meyer, 2004) and DOE++ statistical package were used to analyze the experimental data and response parameters. The significant terms in the model were found by Analysis of Variance at 5% level of significance (95 % confidence level). Based on the 3^3 full factorial design of experiment, 27 combinations were developed (Table 2). Two replications were done for each response. Table 4 shows the regression coefficients, t-values and p-values for the design.

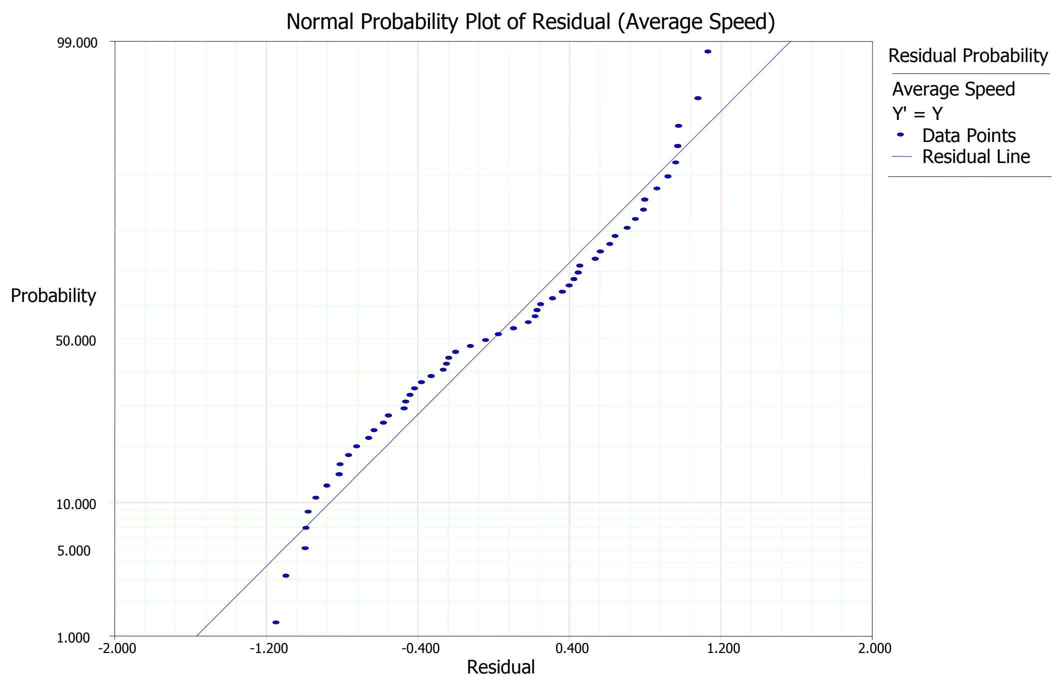
Table 4: Regression coefficients and p-value for full factorial design

Term	Average Speed			Average Delay			Average Trip Time		
	Coefficient	t-value	p-value	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Constant	61.852	481.3020	0.0000[s]	4.0349	154.8897	0.0000[s]	24.8293	475.281	0.0000[s]
A_R	-1.121	-6.1680	0.0000[s]	0.2777	7.5369	0.0000[s]	0.5232	7.0815	0.0000[s]
A_R^2	0.8155	4.4873	0.0001[s]	-0.2237	-6.0712	0.0000[s]	-0.348	-4.7101	0.0001[s]
T_R	-3.2752	-18.0214	0.0000[s]	1.1119	30.1824	0.0000[s]	1.5391	20.8328	0.0000[s]
T_R^2	1.3725	7.5521	0.0000[s]	-0.5756	-15.6227	0.0000[s]	-0.6947	-9.4031	0.0000[s]
V_R	-0.4611	-2.5371	0.0173[s]	0.1498	4.0670	0.0004[s]	0.2393	3.2390	0.0032[s]
V_R^2	-0.0418	-0.2301	0.8198	-0.0216	-0.5851	0.5633	-0.0069	-0.0930	0.9266
A_RT_R	-1.0273	-3.9970	0.0004[s]	0.4049	7.7723	0.0000[s]	0.6542	6.2614	0.0000[s]
$A_RT_R^2$	0.4526	1.7611	0.0895	-0.2151	-4.1277	0.0003[s]	-0.2731	-2.6141	0.0145[s]
$A_R^2T_R$	1.3589	5.2870	0.0000[s]	-0.3674	-7.0515	0.0000[s]	-0.6903	-6.6068	0.0000[s]
$A_R^2T_R^2$	-0.6274	-2.4409	0.0215[s]	0.2043	3.9208	0.0005[s]	0.3365	3.2210	0.0033[s]
A_RV_R	-0.0739	-0.2876	0.7759	0.0049	0.0938	0.9259	0.0617	0.5906	0.5597
$A_RV_R^2$	0.1895	0.7372	0.4673	0.0351	0.6739	0.5061	0.1635	1.5652	0.1292
$A_R^2V_R$	0.3038	1.1819	0.2476	-0.0938	-1.7999	0.0831	-0.2073	-1.9840	0.0575
$A_R^2V_R^2$	-0.2357	-0.9170	0.3673	0.0838	1.6080	0.1195	0.0534	0.5108	0.6136
T_RV_R	-0.7554	-2.9389	0.0067[s]	0.2168	4.1607	0.0003[s]	0.3628	3.4720	0.0018[s]
$T_RV_R^2$	0.2614	1.0169	0.3182	-0.0607	-1.1644	0.2544	-0.0504	-0.4824	0.6334
$T_R^2V_R$	0.3881	1.5100	0.1427	-0.1017	-1.9524	0.0613	-0.1201	-1.1492	0.2605
$T_R^2V_R^2$	-0.0359	-0.1395	0.8901	0.0132	0.2527	0.8024	0.1344	1.2866	0.2092
$A_RT_RV_R$	-0.0066	-0.0183	0.9855	0.0625	0.8482	0.4038	-0.0511	-0.3458	0.7322
$A_RT_RV_R^2$	-0.1725	-0.4747	0.6388	0.0171	0.2322	0.8181	0.3339	2.2598	0.0321[s]
$A_RT_R^2V_R$	-0.3678	-1.0118	0.3206	-0.0185	-0.2511	0.8037	0.0429	0.2904	0.7737
$A_RT_R^2V_R^2$	0.112	0.3082	0.7603	0.0058	0.0784	0.9381	-0.2838	-1.9204	0.0654
$A_R^2T_RV_R$	0.358	0.9850	0.3334	-0.2652	-3.5988	0.0013[s]	-0.3114	-2.1076	0.0445[s]
$A_R^2T_RV_R^2$	0.0405	0.1113	0.9122	0.1591	2.1594	0.0399[s]	0.0122	0.0828	0.9346
$A_R^2T_R^2V_R$	0.0851	0.2341	0.8167	0.1067	1.4477	0.1592	0.0919	0.6220	0.5392
$A_R^2T_R^2V_R^2$	0.0327	0.0899	0.9290	-0.0889	-1.2064	0.2381	0.0989	0.6694	0.5089
	R-Sq = 94.00% R-Sq(adj) = 88.23%			R-Sq = 97.63% R-Sq(adj) = 95.34%			R-Sq = 95.68% R-Sq(adj) = 91.52%		

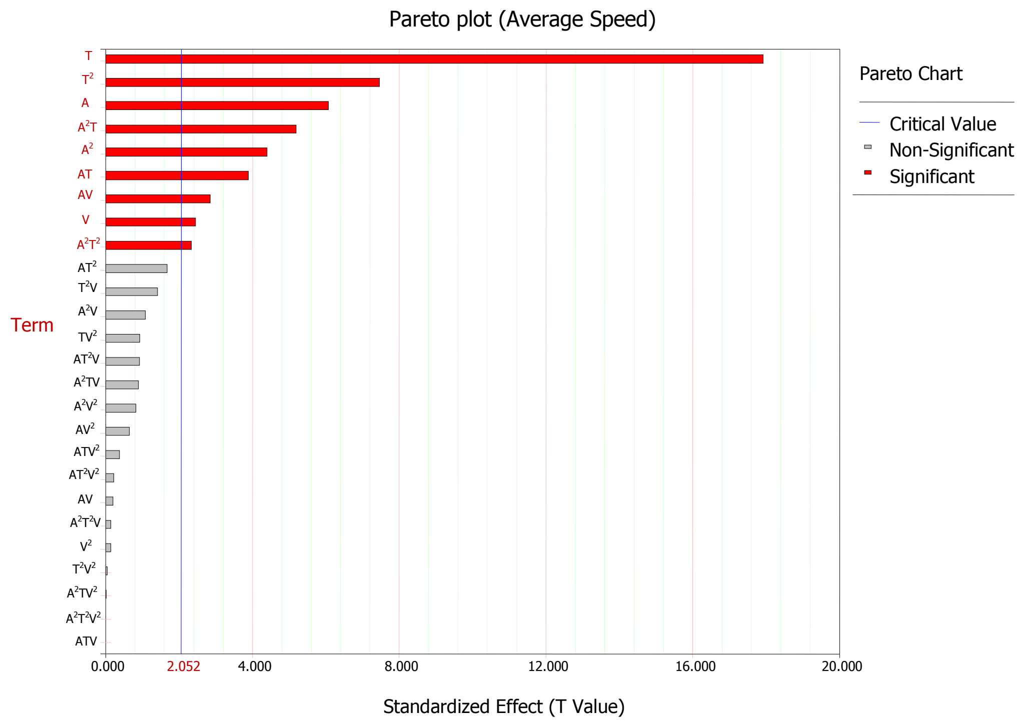
[s]Significant

Regression analysis for the response Average Speed (Table 4) indicates that the main and quadratic main effects of access restriction (A_R), timing restriction (T_R) and some of their interactions (marked as s) are significant whereas the main effect of vehicle restriction (V_R) and one interaction of it with T_R are significant but the p-values are very high compared to the p-values for A_R and T_R. For the response Average Delay (Table 4) indicates the similar with some extra three factor interactions as significant (marked as s) but the p-values indicate that the effects of A_R and T_R are more significant than the others. Same thing happens for the response Average Trip Time as indicated in Table 4.

Examining residuals is a key part of all statistical modeling techniques, including DOE's. Residuals are estimates of experimental error obtained by subtracting the observed responses from the predicted responses calculated from the chosen model, after all the unknown model parameters have been estimated from the experimental data. Carefully looking at residuals tells us that our assumptions are reasonable and our choice of model is appropriate. The Pareto plot of standardized effects shows the significant coefficients for each of the responses in the full factorial design. The normal probability plot of residuals and the Pareto plot of standardized effects for the responses are shown in Figure 10 for average speed, Figure 11 for average delay and Figure 12 for average trip time. The nearly linear plots the residuals for all three responses suggest normal distribution of experimental errors. On the other hand the Pareto plots show the significant effects for each response in full factorial design.

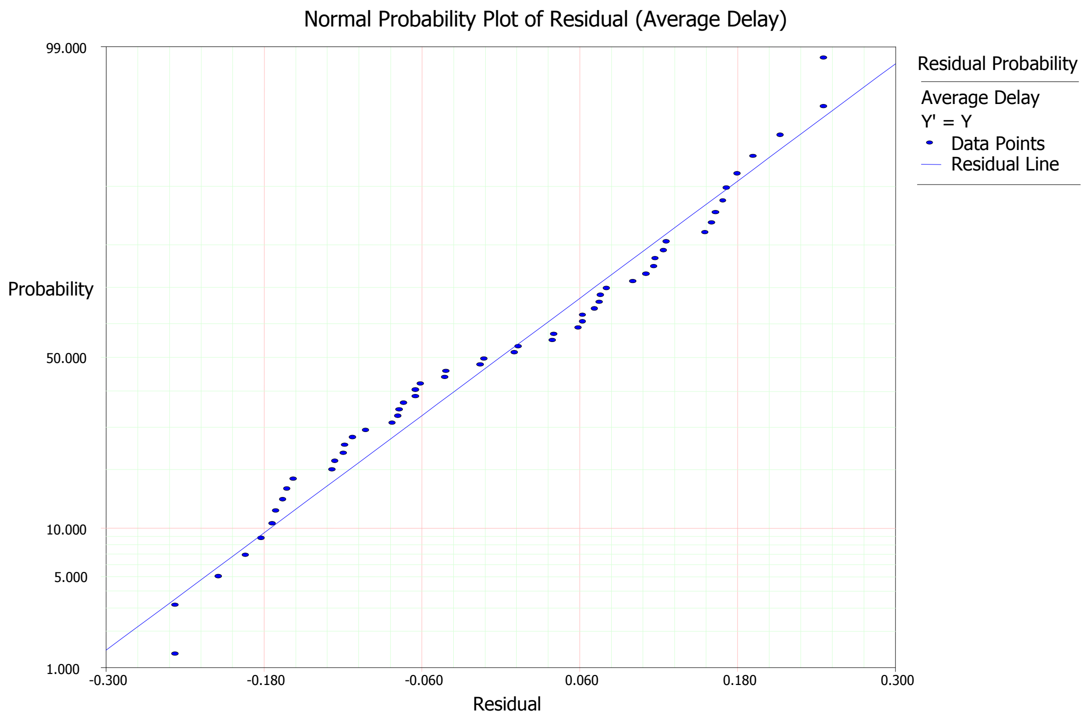


(a)

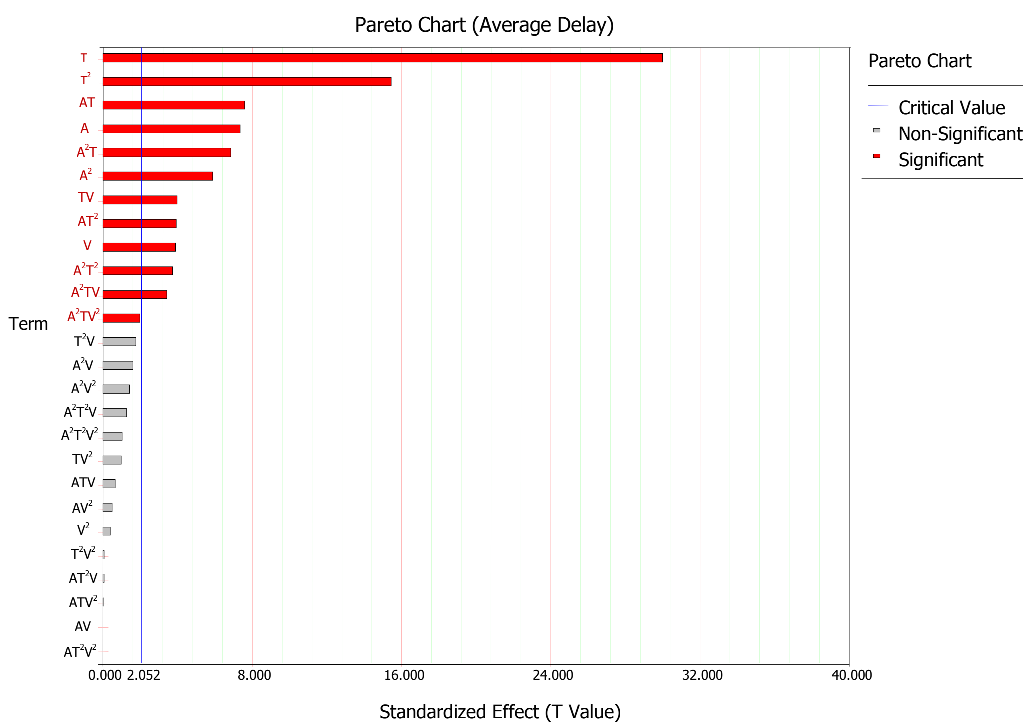


(b)

Figure 10 (a) Normal Probability Plot of Residuals and (b) Pareto plot of Standardize Effect for Average Speed.

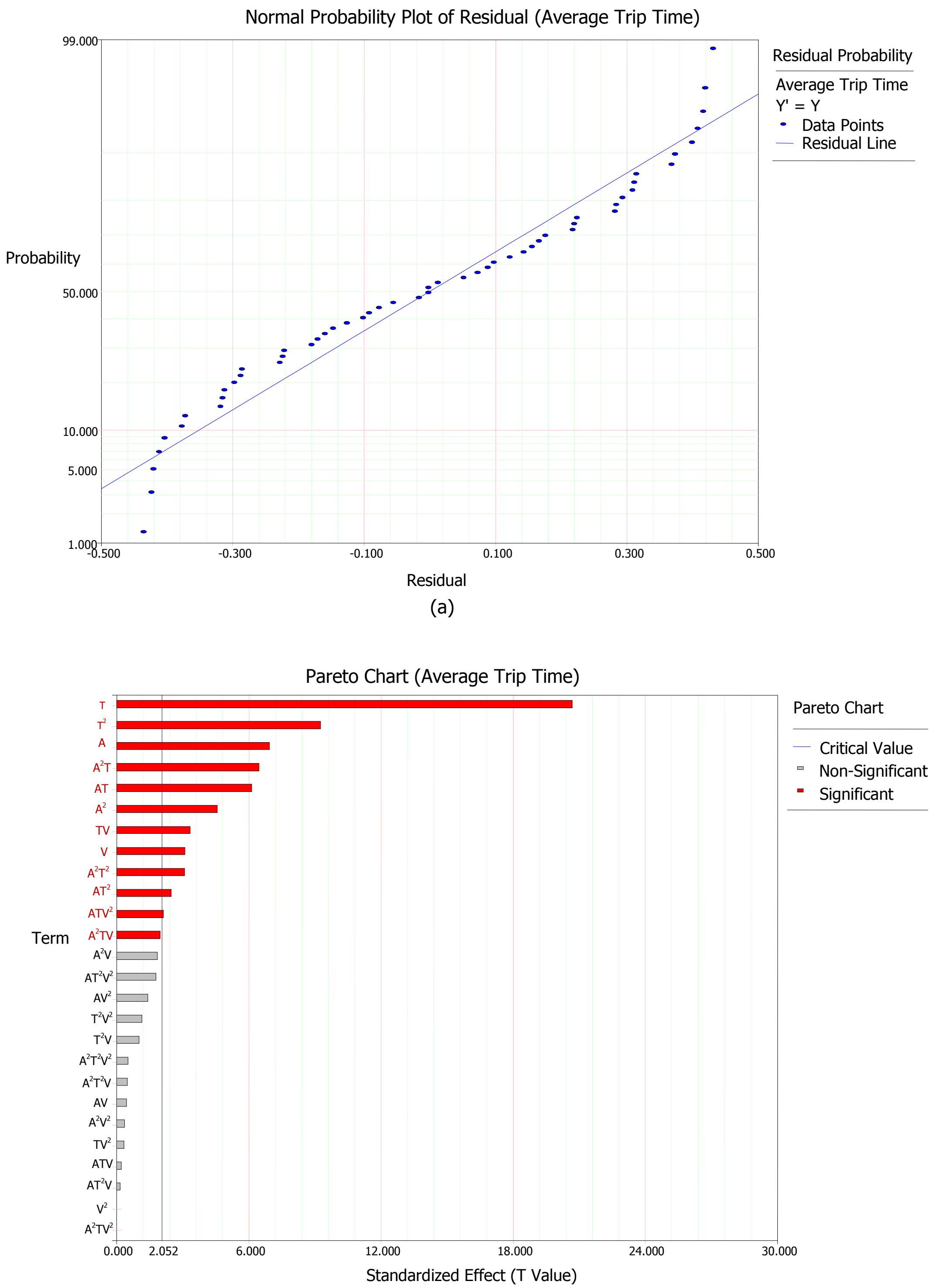


(a)



(b)

Figure 11(a) Normal Probability Plot of Residuals and (b) Pareto plot of Standardize Effect for Average Delay.



(b)

Figure 12 (a) Normal Probability Plot of Residuals and (b) Pareto plot of Standardize Effect for Average Trip Time.

The full factorial designs with three or more levels for each factor generally require more runs than necessary to accurately estimate model parameters whereas some factor combinations may have no significant meaning in real scenario. On the other hand response surface method is an efficient and creative three-level composite design, such as BBD, requires fewer experiments compared to full factorial designs and is more significant when the optimum response is not located at the extremes of the experimental region. On the rest of the study BBD is used to analyze the simulation results and make a better conclusion with less number of experiments for the restriction policies. The regression coefficients are obtained using the uncoded units. Table 5 shows the regression coefficients, t-values and p-values for BBD.

Table 5: Regression coefficients and p-value for Box-Behnken design

Term	Average Speed			Average Delay			Average Trip Time		
	Coefficient	t-value	p-value	Coefficient	t-value	p-value	Coefficient	t-value	p-value
Constant	56.7085	73.367	0.000[s]	5.5601	17.817	0.000[s]	27.3233	47.325	0.000[s]
A_R	3.3645	3.935	0.011[s]	-1.0075	-2.919	0.033[s]	-1.3881	-2.173	0.082[s]
T_R	6.4225	7.511	0.001[s]	-2.4684	-7.150	0.001[s]	-3.2834	-5.141	0.004[s]
V_R	-0.6760	-0.791	0.465	0.2897	0.839	0.440	0.8665	1.357	0.233
A_R^2	-0.9150	-2.688	0.053	0.2829	2.058	0.095	0.2245	0.883	0.418
T_R^2	-1.8420	-5.410	0.003[s]	0.7471	5.453	0.003[s]	0.8045	3.163	0.025[s]
V_R^2	0.6055	1.778	0.135	-0.1753	-1.275	0.258	-0.4937	-1.941	0.011
A_RT_R	-0.6573	-2.009	0.101	0.2547	1.929	0.112	0.5170	2.116	0.088
A_RV_R	-0.2267	-0.693	0.519	-0.0017	-0.013	0.990	0.0173	0.071	0.946
T_RV_R	0.1118	0.342	0.747	-0.0020	-0.015	0.989	0.0343	0.140	0.894
	R-Sq = 96.68% R-Sq(adj) = 90.72%			R-Sq = 95.39% R-Sq(adj) = 87.10%			R-Sq = 93.14% R-Sq(adj) = 80.79%		

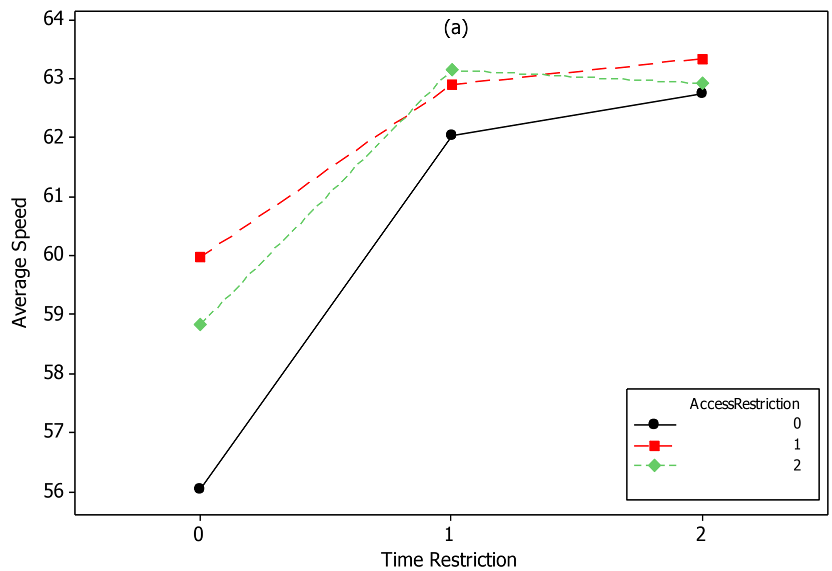
[s]Significant

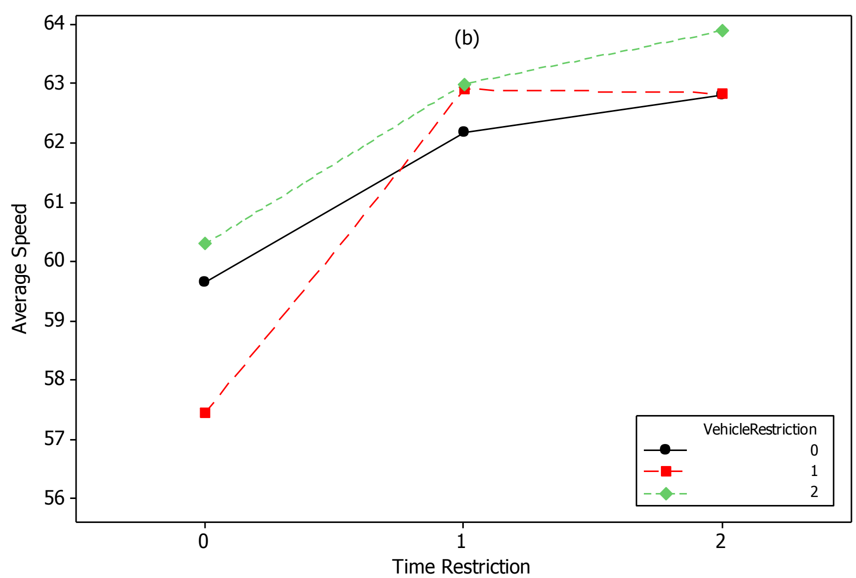
Regression analysis for the response Average Speed (Table 5) indicates that the A_R and T_R individual effects are statistically significant. It is also observed from the table that none of the interaction effects has significant contributions since the corresponding p-value is higher than 0.05. Table 5 shows the result of R^2 and R^2-(adj) for the Average Speed are 0.9668 and 0.9072, respectively. This indicates that the variables (policies) excellently explain the amount of variation in the observed value of the Average Speed. The p-values corresponding to quadratic main effect of T_R closer to zero and a negative coefficient (Table 4) indicates a negative correlation between T_R itself and its significant.

Regression analysis for the response Average Delay (Table 5) indicates that the individual effect of A_R, T_R and the square effect of T_R have significant contributions since the corresponding p-value is < 0.05. The R^2 and R^2-(adj) for the Average Delay are 0.9539 and 0.8710, respectively. This indicates that the amount of variation in the observe value of the Average Delay is excellently explain by the restriction policies. The same analysis for the response Average Trip Time, with reference to Table 5, where R^2 and R^2-(adj) values are 0.9314 and 0.8079 respectively indicates that the restriction policies excellently explain the amount of variation in the observe value of the Average Trip Time.

Average Speed

From the interaction plot shown in Figure 13(a) and 13(b), it is clear that the Average Speed increases with increase in T_R for almost all values of A_R and V_R. For increase in A_R the scenario is not the same as depicted in Figure 13(c). It is observed from Figure 13(b) and 13(c) that the Average Speed at higher T_R (night time delivery only) and medium A_R is higher for higher V_R (small trucks only). Whereas, studies on freight restrictions (Hall and Partyka, 1991) reported that companies which seek to maintain a high level of customer service are most likely to shift to smaller trucks to maintain their service level. It indicates that higher V_R (small trucks only) policy will be counterproductive if trucking company and other firms induce small trucks in their delivery fleet that will result in increased emissions as well as degrade city traffic performance. On other hand only night time delivery can have a direct negative impact on GDP and will obviously increase the 24-hour average concentrations of fuel exhaust pollutants in air (Pani and Beckx, 2007).





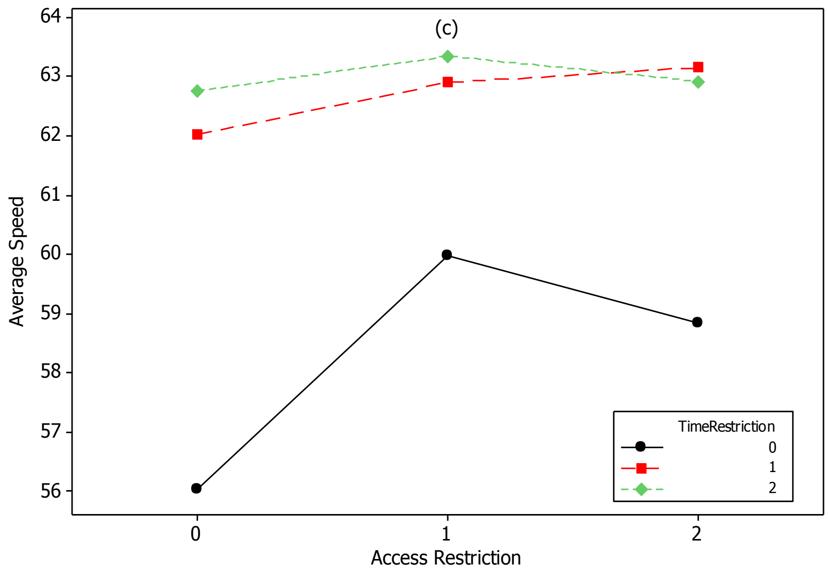


Figure 13 Interaction plots for Average Speed in Box-Behnken analysis.

The relationship between the responses and restriction policies can be further elucidated by constructing surface plots. Figure 14 presents the surface plots for the interaction effects between the response "Average Speed" and restriction policies. The surface plot Figure 14(a) and 14(b) indicate that there exists a significant interaction between A_R and T_R and a very little interaction between V_R and T_R.

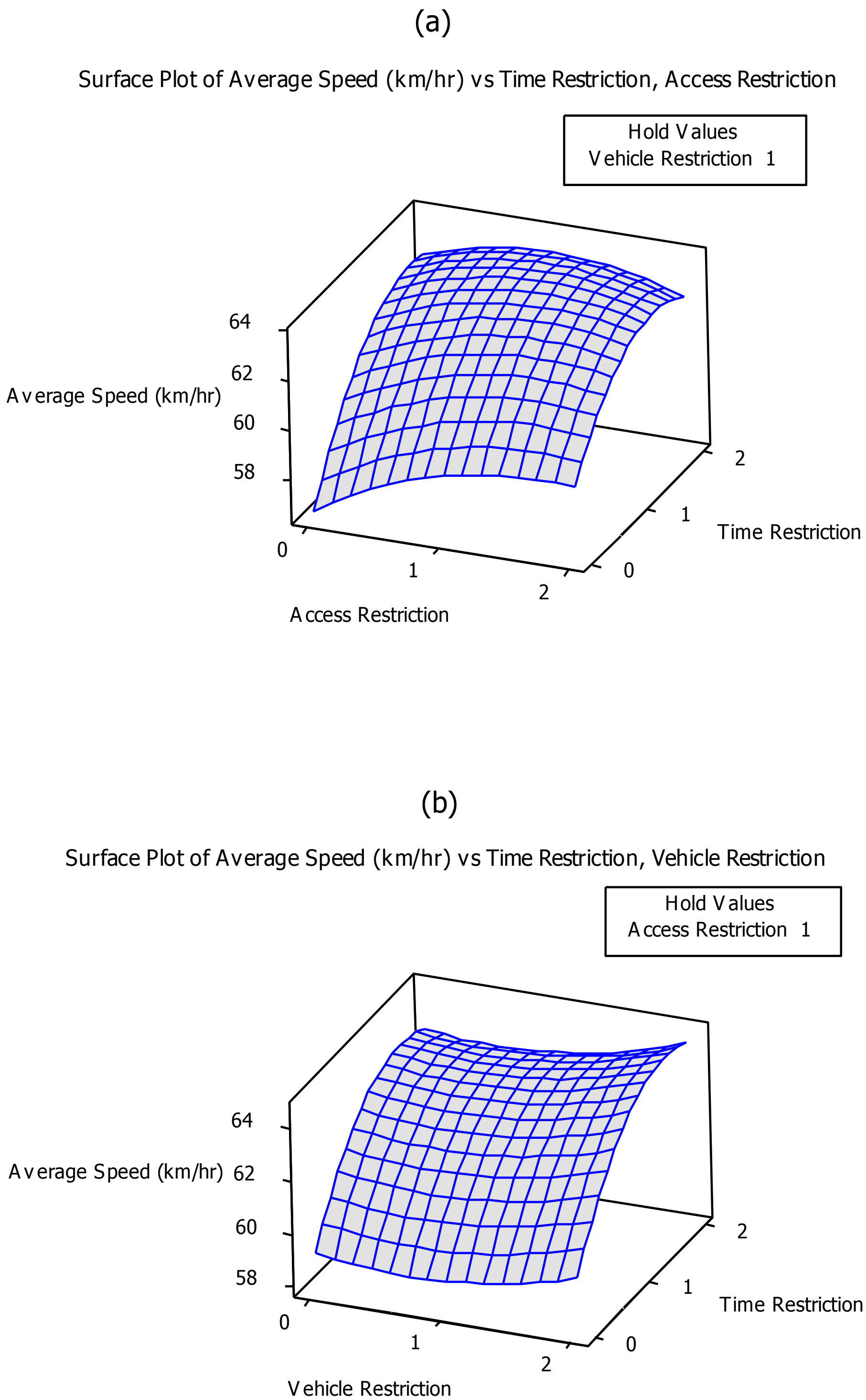


Figure 14 Surface plot for Average Speed in Box-Behnken analysis.

The Average speed (dependent variable) obtained at various levels of the three restriction policies (independent variables) are subjected to multiple regression to yield a second-order polynomial equation (full model):

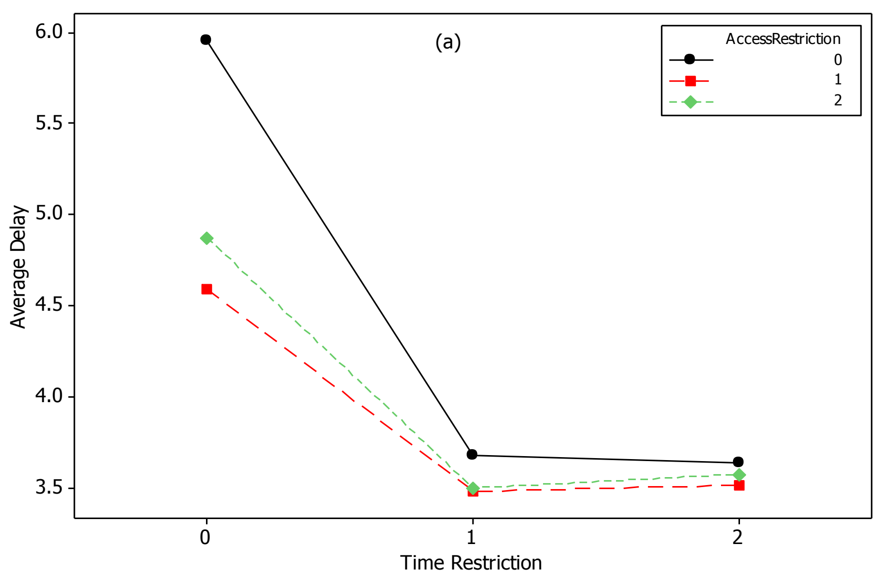
$$Y_1(Average\ Speed) = 56.7085 + 3.3645\mathrm{A_R} + 6.4225\mathrm{T_R} - 0.676\mathrm{V_R} - 0.915\mathrm{A_R^2} - 1.842\mathrm{T_R^2} + 0.6055\mathrm{V_R^2} - 0.6573\mathrm{A_R T_R} - 0.2267\mathrm{A_R V_R} + 0.118\mathrm{T_R V_R} + \mathcal{E} \qquad (4)$$

The value of R^2 and R^2-(adj) of equation (4) was found to be 0.9668 and 0.9072 respectively, indicating good fit. It is clear from table 5 that the A_R, T_R and the square effect of T_R is significant (p-value < 0.05). Hence, omitting the insignificant terms from the full model to obtain a reduced second-order polynomial equation, (4) becomes:

$$Y_1(Average\ Speed) = 56.7085 + 3.3645\mathrm{A_R} + 6.4225\mathrm{T_R} - 1.8424\mathrm{T_R^2} + \mathcal{E} \qquad (5)$$

Average Delay

It is clear from the interaction plots shown below Figure 15 that the Average Delay decreases with an increase in T_R for all values of A_R and V_R.



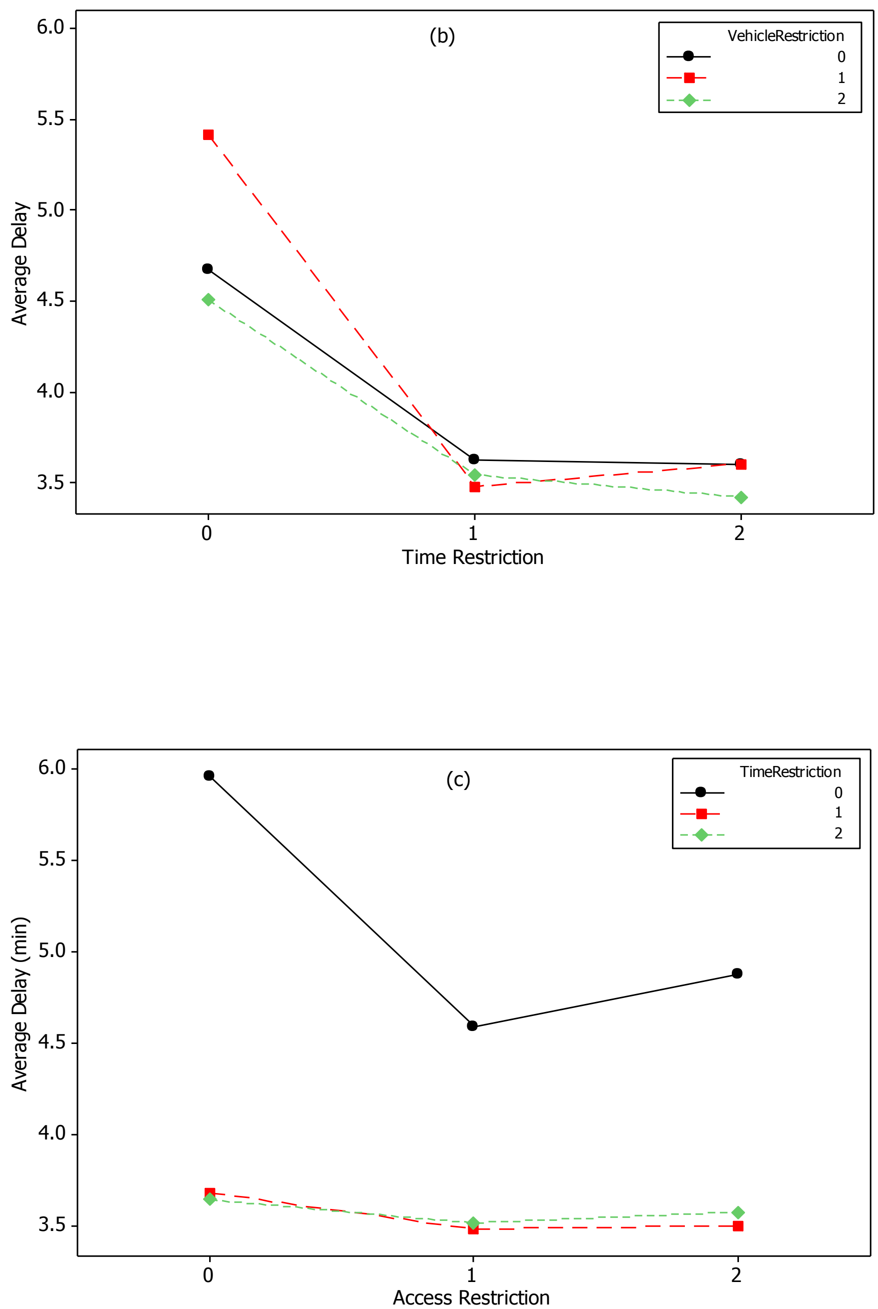
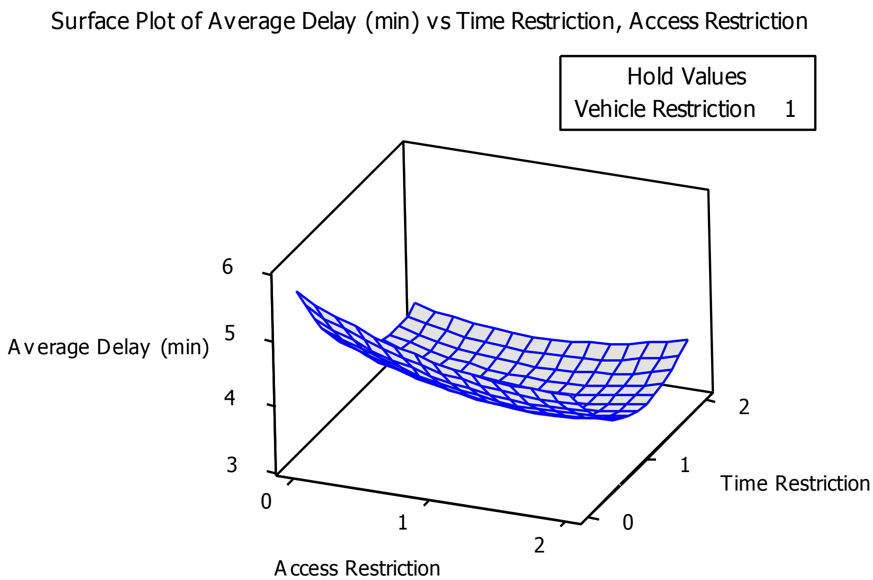


Figure 15 Interaction plots for Average Delay in Box-Behnken analysis.

(a)



(b)

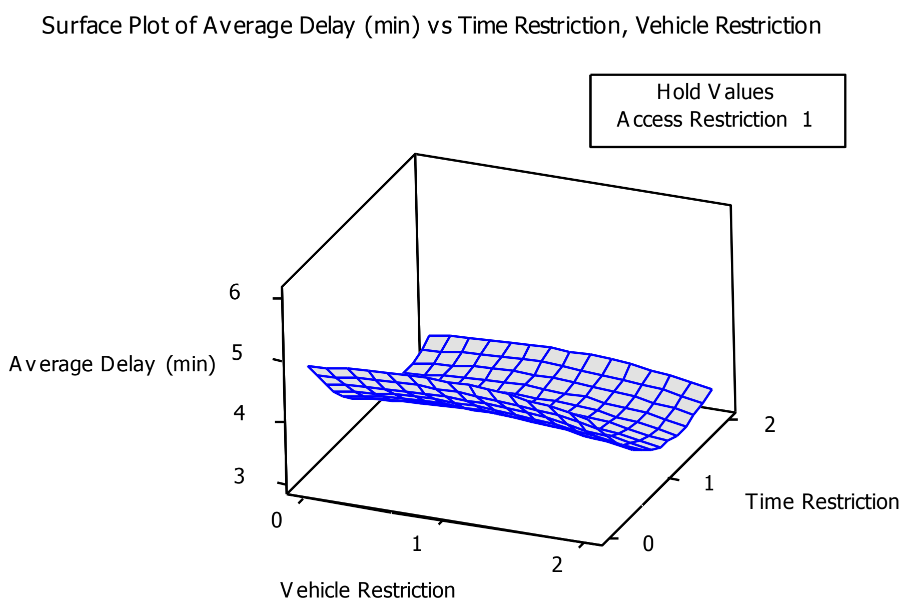


Figure 16 Surface plot for Average Delay in Box-Behnken analysis.

The interaction effects between the response "Average Delay" and restriction policies are further illustrated by the surface plots in Figure 16. The twist in the response surface Figure 16(a) and 16(b) indicate that there exists a more significant interaction between the T_R and A_R than T_R and V_R. The analysis shows that for a city having A_R, T_R and V_R, the increase in T_R results in a decrease in the Average Delay of vehicles in the network is varies more with A_R than V_R.

The polynomial equation for Average Delay of the vehicles in the network can be explained as:

$$Y_2(Average\ Delay) = 5.5601 - 1.0075\mathrm{A_R} - 2.4684\mathrm{T_R} + 0.2897\mathrm{V_R} + 0.2829\mathrm{A_R^2} + 0.7471\mathrm{T_R^2} - 0.1753\mathrm{V_R^2} + 0.2547\mathrm{A_R T_R} - 0.0017\mathrm{A_R V_R} - 0.0020\mathrm{T_R V_R} + \mathcal{E} \qquad (6)$$

It is clear from Table 5 that the A_R, T_R and the square effect of T_R is significant as p-value < 0.05. Hence, omission of the insignificant terms from the full model results:

$$Y_2(Average\ Delay) = 5.5601 - 1.0075\mathrm{A_R} - 2.4684\mathrm{T_R} + 0.7471\mathrm{T_R^2} + \mathcal{E} \qquad (7)$$

Average Trip Time

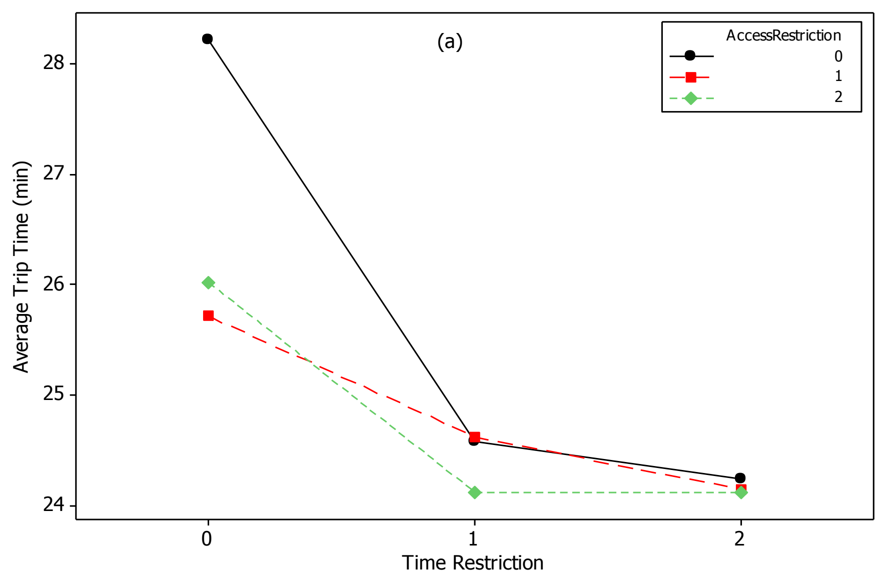
The interaction plots in Figure 17 shows that the Average Trip Time decreases with an increase in T_R for all values of A_R and V_R. The interaction effects between the response "Average Trip Time" and restriction policies are further illustrated by the surface plot in Figure 18. The twist in the response surface indicates that there exists a more significant interaction between the T_R and A_R than T_R and V_R.

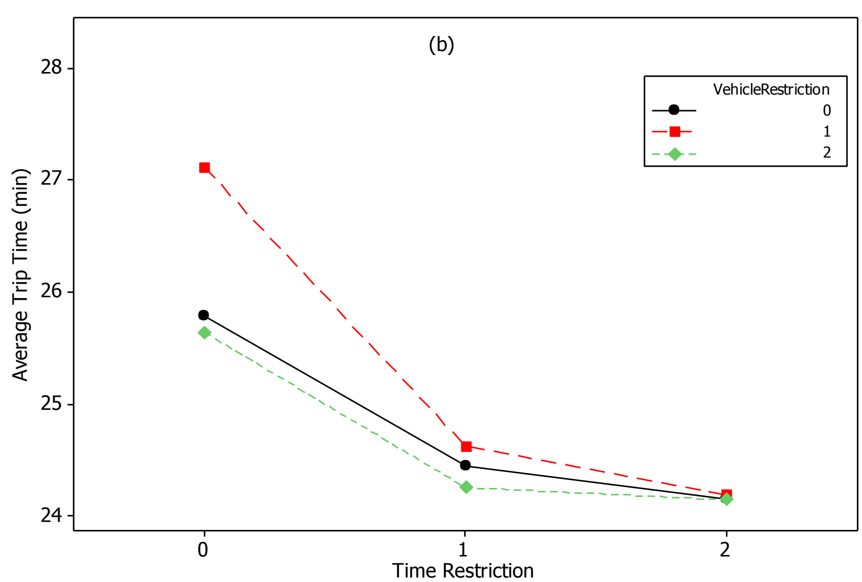
The polynomial equation for Average Trip Time of the vehicles in the network is:

$$Y_3(\text{Average Trip Time}) = 27.3233 - 1.3881\mathrm{A_R} - 3.2834\mathrm{T_R} + 0.8665\mathrm{V_R} + 0.2245\mathrm{A_R^2} + 0.8045\mathrm{T_R^2} - 0.4937\mathrm{V_R^2} + 0.5170\mathrm{A_R T_R} + 0.0173\mathrm{A_R V_R} + 0.343\mathrm{T_R V_R} + \mathcal{E} \quad (8)$$

Omitting the insignificant terms based on p-values the full model becomes:

$$Y_3(\text{Average Trip Time}) = 27.3233 - 1.3881\mathrm{A_R} - 3.2834\mathrm{T_R} + 0.8045\mathrm{T_R^2} + \mathcal{E} \quad (9)$$





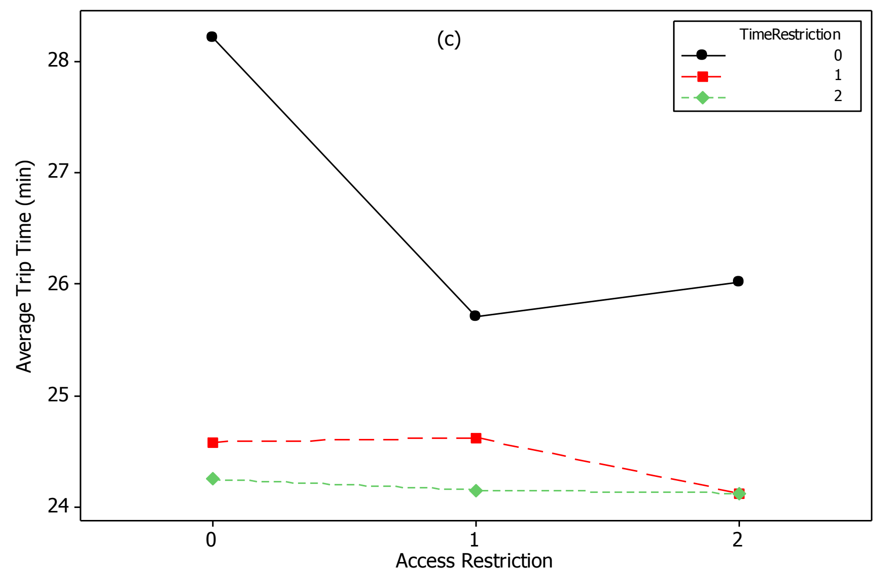
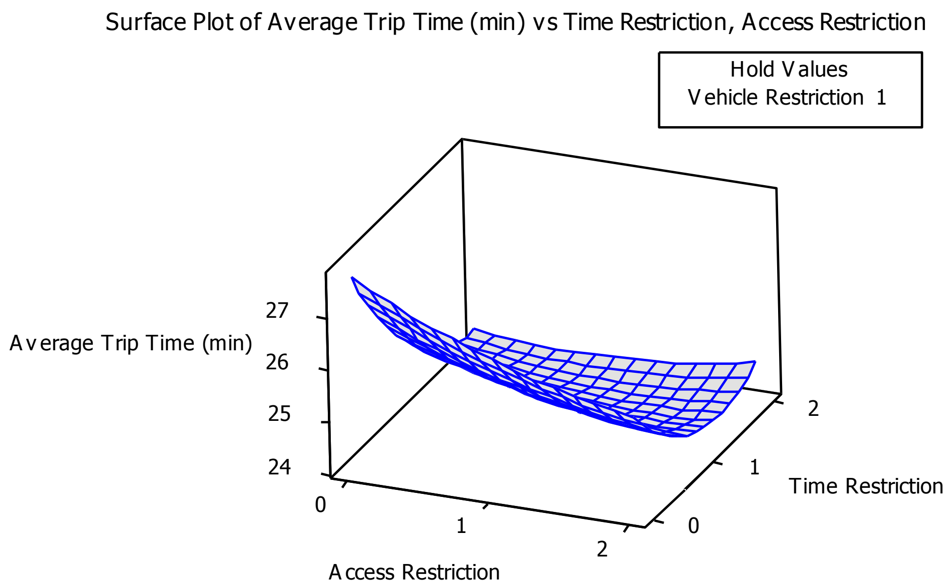


Figure 17 Interaction plots for Average Trip Time in Box-Behnken analysis.

(a)



(b)

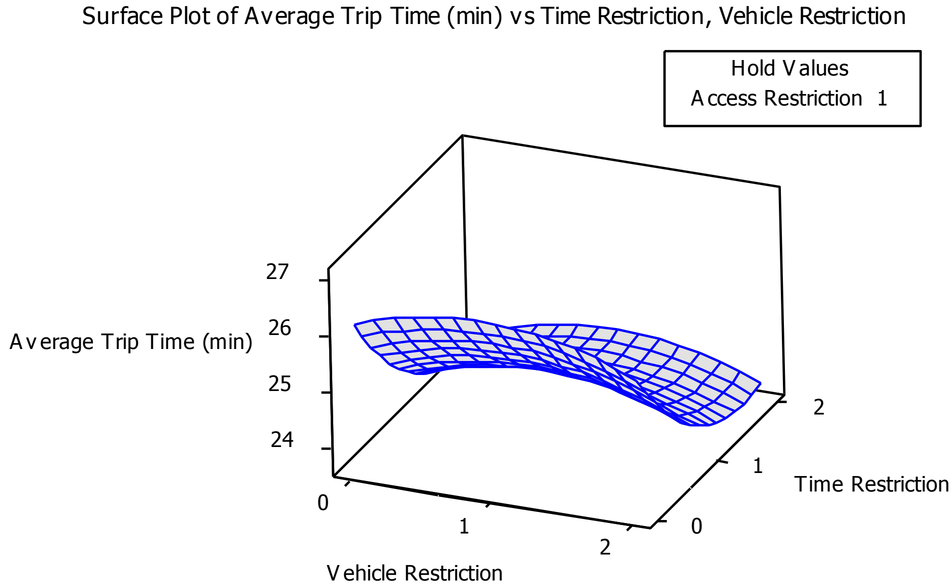


Figure 18 Surface plot for Average Trip Time in Box-Behnken analysis.

Analysis of the above three simulation responses shows that the restriction policies A_R and T_R are significant for the City of Montreal. Similar trend for restriction policies in cities, local authorities increasingly use time-access regulations, was quoted by Quak and de Koster (2006).

4.5. Optimization

To optimize the BBD model a graphical analysis of the significant factors that will produce the optimum value for the responses is performed in DOE++. Although, full factorial design shows access, timing, vehicle-sizing restrictions, and certain interaction between access and timing restrictions is significant but a close observation of the p-values shows vehicle-sizing restriction and other interactions are much less significant compared to the access and timing restriction. On the other hand, the BBD concluded both the access and timing restrictions are significant for all three responses considered in the model where as it was different for individual responses in full factorial design.

Since we have three separate equation for the three responses, average speed equation (5), average delay equation (7) and average trip time equation (9), the optimal setting of A_R and T_R for one of the responses may not be good for the other two. Therefore, a compromise should be made. A balanced setting that can optimize the overall performance should be found. The desirability function approach is used to come up with a balanced solution. This solution tries to satisfy the requirements for each of the responses as much as possible without compromising on any of the requirements too much. Under the desirability function approach, each response is assigned a desirability function d_i. The value of d_i varies between 0 and 1, with 0 representing that the worst acceptable value and 1 representing the response that is the target value. The overall desirability function is defined as:

$$D = \left(d_1^{r_1} \times d_2^{r_2} \times d_3^{r_3}\right)^{1/(r_1+r_2+r_3)}$$

Where r_i represents the relative importance of each response. The bigger the r_i value, the more influence the corresponding response has on the overall desirability function. Usually, r_i is assigned a value from 0.1 to 10.

Depending on the objective for the response (maximization, minimization or target value), the definition of d_i is different (Montgomery, 2007; Myers and Montgomery, 2002).

For maximization:

$$d_i = \begin{cases} 0 & \hat{y}_i < L \\ \left(\dfrac{\hat{y}_i - L}{T - L}\right)^{\omega} & L \le \hat{y}_i \le T \\ 1 & \hat{y}_i > T \end{cases}$$

For minimization:

$$d_i = \begin{cases} 1 & \hat{y}_i < T \\ \left(\dfrac{U - \hat{y}_i}{U - L}\right)^{\omega} & T \le \hat{y}_i \le U \\ 0 & \hat{y}_i > U \end{cases}$$

For target value:

$$d_i = \begin{cases} 0 & \hat{y}_i < L \\ \left(\dfrac{\hat{y}_i - L}{T - L}\right)^{\omega_1} & L \le \hat{y}_i \le T \\ \left(\dfrac{U - \hat{y}_i}{U - L}\right)^{\omega_2} & T \le \hat{y}_i \le U \\ 0 & \hat{y}_i > U \end{cases}$$

Where, $\hat{y}_1$ is the predicted value for the ith response, T is the target value, L is the acceptable lower limit, U is the acceptable upper limit and ω is the weight for a response. The weight, ω, determines how the desirability value changes for a response. A value of ω that is less than 1 is equivalent to saying that any response value between the limit and the target is desirable; a value of ω that is greater than 1 is equivalent to saying that it is very important that the target is met.

The values of the significant restriction policies are optimized, from different scenario data, with the following objectives and assumptions as shown in Table 6:

Table 6 : Optimization of the individual responses.

Responses	Objectives	Values for desirability function
Average Speed	Maximize (eq. 5)	Lower limit (L) : 60km/hr Targeted Speed (T) : 65km/hr Weight of the response ω : 1 Relative importance r_1, r_2 , and r_3 : 1
Average Delay	Minimize (eq. 7)	Upper limit (U) : 5 min Targeted Delay (T) : 3 min Weight of the response ω : 1 Relative importance r_1, r_2 , and r_3 : 1
Average Trip Time	Minimize (eq. 9)	Upper limit (U) : 28 min Targeted Trip Time (T) : 23 min Weight of the response ω : 1 Relative importance r_1, r_2 , and r_3 : 1

The desirability function optimization algorithm in DOE++ software (ReliaSoft, 2011) determines the level of restriction policies for City of Montreal that will result in optimal average-speed, delay and trip time for all vehicles on the city network. The optimization result is shown in Figure 19.

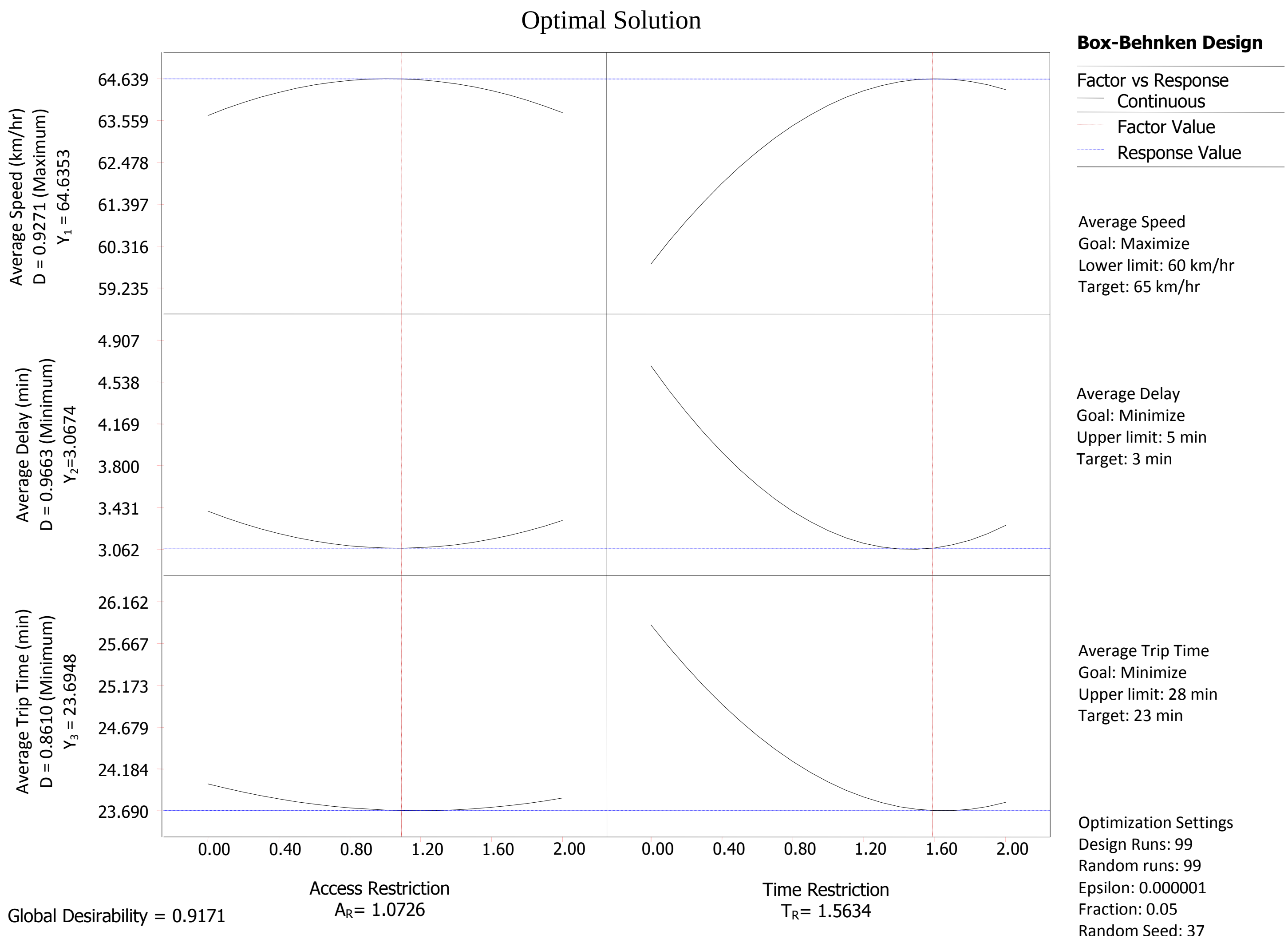


Figure 19 The Optimal level of restriction policies for City of Montreal.

Optimization of the BBD shows that a medium access restriction (A_R=1.0726) and a timing restriction (T_R=1.5634) higher than the medium timing restriction will result in optimum average speed of 64.6353 km/hr, average delay of 3.0674 min, and average trip time of 23.6948 min for all vehicles in simulation network. In the regular, no restriction, scenario these responses were average speed 54.893 km/hr, average delay 6.477 min, average trip time 28.475 min in replica-1 and average speed 55.370 km/hr, average delay 6.050 min, average trip time 27.842 min in replica-2 (Ref. Table 2). The achieved overall desirability value is 0.9171 which indicate the responses are very close to the targets.

In this study, 30% roads were restricted to trucks as a medium level of access restriction. In case of time restriction; medium level of time restriction is defined as restricting trucks from 6am to 10am, the morning-peak, and 3pm to 9pm, the evening peak; the high level of time restriction is defined as restricting trucks from 6am to 9pm, daytime restriction. In summary, definitely more levels in the restriction policies for the DOE analysis will conclude more accurate levels for the significant policies which is part of our future agenda. In this thesis, we limited ourselves to three levels for policies. The optimization result for the City of Montreal indicates a trend towards night delivery for the freight trucks besides access restrictions in around 30% roads of the city. Cooper and Tweddle (1994) also highlighted significantly higher average speeds in central London considering night delivery.

4.6.Conclusion

The present study conclusively demonstrates the use of Traffic Simulation and Design of Experiments (Box-Behnken Design) in evaluation and selection of freight restriction policies for traffic management. A three step approach is proposed for determination of efficient freight restriction policies for a city. The first step involves generation of data on performance of different freight restriction policies on traffic management using VISSIM traffic simulation software. In the second step, the simulated data on freight policies is analyzed through DOE. Finally, in step three, the different responses of the simulation outcome are optimized to determine the optimum level of policies for all three responses (average- speed, delay, and trip time) considered in this study. An application of the proposed approach on City of Montreal is provided.

The results of our study show that access and timing restriction policies are significant in improving traffic management situation in City of Montreal. A substantial amount of improvement (approximate improvement for average - speed 10km/hr, delay 3min, trip time 5min) was seen over the regular, no restriction, scenario. The optimization results of the study show that a medium access restriction and a higher medium timing restriction will result in optimal average speed (64.6353 km/hr), average delay (3.0674 min), and average trip time (23.6948 min) for all vehicles in the city.

Chapter 5

Implementation of Freight Regulatory Initiatives

5.1. Problem Definition

Globalization has resulted in growing quantities of freight movement within cities consequently increasing traffic congestion. Also, cities are the main destinations for freight (trucking) flows, either for consumption or for transfer to other locations. As freight traffic commonly shares infrastructures with the circulation of passengers, the mobility of freight in urban areas has become increasingly problematic. Most of the big cities don't have adequate techniques to deal with the resulting congestion and traffic management problems simultaneously focusing on cities socioeconomic benefits. Some cities do not allow freight trucks to enter the city during the day times causing substantial socioeconomic losses whereas others with no limits on freight trucks lead to huge congestion on city streets due to lack of proper management approaches. Few cities have implemented regulatory policies for freight trucks but several researches have shown the economic inefficiency of the policies and stakeholders, especially freight operators' unsatisfaction. Some highway agencies also implemented restrictions for freight trucks with the aim of improving safety and efficiency of highway travel, occasionally there are concerns from trucking agencies who contend that some of these restrictions are excessive and negatively impact trucks' travel time and thus profitability of trucking companies. Hesse (2004) found that even when a policy existed to reduce truck traffic within the central city, its implementation was lacking. The decentralization of freight activities in urban areas are outlined by Cidell (2008, 2010).

Literature review of the existing implementation models for freight management in urban areas shows that the decentralized nature of the freight flows in cities have not been considered in any of the implementation models, most of them have no background analysis or modeling, just a concrete implementation (Pokahr et al, 2008; Hesse, 2004; Munuzuri et al., 2005). However, in terms of urban formation and the geography of freight distribution decentralization has been theorized by a number of different scholars (Hesse, 2007; Rodrigue, 2006). Another very important challenge, in case of implementing limited freight access policies (access-timing regulation), still ahead is whom to allow and whom not to when socioeconomic values are the main concern. Implementing restriction policies means some freight trucks will not get access to the city or will be delayed or will be shifted to a different route or time period. The regulatory policy implementation challenges are summarized as follows:

Challenges-

- Development of an implementation model and architecture for the decentralized trucking problem.
- Differentiating higher priority freights from the lower priority ones.
- Optimizing the benefit for the city from socioeconomic point of view.

5.2. Solution Approach

Implementing freight regulatory initiatives such as limited access for trucks is a decentralized multilateral decision making problem. It is assumed that, the city has a number of entrances with limited access capacity for trucks in different time periods to balance the traffic flow inside the city. The objective of the city is to maximize its socioeconomic value which is the sum of the values on solution across all selected trucks for the city to access. We propose an agent based decentralized decision making framework for managing and implementing urban freight regulatory policies. The flow of the solution approach is shown in Figure 20.

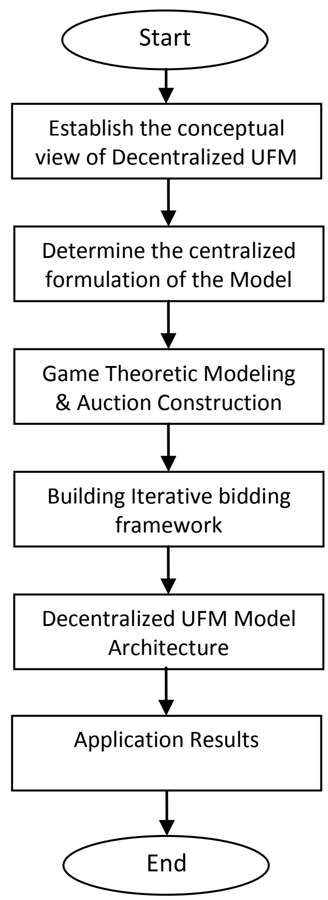


Figure 20 Process flow of the Implementation model for freight restriction policies in city

Our policy implementation framework has several advantages. Firstly, it provides an optimization based strategy, not simple regulatory (time or access restrictions) strategy for the urban freight management problem, the optimization can include several social and economical issues as well as the dynamic aspect of the city traffic. Secondly, it automates the process of balancing urban freight traffic, which is particularly needed in the situation where a large number of trucks need to access the city. Thirdly, it serves as a decentralized negotiation mechanism through which truckers and the city can construct efficient urban freight schedules with automated multilateral negotiation, while at the same time, having control over their private information.

5.2.1. The Decentralized Urban Freight Management (UFM) Problem

A city can have several highway entrances for freight trucks to enter the city and some control mechanism can be established at the entrances, to monitor and control the freight trucks entering the city. Let's consider on these highway entrances there are controls on freight trucks, and limited numbers are allowed to pass within a time period, and the trucks pay negotiable amount for the access. In this case, before an entrance agrees to accept a truck, it evaluates the socioeconomic priority of the freight and profitability of getting more value from other trucks within that interval with its limited capacity. In addition, the truck and the entrance authority need to agree on the terms of the transactions, in particular, on the price and the time interval. If the price or the time period offered by the entrance is too high compared to what the truck is willing to accept, the truck may not choose the access permission for this entrance. Alternatively, if the price the truck is willing to pay is low or the time period requested is too short to make it profitable for the entrance, the authority might decide not to accept the truck. As the decisions are tightly coupled, it is desirable to model the interrelations among them and consider them simultaneously when developing optimal decision policies. More decisions need to be considered concurrently, if counter offers from other trucks are allowed. Given limited capacities to each entrance, the access strategy should have the potential of effectively coordinating the decisions and achieving optimal solutions in terms of entrance utilization. The implementation of this strategy requires a multilateral negotiation mechanism between the entrance and trucks. In terms of multilateral coordination and negotiation systems design and implementation in the context of supply chain, the multi-agent systems design paradigm is often adopted (Lau et al., 2006).

The urban freight transport under access-timing restrictions is a decentralized multilateral decision making process. From the perspective of the city transportation management authority, it combines truck selection, access time setting, entrance limit setting, and maximizing benefits. The decisions facing by truckers (drivers) are whether they should use the entrance given their preference value and access times and how to assign values to the entrance-time combination and select them in a counter offer to maximize benefits. We assume that the city transportation management authority has set limited access for each entrance so as to allow limited number of freight trucks on certain time intervals. The objective of the city authority is to maximize the efficiency, which is the sum of the values on a solution across all trucks, rather than its revenue. This means the solution will include maximum number of trucks with higher social or economical priorities which may be the trucks loaded with daily essential goods, perishable goods, emergency service instruments, important raw materials for industry, etc which have higher socioeconomic values than the revenue city may earn from the access charges. Each truck can only use one entrance to enter the city offered by the city transportation management authority. Each access permit has an access time period and a preferred entrance. The truck's information on a request to access is its identification number which will provide the specification of the truck, the goods it's carrying, the desired access time and deadlines for each entrance that it can reach and the price that he/she is willing to pay. The price may vary with the entrance and access time period. City can subsidize the price value for trucks with higher socioeconomic values. The trucks' value functions are their private information. The UFM problem involves the selection of trucks and allocation of the entrances to the requests such that the deadline requirements of all selected trucks are met and the sum of trucks' value is maximized.

Figure 21 presents a simplified illustration of the decentralized UFM problem considered in this thesis. The city has m entrances with certain access limits for trucks on each in certain time periods (example entrance 1 has access limit 200 in period 1, 0 in period 2, 100 in period 3 and 200 in period 4). Different trucks (example 1, 2, j, j +1 and n) make access request on different entrances (example 1,…, i and m) in certain time periods (example in case of truck 1: period 1 to 3 on entrance 1; truck 2: period 2 to 4 on entrance 1 and period 2 to 3 on entrance i, etc.) and have different preference values for each entrance (example truck 1: preference value on entrance 1 is 15; truck 2: preference value on entrance 1 is 12 and preference value on entrance i is 10) which they can reach.

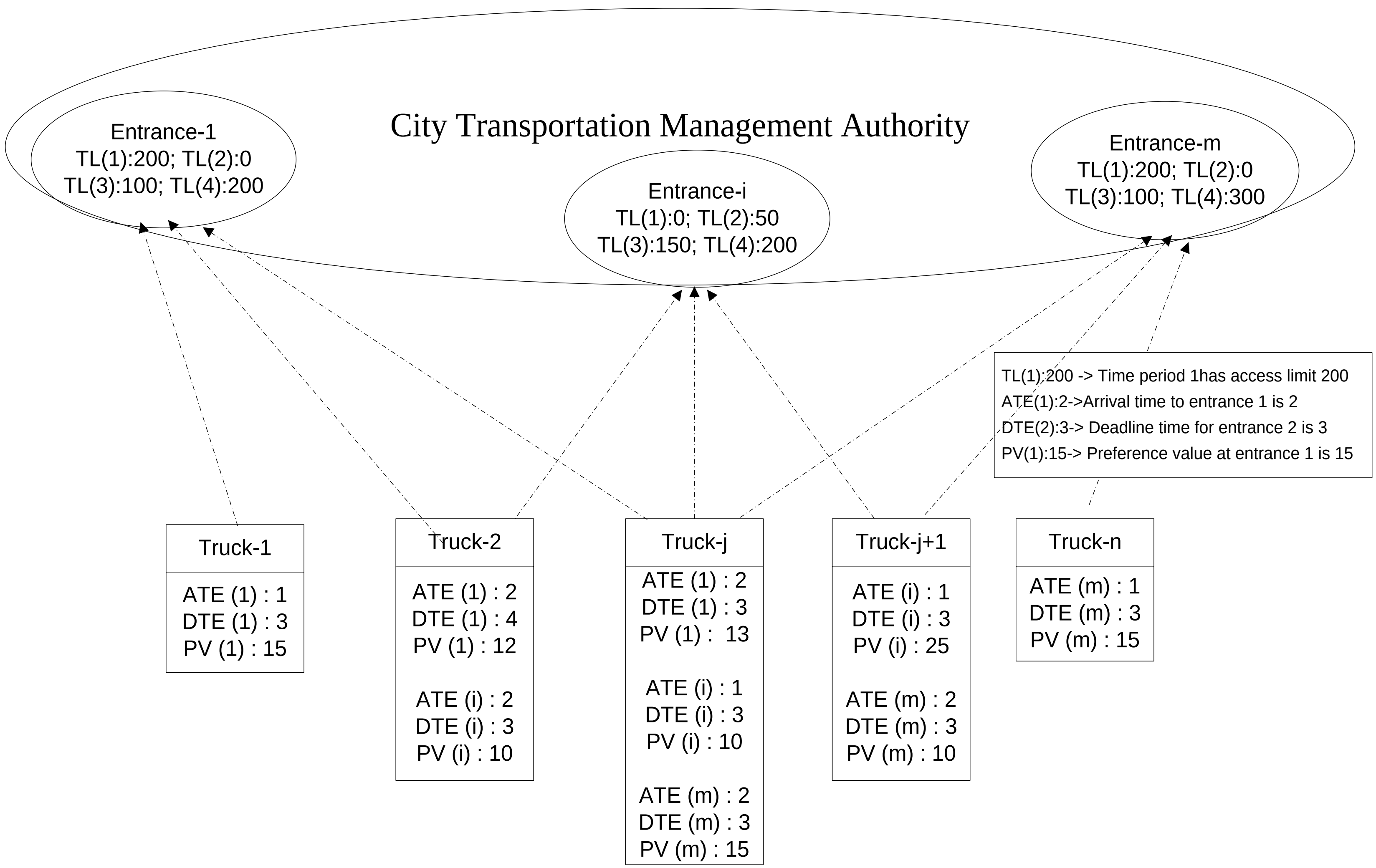


Figure 21 Simplified Conceptual view of Decentralized UFM

Here to simplify the model only one numerical value is considered, but it may be the combination of several socioeconomic priority factors associated with the freight. In this setting, the UFM problem faced by the city transportation management authority is to coordinate the decisions regarding which truck to accept, at what price and with what entrance and access time period. For trucks they need to decide how to adjust their preferences in terms of requested access time and prices offered if their original requests are turned down. Again we consider that the city transportation management authority needs to coordinate its UFM decisions across a larger number of entrances and trucks for some specific time windows, say one day, and the information about trucks' access request are available at the beginning of the decision making process.

Centralized Formulation

As mentioned previously we consider the urban freight management problem as a decentralized decision making problem in the sense that the actual valuation of a driver (truck) on highway entrances is private information to the driver, which is not known to the transportation management authority. However, to clearly demonstrate the combinatorial optimization nature of the problem, we first assume a centralized urban freight management (CUFM) environment, i.e., drivers' valuations are known to the city transportation management authority. With this assumption, we can conveniently model the problem as a mixed integer program. The decentralized characteristic of the problem will be considered when we develop the game theoretic modeling and iterative bidding framework.

Consider an urban freight management problem which consists of a set of n trucks, denoted by N, and a city transportation management authority. Each truck $j(j = 1, \dots n)$ needs to access the city for delivering or collecting goods or just pass through for another city on a particular date. There are m highway entrances that a driver can use to access the city. To balance the traffic and control the congestion on the city streets, the city transportation authority imposes limits on each highway entrance in terms of the number of trucks which will be allowed to access the city through the entrance within a particular time period during the day. The limits are used to balance the freight traffic and control congestion during daytime. For instance, to control the congestion, the number of trucks allowed to enter the city is reduced during rush hours and increased in off-peak hours. Depending on the traffic pattern and condition, the limits may be different across the highway entrances on different time periods. We assume that a particular day is divided into t time periods. For a time period, $1 \leq k \leq t$, of the entrance i, the access limit is $l_{i,k}$. Each truck has an earliest arriving time period $r_{j,i}$, before which it cannot arrive at the highway entrance i due to existing constraints. A truck also has an access deadline period $d_{j,i}$ for entrance i , which is the latest time period at which the truck has to enter the city in order to catch the delivery or pick up deadline. The arrival time to the entrance $r_{j,i}$ and the deadline to enter city $d_{j,i}$ for trucks are assumed as time periods like k. Since for trucks to deliver or picking up the goods on time is important rather than accessing the entrance on particular time, a time interval is more significant. Moreover, for a freight truck to come at a specific entrance on a particular time is almost impossible due to other traffic related issues on roads. We also assume that a driver has different preferences on the highway entrances that he/she will use. These preferences are captured by the value that driver j imposes on the entrances, denoted $v_{j,i}$ assuming that it also includes the subsidy value of the priority that the truck has assigned by city transportation authority, is the price that driver j is willing to pay for his/her access through entrance i within the time window [$r_{j,i}$, $d_{j,i}$]. The urban freight management problem involves the selection of a set of trucks $N^* \subseteq N$ such that the access window constraints of selected trucks and limits of truck accesses imposed by the city transportation authority are respected and, at the same time, the sum of trucks' values is maximized. Let $Z_{j,i,k} = 1$ if truck $j$accesses entrance i during the time period $k$and $Z_{j,i,k} = 0$ otherwise. The urban freight management problem is given by:

$$\max \sum_{j=1}^{n} \sum_{i=1}^{m} \sum_{k=1}^{t} Z_{j,i,k} * v_{j,i} \qquad (1)$$

subject to,

$$k \geq r_{j,i} * Z_{j,i,k}, \qquad \text{for all } j, i, k \qquad (2)$$

$$k * Z_{j,i,k} \leq d_{j,i}, \qquad \text{for all } j, i, k \qquad (3)$$

$$\sum_{i=1}^{m} \sum_{k=1}^{t} Z_{j,i,k} \leq 1, \qquad \text{for all } j \qquad (4)$$

$$\sum_{j=1}^{n} Z_{j,i,k} \leq l_{i,k}, \qquad \text{for all } i, k \qquad (5)$$

$$Z_{j,i,k} \in \{0,1\}, \qquad \text{for all } j, i, k \qquad (6)$$

Formulation (1) represents the objective function which maximizes the preference values of all trucks across all entrances at all time periods for the city authority. The set of constraints (2) and (3) ensures that the scheduled access of a truck does not start before its earliest arrival time and after its access deadline. Here $Z_{j,i,k}$ is added to linearize the logical constraint "if" in (2) and (3). For example, (2) can be read, if truck j is scheduled on entrance i within the time period k, k must be greater than $r_{j,i}$, otherwise there are no restrictions on k. Constraint (4) ensures that, at most, one access can be granted to a particular truck within the planning horizon. Constraint (5) ensures that, for any particular entrance i and time period k, the limit on the number of trucks accesses is respected. Constraint (6) ensures the integer constraints.

Having modeled the urban freight management problem in a centralized setting, we gain insights to the complexity of the problem in terms of number of constraints and variables. Now we turn our attention to the game theoretical modeling of the problem by considering driver's (truck's) valuations as private information not known to the city transportation authority. As the computational complexities inherited from the combinatorial nature of the scheduling problem are not related to the game theoretical modeling, we ignore the scheduling details and focus only on strategic interactions. We first model the decentralized UFM as a game. We then construct a VCG (Vickrey–Clarke–Groves) auction that solves the game with an economically efficient outcome. The auction scheme assigns access permission in a socially optimal manner, while ensuring each truck receives at most one access. This strategy charges each bidder the opportunity cost that their presence introduces to all the other players and ensures that the optimal strategy for a bidder is to bid the true valuations of the items.

Game Theoretic Modeling and an Auction Construction

In the centralized formulation, we have assumed that trucks' (drivers') valuations are known to the city. In the game theoretic modeling, we remove this assumption and consider drivers' valuation on different access time periods and entrances are private information and they will behave strategically to maximize their own benefits. To reflect this self-interested property of the drivers, we call them agents. We also assume the city authority maximizes social welfare. In the context of bidding and auction, we call the city authority auctioneer. The decentralized UFM game can be described as follows. Let N denote a set of n requests. Each represents a request of truck that needs access to the city. Trucks need to be scheduled on the entrances. Let Γ be the set of all feasible schedules (Γ can be obtained by solving constraints of centralized UFM as a constraint satisfaction problem). For an agent $\in N$, if it is included in an assignment $\mathrm{S} \in \Gamma$, the access time and allocated entrance is specified in S. According to the allocated entrance, the agent assigns a valuation $v_j(\mathrm{S})$ to the schedule. A valuation is the monetary value that the agent assigns to the schedule. It can also be interpreted as the price that the agent is willing to pay to obtain the schedule. In practical case, the valuation can be linear or complex combination of the agents' offered price and the sum of socioeconomic valuation of the agent by the auctioneer. An agent j needs to pay the city $p_j(\mathrm{S})$ in exchange for its access to the entrance as scheduled in S. Its net benefit from participating in auction is $v_j(\mathrm{S}) - p_j(\mathrm{S})$. The agents must collectively choose an outcome consisting of (i) a schedule $\mathrm{S} \in \Gamma$, and (ii) a vector of payments $(p_1(\mathrm{S}), p_2(\mathrm{S}), p_3(\mathrm{S}), \ldots, p_n(\mathrm{S}))$.

To construct the well-known VCG auction model, let's consider the total maximum valuation of a schedule is $\mathrm{V}(N)$ and maximum valuation of the schedule when agent j is excluded from the schedule is $\mathrm{V}(N\backslash \mathrm{j})$ where

$$\mathrm{V}(N) = \max_{\mathrm{S}\in\Gamma} \sum_{j\in \mathrm{N}} v_j(\mathrm{S}) \text{ , and}$$

$$\mathrm{V}(N\backslash j) = \max_{S\in\Gamma} \sum_{j\in \mathrm{N}\backslash j} v_j(\mathrm{S}).$$

The sealed bid auction proceeds as follows. Each agent submits its valuations on each element of the set of all feasible schedules Γ. The auctioneer chooses S^* from Γ as the final schedule, such that S^* maximizes $\sum_{j\in \mathrm{N}} v_j(\mathrm{S})$, that is, S^* solves $\mathrm{V}(N)$. In addition, the auctioneer also computes a schedule for each $j \in N$, such that the schedule solves $\mathrm{V}(N\backslash j)$. After the schedules are computer, agent j pays

$$p_j(\mathrm{S}^*) = \mathrm{V}\,(N\backslash j) - \sum_{i\neq j} v_i(\mathrm{S}^*)$$

In the centralized UFM model, drivers' weakly prefer earlier accessing times than later ones. Given the limited number of accesses through each entrance, accommodating a new truck in the existing schedule will not make existing trucks' accessing times earlier. Therefore values of existing agents will not increase. In most cases, these values will decrease because existing trucks' accessing time will likely be delayed when a new truck needs to be squeezed in. Therefore, in decentralized UFM, it will be always the case that $\mathrm{V}(\mathrm{N}\backslash j) \geq \sum_{i\neq j} v_i(\mathrm{S}^*)$, that is, payments always go from agents to the auctioneer. This makes sense in decentralized UFM as drivers always pay the city for an access. On the other hand after paying the auctioneer with $p_j(\mathrm{S}^*)$, agent j's net benefit from participating is

$$v_j(\mathrm{S}) - p_j(\mathrm{S}) = v_j(\mathrm{S}^*) - \left[\mathrm{V}\,(N\backslash\, j) - \sum_{i\neq j} v_i(\mathrm{S}^*)\right]$$
$$= \mathrm{V}\,(N) - \mathrm{V}\,(N \setminus j).$$

It is clear that $\mathrm{V}(N) - \mathrm{V}(N\backslash\, j)$ is non-negative, which means agents always get non-negative net benefits when participating in the auction. In addition to providing agents with the incentive to participate, the auction is also strategic proof meaning that submitting truth valuations to the auctioneer is a dominant strategy. Suppose agent j reports $w_j \neq v_j$ instead. The auctioneer then chooses a different schedule $\tilde{S} \in \Gamma$ that solves $\max_{S\in\Gamma}\left[\sum_{i\neq j} v_i(S) + w_j(S)\right]$. Agent j's net benefit becomes

$$\sum_{i\neq j} v_i(\tilde{S}) + v_j(\tilde{S}) - V(N \setminus j) \leq V(N) - V(N \setminus j).$$

It is clear that no agent can benefit from misreporting its valuation function. Given that the centralized UFM can be used to obtain Γ and we have constructed the VCG auction that finds the optimal schedule in Γ, it seems that we have everything needed to solve the decentralized UFM game. However, the reality is, despite VCG's theoretical elegance, its limitations in terms of implementation restrict its application to the decentralized UFM problems. From the auctioneer's side, the implementation of the VCG auction requires the solution of a $V(N)$ and a $V(N \setminus j)$ for all $j \in N$, that is n+1 NP-hard optimization problem. The computation cost can be prohibitively expensive if the auction is applied to non-trivial size problems. From the agents' side, the VCG auction requires an exponential number of schedules in Γ to be valued by each agent, which presents hard valuation problems to agents. In addition to computation, communicating the large number of schedules to agents can also be a huge burden to the system. Transparency is another practical concern in VCG auctions. It can be difficult to explain to the drivers why a certain schedule is chosen. In the following section, we propose an iterative bidding framework aimed at addressing some of the limitations arising in the application of VCG to decentralized UFM.

5.2.2. The Iterative Bidding Framework

The iterative bidding framework proposed in this thesis is an auction-based approach to the UFM problem. The framework contains three major components, a requirement-based bidding language, a linear integer programming model for winner determination, and an iterative bidding procedure. The requirement-based bidding language allows an agent's bid to be expressed by a request of entrance access, which naturally represents scheduling constraints and objectives. The winner determination model takes bids expressed in the requirement-based language as input and computes feasible schedules which maximize the auctioneer's revenue. The iterative bidding procedure provides a structure for agents and the auctioneer to interact in a systematic way and eventually evolve the provisional solutions towards an optimal or near optimal one. Iterative bidding also reduces agents' information revelation and adds the potential of accommodating dynamic changes during the bidding process. The iterative bidding framework is a multi-attribute auction, which allows negotiation over price and a non-price attribute: the entrance and access time period of an agent's request. In addition, the framework has good privacy preserving properties. For example, unlike VCG auctions, it does not require agents' knowledge about the resources, such as their capabilities, availabilities and limitations. Also, it does not require complete revelation of agents' valuations.

During the access negotiation with the entrance management system, an agent can often express her preferences using a conditional statement. For example, an agent j may say he/she is willing to pay different specific prices if his/her access permission is granted within a specific time window, e.g. $r_{j,i} < c_{j,i} \leq d_{j,i}$ in a specific entrance i. There are three components in this conditional statement, the entrance, the time window and the price. A requirement-based language for the representation of agents' preferences in terms of these three elements can be defined using C-Bids (Wang et al., 2009). C-Bids can be connected by XOR connective as a XOR-C-Bid to represent values that an agent has on different entrances on different time windows. Given the set of XOR-C-Bids from agents, the task of winner determination is to select a subset of bids such that all scheduling constraints of the entrances are satisfied and, at the same time, the sum of customer's value is maximized. A C-Bid can represent a customer's value over a time window defined by the $r_{j,i}$ and $d_{j,i}$. In each round of the bidding, agents do not submit a complete valuation. In fact, partial revelation of agents' valuations is one of the main benefits of iterative bidding.

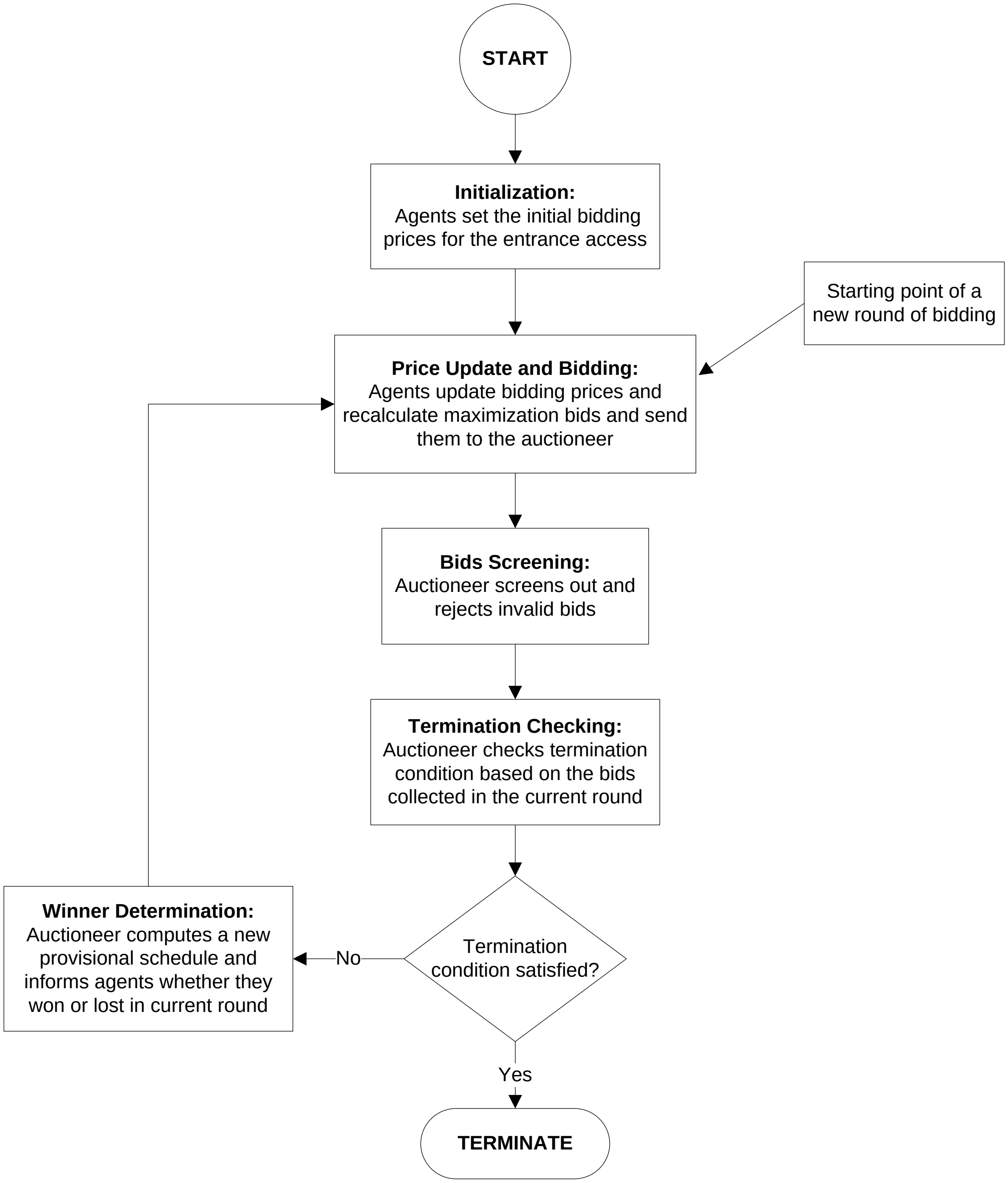


Figure 22 Overview of the iterative bidding process

The iterative bidding procedure is depicted as a flow chart in Figure 22. Initially, a truck has a request to be processed. Before submitting the first bid, the truck needs to initialize a reserve price for the entrances to get access within its preferred access time and deadline.

The reserve price reflects the basic cost of accessing the entrance. Usually the city authority will not go below it for a loss. If an agent/truck has no estimation about the reserve price, it can set the initial reserve prices as minimum as 1. However, appropriate setting-up of initial bidding prices can speed up the overall bidding process and, at the same time, maintain the solution quality.

In our iterative bidding framework, agents have the incentive to obtain the right reserve prices. It is irrational to submit any bids below the cost (reserve price) because those bids will be rejected by the auctioneer. An alternative way is to acquire reserve prices from the auctioneer before the bidding starts. After setting up the reserve prices, agents use them as the first round bidding prices and start bidding process.

5.2.3. Decentralized UFM Model Architecture

A simplified abstract view of the UFM model architecture is shown in Figure 23, where the freight trucks are the client to the system and act like agents. An agent can send a number of requests, to the UFM management center for access permission to one or more entrance(s), considered as bids for that entrance(s) in the model. The optimization module in the UFM management center determines optimal solution considering the bids and the entrance access limits determined from historical and real-time traffic information. The UFM management center will acknowledge individual agents about their access status on regular basis and update irregularly, if needed.

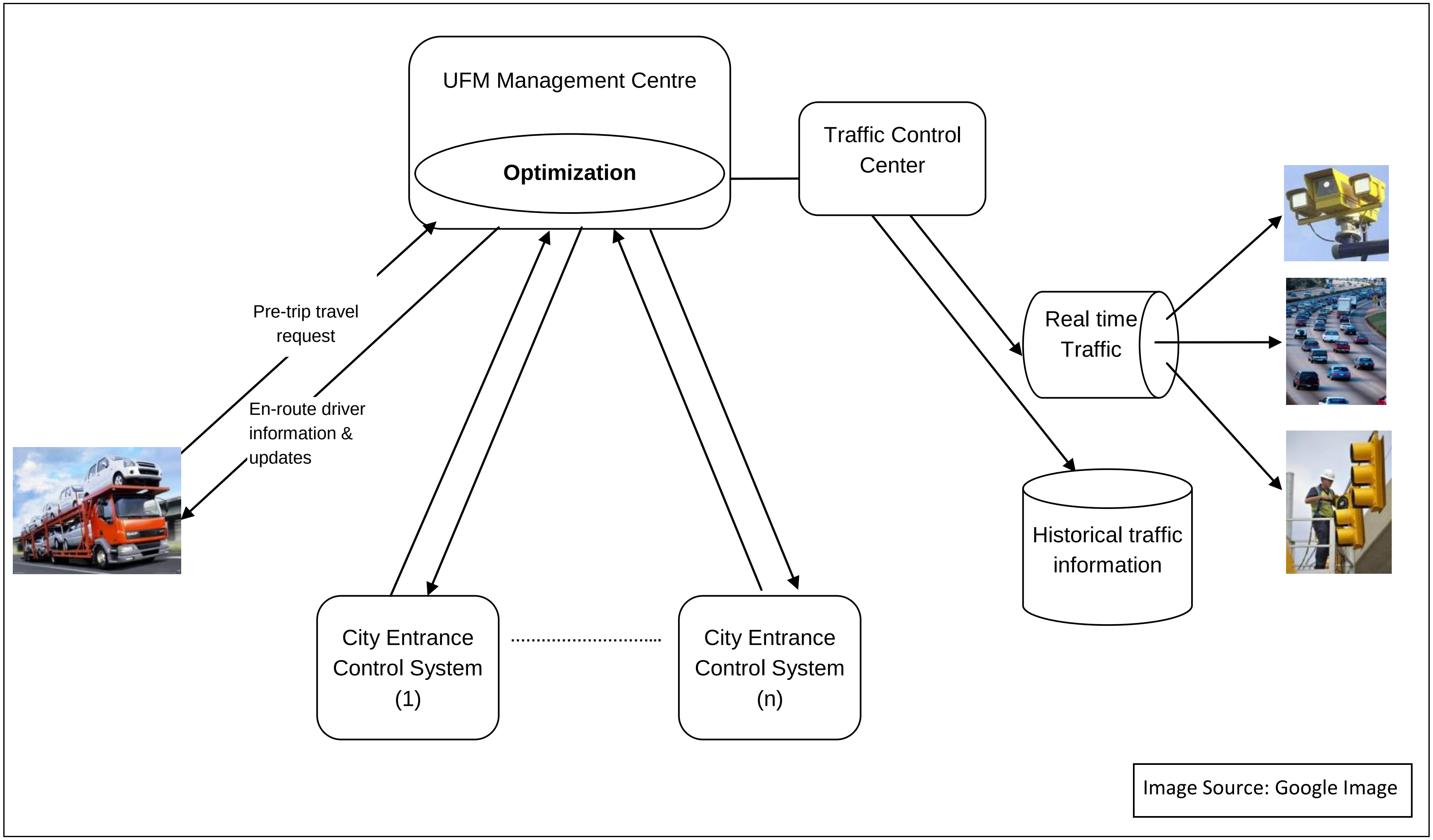


Figure 23 An abstract view of the Decentralized UFM model.

The city entrance control system may comprise of *n* electronic entry gates able to effectuate without user intervention for the identification and/or control the vehicle entrance into the city. The infrastructure may contain a series of technical solutions including different means for vehicle identification and authorization depending on the agents' category and its differing needs. An On-Board-Units (OBU) can guarantee a secure high-speed transaction with the roadside installations via microwave transponder and allow debiting fares automatically from an electronic purse inside the inserted smart card. The Vehicle Identification Number (VIN) or the Vehicle Registration Number (VRN) can be used to automate the transactions at the entrances. In addition, support from the government to provide new technologies (such as OBU or web-based technology) at affordable prices, is critical to the success of this implementation model. In case of the specific City of Montreal, used as a context of study in this thesis, the city is one step ahead for implementing such system as the Ministry of Transports Quebec has already developed a system (semi-automated technique and GPS technology in traffic data collection) by the help of the Genivar consulting group of Montreal that measures the position, speed and travel time of vehicles on road networks and highways (MTQ, 2000).

5.2.4. Application Results

The primary motivation for this research is to explore a balanced innovative approach to urban freight management that will simultaneously improve efficiency of urban freights and maximize cities socioeconomic value. Here we describe both the analytical model testing and the ways to improve performance of the system via simulation.

UFM Model Performance

We compare the decentralized iterative bidding framework with the most generic first come first serve (FCFS) and the centralized model to observe the performance. Here it is assumed that the agents (trucks) report their complete valuations of different entrances at the beginning. We have coded the model into ILOG CPLEX to compute the optimal schedule in centralized model while maximizing the cities preference values and used Java to implement the iterative bidding part in the decentralized model. For the test cases, datasets with total number of trucks or agents n=10,000, number of city entrances m=10, city entrance scheduling periods t=4 are used. The maximum number of entrances that a truck may reach to enter the city were randomly varied from 1 to 4 assuming an incoming highway has a maximum 4 entrances for that specific city to enter. The access periods for the trucks to the entrances which include the arriving time period and deadline for each entrance, and also the preference values for trucks, varying from 10 to 30, are generated randomly. The randomly generated first bid for reachable entrance-time period combination for each truck is considered as the value of the truck in FCFS scheme for that entrance-time period.

These models were implemented on a 2.67 GHz Intel Core i7 CPU with 6GB memory. Several iterations with different combination of these datasets as shown in Figure 24 concludes that the decentralized iterative bidding model always has higher values than generic FCFS scheme except in the region where the city entrance access limit reaches very close to the number of trucks seeking access for the city. On the other hand centralized preference values are higher than the decentralized iterative bidding model which in turn proves our theoretic assumption that in case of decentralized iterative bidding architecture the agents always get non-negative net benefits when participating in the auction. Though the centralized values are higher than the decentralized ones it is not possible to implement the centralized system due to the decentralized nature of the freight trucks decision making problem in the sense that the actual valuation of a driver (truck) on highway entrances is private information to the driver, which is not known to the transportation management authority. Figure 25 shows the running time for iterative bidding model reduces with higher increment bid size and reaches close to the centralized one which can be helpful in setting minimum increment bid restriction for agents in real scenario to improve the performance of the system.

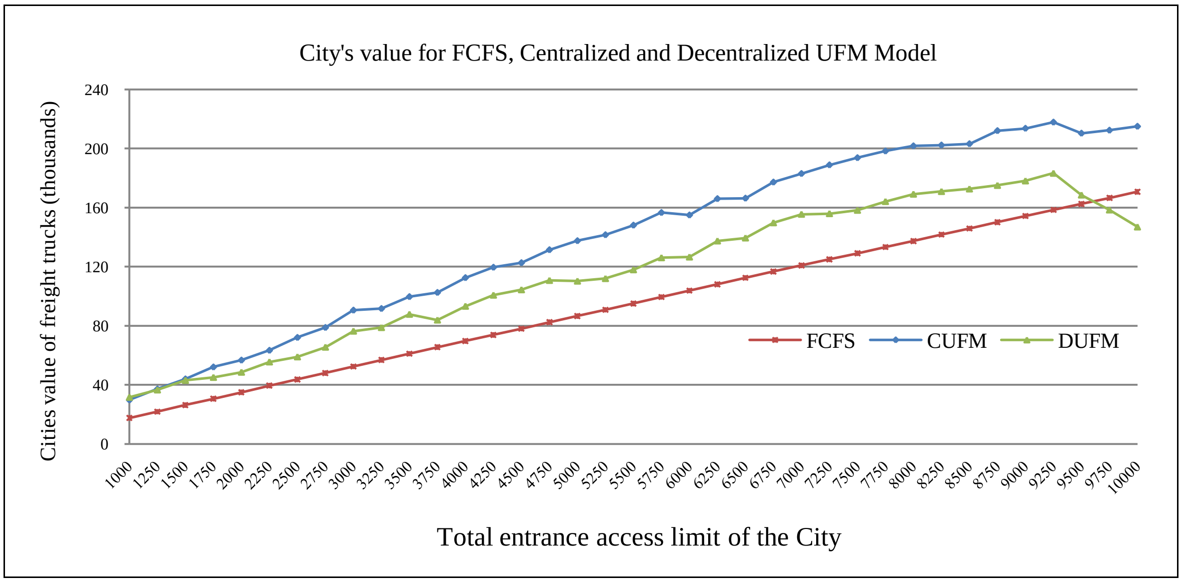


Figure 24 UFM Model Performance (City's value).

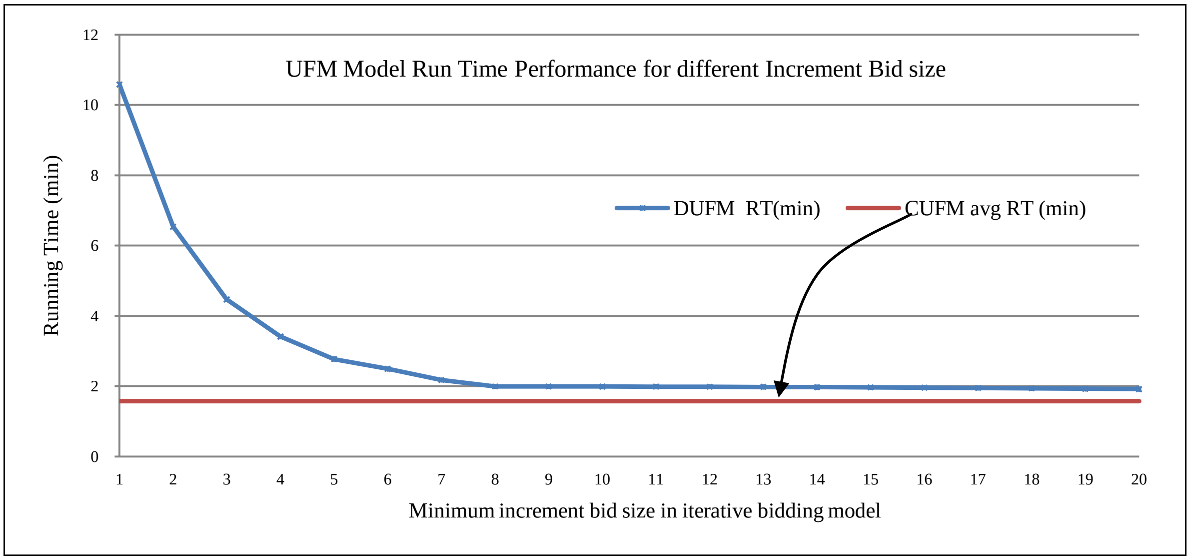


Figure 25 UFM Model run time Performance (minimum increment bid size).

5.3. Conclusion

We present an agent based decentralized iterative bidding model for urban freight transport management under access-timing restriction scenario. The proposed framework has several advantages for freight transport access management in cities that require implementing periodic access limits on certain entrances with a goal to maximize socioeconomic welfare. When assigning values to the agents, the priorities of the agents, city authority may include several issues regarding social welfare which could be subsidized by equivalent economic values in the model. The uniqueness of the proposed approach is that it integrates the exploration of agent's access deadline flexibility and supports city's entrance access-timing restrictions with an iterative bidding framework, which has the potential to coordinate the behaviors of self-interested parties in decentralized supply chain environments. As our iterative bidding procedure does not terminate with VCG payments, it is not incentive compatible under the game theoretic assumption of agent behavior. However, we are designing the system for the type of requests to access cities with large number of freight access requests. In this context, it is reasonable to take the market assumption, that is, agents will bid myopically given that each individual agent will have very little impact on the market prices.

Chapter 6

Conclusion and Future works

6.1. Conclusion

Analyzing the impact of restriction policies for a city is a complex process that requires one to consider a large number of policies at all possible levels along with interactions with others. Besides, presence of limited data or no prior experience with similar studies can pose additional challenges for cities in the evaluation of restriction policies. Part one of the thesis presents an integrated approach based on microscopic traffic simulation and DOE to evaluate a set of freight restriction policies significant for a specific city. The findings for the City of Montreal have shown a substantial improvement in average speed, average delay, and average trip time with policy implementation over the regular or no policy restriction scenario. The most challenging aspect in simulating any city network with real-time dependent traffic scenarios is to get minute details of all parameters affecting traffic movement, which is possible only with an access to the freight data and other traffic related information of city. For some cities, enough information may not even exist. This challenge was overcome in this thesis by the use of simulated data generated through microscopic traffic simulation software VISSIM.

Part two presents an agent based iterative bidding implementation framework for selected freight regulatory policies. The iterative bidding auction model is used to aggregate all the socio-economic freight concerns of the city and the decentralized freight behavior in the implementation model. The uniqueness of the proposed approach is that it integrates the exploration of agent's access deadline flexibility and supports city's entrance access restrictions with an iterative bidding framework, which has the potential to coordinate the behaviors of self-interested parties in decentralized supply chain environments. This framework could be further developed to assist the introduction of transport demand management policies stimulating a regime shift towards a more sustainable transport system. The framework can also be used to organized freight trucks into platoons with the objective of maximizing lane capacity.

6.2. Future works

Usually, in the absence of real data traffic simulators are used to model the behavior of each goods vehicle inside the whole traffic network. That way, it is possible to show the fine reality of the behavior of each vehicle and of each generator of movements along the day. But, in order to implement it on the whole urban area, a thorough knowledge of the behavior of each type of agent (generators and transport operators) is required, which is difficult and costly to gather in a comprehensive way. So, traffic simulators are used as a general rule in local or theoretical cases to simulate changes to improve the efficiency of the transport system. In this thesis, the policy selection study was limited only to highways of the city and the presences of traffic signals on road network are not considered. Therefore, in the next step of our work we will also investigate the impact of traffic signals and speed limits of roads on freight restriction policy selection for traffic management in urban areas and provide recommendations for improvement.

On the other hand in the policy implementation framework, the iterative bidding procedure does not terminate with VCG payments, it is not incentive compatible under the game theoretic assumption of agent behavior. Despite this game theoretic vs market argument, designing an incentive compatible iterative bidding auctions for the entrance access management problems is a very important research task on my agenda. In this thesis, we have focused only on the off-line entrance access management model. On-line models which allow trucks access request to arrive randomly during decision making process present additional challenges due to the uncertainty of the environment. How to design automated systems which support the decision making in on-line context is also an important research question that we would like to answer in the future.

Bibliography

Adler, J.L., Satapathy, G., Manikonda, V., Bowles, B., Blue, V.J. (2005). A multi-agent approach to cooperative traffic management and route guidance, Transportation Research Part B 39 (4), 297–318.

Allen, J., Anderson, S., Browne, M. and Jones, P. (2000). A Framework for Considering Policies to Encourage Sustainable Urban Freight Traffic and Goods/Service Flows; Summary Report, Transport Studies Group, University of Westminster, London.

Allen, J., Browne, M., Tanner, G., Anderson, S., Chrisodoulou, G. and Jones, P. (2004). Analysing the potential impacts of sustainable distribution measures in UK urban areas. E. Taniguchi, R. G. Thompson, eds. Logistics Systems for Sustainable Cities, Proc. 3rd Internat. Conf. City Logist. Elsevier, Amsterdam, pp. 251–262.

Allen, J., Tanner, G., Browne, M., Anderson, S., Christodoulou, G. and Jones, P. (2003). Modelling Policy Measures and Company Initiatives for Sustainable Urban Distribution, Transport Studies Group, University of Westminster.

Ambrosini, C. Routhier, J. and Patier-Marque, D. (2001). Objectives, methods and results of surveys carried out in the field of urban freight transport: an international comparison, 9th World Conference on Transport Research (WCTR) in Seoul: Korea, pp. 22-27.

Anderson, S., Allen, J. and Browne, M. (2005). Urban Logistics: How can it meet Policy Makers' Sustainability Objectives?, Journal of Transport Geography 13 (1), pp. 71–81.

Awasthi, A. and Proth, J. M. (2006). A Systems Based Approach for City Logistics Decision Making, Journal of Advances in Management Research, 3(2), pp.7-17.

Banister, D. (2000). Sustainable Urban Development and Transport -a Eurovision for 2020. Transport Reviews 20, pp.113-130.

Battilana, J. and Hawthorne, I. (1976). Design and Cost of a Transhipment Depot to Serve Swindon Town Centre, Laboratory Report 741, TRRL, Crowthorne.

BESTUFS (2000). Statistical data, data acquisition and data analysis regarding urban freight transport, BESTUFS Best Practice Handbook Year 1, BESTUFS.

BESTUFS II (2006). Control and Enforcement in Urban Freight Transport, and City Access Restriction Schemes, BESTUFS II Best Practice Handbook Year 2, BESTUFS.

BESTUFS II (2007). Best Urban Freight Solutions II – BESTUFS Policy and Research Recommendations III :Port cities and innovative urban freight solutions Managing urban freight transport by companies and local authorities, BESTUFS.

BESTUFS II (2008). Best Urban Freight Solutions II – BESTUFS Best Practice in data collection, modeling approaches and application fields for urban commercial transport models, BESTUFS.

Box, G. E. P. and Behnken, D. W. (1960). Some new three level designs for the study of quantitative variables. Technometrics, 2, pp. 455-475.

Browne, M. and Allen. J. (1999). The impact of sustainability policies on urban freight transport and logistics systems. 8th World Conf. Transport Res. WCTR, Antwerp, Belgium, pp.505–518.

Browne, M., Allen, J., Anderson, S., and Woodburn, A. (2005). Night-Time Delivery Restrictions: A Review, The Fourth International Conference on city Logistics, Langkawi, Malaysia.

Browne, M., Allen, J., and Attlassy, M. (2007). Comparing freight transport strategies and measures in London and Paris, International Journal of Logistics: Research and Applications (10), pp. 205-219.

Böhler, S., and Reutter, O. (2006). Delivery Services For Urban Shopping: Experiences & Perspectives, World Transport Policy & Practices, Vol. 12, No. 1, pp. 47-53.

California Department of Transportation, (2009). Annual Data Compilation, 2008 State Highway Congestion Monitoring Program (HICOMP), California.

Campbell, J. F. (1995). Using Small Trucks to Circumvent Large Truck Restrictions: Imnpacts on Truck Emissions and Performance Measures, Transportation Research-A, Vol. 29A, No. 6, pp. 445-458.

Castro J.T. and Kuse. H. (2005). Impacts of Large Truck Restrictions in Freight Carrier Operation in Metro Manila. Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 2947-2962.

Cityports (2005). Interim Report, Quaderni del Servizio Pianificazione dei Trasportie Logistica, vol. 7, Maggio.

Cidell, J. (2008). The Decentralization of Freight Transportation: Chicago in Context, Transport Chicago 2008 Conference.

Cidell, J. (2010). Concentration and Decentralization: The New Geography of Freight Distribution in U.S. Metropolitan Areas, Journal of Transport Geography, 18(3), pp. 363-371.

Comité Interrégional pour le Transport des Marchandises (CITM) (1999). Le Diagnostic sur la Congestion Routiere et le Transport des Marchandises (The Diagnosis on the road Congestion and the Transport of Goods), Montreal, Canada.

Cooper, J. and Tweddle, G. (1994). Distribution Round the Clock, in Cooper, J.(ed.), Logistics and Distribution Planning: Strategies for Management, Kogan page, London.

Crainic, T. G. , Ricciardi, N. and Storchi, G. (2004). Advanced freight transportation systems for congested urban areas. Transportation Research Part C: Emerging Technologies 12(2), pp. 119-137.

CSPPSFT (1996). Paying Our Way; Estimating Marginal Social Costs of Freight Transport, Committee for Study of Public Policy for Surface Freight Transport, TRB, National Academy Press.

Cybernetix (2002). CITY FREIGHT Inter- and Intra- City Freight Distribution Networks Work package 1: Annex report France. Comparative survey on urban freight, logistics and land use planning systems in Europe.

Czerniak R.J. Lahsene, J.S. and Chatterjee, A. (2000). Urban freight movement. What form will it take? Transportation in the New Millennium. Transportation Research Board. The National Academies, Washington, DC.

Dablanc, L. (2007). Goods transport in large European cities: Difficult to organize, difficult to modernize, Transportation Research Part-A 41, pp. 280-285.

Dablanc, L. (2009). Freight Transport, A Key for the New Urban Economy, World Bank, Freight Transport for Development: a Policy Toolkit, July, pp. 52.

Davidsson, P., Henesey, L., Ramstedt, L., T¨ornquist, J., Wernstedt, F. (2005). An analysis of agent-based approaches to transport logistics. Transportation Research Part C 13 (4), pp. 255–271.

Delaitre, L., Awasthi, A., Molet, H. and Breuil, D. (2008). Systems Science for selecting urban freight solution : application to La Rochelle, Internation Conference on Research Challenges in Information Science, RCIS 2008, Marrakech, pp.401-407.

Docherty, I. (2004). Transport and regional economic competitiveness in the global economy, Journal of Transport Geography, 12(4), pp. 341-342.

Doniec, A., Mandiau, R., Piechowiak, S. and Espie, S. (2008). A behavioral multi-agent model for road traffic simulation, Engineering Applications of Artificial Intelligence 21, pp.1443– 1454.

European Commission (2009). A sustainable future for transport: Towards an integrated, technology-led and user-friendly system. Brussels.

European Commission (2006). Urban freight transport and logistics - An overview of the European research and policy. Brussels, Belgium: European communities.

European Commission (2010). Study on Urban Access Restrictions- Final Report, European Commission of Mobility & Transport, Rome.

Federal Highway Administration (FHWA) (1986). Effects of Lane Restrictions for Trucks. Draft Report. Washington, D.C.

Freight Transport Association (2003). Relaxing delivery restrictions could reduce HGV traffic growth by more than 50% says FTA, FTA press release, 6.

Freight Transport Association (1996). Lorries in urban areas - delivering the goods and serving the Community. Freight Matters. 5/96. Freight Transport Association

Geroliminis, N. and Daganzo, C. (2005). A review of green logistics schemes used in cities around the world. U.C. Berkeley Center for Future Urban Transport, A Volvo Center of Excellence, Berkeley.

Gorman, M. F. (2008). Evaluating The Public Investment Mix In US Freight Transportation Infrastructure, Transportation Research A, Vol. 42, Issue 1, pp. 1-14.

Gourvil, L. and Joubert, F. (2004). Evaluation of the congestion routiere in the area of Montreal: Studies and Research in transport. Socio-economy Of transport, Quebec.

Hall, R.W. and Partyka, J. G. (1991). Peak Period Truck Restrictions: Impacts on the Los Angeles Economy Logisolve, Walnut Creek, California.

Hassell, M, Foulkes, M, and Robertson, J. (1978). Freight planning in London: the existing system and its problems, Traffic Engineering & Control 19 (1), pp. 60-63.

Hesse, M. (2004). Logistics and freight transport policy in urban areas: a case study of Berlin-Brandenburg/Germany. European Planning Studies 12 (7), pp. 1035–1053.

Hesse, M. (2007). The system of flows and the restructuring of space: elements of a geography of distribution. Erdkunde 61 (1), pp. 1–12.

Hernandez, J.Z., Ossowski, S., Garcia-Serrano, A., (2002). Multiagent architectures for intelligent traffic management systems. Transportation Research Part C 10 (5–6), pp.473–506.

Hoel, L. A. and Peek, J. L. (1999). A Simulation Analysis of Traffic Flow Elements for Restricted Truck Lanes on Interstate Highways in Virginia, VTRC 99-R1, Final Report, Virginia Transportation Research Council, Charlottesville, VA.

Holguin-Veras, J., Wang, Q., Xu, N., Ozbayb, K. , Cetinc, M. and Polimenid, J. (2006). The impacts of time of day pricing on the behavior of freight carriers in a congested urban area: Implications to road pricing, Transportation Res. Part A 40, pp. 744-766.

Holguín-Veras, J., Silas, M., Polimeni, J. and Cruz, B. (2007). An Investigation on the Effectiveness of Joint Receiver–Carrier Policies to Increase Truck Traffic in the Off-peak Hours. Part I: The Behavior of Receivers, Network Spatial Economics 7(3): pp. 277–295.

Holguín-Veras, J., Silas, M., Polimeni, J. and Cruz, B. (2008). An Investigation on the Effectiveness of Joint Receiver–Carrier Policies to Increase Truck Traffic in the Off-peak Hours, Network Spatial Economics 8 (4): pp. 327–354.

Jenkins, I. and Kennedy, T. (2000). Transport Policy Issues for Regional Cooperation in the Central Asian Region, Asian Development Bank.

Jorna, R. and van Drunen, E. (2002). Intelligent Freight Transport System: Integrating Traffic management with Freight Transport management, Association for European transport.

Karrer, R., Martin, R. and Rapp Trans, A. G. (2007). Best Urban Freight Solutions II, BESTUFS II, Deliverable D2.3 Part I.

Kearney, A. T. (1975). Inc. Urban Goods Movement Demonstration Project Design Study. Prepared for Urban Mass Transportation Administration.

Kirby, R.F., Tagell M.T. and Ogden K. W. (1986). Traffic management in Metro Manila: Formulating traffic policies. Traffic Engineering Control, Vol. 27, 262-269.

Kleijnen, J. P. C. (1995). Sensitivity analysis and optimization of system dynamics models: Regression analysis and statistical design of experiments. System Dynamics Review, 11(4), pp. 275-288.

Lau, R. Y. K., Tang, M. L., Wong, O., Milliner, S. W., and Chen, Y. P. P. (2006). An evolutionary learning approach for adaptive negotiation agents. International Journal of Intelligent Systems, 21(1), pp. 41–72.

LEAN (1999). Integration of Lean Logistics into Urban Multimodal Transport Management in order to reduce space requirements and optimize the use of transport. PL97-2113. DGVII, European Union.

Lee, W. H., Tseng, S. S., and Shieh, W. Y. (2010). Collaborative real-time traffic information generation and sharing framework for the intelligent transportation system, Information Sciences 180, pp. 62-70.

Lindholm, M. and Behrends, S. (2010). A holistic approach to challenges in urban freight transport planning, 12th WCTR, Lisbon, Portugal.

Litman, T. (2003). Measuring Transportation: Traffic, Mobility and Accessibility, ITE Journal, Vol. 73, No. 10, October 2003, pp. 28-32.

Littiere, H. (2006). Control of delivery areas in Reims (France), Freight and city logistics, France.

Logi, F. and Ritchie, S.G., (2002). A multi-agent architecture for cooperative inter-jurisdictional traffic congestion management. Transportation Research Part C 10(5–6), pp. 507–527.

Maggi, E. (2007). La logistica urbana delle merci. Aspetti economici e normativi, Polipress, Milano.

Mannering, F.L., Koehne, J.L. and Araucto. J. (1993). Truck Restriction Evaluation: The Puget Sound Experience, Washington State Department of Transportation.

May, A. D., Jopson, A. F. and Matthews, B. (2003). Research challenges in urban transport policy. Transport Policy, 10 (3), pp. 157-164.

May, A. D., Kelly, C. and Shepherd, S. (2006). The principles of integration in urban transport strategies. Transport Policy, 319-327.

Mckinnon, A. C. (2006). A review of European truck tolling schemes and assessment of their possible impact on logistics systems, International Journal of Logistics: Research and Applications, 9(3): pp. 191–205.

McKinnon, A. C. (1998). Urban Transhipment: Review of Previous Work in the UK, Report prepared for the Retail and Distribution Panel of the UK Government’s Foresight Programme, Heriot Watt University.

Meimbresse, B. and Sonntag, H. (2000). Modelling Urban Commercial Traffic with the Model Wiwer, paper presented at Jacques Cartier Conference, Montréal: Canada, 4-6 October 2000.

Metrolinx,(2011). GTHA Urban Freight Study February 2011, Government of Ontario, Canada.

Miller, G., Kiguel, D., and Zielinski, S. (2001). Moving Goods in the New Economy: A Primer for Urban Decision Makers, produced by Moving the Economy and the Canadian Urban Institute.

Ministry of Transports Quebec (MTQ) (2009). The Policy on Road Freight Transport 2009-2014, Bibliotheque et Archives nationales du Quebec, Canada.

Ministry of Transports Quebec (MTQ) (2004). Évaluation de la congestion routière dans la région de Montréal, rédigé par Louis Gourvil et Fannie Joubert, Collection Études et recherches en transport -RQ-04-01, Canada.

Ministry of Transports Quebec (MTQ) (2003). Interurban Displacements of Heavy Vehicles in Quebec - Investigation into the haulage of 1999, Quebec, Canada.

Ministry of Transports Quebec (MTQ) (2000). Computerized Study of Traffic Congestion in Montreal, Computerized assessment of traffic congestion along Montreal's road and highway networks using semi-automated methods and GPS technology/Projet d'évaluation informatisée de la congestion du réseau routier de Montréal, Canada.

Montgomery, D. C. (2007). Design and Analysis of Experiments, 5th ed., Wiley, Singapore, pp. 21–46.

Munuzuri, J. Larraneta, J. Onieva, L. and Cortes, P. (2005). Solutions applicable by local administrations for urban logistics improvement, Cities 22 (1), pp. 15–28.

Mussa, Renatus (2004). Safety and Operational Evaluation of Truck Lane Restrictio, Journal of the Transportation Research Forum, Vol. 43, No. 2, pp. 117-127

Myers, R. H. and Montgomery, D. C. (2002). Response Surface Methodology: Process and Product Optimization Using Designed Experiments, 2nd edition, John Wiley & Sons, New York, United States.

Meyer, R. K. and Krueger, D. D. (2004). A Minitab Guide to Statistics (3rd ed.). Upper Saddle River, NJ: Prentice-Hall Publishing.

Ogden K.W. (1992). Urban Goods Movement: A Guide to Policy and Planning (Brookfield, Vermont: Ashgate Publishing Co. Ashgate, Aldershot, England, Ch. 6.

Oktem, H., Erzurumlu, T. and Kurtaran, H. (2005). Application of Response Surface Methodology in the Optimization of Cutting Conditions for Surface Roughness, J. Mater. Process. Tech., 170, pp.11–16.

Pani, L. I. and Beckx, C. (2007). Trucks Driving At Night And Their Effect On Local Air Pollution, European Transport Conference.

Piecyk, M., and McKinnon, A. (2007). Internalising The External Costs Of Road Freight Transport In The UK, Logistics Research Center, Heriot-Watt University.

Planung Transport Verkehr (PTV) AG. (2008). VISSIM User Manual, Version 5.10, Germany.

Pokahr, A., Braubach, L., Sudeikat, J., Renz, W., Lamersdorf, W. (2008). Simulation and Implementation of Logistics Systems based on Agent Technology, HICL-2008: Logistics Networks and Nodes, Erich Schmidt Verlag, pp. 291-308

Punzalan, J. D. (2000). The impact of truck ban on the trucking industry in Metro Manila. Dissertation Thesis, University of the Philippines Diliman.

Quak, H. J. and de Koster, M. B. M. (2006). Urban distribution: The impacts of different governmental time-window schemes, Proc. 9th TRAIL Congress 2006. Research School TRAIL, Delft, the Netherlands.

Quak, H. and de Koster, R. (2006b). The Impacts of Time Access Restrictions and Vehicle Weight Restrictions on Food Retailers and the Environment", EJTIR, 6, no. 2, pp. 131-150.

Quak, H.J. and de Koster, M.B.M. (2007). Exploring retailers' sensitivity to local sustainability policies, Journal of Operations Management, 25, pp. 1103–1122.

Quak, H. J. and de Koster, M. B. M. (2009). Delivering goods in urban areas: How to deal with urban policy restrictions and the environment, Transportation Science 43 (2), pp. 211–227.

Rasch, A. (2006). Access restrictions Enschede (The Netherlands), Freight and city logistics, BESTUFS.

ReliaSoft (2011). DOE++: Software Tool for Experiment Design and Analysis (DOE), www.reliasoft.com

Rodrigue, J. P., (2006) Transport geography should follow the freight. Journal of Transport Geography 14, pp. 386–388.

Russo, F. and Comi, A. (2005). Demand models for city logistics: a state of the art and a proposed integrated system, In: Proprints of 4th City Logistics Conference, Langkawi, Malaysia.

Schrank, D. and Lomax, T. J. (2007). The 2007 Urban Mobility Report. Texas Transportation Institute, Texas A&M University, College Station, TX.

Seattle Urban Moblity Plan, (2008). 10 Best Practices: Freight Mobility: Managing Freight Effectively from the City and Shipper Perspective.

Song, J. and Regan, A. C. (2004). An Auction Based Collaborative Carrier Network, Proceedings of the 83rd Annual Meeting of Transportation Research Board, Washington D.C.

Sonntag, H. (1985). A Computer Model of Urban Commercial Traffic, in Transport, Policy and Decision Making, Vol. 3 (2).

Stantchev, D. and Whiteing, T. (2006). Urban Freight Transport and Logistics. An overview of the European research and policy, Web Project, DG Energy and Transport.

Stokes, R.W. and McCasland, W. R. (1984). Truck Operations and Regulations on Urban Freeways in Texas. Research Report 338-1F, Texas Transportation Institute.

Summerfield, C. and Babb, P. (Eds.) (2003). National Statistics Trends, No. 33, the Stationery Office, London.

Thompson, R., Taniguchi, E. (2001). City Logistics and Freight Transport, Handbook of Logistics and Supply Chain Management, pp. 393-404.

Taniguchi, E., Thompson, R. G. and Yamada. T. (2004). Visions for city logistics, Logistics Systems for Sustainable Cities, Proc. 3rd Internat. Conf. City Logist., Elsevier, Amsterdam, pp.1–16.

Taniguchi, E., Thompson, R.G. and Yamada, T. (2003). Predicting the effects of city logistics. Transport Reviews, vol. 23, no. 4, pp. 489-515.

Taylor, B. D. (2002). Rethinking Traffic Congestion, Access 21, pp. 8-16.

Team Transportation Plan of the City of Montreal (TTPCM) (2005). Plan of transport of Montreal - Portrait and diagnosis, Technical Note 9: Transport of goods.

Transport Canada (2004). Integration Technologies for Sustainable Urban Goods Movement, Program of Energy Research and Development (PERD) and the Urban Intermodal and Motor Carrier Branch, Canada.

Transport Canada (2006). Transportation In Canada 2005, Annual Report (Addendum Tables), available at http://www.tc.gc.ca/pol/en/Report/anre2005/add/index.htm.

van Dam, K. H. Lukszo, Z. Ferreira, L. and Sirikijpanichkul, A. (2007). Planning the Location of Intermodal Freight Hubs: an Agent Based Approach, Proceedings of the 2007 IEEE International Conference on Networking, Sensing and Control, London, UK, pp. 187-192.

van Isacker, N. (2006). Transit ban for HGVs in Liège (Belgium), Freight and city logistics, Belgium.

Visser, J., Van Binsbergen, A., and Nemoto, T. (1999) Urban freight transport policy and planning. City Logistics 1, pp.1-35.

Wang, C., Ghenniwa, H., Shen, W. (2009). Constraint-Based Winner Determination for Auction-Based Scheduling, IEEE Transactions on Systems, Man and Cybernetics, Part A, 39, (3), pp. 609-618

Whiteing, T., Browne, M. and Allen, J. (2003). City Logistics: The Continuing Search for Sustainable Solutions. In: Waters, D., (ed) Global Logistics and Distribution Planning: Strategies for Management, London: Kogan, pp.308-320.

Wisetjindawat, W. (2006). Micro-Simulation of Freight Agents in Supply Chain for Modeling Urban Freight Movement. Dissertation. Nagaoka University of Technology.

Wisetjindawat, W. (2010). Review of good practices in Urban Freight Transportation, Eco-Efficient and Sustainable Urban Infrastructure Development in Asia and Latin America, UNESCAP, Bangkok.

Wishart, H .L. and Hoel, L. A. (1996). Analysis and Evaluation of Truck Traffic Restrictions and Separation Methods on Interstate Highways, Prepared for Mid-Atlantic Universities Transportation Research Center. Sponsored by the U.S. Department of Transportation and the Virginia Department of Transportation.

Wu, C. F. J. and Hamada, M. (2000). Experiments: Planning, analysis, and parameter design optimization, New York: Wiley, ISBN 0-471-25511-4.