Freight shipper mode choice in the Quebec City - Windsor Corridor and its impact on carbon dioxide emissions

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DEDICATION

This thesis is dedicated to Judith.

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ABSTRACT

The Quebec City-Windsor corridor is the busiest and most important trade and transportation corridor in Canada. The transportation sector is the second largest greenhouse gas (GHG) emission category in the country. Governments around the world, including Canada, are considering increased mode share by rail as a way to reduce transportation emissions. To understand whether freight mode shift is a realistic means to reduce transportation emissions, an analytical model is needed that can predict the effect of government policy on mode split.

This thesis provides background on the freight transportation-GHG nexus in Canada and describes the development, implementation, reasoning behind, and results of, a Stated Preference shipper carrier choice survey for the Quebec City – Windsor corridor conducted during the fall of 2005. It then describes how the resulting carrier choice models are used to estimate the potential to displace truck traffic to rail (premium-intermodal) under current conditions, as well as to test the effectiveness of different possible future policy or service offering scenarios.

The results show that premium-intermodal has the potential to capture a substantial share of traffic between the main destinations in the Quebec City – Windsor Corridor. However, its ability to contribute significantly to reducing CO_2 emissions is limited. According to the analyses conducted, potential reductions are considered to be in the range of nil to 0.413 Mt – a fraction of what the federal government was hoping to be able to achieve through "further public-private collaboration to promote the use of intermodal freight opportunities and to increase the use of low-emission vehicles and modes" (Government of Canada 2002).

At the same time, these potential reductions are based on a small proportion of total truck-related emissions and a few city-pairs. Extension of the current analysis to more city-pairs separated by longer distances might arrive at different conclusions.

ABRÉGÉ

Le corridor Québec-Windsor est l'axe d'échange et de transport le plus important au Canada. Le secteur du transport est le deuxième plus grand émetteur de gaz à effet de serre (GES) du pays. Certains gouvernements, dont le Canada, considèrent le transfert du transport de marchandises de la route au rail comme un moyen de réduire les émissions dues au transport.

Afin de bien comprendre si ce transfert du transport de marchandise de la route au rail est un moyen réaliste pour la réduction des émissions des GES, il est nécessaire d'évaluer l'effet des politiques environnementales sur ce transfert modal au moyen d'un modèle analytique.

Cette these présente le développement, l'élaboration, la réalisation et les résultats d'un sondage à préférences déclarées sur le choix de transporteurs pour le corridor Québec-Windsor conduit durant l'automne 2005. Il décrit ensuite comment les modèles de choix de transporteurs sont utilisés afin d'estimer le potentiel du transfert du trafic de camion au rail (premium-intermodal) dans les conditions actuelles, ainsi que dans des conditions futures selon différents scénarios économiques et législatifs.

Les résultats des analyses démontrent comment le premium-intermodal a le potentiel de s'approprier une partie non-négligeable du trafic entre les destinations les plus importantes du corridor Québec-Windsor. Sa contribution à la diminution significative des émissions de CO_2 est cependant limitée. Selon les analyses présenteés dans cette thèse, les réductions potentielles sont estimées d'être comprises entre zéro et 0.413 Mt – une fraction de ce que le gouvernement espérait être capable d'accomplir "une collaboration plus poussée entre les secteurs public et privé pour promouvoir la mise en valeur des possibilités de transport intermodal des marchandises et accroître le recours aux véhicules et aux modes de transport à faibles émissions" (Gouvernement du Canada 2002).

D'un autre côté, ces réductions potentielles sont basées sur une petite proportion des émissions totales liées aux camions et incluent peu de villes.

L’extension de l’analyse actuelle à d’autres villes séparées par de plus longues distances pourrait bel et bien amener à d’autres conclusions.

1 Introduction

Canada, like many countries, is searching for ways to decrease its greenhouse gas (GHG) emissions. Because transportation is such a large contributor to GHGs (the largest emission category after "Stationary Sources"), it is also seen as a category where significant GHG reductions are possible. This is as true for freight transportation as it is for passenger transportation. One method often considered to reduce GHG emissions in freight transportation is to increase the proportion of freight that is transported by rail relative to road. The reason for this is simply that rail transportation is far more energetically, and thereby GHG, efficient than road transportation. In fact, road freight transportation is more than 10 times as GHG intensive per tonne-kilometre than rail. The consequence of this is that road freight contributes 50% of national freight emissions while carrying only one third of land-based freight. Rail carries roughly two-thirds of this freight, yet contributes about 10% of national freight emissions. However, being able to estimate the degree to which freight can realistically be transferred to rail requires accurate and rigorous models of freight mode choice.

As such, the objectives of this research are to answer the questions: (a) what form do shippers' utility functions take in selecting carriers for freight shipments in the Quebec City - Windsor corridor; (b) are there substantial differences in these functions for different types of shippers and shipments; and (c) given these, what are the prospects for a substantial amount of truck-borne freight in the corridor being diverted to rail under a variety of possible future scenarios and what the different scenarios would imply for freight related carbon dioxide (CO_2) emissions in Canada?

These three research objectives were accomplished in four stages. The first stage involved the development and administration of a stated preference carrier choice study for the Quebec City – Windsor Corridor. The study focus was firm-level, and as a result, the shipping managers of 7,229 manufacturers, wholesalers and retailers and third party logistics companies (end-shippers in the study) located in the Corridor made up the sampling frame. The list of companies included in the sampling frame was drawn from the Ontario and Quebec portions of the Dun & Bradstreet "Million Dollar Database." Just under 400 end-shippers responded to the survey (18 questions in each survey) between August and December 2005, resulting in over 7,000 observations in the entire dataset.

The second stage involved the estimation of shipper utility functions using simulation-based (mixed-logit) discrete choice analysis. This analysis resulted in five separate error-component models applied to different shipment subgroups of the overall dataset.

The third stage involved the application of the resulting models, under various policy and service offering scenarios, to estimate the potential for current truck traffic in the 'Corridor' to be transported intermodally. Truck traffic (and potential intermodal traffic) estimates between the major destinations of the Corridor (Quebec City, Montreal, Toronto, Windsor and Chicago) were derived from the Ontario Ministry of Transportation's 2001 Commercial Vehicle Survey (CVS) database.

The final stage of the analysis involved estimating the potential to reduce CO_2 emissions by first calculating current emissions and comparing them with those implied by the different market-share estimates. Trucking CO_2 emissions were estimated using MOBILE6.2C, and rail emissions estimates were derived from data provided by Canadian Pacific Railways. The resulting reductions estimates were compared with federal government targets for CO_2 reductions through the use of intermodal freight transportation.

The thesis begins with background information on the transportation sector in Canada, its contribution to overall GHG emissions, how Canada expects to be able to reduce emissions in the freight transportation sector, the study region, as well as some information on the performance to date of intermodal freight transportation in Canada. A literature review of freight transportation modeling in general, and freight mode choice in particular, is followed by a description of the development and design of the current study. Afterwards, the main results of the survey, including a description of the shipper choice models, are presented. Chapter 7 provides background information on the data, as well as the important assumptions used in the market-share and emissions simulations. Chapter 8 reports the results and findings of the market-share and emissions simulations. Chapter 9 describes some possible avenues for future research and is followed by some concluding remarks.

2 Canada, Kyoto & Freight Transportation

2.1 Freight CO_2 Emissions in Canada

Transportation is a critical component in the economies of countries. In 2005 transportation contributed 5% directly to Canadian GDP (Transport Canada 2005) with the total extent of the sector's economic activity having been estimated to be on the order of 19% (Transportation Climate Change Table 1999). Cheap and reliable freight movement is the lifeblood of an economy and helps business to be competitive especially for a trading nation like Canada where the total value of merchandise trade was close to 800 billion Canadian dollars in 2005 (Transport Canada 2005). At the same time, transportation more generally, and freight transportation in particular, imposes many external costs on society. These costs take many forms. They can be in the form of habitat loss from road construction, noise pollution, congestion, and atmospheric emissions among others.

Table 1: Transportation Sector Contributions to GHGs in Canada (Mt)

	1990	**2000**
National GHG Emissions		
Total Canadian GHG Emissions	607	726
Transportation Sector GHG Emissions	146	179
% of Emissions from Transportation	24%	25%
National Freight Emissions		
Total Freight Emissions	61	82
Freight as % of Emissions	10%	11%
Total Road Freight Contribution	31	45
Road Freight as % of Total Freight Emissions	50%	54%
Total Rail Contribution	7	6
Rail Freight as % of Total Freight Emissions	11%	8%
Derived by the author based on Environment Canada (2004).		

The transportation sector (see Table 1 above) is the second largest GHG contributing source category in Canada, producing around a quarter of all emissions (Environment Canada 2004). Freight's GHG contribution stands at around 10% of overall Canadian emissions, with road freight making up more than half of these emissions and rail freight around 10%. The balance of freight emissions come from the off-road, domestic marine and air freight categories. One thing to notice about road and rail contributions is that road freight's contribution to freight emissions is increasing while rail's has been declining. It might be thought, given this information, that the reason for road freight making such a large contribution to GHG emissions is because road carries much more freight.

As can be seen from Table 2, this is not the case. In fact, rail carries the lion's share of all freight in Canada, although this pattern is changing very quickly. In 1990 rail carried 76% of all surface freight, whereas by 2003, it carried only 63% showing the very rapid growth in road freight. While these figures may seem surprising, it is worth noting that much of rail freight is bulk commodities such as grain, coal and sulphur. These commodities are very heavy, of low value per kilogram and tend to be transported over long distances, thus accounting for a large proportion of tonne-kilometres (t-km) transported by rail. In fact, around 90% of railway freight is made up of bulk commodities, petroleum and cars and car parts (Transport Canada 2004).

Table 2: Freight Activity in Canada

	Road[1]		**Rail[2]**		
	Billions of t-km	**%**	**Billions of t-km**	**%**	**Total**
1990	78	24	248	76	326
2003	184	37	318	63	502
Growth (%)	137		28		
1 - Total for-hire truck traffic annual t-km					
2 - Revenue t-km by railway sector					
Source: Transport Canada (2005) Appendix A7-9					

The fact that rail moves a much larger proportion of freight, and yet road freight contributes five times more GHG emissions indicates that rail is much more GHG efficient. Table 3 shows the GHG intensity of the different modes. Note that rail is thirteen times more efficient than road, although both modes have been increasing their GHG efficiency at a similar relative rate (30% between 1990 and 2000).

The trends are clear – more and more freight is being carried by road, and despite substantial improvements in the GHG intensity of road freight transportation, it remains more than ten times less GHG efficient than rail. Therefore GHG emissions in the transportation sector will continue to increase substantially if current trends persist.

Table 3: Trends in Shipping/Freight-Related GHG Intensity

	1990	2000	Change Since 1990	
			Absolute	Relative
Rail				
GHG Emissions[1]	6.9	6.5	-0.4	-6.2%
Activity[2]	235.9	320.5	84.6	35.9%
GHG Intensity[3]	29.2	20.2	-9.1	-31.0%
Trucking				
GHG Emissions[1]	27.7	43.7	16	57.8%
Activity[2]	74.7	165.1	90.3	120.9%
GHG Intensity[3]	370.4	264.7	-105.8	-28.5%

[1] Mt CO_2 equivalent

[2] tonne-kilometres shipped (Billions)

[3] grams CO_2 equivalent per tonne-kilometre shipped

Source: Environment Canada (2004)

2.2 Freight Transportation and the Kyoto Protocol

In December 2002, Canada ratified the Kyoto Protocol thereby committing itself to reducing its GHG emissions by 6% relative to 1990 levels during the first implementation period (2008-2012). Leading up to Canada's ratification, the federal government released its Climate Change Plan for Canada (Government of Canada 2002). This document outlined how the government expected to be able to attain its GHG reduction commitments, by assigning reduction targets to identified sectors of the economy.

Perhaps not surprisingly given the large contribution that the transportation sector makes to GHGs in Canada, it was identified as one of the "key areas for action" in the reduction of GHGs. In fact, the transportation sector was targeted as an area where 21 mega tonnes (Mt) of reductions are to be made.[1] Of these 21 Mt, 1 Mt is expected to come from "further public-private collaboration to promote the use of intermodal freight opportunities and to increase the use of low-emission vehicles and modes"(Government of Canada 2002: 24). More recently, the government published *Project Green*. While not assigning goals as in the Climate Change Plan, it does refer to exploring "options for more efficient integration of intermodal freight transportation" (Government of Canada 2005). Although it is true that since the election of a new government in January 2006, Canada's position with respect to the Kyoto Protocol has been uncertain (The Economist 2006). This is perhaps even more the case since the announcement of the government's proposed *Clean Air Act* in October of 2006 (Government of Canada 2006). This proposed legislation includes short term GHG-intensity based targets, but overall GHG emissions targets are only planned for the year 2050. Despite of these changes in governmental priorities, the *Climate Change Plan* remains the most up-to-date public document that has outlined potential targets for CO_2 emissions reductions for intermodal freight transportation in Canada. As well, and even though it is not clear what portion of the 1 Mt described in the *Climate Change Plan* was expected to come from intermodal transportation uniquely, this figure is used as point of comparison in this thesis.

To put the goals mentioned in the Climate Change Plan into context, a "back-of-the-envelope" calculation of the impact of diverted freight transportation on GHGs was done. Using the GHG intensities of the road and rail modes for the year 2000 provided in Table 3, the calculation suggests that in order to reduce GHG emissions by 1 Mt, around 4 billion t-km of freight would need to be diverted from road to rail – a 2% decrease in road freight traffic, and a 0.8% increase in rail over 2000 levels.

2.2.1 Intermodal Transportation

[1] A mega tonne is one million metric tonnes. According to the federal government's climate change website, the average Canadian produces 5 tonnes of GHGs per year.

Intermodal transportation is simply transportation using more than one mode, or form, of transportation (e.g. truck, train, plane, etc.). Intermodal ground transportation involves trucks and trains of which there are four common configurations. Two configurations involve container-on-flat-car (COFC) where containers (most commonly international marine containers, but increasingly domestic containers as well) are transported directly on top of railcars for the rail portion of the journey. The containers can be either single- or double-stacked.

Alternatively, truck trailers themselves can be carried on railway cars. This configuration is also known as trailer-on-flat-car, or TOFC. A variation of the TOFC configuration is for trailers to be mounted directly on rail bogies. Intermodal rail freight transportation was first developed on a large scale by Canadian Pacific Railway (CP) in the 1950s with its TOFC service between Montreal and Toronto (Canadian Pacific Railway 2002a).

Intermodal transport more generally took off internationally, and particularly in the international marine trade, with the advent of containerization (Slack 2001). While contemporary land-based intermodal freight transportation has existed since the 1950s, the advantages of truck transportation (explained below) have given trucks a large advantage over rail transport, helping to explain the rapid increase in truck traffic. The increase in truck traffic in Canada (resulting in a 130 percent increase in road diesel emissions between 1980 and 2001) can also be explained by freer trade in North America, the shift towards Just-In-Time (JIT) delivery and production processes, as well as by the deregulation of trucking activities (Transports Canada 2003).

2.2.2 Premium-TOFC

Of particular interest to this research is intermodal transportation that competes directly with truck-only freight transportation in the study area (the Quebec City - Windsor Corridor). Below is a description of service configurations that have been offered to do just this.

Traditionally, rail transportation has suffered from three main disadvantages that have made it less competitive than truck-only transportation.

First, railway services were often unpredictable with respect to timing. This was due to the more general constraints of operating over relatively inflexible rail networks, but also because trains would often not leave before they had full loads. As a result, departure and arrival times could be unpredictable. Second, train loading times could be substantial thereby increasing total shipment transit time. Third, rail transportation was less secure from a damage perspective because of load instability caused by shocks related to train stops and starts, as well as railcar sorting.

In order to overcome these disadvantages, both Canadian National Railway (CN) and CP developed intermodal services with new technologies and new service configurations. Both of these services aimed to decrease loading/unloading times, improve service reliability and reduce damage risk. Since both of these services are trailer-on-rail services, they are referred to in this thesis as 'premium-TOFC' services.

With respect to CN, it made adjustments to service and adopted new technologies to make it more competitive with trucks. One factor contributing to this was the introduction of scheduled rail service for its entire network in 1998. In addition to this, in 1999 CN introduced the use of dual-mode RoadRailer® equipment. RoadRailer® was developed by Wabash National and involves the use of specially designed dual-mode trailers that can be pulled on the road by truck, and can be mounted onto specially designed rail bogies that carry the trailer along rails. The system is engineered to have improved ride so as to prevent damage associated with load movement, and is thereby referred to as a smooth-ride system. It was also designed to require short loading and unloading times. The system was initially implemented on routes between Montreal and Toronto and by September 2000, service was extended from Montreal to Chicago (Canadian National Railway 2000a, Wabash National 2004). Subsequently, however, this service has been mostly discontinued.

In 1996-1997 CP developed and tested its Expressway™ service which came online in 2000. Expressway™ aims specifically at providing time-predictability and reliability with its scheduled rail service. As well, the service involves only 15-minute terminal turnaround times for trucks, thereby mitigating the disadvantages of long loading times. Moreover, damage risk for this service is reduced. This is first because of the re-engineering of railcars that provide superior coupling. Second, specially developed railcars allow for regular, non-reinforced truck trailers to be carried (unlike RoadRailer® that requires specially reinforced trailers) with smoothness of ride comparable to trucks. Moreover, since the trailers are driven onto railcars, the crane-lifting associated with traditional container placement on train cars is avoided. As such, it is also a smooth-ride piggy-back system (Canadian Pacific Railway 2002b, Canadian Pacific Railway 2004). CP has at various times provided this service to Montreal, Toronto, Windsor-Detroit and Chicago, although currently it is provided only between Montreal and Toronto.

2.2.3 Trends in Intermodal Traffic

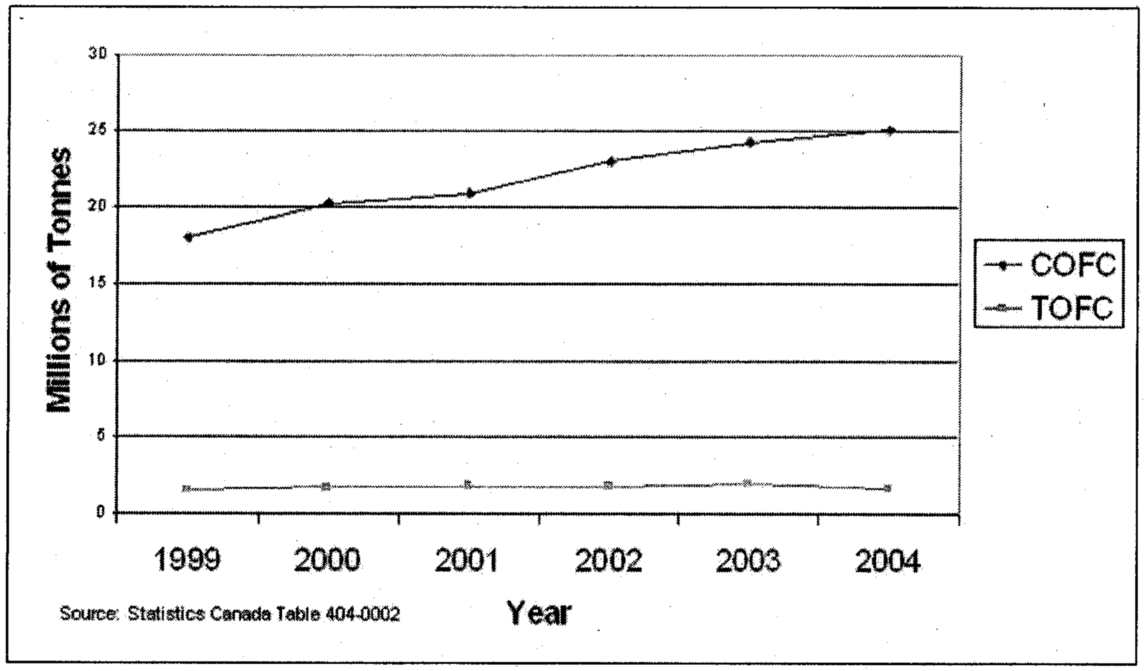
While it is quite straightforward to obtain data on the importance of intermodal traffic for railways – intermodal has now become the largest single revenue generator for CP and one of the top three single revenue generators for CN (Canadian National Railway 2005, Canadian Pacific Railway 2005) – determining the proportion of all freight traffic carried by premium-TOFC is more difficult, and is not publicly available from the railroad companies.

However, evidence from the federal government suggests that these intermodal systems carry a very small proportion of all rail-borne freight. According to Statistics Canada (2004), intermodal traffic makes up about 10% of railroad car loadings. At the same time, Transport Canada (2003) reports that between 1996 and 2001, the proportion of COFC increased from 77% to 92% at the expense of TOFC. Evidence of this trend continuing is seen in data obtained from Statistics Canada and presented in Figure 1 (below).

This figure shows that not all is lost for rail. In particular, it shows that intermodal rail, at least COFC, has proven to be performing quite well - this is largely due to fast-growing container traffic resulting from increasing overseas trade in manufactured goods from Asia (Transport Canada 2005: 7). At the same time, it does not seem that efforts by CN and particularly CP have resulted in increases in TOFC traffic, at least at the national level.

With this background on freight transportation and GHG emissions in Canada, the following chapter continues by describing the geographical scope and approach to the main research undertaken for this thesis.

Figure 1: COFC and TOFC Activity in Canada from 1999 to 2004



3 Geographical Scope, Literature Review and Methodology

In order to be able to reach the goals set out under the *Climate Change Plan*, policy intervention will likely be required. As a result, there is a need to be able to evaluate the effect of policy on variables of interest, in this case, GHG emissions from the freight transportation sector. Since the key question to be answered is how policy might affect freight mode choice and diversion, some method of understanding this is required. There are potentially many types of models that could be used to analyze the effects of policy on freight mode choice, but given the focus of this research and the effects on freight mode choice that policy might be expected to have, the best candidates are disaggregate mode choice models.

3.1 Geographical Scope of Analysis

Before choosing a model to use to evaluate policy effects, it is important to define the geographical scope of the analysis, as well as the characteristics of models that have traditionally been used to model freight at different geographical scales. With respect to the geographical scale of the analysis, there are two major constraints. Given the human and financial resource constraints associated with a doctoral thesis, it was necessary to place well defined limits on a modeling exercise such as this. Two main criteria were used to narrow down the geographical focus of the research:

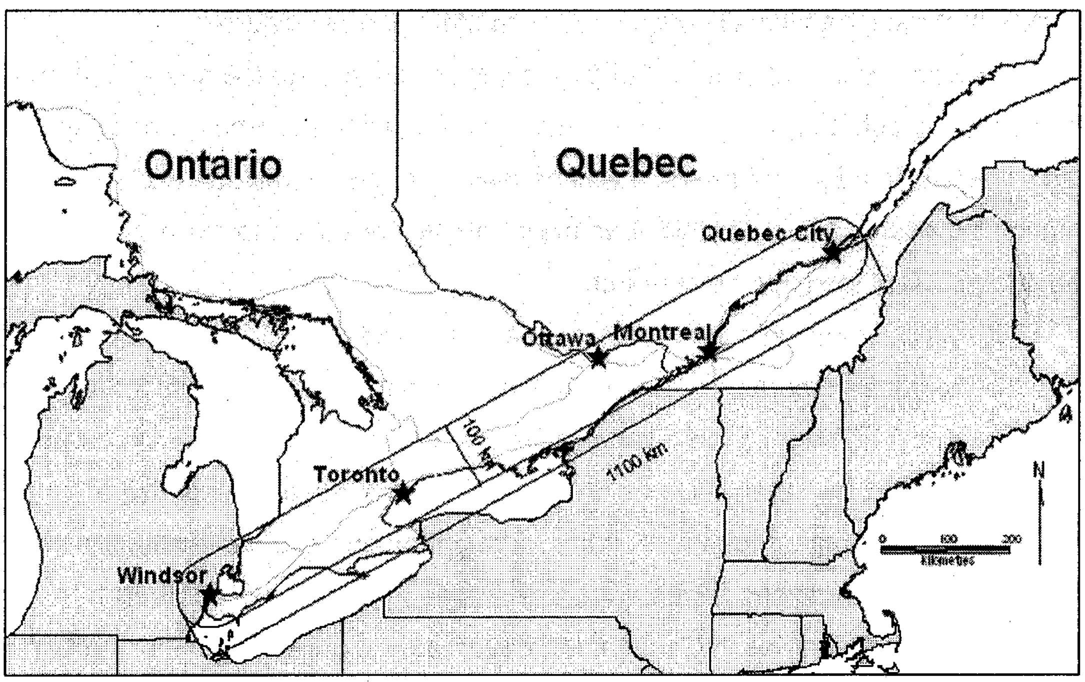
1. it was deemed sensible to restrict analysis to regions with large amounts of freight transportation, and regions where there is the potential for large amounts of freight to be diverted from one mode to another.
2. in order for the analysis to be tractable, it was necessary to choose a region with a manageable number of freight origins and destinations.

These two conditions helped to reduce the geographical scope of the project to only a few areas in Canada. Moreover, as it is unlikely that much urban freight could be diverted to rail, an urban analysis was ruled out. This led to a more regional focus. The most obvious candidate for a regional freight analysis in Canada was the Quebec City - Windsor corridor which is Canada's busiest trade corridor.

3.2 The Quebec City – Windsor Corridor

The Quebec City-Windsor corridor (hereafter referred to as 'the Corridor') is the strip (more or less 100-kilometre-wide) that hugs the Canada-United States border for roughly 1,100 kilometres between Quebec City, Quebec and Windsor, Ontario (see Figure 2). Quebec and Ontario are the two most populous provinces of Canada containing roughly half its population. The Corridor is home to 85 percent of the populations of Quebec and Ontario, and the location of 3 of the 4 largest Canadian cities. It is also the industrial heartland of the country (Environment Canada 2002). Due to this concentration of industry and population, it is known to be the busiest and most important trade and transportation corridor in Canada. As a result, it is also of considerable interest for any attempts to increase the rail mode share of freight in the country.

Figure 2: The Quebec City - Windsor Corridor[2]



[2] Source of map layers: provincial and state boundaries, MapInfo; city locations (based on location of city hall) were determined and geocoded by the author.

Despite the importance of this corridor, however, there is remarkably little easily-available, up-to-date research that focuses on transportation in the Corridor, or even on the entire Corridor itself. This is not to say that there has not been research encompassing parts of the Corridor. For example, two recent governmental initiatives (*Goods Movement in Central Ontario* (Ministry of Transportation Ontario (MTO) 2004) and the Border Transportation Partnership see (URS 2004)) have looked specifically at freight transportation in central Ontario and the Ontario-Michigan border respectively. However, as the names suggest their focus is not the Corridor, but rather a subset of it. The work by Crainic, Florian, Guélat and Spiess (1990) is an example of academic research modeling freight transportation in the region, but in this case, the application is to Ontario, and not the Corridor as a whole.

The Montreal-Toronto section forms the busiest segment of the Corridor with just under 1,700 daily truck trips between these two destinations alone.[3] Table 4 shows freight mode-split in the Corridor. Measured in t-km, trucks carried 64.6% of freight, and rail 34.7%, leaving the air mode with less than 0.7% in 1997.

Table 4: Toronto-Montreal Corridor Mode Share in 1990 and 1997

	1990		1997		
	Tonne-km (000s)	**% share**	**Tonne-km (000s)**	**% share**	**Annual Growth (%)**
Air	15,800	0.6	20,513	0.7	3.8
Marine	N/A	0	N/A	0	N/A
Rail	952,487	39.1	989,223	34.7	0.5
Truck	1,467,356	60.3	1,841,008	64.6	3.3
Total	2,435,643	100	2,850,744	100	2.3
Source: Transport Canada (1998) and Delcan et al. (1999)					

Between 1990 and 1997 trucking increased its mode share, while rail saw its share erode from 39.1% in 1990 to 34.7% in 1997. These data suggest two things: First, freight transportation is much more truck dependent in this corridor

[3] 2002 results from the Ontario Ministry of Transportation Commercial Vehicle Survey. Based on trips between Montreal and Toronto CMAs

than for the country as a whole (see Section 2.1), since rail's mode share is only 30% compared to roughly two-thirds nationally. Second, it reveals the trend of increasing road's mode share for this important trade corridor.

While freight transportation trends are clear, it is not clear what can be done to manage the observed trends. Understanding what can be done requires good, quantitative analysis that can help to explain, as well as to realistically evaluate, the potential for rail to increase its freight mode share. Luckily, there is considerable experience using freight modeling techniques that can be used to answer just these types of questions.

3.3 Literature Review

3.3.1 Policy Models for Freight Traffic Diversion

Turning to the methodologies used for modeling freight traffic, in the past, techniques used to model freight transportation have been classified in several ways. Harker (1985) classifies models into econometric models, spatial price equilibrium models and network equilibrium models. Strong, Harrison and Mahmassani (1996) divide freight mode split models into econometric and network-based models. Another classification to appear in the literature is Winston's (1983) which classifies models as either aggregate or disaggregate. A more recent classification, one that covers a somewhat wider swath of freight models is Regan and Garrido's (2001) classification. Theirs is based on the geographical scope of the freight movements under consideration. Accordingly, they divide freight transportation demand models between international, intercity and urban models. Given the regional focus of the current analysis, freight models used for international and urban freight movements are irrelevant, which leaves intercity models, of which there are several kinds.

3.3.2 Aggregate and Disaggregate Models

Regan and Garrido's discussion classifies intercity models in the same way as (Winston 1983) and Chow and Waters (1994). The difference between these two types of models has to do with the level of aggregation of the data used to develop the models. Disaggregate models consider individual decision-makers' choice of freight mode for a given shipment as the basic unit of observation. Aggregate models on the other hand use as the basic unit of analysis observations on the aggregate share of freight that each mode has at some scale of geographic aggregation or other.

Aggregate models have tended to be *ad hoc* and empirical, because of generally not being grounded in economic theory. Traditionally, they have been empirical models relating total traffic by mode between different pairs of origins and destinations to different characteristics of the modes for each origin-destination pair such as price, transit time, etc. They have also modeled (e.g. Morton (1969) or Levin (1978)) the ratio of two modes' market shares as a function of differences in modal attributes. In some cases, aggregate data have been used to estimate models generally associated with disaggregate methods, such as Chiang, Roberts and Ben-Akiva (1980) who applied a logit model to aggregate data. While these models are intuitive and relatively easy to develop, the models, or perhaps more aptly the use of aggregate data has been criticized by, for example, Chow and Waters (1994: 40). They argue that a high degree of disaggregation is necessary in order to produce reliable predictions of freight mode substitution that might follow from alternate public policy decisions such as size/weight restrictions, user charges, etc.

Accordingly, their criticism of the use of the aggregate data is associated with the fact that much information is lost in the use of aggregate data, information that is very important to understanding how freight mode share will react to changes in the market or policy environment at a high level of aggregation.

Disaggregate models are different in that they are behavioural models with a strong basis in economic theory, and try to explain choices based on the process of utility maximization. Disaggregate models are also probabilistic models of individual decision-maker choices, from which it is possible to develop aggregate forecasts of mode split. These models are also known as discrete choice models because the dependent variable, instead of being continuous (as in most traditional statistical or econometric analysis) is discrete. That is, the dependent variable takes on a value of either 0 or 1, where 1 represents a particular choice having been made and 0 that the choice has not been made.

There is a long history of discrete choice models in freight modeling dating back at least to Miklius (1969) who applied a disaggregate method called discriminant analysis to data on truck and rail shipments of frozen vegetables taken from the 1963 US Census of Transportation. Despite their long history, these models are still popular for mode choice studies. The single largest conceptual advance in disaggregate mode choice studies was Daniel McFadden's (1974) use of random utility theory to develop the conditional logit model. This has become ubiquitous in passenger mode choice studies for which it was developed. The conditional logit (and variants thereof) has become the workhorse of freight mode choice studies as well. It is described in greater detail in Section 6.1.2. For now, it suffices to say that this model, as well as similar models distinguished from the logit by assumptions about the distribution of the error term, such as the probit, are the most common methods for analyzing mode choice (Regan and Garrido 2001).

3.3.3 SP Data, RP Data and Stated Choice Methods

As mentioned above, apart from the statistical methods used to estimate discrete choice models, another defining feature of disaggregate, or discrete choice models, is the type of data they require. The data used are individual or firm-level observations about freight mode choice together with information about the freight being shipped and the firms and decision-makers themselves. The choice data belongs in two categories – stated (SP) or revealed preference (RP) data. Before explaining the advantages and disadvantages of SP relative to RP data, it is necessary to understand more about stated choice methods in general.

While there has been a great deal of research undertaken in the field of stated choice methods, the vast majority of this work has been summarized and compiled in two books: *Stated Choice Methods: Analysis and Application* (Louviere, Hensher and Swait 2000) and *Applied Choice Analysis: A Primer*

(Hensher, Rose and Greene 2005). The relatively recent date of publication of these books should not be thought to suggest that stated choice methods are a recent innovation. Stated choice methods have been used since at least the late 1980s, with roots dating back as far as the 1970s (see for example Green and Rao (1971)). These methods were originally developed and used extensively in the field of marketing through the use of conjoint analysis, and have subsequently developed over time to use more sophisticated statistical techniques and to be applied to passenger as well as freight transportation.

In general, Stated Choice Methods involve the use of specially designed surveys whereby respondents express their preferences by choosing an outcome from a set of alternatives which has been generated according to a particular experimental design.[4] The survey questions provide hypothetical, but (hopefully) realistic alternatives (as well as relevant information needed to make a choice) involving several alternatives between which respondents are asked to choose. Once the experimental choice sets have been designed and respondent choices have been elicited, the results can then be analyzed statistically to produce estimates of, among other things, the probabilities of respondents choosing particular alternatives under differing circumstances and differing choice options. The SP data resulting from these surveys has several advantages over RP data.

Revealed preference data represent the world as it is. In the context of mode choice, it includes information about the actual shipment choice that a firm has made (e.g. cost, time, type of freight, etc.). It also includes information (i.e., cost, time, etc.) about the alternatives that were *not* chosen. In this sense, gathering information on revealed preferences while intuitive (because it is based on decisions that people have actually made) can be quite demanding of the people surveyed, as well as of the investigators, if information about the rejected alternatives needs to be inferred or gathered from other sources. Apart from being more demanding for respondents or researchers, the information gathered on rejected alternatives is also likely to be inaccurate, thereby introducing

[4] This type of survey is also referred to as a choice-based conjoint survey in the marketing literature and the terms choice-based conjoint survey and stated choice survey are used interchangeably throughout the rest of this thesis.

measurement error into the explanatory variables. Another drawback of RP data is that they can suffer from the fact that explanatory variables in the real world are often highly correlated. As explained further in Section 5.3.1 this complicates coefficient estimation. Finally, and particularly important in the current context, because RP data only consider current options, they are limited to helping understand preferences under prevailing conditions.

SP data are not similarly limited. Because SP data arise from surveys where all relevant information required to make a choice between alternatives is provided to the respondent, this helps to overcome the above limitations of RP data.

First, because all the information relevant to the choice of interest is provided to the respondent, the informational burden is lower for the respondent, and there is no possibility for measurement error in the explanatory variables. Second, as will be explained in Section 5.3.1, explanatory variables can be designed not to be correlated. Third, and of particular interest in this context, SP surveys can present respondents with choice sets that reflect not only current conditions, but also new choice options or combinations of attributes of existing alternatives which do not currently exist. As such, they can be used to estimate how overall market outcomes might change as a result of new choice options or attribute combinations being introduced into the marketplace.

That having been said, a disadvantage of SP data in this context needs to be acknowledged. Whereas SP data can be very good at predicting choice dynamics (i.e. how the likelihood of choosing given alternatives from changes in explanatory variables) they do not always predict overall market share as well (see e.g. Ben-Akiva and Morikawa (1990), Ben-Akiva, Morikawa and Shiroshi (1991) and Louviere, Hensher and Swait (2000: 231)). This can be the case because of 'inertial' and 'policy' effects. Inertial effects describe the tendency of people to select alternatives that are consistent with their current behaviour. This tendency has the effect of downwardly biasing SP market-share estimates of newly available alternatives. Policy effects describe the tendency for people to select alternatives out of conviction in an SP context. This tendency can bias market-share estimate upwards or downwards. For this reason SP data are often grounded in real world results by calibrating SP models using alternative-specific constants developed using RP data (Louviere, Hensher and Swait 2000: 231-251). Despite this weakness, it was believed that, given the resources available for this thesis, the negative effect on respondent response rates of obtaining RP data outweighed the benefits of collecting them. As a result, only SP data were collected and used in model development.

Because of the benefits associated with stated choice methods, particularly in a context as fraught with concerns about the competitive sensitivity of revealed preference data as freight transportation, there have been numerous stated preference freight choice studies reported recently in the literature (Fowkes and Tweddle 1988, Fridstrom and Madslien 2001, Norojono and Young 2000, Norojono and Young 2003, Shinghal and Fowkes 2002, Vellay and de Jong 2003, Wigan, Rockliffe, Thoresen and Tsolakis 2000). These studies will be described in Section 4.2 below.

3.4 The Modeling Framework Chosen

Despite a wide range of possible techniques for estimating the potential for intermodal freight transportation to reduce CO_2 emissions in Canada, a combination of factors has led to the modeling framework chosen for this research. The geographic scope, as well as the nature of the research question narrowed the choice of potential models to intercity models.

Aggregate models were ruled out firstly, because they lack the precision needed to undertake the type of analysis required to answer the types of research questions proposed in this study. Secondly, aggregate models are inappropriate for testing hypothetical scenarios.

Recognizing the difficulty in obtaining RP data, as well as the fact that the RP approach is not well suited to scenario testing, it was reasoned that the study should develop and use SP data. As a result, it was reasoned that the best modeling framework for the proposed study was a disaggregate discrete choice methodology using stated preference data derived from the design and administration of a stated preference survey, in short, the use of a Stated Choice Methodology.

Chapters 2 and 3 have set the stage and provided the background to the primary research undertaken and reported in the thesis. The following five chapters describe how the Stated Choice methods described in (Louviere, Hensher and Swait 2000) and (Hensher, Rose and Greene 2005) were applied in the present context of freight mode choice in the Quebec City - Windsor Corridor.

4 Survey Development - Background

This chapter describes the background and reasoning applied in the development of the survey used in this research. It describes how the survey itself was framed, leaving the description of the development of the actual survey for the following chapter.

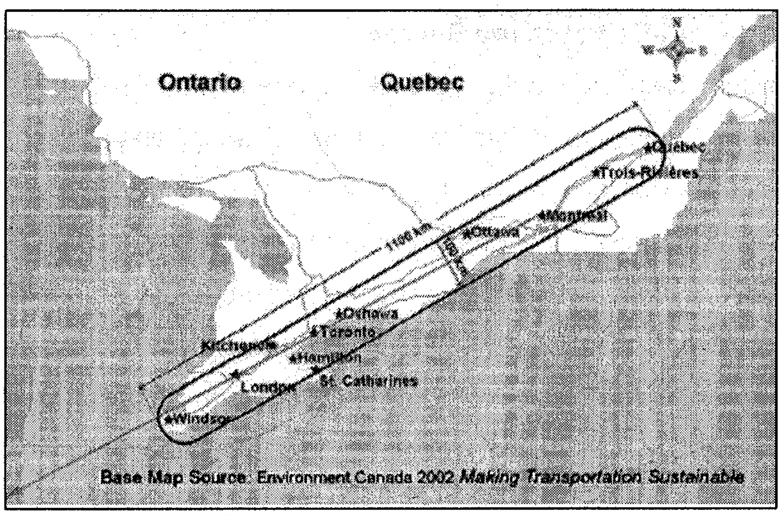
The goal of the present research was to develop statistical models based on a Stated Preference survey in order to evaluate the potential for rail to increase its freight mode share relative to road transportation in the Corridor. Before an actual survey instrument could be developed, it was first necessary to frame the survey so that the right questions were asked of the right respondents.

This chapter is composed of two main sections and describes four fundamental elements that served to frame the form that the survey took. The first section considers the definition of the shipments of interest in the study and explores the issue of traffic contestability. The second section considers the issues of how mode choice is incorporated into the study, and the determination of the respondent population.

4.1 Shipments of Interest in the Survey

As the basic question is about how rail's share of shipments could increase, the survey needs to focus on shipments that could conceivably be shipped by rail (or intermodally) instead of by truck. The universe of shipments, however, is extremely large and therefore needs to be narrowed down to the type of shipments relevant to the research question. The first defining element to consider in a survey is location. Given the present research interest, it is relatively straightforward to restrict shipments to those that pass through and along the Quebec City - Windsor Corridor – that is, not shipments that only travel a short distance in the corridor before exiting, such as Montreal to New York City shipments. Moreover, given obvious disadvantages of rail over short ranges and within cities, the focus is on intercity shipping in the Corridor. Since the focus of the research is to see how shipments can be moved from truck-only to rail (or intermodal), another criterion is that the shipments would normally be transported by truck - and since intercity, generally by standard intercity trucks. A final defining element of the selection of shipments to be considered was affected by the ease of finding survey respondents - only shipments that had their origin in the Corridor were considered as being part of the survey. As decisions involving shipments destined for the Corridor could be made anywhere in the world, it was decided to exclude decision-makers from outside the Corridor for practical reasons because of the difficulties and costs associated with defining and contacting such a population. As a result of these criteria, the survey was conceived as a survey of shipping decision-makers in the Corridor routinely making shipping decisions about intercity shipments originating in the Corridor, and if not destined within Corridor, then transiting for a meaningful distance through the Corridor. The following map provides a sense of the types of shipments considered in the survey - this particular map was used to explain the shipments of interest to the survey respondents, in this case a shipment from Montreal to Chicago.

Figure 3: Example of Shipments Considered in the Survey



While these criteria provide a relatively precise definition of the types of shipments about which respondents were to be surveyed, it was not quite precise enough to allow for the development of the survey. Before the survey could actually be designed, more precise information relating to the contestability of freight traffic needed to be considered.

4.1.1 Freight Traffic Contestability

The dramatic increase in road's share of freight traffic over recent decades can be attributed to truck transportation being more flexible and therefore performing more easily in a timely and reliable manner. Timeliness and, even more importantly, reliability have become the defining features of success in attracting market share in an era of just-in-time inventory management, production and retail techniques. Due to the inherent advantages of truck transportation in these domains, it has become the benchmark for service in the freight business. As a result, increasing rail's mode share implies competing with trucks for shipments, or, for freight traffic. Shipments (or traffic) for which rail and road compete are referred to as contestable. At the same time, freight traffic is only contestable if rail service offerings can provide the same exacting levels of service as trucking, or if rail offerings are inferior, at a lower price relative to road. As a result, evaluating the potential for rail to increase its mode share, amounts to evaluating two things at once: what traffic can be considered contestable and by what type of rail service. Understanding this potential, therefore, requires understanding both shipping requirements as well as rail service offerings in the Corridor.

4.1.1.1 Standard Shipping Service Offerings in the Corridor and Contestability

Through interviews with shippers in the Corridor (described in greater detail in Section 5.2), it was established that shipping service offerings in the Corridor conform to relatively standardized criteria. From the perspective of the shipper, the time required for a shipment to be delivered falls into discrete categories of 'sameday', overnight or over multiple nights. Within the Corridor, all destinations will generally be reachable overnight, with closer destinations being reachable on the same day, and further destinations outside the Corridor requiring two nights. The cut-off between 'sameday' and overnight depends upon the travel time between destinations. As a rule of thumb, destinations that can be reached and returned from during a working day will receive sameday deliveries. Those farther than that will receive overnight deliveries.

These delivery schedules are described as 'standard' in the sense that deliveries between destinations will generally be the same - Montreal-Toronto, for example, is an overnight delivery. This is not, however, always the case - some exceptional shipments, for example, might be delivered the same day between Montreal and Toronto, although the proportion of such shipments appears to be small. Moreover, for non-sameday shipments, the 'standard' shipping day is divided into morning and afternoon. The morning is generally reserved for incoming shipments, and the afternoon for outgoing shipments.

As a result, in addition to being standard, non-sameday shipments are also 'lumpy' in the sense that delivery times are not continuous. That is, shippers do not think of non-sameday delivery times in terms of hours and minutes, but rather, in terms of number of overnights. This feature of non-sameday shipments has implications for the form that the survey takes (as will be discussed in Section 5.3) with respect to how delivery time information is included in the survey.

In particular, in the survey used for this analysis, because of the standard nature of shipment timing on this corridor, shipment delivery time is considered as a given, and thereby considered a shipment, and not a carrier characteristic. It should be noted, however, that this is not necessarily the case for shipment originating or terminating outside the corridor. For example, whereas Montreal - Toronto involves an overnight shipment, longer-haul deliveries such as Montreal - Vancouver, can have quite variable delivery times from 3 to 7 days. With this type of delivery, one would expect delivery time to become an important factor for choosing between carriers and would thereby need to be included as a carrier attribute. As a result, the restricted geographical scope of this research not only reduces complexity by reducing the number of city pairs, but also obviates the need for a separate survey involving differences between carriers' trip durations.

This brief description provides the key features of standard shipping services offered in the Corridor. To complete the picture of what freight traffic can be considered contestable, it is necessary to consider what rail service configurations exist and which ones (and to what extent) they can accommodate the exacting criteria of standard shipments.

4.1.1.2 Rail Service Configurations

While road transport is restricted to a single service configuration (road all the way), rail has several possible configurations. These range from predominantly-rail bulk commodity shipments over long distances, to intermodal configurations, such as COFC and TOFC to which there is an important rail component. As a result, the conceivable universe of rail transportation configurations to compete with road-only transport is large.

To be sure, there is no *a priori* reason why any given rail configuration could not accommodate the exacting criteria of standard shipments. At the same time, some rail configurations, such as rail-only services or railcar-trucking combinations face many hurdles to being able to accommodate standard shipments. Rail-only options are limited by available infrastructure (a small proportion of shippers have direct rail access) and the logistics involved using railcars to carry freight are very cumbersome.

Because the research focus is on estimating the potential for rail to increase its mode-share in the Corridor, when developing the survey, existing rail configurations competitive with truck-only transportation in the Corridor were sought. The intermodal configuration referred to above as 'premium-TOFC' was the only one found to meet these criteria, and hence is the configuration upon which the survey was conceived and designed. While this service configuration was used as the 'model' configuration, the survey does not preclude the use of any other rail configuration, unless that configuration can't accommodate 'standard' shipping along this corridor. As a result, while the following section describes premium-TOFC services in the Corridor, the study should not be seen as a study of the potential only of premium-TOFC services. Rather, it is a study of the potential for premium-*intermodal* services. The distinction is made because in reality, the study evaluates the potential for any rail configuration that can accommodate standard shipping requirements, but uses premium-TOFC as the model, because it is the only existing rail configuration to satisfy these requirements.

4.1.1.3 Current Expressway Service

Section 2.2.2 described the main features of CP's Expressway service. This section describes the service at operating-level detail.

The current schedule for Expressway trains between Montreal and Toronto is that they leave Montreal at 9:30PM and arrive in Toronto at 6:15AM. In the other direction, trains leave Toronto at 7:30PM and arrive in Montreal at 4:15AM. Carriers can pick up their outbound consignments from shippers in the afternoon, bring their trailers to the Expressway train yards for the evening departure, and have them picked-up the following morning in the arrival city so that they can be delivered before noon. There is also a daytime train in each direction that leaves in the morning and arrives in the afternoon. These trains are meant (by CP) to take trailers for which there was not room on their previous overnight train, or to take trailers that would not have been able to go overnight for other reasons. Although these trains do not provide overnight service, they do compete directly with 'standard' deliveries between the two cities. The idea of these services is that from a *shipper's* perspective there is no effective difference in shipping time by the two modes, truck-only or Expressway, between Montreal and Toronto. In other words, this service takes advantage of the fact that delivery times are lumpy so that even with constraints on rail service's temporal and locational flexibility, it is able to provide a service that allows carriers to provide the same quality of service to their clients in this market, and thereby competes directly with truck-only services.

There is one nuance that needs to be added. That is that given current service offerings, and despite the seemingly early arrival times, this service is almost exclusively a truckload (TL) service. That is, Expressway trains do not arrive quite early enough to allow for trailers containing less-than-truckload (LTL) shipments to be brought to LTL distribution centers in the destination city, sorted into the appropriate delivery vehicle (i.e. cross-docked) and delivered before noon. As such, and given current service offerings, LTL shipping cannot really be considered contestable.

This section on shipments of interest in the survey described the relationship between standard shipping services, rail service configurations and traffic contestability. Understanding these issues is crucial, although not sufficient (as will be explained later in this chapter), to developing estimates of contestable traffic. In addition, this information is necessary to understanding (as explained in the following section) the choices that respondents were asked to make, as well as in the selection of the respondent population.

4.2 Previous SP Freight Studies: Mode Choice, Respondent Population

Section 3.3.3 referred to recent stated preference freight choice studies, but did not describe them in much detail. In this section, the relevant features of these studies are examined in order to explain the reasoning behind how mode was incorporated, and the respondent population selected, in the present survey. As a reminder, the studies referred above were (Fowkes and Tweddle 1988, Fridstrom and Madslien 2001, Norojono and Young 2000, Norojono and Young 2003, Shinghal and Fowkes 2002, Vellay and de Jong 2003, Wigan, Rockliffe, Thoresen and Tsolakis 2000). Each of these studies is different in terms of geographical and research focus. Some develop freight value-of-time estimates, e.g. Wigan et al. (2000), while others estimate the relative competitiveness of road versus rail Vellay & de Jong (2003).

In addition to being distinguished by their geographical and research foci, stated preference freight studies can be classified along two other important dimensions. The first has to do with how shipping mode was dealt with in the surveys. The second has to do with the respondents who participate in the surveys.

With respect to shipping mode, it has generally been incorporated in two different ways. In some studies, it has been incorporated implicitly by not including choices between different modes, but rather within-modes. Appropriately, such studies (Fridstrom and Madslien 2001, Wigan, Rockliffe, Thoresen and Tsolakis 2000) are referred to as within-mode studies (Vellay and de Jong (2003) also include some within-mode analysis). An example of a within-mode study is one in which respondents are asked to choose between alternative truck-only carriers.

In other studies, mode is included explicitly by asking respondents to choose between alternative carriers with differing modal configurations. These are referred to as between-mode choice surveys (Norojono and Young 2000, Norojono and Young 2003, Shinghal and Fowkes 2002, Vellay and de Jong 2003). In between-mode choice surveys more than one mode is considered explicitly and respondents choose between modes. For example, respondents might choose between truck-only and intermodal configurations, as in Vellay and de Jong (2003).

Freight choice studies can also be classified by the type of respondent that is surveyed. This point is of particular interest and alludes to a more general question about who decides on shipping mode. Shipping decision-makers are generally classified into three categories: shippers, receivers and carriers. Shippers are agents with a shipment requiring delivery. The receiver is the agent to whom the shipment is destined. Carriers are the agents (trucking company, rail company, etc.) that actually move the shipment from the shipper to the consignee. To be sure, these categories are not necessarily mutually exclusive. For example, it is possible for shippers to own their own equipment and deliver their own goods. Shippers that ship their own goods are known as own-account shippers (or private shippers) whereas shippers who hire other companies (carriers) to ship their goods are referred to variously as 'hire and reward' shippers or shippers using for-hire carriers, and are referred to here as 'end-shippers'. It is also possible for receivers to organize shipments to themselves. In this case, receivers can be thought to behave as shippers.

When considering the question of the use of intermodal services, there are potentially two agents who make the decision about using such services: shippers and carriers. It is generally the case that the decision to use intermodal services will be a carrier's, since the carrier organizes movements of consignments from end-shipper to receiver. That having been said, and while it should be the case that end-shippers are indifferent to how their shipments are shipped (as long as they arrive in good condition and on time), carrier decisions about whether or not to use intermodal services will ultimately be constrained by shipper preferences. For example, if it is the case that shippers have a strong positive/negative preference for the use of intermodal service to transport their goods, this will encourage/dissuade the use of intermodal by carriers. In effect, the end-shipper is the true determinant of the for-hire shipping demand for intermodal services.

This reasoning is the basis for the form of survey used in the study. As a result, while previous mode choice studies have surveyed both end-shippers and own-account shippers, this study focused exclusively on end-shippers. In particular, it was designed to be able to establish whether a carrier's use of intermodal services would affect the end-shipper's choice of carrier. This is not an insignificant point.

Own-account shippers and end shippers have different choices. Own-account shippers actually do (at least theoretically) make the choice of whether or not to send their trailers intermodally, whereas end-shippers choose carriers and do not directly choose mode. As a result, it is not correct to use the same survey for these different groups of shippers. If anything, it would be more appropriate to have a survey for own-account shippers and for-hire carriers than it would be to have the same survey for own-account and end shippers.

Naturally, it would have been ideal to have conducted two separate surveys: one for end-shippers and another for own-account (and for-hire carriers?) in case these different types of shippers had significantly different preferences for intermodal shipping. Unfortunately, this was not possible for two reasons. The first was that conducting a second survey was far outside of the budget for the research in this thesis. Second, developing and managing the administration of an entirely different survey was not possible for the author, given the amount of time and energy required to undertake just one. As well, it should be noted (as will be explained in Section 7.2) that for-hire shipping makes up the vast majority of the shipping considered in the Corridor.

Because of this, the form that the survey instrument took was most similar to a within mode end-shipper survey of freight services choice such as that undertaken by Wigan et al. (2000). The main difference is that the current study includes not only standard carrier and shipment attribute information, but also information on whether the shipment would be carried by rail on a portion of the trip. This type of study is referred to as a carrier choice study.

4.3 Contestable Traffic in the Corridor

With this description of both the shipment types and respondents of interest, it is possible to arrive at an overall definition of the shipments believed to be contestable and that are covered by this survey. From the first part of this chapter, a definition of contestability was arrived at, given current service offerings, of truckload (TL) shipments between major non-sameday destinations in the Corridor. From the second part of the survey was added the constraint that the shipments be carried by for-hire carriers on behalf of end-shippers.

In the simulations chapter, the constraint of only TL shipments will be tested since this is simply a question of changing rail service schedules. The constraint that the shipments be by for-hire carriers only, however, cannot be removed since the survey is of end-shippers only.

5 Survey Population, Development, Description and Implementation

Whereas the previous chapter concentrated on broad-reaching issues affecting the form that the survey took, this chapter concentrates on more prosaic issues related to the development and implementation of the survey instrument actually used. However, this chapter is not independent of the previous one because each of the elements described in this chapter (survey population, survey instrument, etc.) took the form that they did on the basis of the reasoning in the previous chapter. The current chapter describes: the survey population used, the development and final form of the survey instrument, and how the survey was implemented.

5.1 Survey Population

As described in Section 4.2, the population of interest was "end-shippers" involved in shipping decisions related to truckload and less-than-truckload shipments originating in the Corridor, and if not destined within the Corridor, then transiting for a meaningful distance through the Corridor. Based on this, the initial perceived universe of end-shippers was considered to be manufacturers, wholesalers and large retailers, and third party logistics companies (3PLs) located in the Corridor. Third party logistics companies are businesses that provide one or many of a variety of logistics-related services. Services offered by 3PLs can include public warehousing, contract warehousing, transportation management, distribution management, freight consolidation, etc. The people sought to be interviewed were the shipping managers responsible for their establishments.

The sampling frame was drawn from the Dun & Bradstreet's Million Dollar Database (MDDI) of all companies in Ontario and Quebec with more than $1 million in sales or more than 20 employees. This database contains a great deal of information about business establishments such as location, phone number, industry, etc. and whether the establishment is a branch location, a headquarters or a single location. Initially, the possibility of using a subset of the *Statistics*

Canada Business Registry provided by Transport Canada was explored. After discussions with Transport Canada and Statistics Canada, Statistics Canada offered to provide the data. Unfortunately the cost (~$100,000) was outside the budget of the work, and the delay required to obtain the data (~1 year) was too long.

The population was narrowed and nuanced through the initial interview process (described in the following section) used while developing the survey, and during the preparation of the list of companies to be surveyed. In the end, the survey population included all manufacturing facilities with more than 50 employees, wholesalers and retailers that were either head offices or single locations with more than 50 employees at that location, and all 3PLs. In total, 7,229 companies belonged to this population. The location of all the companies included in the survey can be seen in Figure 5 in Section 5.4 .

Due to restrictions on the use of the D&B database, the geographical selection of these companies had to be done manually. As a result, some companies located in Ontario and Quebec, but not in the Corridor *per se*, were included in the sampling frame. While the intention was to include only companies located in the Corridor, the appropriateness of potential respondents for the survey was ensured by confirming, through preliminary interviews (see Section 5.4) that respondents routinely organized a significant portion of shipments through the corridor. That is, shipping managers of a company not located in the Corridor might still organize shipments in the Corridor on behalf of their company. Respondents would only have been included in the survey, even those located outside of the Corridor, if they organized shipments there and would therefore have been appropriate as a respondent for the survey.

Initially, a random sample of 1,600 companies was drawn weighted by the number of employees at the facility. It became clear a couple of weeks after the survey began that given the low response rate, this was far from enough to obtain the desired (500) number of respondents. Hence the entire population was solicited. The goal of 500 respondents was established without prior knowledge of the final form that the survey instrument was to take. It was chosen in order to ensure a sample size that would result in reasonably narrow confidence intervals around coefficient estimates.

5.2 Survey Development

An initial literature review of stated preference freight studies was undertaken to establish the attributes used in previous studies. A preliminary list of attributes was compiled and used as the basis of telephone interviews of potential respondents.

Initial interviews with potential respondents involved asking about the factors that affected a shipper's choice of carrier, employing as a guide the attributes commonly used in other studies. Respondents were asked whether these attributes provided sufficient information to allow them to make a choice between carriers, and whether other information would be required. In addition to what information was required to choose between carriers, respondents were also asked what would be realistic ranges of each attribute's values. For example, they were asked what would be the largest difference in price between different carriers before price would dominate the choice of carrier. Particularly knowledgeable respondents in the Montreal area were also asked whether they would be interested in participating in a focus group relating to the design of the survey.

Altogether, five hundred and fifty phone calls were made to two hundred and twenty-seven companies. Sixty-five interviews were completed and six people agreed to attend the focus group (another six said that they would like to attend but were unable to). In the end, only one person attended the "focus group." Recognizing the difficulty in recruiting this category of worker (relatively well-paid individuals in an often stressful occupation), and that the benefits of using a focus group to elicit information were not necessarily that great in this context, it was decided to undertake individual in-depth, structured interviews in person. This turned out to be a good approach, and all six people who had agreed to participate in the focus group in addition to one other respondent, were interviewed.

Once the telephone and in-person interviews were completed, the actual survey instrument was developed. The intention was to host the survey on the internet, and Sawtooth Software's SSI Web software package was used to develop a web-based survey. SSI Web is designed to develop choice-based conjoint studies hosted on the internet. It's a flexible webpage editor that can be used to build the pages required for a comprehensive choice-based conjoint study. It also allows the user to produce factorial designs as part of the survey design process (see 5.3.1).

A preliminary version of the survey was tested by asking for comments from respondents interviewed in the first stage of development, as well as various other knowledgeable informants either in the field of freight transportation or in web-based surveys. In all, sixteen people provided comments on the survey. Of particular interest in testing the survey was whether or not it was easily understandable; whether there was enough information to select between alternative carriers; whether it was possible to complete the survey in the desired time; and whether or not the attribute values were realistic in terms of both their absolute value and their value relative to those of the other alternatives. Based on comments received, the survey was finalized and launched.

5.3 Survey Instrument

The survey took the form of what has been called in the literature a 'contextual stated preference' or CSP survey. In fact, there were two surveys, one each in English and French, reflecting the primary mother tongues of respondents (see Appendix 4 and Appendix 5 for English and French examples of an entire survey). The surveys were divided in two. The first section described the purpose of the survey and how it was meant to be completed. In addition, some information believed relevant to the post-analysis phase was asked (e.g. the proportion of shipments by the respondent's company that were 'by-appointment'[5]), and whether the shipper used intermodal carriers.

[5] "by-appointment" shipments are shipments that are expected to be delivered at a precise time, e.g. 10 AM.

The second section was the actual CSP, involving 18 questions (choice tasks) for each respondent. For each choice task, the respondent was asked to choose between three alternative carriers in the context of a particular shipment, whose details were described. The shipment information provided was the origin and destination, when the shipment was to arrive, whether it was 'by-appointment,' whether it was of high or low value, whether it was fragile or perishable, and its size (truckload or LTL). Information on value and fragility was provided implicitly through the type of commodity being shipped. For example, televisions were the shipment used to represent high-value, fragile goods.

One way this study, particularly the stated preference survey, differs from previous mode and carrier choice studies is that transit time for shipments was not included as a distinguishing attribute of alternative carriers. That is, the amount of time that a shipment took to arrive at a destination was not considered to be a carrier attribute, but rather a shipment attribute. The reason for this is that through interviews conducted during the survey development phase (as described in Section 4.1.1.1), it was established that for the population of interest (end-shippers), while the time required for a shipment is certainly important, intercity delivery times are more or less standardized in the Corridor and as a result were seen to be more a shipment characteristic than a carrier attribute.

The number of choice sets per respondent was set at eighteen for two reasons. The first relates to the shipment characteristics deemed to be necessary for the shippers to be able to select between carriers. The total number of shipment attribute combinations (contexts) was seventy-two. This would have been far too many choice sets for a single respondent to consider. As a result, it was decided to divide the seventy-two shipment attribute combinations between different versions of the CSP part of the survey.

Recognizing that most respondents can effectively answer between 10 and 20 CSP questions (Sawtooth Software 2005; Johnson and Orme 1996; Louviere, Hensher, and Swait 2000), and since there were seventy-two shipment attribute combinations (contexts) it was decided that four versions (with 18 questions each) of the survey would be used. The seventy-two contexts were randomly divided between the four different versions of the survey. Each respondent randomly received one of the four versions of the survey.

In addition to the constraint of choosing between 10 and 20 choice tasks per respondent, there was another factor contributing to the choice of 18 choice tasks. That factor was that the author wanted to be able to use the survey data to perform Hierarchical Bayesian (HB) analysis in future, post-PhD research. Empirical evidence suggests that HB analysis is best performed starting with 15 choices per respondent (Sawtooth Software 2005). As a result, the number of choice tasks needed to be greater than 15, less than 20 and a factor of 72 – the only possibility was 18. Figure 4 shows a sample CSP question from the survey.

With respect to the carrier attributes, after the literature review, initial interviews and survey testing, it was decided that five carrier attributes would be used. These were: cost, on-time reliability, damage risk, security risk and whether the carrier would send the shipment by rail for a portion of the journey. Each of these is discussed below.

As expected, obtaining information about prices was one of the harder elements of the design process. Because shipping rates are so competitively sensitive and vary somewhat between carriers, and even between clients of the same carrier due to volume discounts, it was not possible to get 'real' shipping costs. However, it was possible to obtain 'reasonable' estimates of costs from the Freight Carriers Association of Canada and the North American Transportation Council (FCA-NATC) Rating System – Version 3 software.

This software estimates shipping costs based on how much of a particular class of good is being shipped between a particular origin and destination. These estimates were then adjusted on the basis of advice from the person responsible for the Rating System in Canada, and finally checked for realism by shippers contacted during the survey development and testing phase.

Figure 4: A Sample Question from the Survey

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It is the beginning of your work day. You are responsible for sending a pallet of televisions from Montreal to Chicago. This is a by-appointment shipment that is supposed to arrive at 11 AM in two days.

Given the characteristics of the carriers, please select which carrier you would choose for this shipment:

Company	Company C	Company A	Company B
Price	$500	$450	$550
On-Time Reliability	98%	85%	92%
Damage Risk	0.75%	3%	1.5%
Security Risk	0.5%	1%	1.5%
How the shipment will be carried	By rail on a portion of the trip	By rail on a portion of the trip	Truck only

Follow these links for more information on carrier attributes,"by-appointment shipments," or other shipment attributes.

Based on the values arrived at by this process, the maximum cost difference between carriers in any choice set was 20%. The attribute itself had 3 levels (low, medium and high) with the medium cost being the cost estimate arrived at by the method described above. That is, the highest cost was 10% higher than the estimated shipment cost and the lowest 10% lower. It is hypothesized that as relative cost increases, the probability of choosing a carrier would decrease (see Section 6.2.2 for a lengthier discussion a priori expectations for the effect of carrier attributes on carrier choice) .

The other continuous attributes also had three levels. On-time reliability ranged from 85% to 98% and had a low, medium and high value. The actual values used were 85% for the "low" reliability value, 92% for the "medium" reliability value and 95% for the "high" reliability value. It should be noted here that in the literature, the measure for reliability has often been percent late as opposed to percent on-time. The reason for choosing percent on-time in this study was simply a function of discussions with shippers during survey development. From these discussions shippers thought of reliability as percent on-time as opposed to percent late. This does not present any conceptual complications, although the use of percent on-time will result in coefficient estimates of the opposite sign from studies using percent late, although the magnitudes of the coefficients should be comparable.

Damage risk (the proportion of shipments suffering from damage) also had a low, medium and high value. However, there were actually two sets of values used in the survey depending upon whether the shipment was truckload or LTL. The fact that two sets of values were used has no implications for the factorial design (see Section 5.3.1 below). The factorial design simply determined whether the damage risk attribute associated with the given carrier was low, medium or high. The actual value as seen by the respondent was adjusted for whether the shipment was TL or LTL. For truckload shipments, the three values of damage risk were 0.5%, 1% and 2% for low, medium and high damage risk, respectively. For LTL shipments, damage risk took the values of 0.75%, 1.5% and 3% for the three levels, respectively. These two sets of values were used because through discussions with shippers during the survey development phase, it was clear that shipper expectations for damage risk were different for truckload and LTL shipments.

Security risk was the proportion of shipments suffering from theft. It varied across three values as well. The three levels took on the values 0.5%, 1% and 1.5% for low, medium and high security risk, respectively. Based on discussions with shippers during survey development, there did not seem to be any need to have different sets of values for truckload and LTL shipments.

The likelihood of choosing a carrier is hypothesized to increase with on-time reliability and to decrease with damage and security risk.

The last attribute was whether the carrier would send the shipment by rail on a portion of the journey. Whereas in previous studies separate modes have been characterized as separate alternatives, it was decided that in this study it would be considered as an attribute of the carrier. The reason for this was that in interviewing shippers it seemed that for the most part shippers were not very concerned with the mode of transport of their shipments provided they arrived on time and in proper condition. One did note, however, that some shippers might find a benefit for public relations or environmental reasons to use rail. The shipper in question did use a rail service for just this reason. It was therefore decided to include the variable to test whether the fact that a carrier used rail would affect a shipper's choice of carrier.

5.3.1 Factorial Design[6]

As mentioned in Section 3.3.3, SP surveys are used for three primary reasons. The first is that they reduce the informational burden placed on respondents. The second is that they allow for the inclusion of hypothetical choice situations in the survey. Third, while RP data frequently suffer from multicollinearity, SP data are explicitly designed so as not to suffer from this limitation. Multicollinearity is the term used to describe the collinearity between explanatory variables in regression or discrete choice estimation. Examples of variables that might be collinear in an RP carrier-choice context are cost and on-time reliability. These variables are often collinear 'in the real world' because it is normally the case that carriers that have better on-time performance are also more expensive. If variables are collinear, it can make estimating the effect of one of the variables independently of the other difficult. The direct effect of an explanatory variable on the dependent variable is referred to as a main effect. While main effects are naturally very important, they are not necessarily the only effects that are of interest. In particular, higher-order effects are sometimes of interest as well. For example, a researcher might be interested not only in the effect of price on carrier choice, but also on how the effect of price on carrier choice might change with on-time reliability. In essence the researcher might like to know if shippers become less price-sensitive as on-time reliability improves. Collinearity between variables can make it difficult to estimate such higher-order effects.

Before continuing, it is helpful to explain some terminology used in choice based conjoint analysis, some of which was used above. Any choice experiment

[6] This section draws on Chrzan and Orme (2000), Kuhfeld (2005), Louviere, Hensher and Swait(2000) and Sawtooth Software(2005).

is made up of at least one choice task (or choice). In our example, the choice experiment is the SP survey, and the choice tasks are each of the questions like the one in Figure 4. Each choice task is made up of alternatives between which the respondent is asked to choose (carriers in this survey). The alternatives are described by characteristics, or attributes (e.g. cost, on-time reliability, etc.). Each of the alternatives is defined by the values assigned to its attributes (attribute values), which can take different values or levels. For example, in this study there were three levels for the on-time reliability attribute (high-, medium- and low-reliability).

Given this structure (choice tasks with a few attributes, each with a few levels), getting around the problem of correlation between variables might at first seem to be a simple problem to solve. Respondents could simply be asked to choose between all of the combinations of the different attributes and their levels - this is referred to as using a full factorial design. This would avoid the problem of collinearity described above, because all possible values of the different variables would appear together in different questions. For example, in some questions, a more expensive carrier would have poorer on-time reliability than a low-cost carrier. As a result, it would not always (or even very often) be the case that price and on-time reliability 'moved' together. In fact, they would be independent of each other by construction, and as a result, it would be possible to estimate the effect of on-time reliability independently of price. Moreover, if a full factorial design is used, all main-effects, and all higher-order effects are estimable and uncorrelated.

Using a full factorial design might be feasible in some contexts. As a simple example, if one were to consider a carrier choice experiment with two alternatives (carriers) and two attributes (cost and reliability) each with three levels, all of the attribute value combinations would be exhausted in 3^2, i.e. nine choice tasks. The problem is that the number of combinations increases very quickly for relatively modest increases in the complexity of the choice. For example, if there were six attributes with three levels each, there would be 3^6, i.e.

729 unique combinations in the full factorial, and 3^{10}, i.e. 59,049 unique combinations if there were ten attributes with three levels.

Because the total number of combinations can easily become very large, choice experiments are designed so that the number of combinations that are used is reduced to make the respondent's task manageable. Reducing the number of combinations, however, does involve a trade-off. In particular, reducing the number of unique combinations can reduce the degree to which the main- and higher-order effects are estimable and uncorrelated. The purpose of a 'fractional factorial design' is to reduce the number of attribute value combinations used in survey questions while at the same time preserving, as much as possible, the positive characteristics of the full factorial design - namely the independence of main- and higher order effects. Fractional factorial designs are referred to as orthogonal when the main-effects (or particular higher-order interaction effects which they are designed to test for) are uncorrelated.

SP studies have traditionally used fixed fractional factorial designs. Such designs can employ a single version of the questionnaire that is seen by all respondents. Sometimes respondents are divided randomly into groups, with different groups receiving different 'blocks,' or versions of the survey. Each of the blocks contains a subset of the questions in the fractional factorial design. For example, if the fractional factorial design contained thirty questions with different unique attribute value combinations, three different survey versions (ten questions each) might be distributed to respondents.

One criterion upon which fractional factorial designs are evaluated is efficiency. Efficiency is a relative measure of the 'size' of the variance-covariance matrix of the estimated coefficients in model estimation. This is a relative measure because it compares the size of the variance-covariance matrix resulting from the design of interest, to its size for a hypothetical orthogonal design. One advantage of fixed orthogonal designs is high efficiency in measuring main-effects and the particular interactions for which they are designed. The disadvantage of such designs, however, is that they are not necessarily efficient at measuring higher-order interactions for which they were not designed. That is, if there are higher-order effects which the researcher did not think possible in the survey development stage, it could be hard to test for them afterwards, because the fixed design would not necessarily allow for efficient estimation of them.

An alternative to using a fixed design is to use a 'random' design. This was the approach adopted in the current study, an approach facilitated by the fact that the survey design software (Sawtooth Software SSI Web - described in 5.2) included functionality to produce random factorial designs.

While the type of design strategy used here is termed a random design it is not, strictly speaking, random. To produce its random design, SSI Web considers all possible attribute value combinations and chooses each one so as to produce the most nearly orthogonal design for each respondent, in terms of main effects. That is, each survey of 18 questions was 'randomly' designed with the constraint that it also be as close to orthogonal with respect to main-effects as possible, while also taking into account the following constraints. The alternatives within each task are also kept as different as possible (minimal overlap); if an attribute has at least as many levels as the number of alternatives in a task, then it is unlikely that any of its levels will appear more than once in any task.

One 'random' design was used for each version of the survey. Because the English and French surveys each had four versions (see 5.3), there were actually eight separate designs used, each with 300 different versions of the questionnaire. That is, each version of the survey had 300 different versions of the 18 questions presented to respondents.

While it is true that some efficiency is often sacrificed when SSI Web produces random designs compared to strictly orthogonal designs of fixed tasks, the loss of efficiency is quite small, usually in the range of 5 to 10% (Sawtooth Software 2005). Moreover, in the current context with such a large number of responses, the designs were expected to be 100% efficient. The advantage, however, is that over a large sample of respondents, so many different combinations occur, that random designs can be robust in the estimation of all effects, rather than just those anticipated to be of interest when the study is undertaken.

While the overall results of the survey implementation and analysis will be presented in detail in Section 5.4 and Chapter 8 below, it is appropriate to present the factorial design results here.

Table 5 shows the correlation between the variables for all of the survey responses. As can be seen, there is very little correlation (values are very close to zero) between most of the variables. The one exception is the correlation between Price and Damage Risk between which there is a correlation of -0.23.

Table 5: 'Random' Factorial Design - Correlation between Attribute Values

	On-time Reliability	Security Risk	Intermodal	Price	Damage Risk
On-time Reliability	1				
Security Risk	0.0001	1			
Intermodal	-0.0011	0.0009	1		
Price	0	-0.0002	-0.006	1	
Damage Risk	0.0028	0.0024	0.0036	-0.2253	1

It is unclear why SSI Web produced a design with such a high correlation between these variables. Despite this seemingly high number, this amount of correlation between variables is not generally considered to be problematic in coefficient estimation. Moreover, and as will be seen below in Chapter 6, there is no evidence that this correlation affected the estimation for these variables' coefficients. That is, whereas a consequence of extreme collinearity between variables is that coefficient estimates of one or both of the correlated variables may appear to be statistically insignificant even when they are not, neither of the variables for price or damage risk is ever found not to be significant.

5.4 Respondent Contact and Survey Implementation

Survey respondents were contacted by a firm specializing in telephone market research. The responsibilities of the firm were to contact the companies in the list provided to them; determine whether or not there was a shipping manager; conduct a preliminary interview to ensure that the company was indeed within the survey population; and to ask whether or not the shipping manager was willing to participate in the study. If the individual agreed, they were sent an invitation e-mail with a link to a URL and a password by which the individual could be associated with his/her responses. Follow-up calls were made if respondents who had agreed to take the survey did not complete it. Once a survey was completed, the results could be downloaded from the survey host site (also Sawtooth Software) and after some automated manipulation and preparation, the data were ready to be analyzed.

Table 6: Characteristics of Sample Frame vs. Actual Sample

Sample Frame				
	Freq.	**Percent**		
Industry				
Manufacturers	4,300	59		
3PLs	781	11		
Wholesalers & Retailers	2,146	30		
Total across Industries	7,227	100		
Location				
ON	4,503	62		
QC	2,726	38		
Total across provinces	7,229	100		
Establishment Size				
	Min.	**Max.**	**Mean**	**Std. Deviation**
Employees	2	14000	146	357
Actual Sample				
	Freq.	**Percent**		
Industry				
Manufacturers	264	67		
3PLs	25	6		
Wholesalers & Retailers	103	26		
Total across Industries	392	100		
Location				
ON	104	27		
QC	288	73		
Total across provinces	392	100		
Establishment Size				
	Min.	**Max.**	**Mean**	**Std. Deviation**
Employees	2	1400	132	141

The survey was conducted between mid-August and early December 2005. All companies in the list given to the marketing firm were contacted (7,229). Of these, 680 agreed to participate. In the end, completed results were obtained for 392 respondents.

Table 6 provides a comparison of the characteristics of the sample frame and the responding companies. Respondents came from all of the industries in the initial survey in the approximate proportion of the original company, although "Manufacturers" were slightly overrepresented at the expense of both "Wholesalers and Retailers" and 3PLs list with roughly two-thirds of respondents being from manufacturing, a quarter from wholesalers and retailers and 6% from 3PLs.

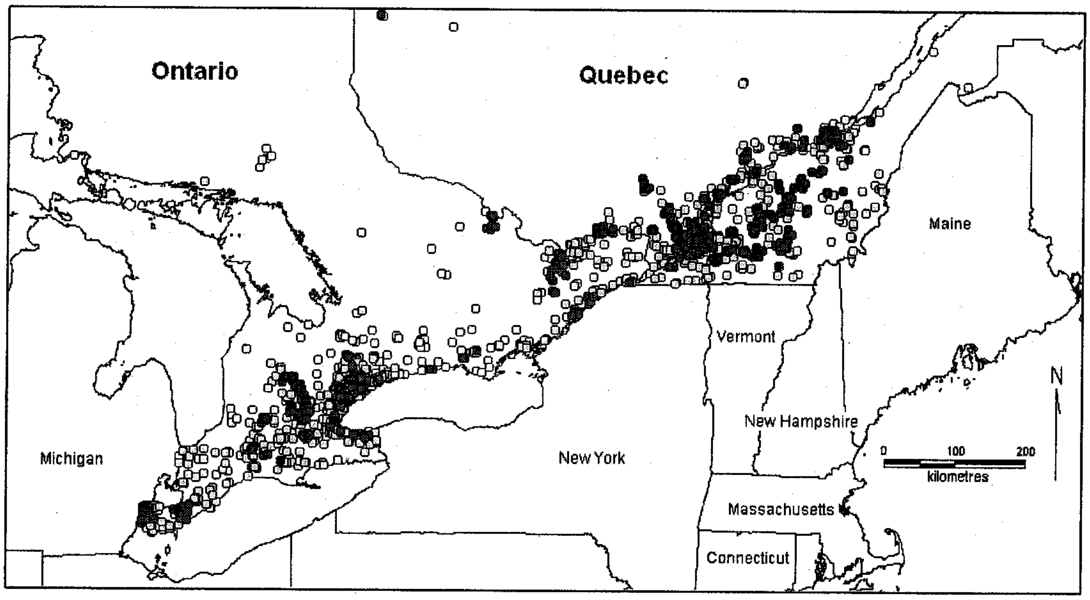
Differences in preferences between industry groups were tested for. No statistically significant differences were observed between Manufacturers and Wholesalers and Retailers. Differences, however were found between these two industry groups and 3PLs - differences, that as will be seen in Chapter 6, were controlled for when the data were modeled.

The respondents represented a relatively large spectrum of establishment sizes with the smallest being a 3PL of only a few employees and the largest being an electronics wholesaler with 1,400 employees. Moreover, the average number of employees in the respondent population was very close to that for the population as a whole at 132 instead of 146 for the entire population. Note that the existence of firms smaller than 50 employees is due to the inclusion of all 3PLs, not just 3PLs with greater than 50 employees.

With respect to geography, there was an overrepresentation of companies located in Quebec with 73% of the respondent companies being located there relative to 38% in the original company list. Figure 5 shows the location of the companies that were included in the survey and also locates the respondent companies. This overrepresentation of Quebec respondents was identified early on when the survey was 'live.' Despite several requests to the polling firm to correct this imbalance while the survey was being undertaken, this geographical imbalance remained. It seems that the polling firm, located in Montreal was much better at recruiting Francophone than Anglophone respondents.

Differences in preferences between respondents in the different provinces were tested for, and for the most part no statistically significant difference between them could be identified. The one exception to this, as will be explained in Chapter 6, has to do with shipper preferences with respect to the use of intermodal transportation - a difference that is accounted for in model estimation.

Figure 5: Companies Included in the Survey (respondent companies dark)



With this description of the survey developed and implemented, as well as an analysis of the general characteristics of the resulting data by industry type, location and size, the following chapter to describes the development and analysis of the survey data.

6 Survey Data Analysis

This chapter describes how the survey results were analyzed econometrically. It begins with an explanation of how the conditional logit model is extended through the use of simulation techniques to estimate a "random effects" mixed logit model. The development and results of a 'global' model using all of the data is presented, followed by the methodology for selecting the sub-models by shipment type. Finally, each of the five sub-models is presented.

6.1 The Discrete Choice Random Effects Mixed Logit Model

Before describing the random effects mixed logit model used to estimate the global and subgroup models, a description of the conditional logit, the multinomial logit and the mixed logit will be provided.

6.1.1 An Aside on Nomenclature

Before continuing with a description of various members of the logit family of models, a short word on nomenclature is in order. There is a general confusion in the literature in the nomenclature used for polychotomous discrete choice models derived through the use of the assumption of logistically distributed error terms. The terms: Logit (Train (2003)), McFadden's Conditional Logit (Maddala 1983, Stata Corporation 2003a), Multinomial Logit (Judge, Griffiths, Hill, Lütkepohl and Lee 1985, Maddala 1983, Stata Corporation 2003b), Generalized Logit and Mixed Logit (So and Kuhfeld 1995) are all used. This unexhaustive list gives a few of the names used to describe logit family models.

The various names given to the different models arise for two reasons. First, different disciplines use different terms to describe the same models and in some cases, different names are given to the same model even in the same discipline.

Second, different models result depending on whether the choice being modeled is considered a function of explanatory variables that: change across alternatives, do not change across alternatives, or a combination of the two (i.e. explanatory variables include some that change and others that do not change across alternatives). The nomenclature adopted in this thesis for the conditional and multinomial logits is the same as that used by Maddala (1983). As such, *conditional logit* is used to describe models where characteristics change across alternatives. The term *multinomial logit* is used to describe models where explanatory variables do not change across alternatives. The term *mixed logit* is used as in Train (2003). These three logit family models are described in greater detail in the following sections.

6.1.2 The Conditional Logit[7]

As mentioned in Section 3.3.2, the conditional logit (or CL) model is the workhorse for discrete choice modeling because of the relative ease with which it is estimated, applied and interpreted. The derivation of the CL has its basis in random utility theory.

Essentially, random utility theory assumes that decision-makers choose between alternatives available to them so as to maximize their utility. Consider a decision-maker (shipper in this study) who faces a choice between alternatives (carriers). Let us index the decision-maker with n and the alternatives with j. According to the random utility framework, the decision-maker will choose the alternative with the highest utility (U_{nj} in Equation 1). While the decision-maker "knows" his own choice rule, the researcher does not. The researcher can only observe the choice made, as well as some characteristics of the alternatives and the decision-maker. The researcher can specify a function using the observed characteristics and choice outcomes to produce estimates of what is called representative utility, or the deterministic portion of the utility function. This is represented by V_{nj} in Equation 1. The deterministic portion of utility is generally represented as a linear function combining alternative and decision-maker characteristics, as can be seen in Equation 2, where the observable characteristics are represented by Xs.

$$U_{nj} = V_{nj} + \varepsilon_{nj} \ \forall j \tag{1}$$

$$U_{nj} = \beta' x_{nj} + \varepsilon_{nj} \ \forall j \tag{2}$$

[7] This subsection draws heavily on Train (2003).

At the same time, there are aspects of utility that the researcher cannot observe and which are considered to make up an 'error' term denoted as ε_{nj}. The error term is assumed to be random and to be distributed by the joint density function $f(\varepsilon_n)$, hence the name 'random utility.' Knowledge of the error term allows the researcher, with the information from the deterministic part of the utility, to make probabilistic statements about the decision-maker's choice.

The probability, P_{ni} that a particular alternative (i) is chosen by a given decision-maker (n) is the probability that the particular alternative results in the highest utility:

$$P_{ni} = P(U_{ni} > U_{nj}) \forall j \neq i \tag{3}$$

$$P_{ni} = P(V_{ni} + \varepsilon_{ni} > V_{nj} + \varepsilon_{nj}) \forall j \neq i \tag{4}$$

$$P_{ni} = P(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj}) \forall j \neq i \tag{5}$$

This is, in effect, the cumulative distribution of the probability that the random term $(\varepsilon_{nj} - \varepsilon_{ni})$ is less than the observed value $(V_{ni} - V_{nj})$. Using the above density function, this can be rewritten as:

$$P_{ni} = \int_{\varepsilon} I(\varepsilon_{nj} - \varepsilon_{ni} < V_{ni} - V_{nj}) \forall j \neq i \tag{6}$$

Where $I(\cdot)$ is an 'indicator' function equal to 1 when the statement in parentheses is true and 0 otherwise. Different discrete choice models result from the use of different specifications of the density function. The probit model results when the density function is multivariate normal. The logit model results when the density function used is logistic. Since the logit and mixed logit were used in this analysis, a description of the logit and then the mixed logit follow.

The logit is obtained by the critical assumption that each ε_{nj} has an independent and identical extreme value distribution, IID distribution. The extreme value density (the probability that ε_{nj} takes a particular value) is:

$$f(\varepsilon_{nj}) = e^{-\varepsilon_{nj}} e^{-e^{-\varepsilon_{nj}}}$$

The cumulative distribution of this function is:

$$F(\varepsilon_{nj}) = e^{-e^{-\varepsilon_{nj}}}$$

The reason that the IID assumption is critical has to do with the fact that if two variables are extreme value, then the difference between them is distributed as a logistic function. That is, since ε_{ni} and ε_{nj} are extreme value, then $\varepsilon^*_{nji} = \varepsilon_{nj} - \varepsilon_{ni}$ has the cumulative density function:

$$F(\varepsilon^*_{nji}) = \frac{e^{\varepsilon^*_{nji}}}{1 + e^{\varepsilon^*_{nji}}}$$

To continue consider the derivation by McFadden (1974) found in Train (2003). Following this derivation, Equation 5 is reorganized as follows:

$$P_{ni} = P(\varepsilon_{nj} < \varepsilon_{ni} + V_{ni} - V_{nj}) \forall j \neq i \tag{7}$$

Now, if ε_{ni} is considered to be given, then this expression is the cumulative distribution of each ε_{nj} evaluated against $\varepsilon_{ni} + V_{ni} - V_{nj}$.

Since the errors are independent, the cumulative distribution of all the alternatives that are not i is the product of the individual cumulative distributions, that is:

$$P_{ni} \mid \varepsilon_{ni} = \prod_{j \neq i} e^{-e^{-(\varepsilon_{nj} + V_{ni} - V_{nj})}} \tag{8}$$

The problem, of course, is that ε_{ni} is not given and as a result, the choice probability is the integral of Equation 8 over all values of ε_{ni} weighted by its density.

$$P_{ni} = \int (\prod_{j \neq i} e^{-e^{-(\varepsilon_{nj} + V_{ni} - V_{nj})}}) e^{-\varepsilon_{ni}} e^{-\varepsilon_{ni}} de_{ni} \tag{9}$$

Algebraic manipulation of (9) results in the well-known, closed form expressions (10) and (11) for the conditional logit.

$$P_{ni} = \frac{e^{V_{ni}}}{\sum_{j=1}^{J} e^{V_{nj}}} \tag{10}$$

$$P_{ni} = \frac{e^{\beta' x_{ni}}}{\sum_{j=1}^{J} e^{\beta' x_{nj}}} \tag{11}$$

In order to understand the final random effects model, it is also helpful to understand how the conditional logit is estimated. The final CL model is arrived at using maximum likelihood estimation. The base unit of the likelihood function is the probability of a given person choosing the alternative that they actually chose, where y_{ni} is 1 if the person chose alternative i and 0 otherwise.

$$\prod_{i} (P_{ni})^{y_{ni}} [1-(P_{ni})]^{1-y_{ni}} \tag{12}$$

Based on this, and assuming that all the decision-makers are independent, the probability of all of the decision-makers in a sample choosing what they actually chose (i.e. the likelihood function) is shown in Equation 13.

$$L(\beta) = \prod_{n} \prod_{i} (P_{ni})^{y_{ni}} \tag{13}$$

While this is the likelihood function, this is not the function that is maximized. In reality, it is the logarithm of the likelihood function that is maximized, namely:

$$LL(\beta) = \sum_{n} \sum_{i} y_{ni} \ln P_{ni} \tag{14}$$

This function is maximized through an iterative process.

6.1.3 Difference between the Conditional and Multinomial Logit[8]

After this description of the conditional logit, some readers may be confused or unfamiliar with this formulation of a polychotomous logit model. In particular, these readers may be familiar with a formulation of Equation 11 that looks more like Equation 15, or more probably like Equation 16. As will be described a little further below, in this formulation, it is the characteristics of the individual that are of interest. As a result, since these characteristics do not

[8] This section draws on Judge, Griffiths, Hill, Lütkepohl and Lee (1985: 753-796), Maddala (1983: 22-46) and Stata Corporation (2003b: 504-520).

generally change between alternatives, the Xs in Equation 16 are not indexed by the alternative, but only by the individual.

$$P_{ni} = \frac{e^{\beta_i' x_{ni}}}{\sum_{j=1}^{J} e^{\beta_j' x_{ni}}} \tag{15}$$

This formulation is what Maddala (1983) refers to as the multinomial logit. In order to understand the difference between these formulations, it is easier to compare not so much the individual probabilities of choosing one of the alternatives, but rather the odds of choosing one alternative relative to another.

$$\begin{aligned} P_{n1} &= \frac{1}{1+\sum_{2}^{J} e^{\beta_j' x_n}} \\ P_{nj} &= \frac{e^{\beta_j' x_n}}{1+\sum_{2}^{J} e^{\beta_j' x_n}}, \qquad j = 2, \ldots, J \end{aligned} \tag{16}$$

In the case of the conditional logit, the odds of choosing one alternative relative to another can be expressed as in Equation 17.

$$\begin{aligned} \frac{P_{n1}}{P_{n2}} &= \frac{e^{\beta' x_{n1}}}{e^{\beta' x_{n2}}} \\ \frac{P_{n1}}{P_{n2}} &= e^{\beta'(x_{n1}-x_{n2})} \end{aligned} \tag{17}$$

In the case of the multinomial logit, in contrast (from Equation 16), the odds of choosing one alternative relative to another can be expressed as in Equation 18.

$$\begin{aligned} \frac{P_{n2}}{P_{n3}} &= \frac{e^{\beta_2' x_n}}{e^{\beta_3' x_n}} \\ \frac{P_{n2}}{P_{n3}} &= e^{(\beta_2-\beta_3)' x_n} \end{aligned} \tag{18}$$

Equation 17 shows that in the conditional logit model, the parameters are assumed to be constant across the alternatives. For example, in the context of carrier choice, it would assume that the effect of price on carrier choice is the same for all carriers considered. At the same time, it suggests that if an explanatory variable is the same across the alternatives, then the variable in question does not contribute to the explanation of why one alternative is chosen over another and its parameter cannot be estimated. As a result, using this strict definition of the conditional logit model, variables such as the size of a firm, or the type of shipment should not be able to affect carrier choice since they are constant across the alternatives for a given choice. In other words, for the strict conditional logit it is the difference between the alternatives that drives choice. The conditional logit, as will be explained below, can be adapted so that it can incorporate variables that do not vary across the alternatives.

Equations 16 and 18 show that each attribute can have j (the number of alternatives) different sets of coefficients, with one set arbitrarily assumed to be 0 so that the model is properly identified. For example, it allows price to be more important in influencing the choice of one alternative carrier than another.

At the same time, explanatory variables are fixed (when using this strict definition of the multinomial logit) across the alternatives. In other words, for the multinomial logit, it is characteristics of the subject that drive the resulting choice between alternatives, not the characteristics of the alternatives themselves. While this is not necessarily always true, it is in the most common cases where data used in the models is related to the individual and thereby does not change across alternatives.

While this type of presentation of the conditional and multinomial logit models is useful to understanding the difference between them, it does in effect present a false dichotomy. In other words, the conditional logit can be modified (or rather the data can be modified) so that it can incorporate data that does not vary across alternatives. This is done by creating new variables that are interaction terms between the fixed explanatory variables and those that vary across the alternatives.

Consider an example where a researcher is trying to explain vehicle type ownership based on the age and sex of the subject. Suppose there are three types of vehicles: small car, large car and other. Modeling this using a multinomial logit would involve estimating coefficients for age and sex on the probability of vehicle type ownership for two of the three vehicle categories.

Equivalent results (i.e. the same coefficients) will result from a conditional logit where the explanatory variables age and sex are interacted with the alternative specific variables for two of the three categories (the same two as for the multinomial logit). An example of one of these interacted conditional logit coefficients would be the age-large car coefficient. This coefficient would explain how the probability of choosing a large car would change as age increased by one year.

As such, it is relatively easy to incorporate explanatory variables that do not change across alternatives in a conditional logit model. This is what was done in the estimation of the models presented in this thesis.

6.1.4 Random Effects Models[9]

The above discussion makes a number of assumptions about the data used when calculating the model. Particularly important in the current discussion is the fact that errors from each of the observations are independent, both between alternatives, as well as across responses. The independence of errors across responses seems a reasonable assumption to make when each response represents one choice by one person. However, the validity of this assumption becomes questionable in a context where observations involve more than one response from the same person. The reason for this is that one might expect the errors across multiple responses from the same person not to be independent. In the context of carrier choice, if a particular shipper has a very strong preference for truck-only, relative to intermodal carriers, then it would be expected that the respondent's errors would reflect this. If errors are not independent across observations, and if they are correlated with explanatory variables, then bias is introduced into the estimation.

This is an issue that is commonly referred to in the context of 'panel data,' that is data where multiple observations are from the same respondent or unit (e.g. a country). A relatively common method of accounting for this problem is

[9] The following two sections draw heavily on Train (2003), as well as for some sections on Kennedy (1998) and Hsiao (2003).

known as a random effects model. The random effects model tries to incorporate the non-independence of errors across the same individual's responses by including an extra, random component in the standard utility model as in Equation 19.

$$U_{njt} = \beta' x_{njt} + \varepsilon_{njt} + \alpha_{nj} \; \forall j \tag{19}$$

As can be seen, the deterministic ($\beta' x_{nj}$), as well as the traditional error component of the utility function (ε_{nj}) are now indexed across time (t) as well as across respondents (n) and alternatives (j). The new error term (α), however is only indexed across responses and alternatives, but not time. In other words, this error is individual-specific. As such, it represents the extent to which the intercept of the n^th respondent differs from the overall intercept. Since it captures correlation across responses of the same respondent, it removes bias from the estimation of the vector of coefficients, $\boldsymbol{\beta}$.

This model, however, cannot be estimated using the standard conditional logit technique, and so other modeling techniques must be used. To understand how this model can be estimated requires knowledge of the mixed-logit model. Understanding the mixed-logit model in turn requires some background on the close relationship between choice probabilities and integration.

6.1.5 Choice Probabilities, Integration and the Random Effects Mixed Logit Model

In the derivation of the conditional logit above, the important relationship between choice probabilities and integration was referred to implicitly, but here it will be made explicit. In order to do this, let us return to the question of choice and revisit the notion of utility. Instead of considering a particular, or explicit, utility function that affects choice, let us think of a choice outcome (y) as being a function of observed (x) and unobserved (ε) factors so that $y = h(x, \varepsilon)$. As reasoned above, although (ε) is not observed, it is assumed to be randomly distributed with a density function $f(\varepsilon)$. As a result, the probability that an agent chooses a particular outcome can be thought of as:

$$P(y \mid x) = P(\varepsilon \mid h(x,e) = y) \tag{20}$$

An even more intuitive way to think about this is through the use of an indicator function, a function where $\mathrm{I}[\mathrm{h}(\mathrm{x},\varepsilon) = \mathrm{y}] = 1$ if the statement in the brackets is true and 0 otherwise. In other words $I[\cdot]$ =1 if x and ε take on values such that the choice outcome is y. In this case, the probability of an agent choosing outcome y is simply the expected value of the indicator function over all values of ε (Equation 21). In order to calculate this of course, the integral must be evaluated.

$$P(y \mid x) = \int I[h(x,\varepsilon) = y] f(\varepsilon) d\varepsilon \tag{21}$$

The evaluation of integrals can be done in three broad ways. First and perhaps most intuitively, integrals can be evaluated analytically, thus arriving at a closed form solution. This is the method used when deriving the closed form solution for the CL as shown when going from Equation 9 to Equations 10 and 11. The second method is to find the solution of the integral through simulation.

Consider as an example the integral $\bar{t} = \int t(\varepsilon) f(\varepsilon) d\varepsilon$ where $t(\varepsilon)$ is a given statistic. The integral itself is simply the weighted average of $t(\varepsilon)$ over all values of ε, weighted by the probability of ε taking any particular value, i.e. $f(\varepsilon)$. This can be simulated by taking many draws of ε from $f(\varepsilon)$, evaluating t, and averaging the results. As more and more draws are made, the closer and closer the calculated or *simulated* average is to the real value of the integral.

The third method for finding the solution of the integral is to use a combination of the first and second methods. Imagine, for example, that the error term could be decomposed into two parts ε_1 and ε_2 with joint density $f(\varepsilon) = f(\varepsilon_1, \varepsilon_2)$. By Bayes' theorem, $f(\varepsilon_1, \varepsilon_2) = f(\varepsilon_2 \mid \varepsilon_1) f(\varepsilon_1)$, i.e. the joint density of ε_1 and ε_2 is the same as the product of the conditional density of ε_2 on ε_1 and the density of ε_1. Applying this to Equation 17, Equation 18 results.

$$= \int_{\varepsilon_1}\left[\int_{\varepsilon_2} I[h(x,\varepsilon_1,\varepsilon_2)=y]f(\varepsilon_1 \mid \varepsilon_2)d\varepsilon_2\right]f(\varepsilon_1)d\varepsilon_1 \tag{22}$$

If a closed form expression exists for the portion of the expression between the large square brackets ($g(\varepsilon_1)$ conditional upon ε_2), then the entire expression can be written as in Equation 22. In other words the joint distribution of ε_1 and ε_2 can be reduced to an expression that is a function only of ε_1. As a result, even if the entire expression could not be written in a closed form, it could still be approximated through simulation by taking many draws of ε_1 and averaging the results.

$$P(y \mid x) = \int_{\varepsilon_1} g(\varepsilon_1)f(\varepsilon_1)d\varepsilon_1 \tag{23}$$

Equation 22 amounts to a weighted average of the two functions g and f. This type of function is more generally referred to as a mixed function. The function with the density that provides the weights is called the mixing function. If $g(\varepsilon_1)$ is a logit, then the entire function is referred to as a mixed logit. Using a mixed logit framework, it is possible to incorporate a random error component and to estimate a random effects model.

Recalling Equations 12 and 19, a mixed logit formulation can be used to incorporate a random error component as in Equation 24

$$\log L = \sum_n \log \int \prod_t (P_{nit})^{y_{it}} (1-P_{nit})^{1-y_{it}} dG(\alpha \mid \delta) \tag{24}$$

where:

$$P_{nit} = \frac{e^{\beta' x_{nit}+\alpha}}{\sum_{j=1}^{J} e^{\beta' x_{njt}+\alpha}}. \tag{25}$$

Here, $G(\alpha \mid \delta)$ is the distribution function of α, and δ represents the parameters of the distribution. Because α is a random error component, its mean is assumed (and forced) to be 0 while δ is a measure of its dispersion, or standard error.

Intuitively, this model can then be estimated in the following way and following the discussion above. Starting values are used for the model coefficients (βs as well as δ). Then, numerous values (in this case 1,000) of δ (the standard error of the error term - in this case assumed to be normal) are drawn from this assumed distribution. Errors (α) for each individual are drawn from the distributions for each draw of δ . The average of the likelihood function across all these draws of δ is then taken. New values for all of the estimated coefficients result from an iteration of the maximum likelihood estimation and new draws of α are taken from its distribution with the new values of δ and the βs , arriving at a new average of the likelihood function. This process is continued until the likelihood function is maximized, resulting in the final estimated model coefficients.

For the purposes of this research, BIOGEME was used to estimate the random effects model described above. BIOGEME is a statistical package designed specifically for discrete choice estimation. It is capable of estimating many different types of discrete choice models, including models requiring the use of simulation techniques for solving integrals for which closed form solutions do not exist. It was designed by Prof. Michel Bierlaire of the Ecole Polytechnique Fédérale Lausanne, in Lausanne, Switzerland. BIOGEME is free and can be downloaded by internet.[10]

6.2 The Global Error Components CL

6.2.1 Summary Statistics

Before presenting the results of the model, it is useful to present some summary statistics of the data used in the estimation of the final model. This helps to provide the reader with a better understanding of the variables in the model, and can also provide intuition into some of the results of the model.

[10] For more information on BIOGEME or to download it please refer to http://transp-or.epfl.ch/page63023.html.

To begin with, Table 7 presents a summary of the main explanatory variables used in the survey. The mean and standard deviation of the carrier attributes described in Section 5.3 are presented.

Table 7: Summary Statistics of Explanatory Variables

Variable	Observations	Mean	Std. Dev.	Min	Max
Cost(ln)	7074	6.49	0.68	4.91	7.59
On-time Reliability	7074	91.67	5.31	85.00	98.00
Damage Risk	7074	1.45	0.85	0.50	3.00
Security Risk	7074	1.00	0.41	0.50	1.50
Shipment Distance	7074	968	376	555	1462

Table 8 presents the frequency of the different characteristics of the shipments presented to the respondents of the survey. Characteristics of the respondents to the survey can be found in Table 6 in Section 5.3 above.

Table 8: Summary Statistics of Shipment Characteristics

Shipment Type	Frequency	Percent	Cumulative Frequency
High-value Fragile	1079	15.25	15.25
Low-value Fragile	1165	16.47	31.72
High-value, Non-fragile	1179	16.67	48.39
Low-value, Non-fragile	1272	17.98	66.37
High-value, Perishable	1206	17.05	83.42
Low-value, perishable	1173	16.58	100
Total	7074	100	

Distance	Frequency	Percent	Cumulative Frequency
555 km	2267	32.05	32.05
864 km	2409	34.05	66.1
1,462 km	2398	33.9	100
Total	7074	100	

Appointment Type	Frequency	Percent	Cumulative Frequency
By-appointment	3618	51.15	51.15
Not by appointment	3456	48.85	100
Total	7074	100	

Consideration of the actual respondent choices can help to provide some idea of what to expect in the estimated discrete choice models. Two interesting results that can be observed just by considering respondent choices are: a reluctance of respondents to choose intermodal carriers, and a tendency for respondents to choose the first and second alternative at the expense of the third.

In terms of a reluctance on the part of shippers to choose intermodal carriers, this can be seen by considering the number of intermodal relative to truck-only carriers that were chosen by the respondents.

Table 9 first shows the number of intermodal vs. truck-only carrier alternatives that were presented to the respondents. As can be seen, exactly 50% of the alternatives were intermodal and truck-only carriers, respectively. At the same time, the lower part of the table shows that truck-only carriers were chosen almost twice as often. As will be seen below, this characteristic of the data has interesting implications for the model provided in the next section.

With respect to the relative positioning of the alternatives, Table 10

Table 9: Respondent Choices – Intermodal vs. Truck-only Carriers

Respondent Choices	Observations
Intermodal Carriers	3537
Truck-only Carriers	3537
Total	7074
Truck-only carriers chosen	4405
Intermodal Carriers Chosen	2669
Total	7074

suggests that respondents were more likely to choose an alternative that was in the left-most or middle position in the survey. As can be seen, whereas respondents chose alternatives in the left-most and middle positions with almost equal frequencies, right-most alternatives were chosen noticeably less. As will be seen below, this characteristic of the data also has interesting implications for the model provided in the next section.

Table 10: Respondent Choices – Relative Position of Alternative

Alternative Chosen	Frequency	Percent	Cumulative Frequency
Left-most Alternative	2632	37.21	37.21
Middle Alternative	2655	37.53	74.74
Right-most Alternative	1787	25.26	100
Total	7074	100	

6.2.2 Setting up the Model

A description of the results of the global model follows. This model (Table 11) was arrived at by beginning with a more general form of the model and removing insignificant variables iteratively. In other words, this more specific model was developed by "testing down" from a more general form of the model to the more specific model presented here.

Before continuing with model description, a quick aside is needed with respect to the appropriateness of using random-effects to model panel data. As mentioned by Hsiao (2003) in the section entitled "Random-effects Models," if random-effects models are used in a context where the random error is correlated with explanatory variables, then coefficient estimates can be biased. At the same time, fixed-effects models (models where alternative specific constants are estimated for each member of the panel) while not efficient (resulting in low t-statistics), will at least produce consistent and non-biased coefficient estimates. As a result, it is possible to test for correlation between the error term and the explanatory variables by comparing the coefficient estimates of fixed-effects and random-effects models. The procedure used for testing this is a Hausman test (see Greene (2000: 443-445)). This test was performed on the global model presented below and turned out non-significant, implying that a random-effects model could be used in the current analysis. The test was not performed for the sub-group models because of the heavy decrease in degrees of freedom available for estimating those models when there were only a fraction of the observations compared to the global model. Even in the global model, very few coefficients came out statistically significant. A description of the models now follows.

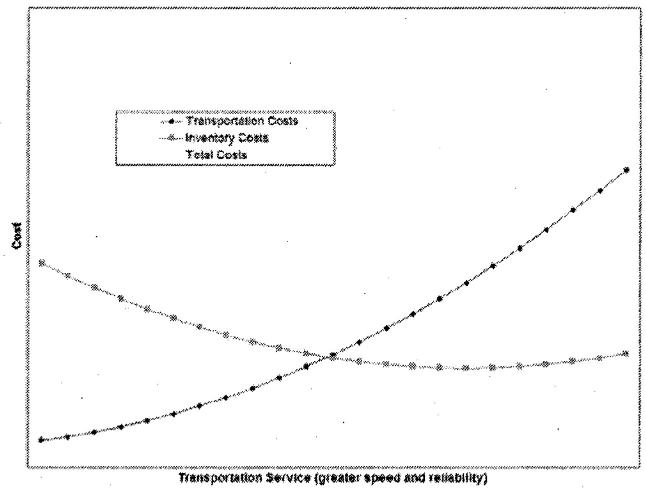
Altogether there were three different types of variables used in model development. First, there were carrier attributes. These included cost, on-time reliability, damage and security risk and the variable indicating the shipment as intermodal. Based on previous studies and the logistics literature (see for example Ballou (2004) Chapter 6) more generally, the expected effects on carrier choice of these variables were as follows. Cost, damage risk and security risk were expected to have a negative affect on carrier choice. That is, the likelihood of choosing a carrier was expected to decrease as cost, damage and security risk increased. At the same time, on-time reliability was expected to have a positive effect. That is, the likelihood of a carrier being chosen was expected to increase as on-time reliability increased.

With respect to the intermodal variable, it was unclear what its sign might be. During in-person shipper interviews, the only respondent to believe knowledge of the mode of shipment might be important thought that it would have a positive effect on carrier choice. At the same time, given the business press (see e.g. Luczak (2005) for a recent example) reporting discontent with rail service, as well as the rapid increase of road transportation, it was considered as possible that identification of a carrier as an intermodal carrier would be negative. In the interview development phase when the question of the use of rail or intermodal transportation came up, respondents generally assumed that rail/intermodal service offerings were weaker and that these weaknesses would need to be compensated through lower transportation costs. Taken as a whole, it was not clear that rail, in and of itself, all else equal, should have an important effect on carrier choice.

The second type of variable used was shipment and shipper attribute interactions with carrier attributes. These included, for example, interactions between cost and shipment type dummy variables, such as by-appointment, high-value or perishable goods. *A priori* assumptions about the effect of these interacted variables came mainly from drawing on logistics theory, and in particular the concept of total logistics cost (see e.g. Ballou (2004) Chapter 2).

According to logistics theory, firms often find themselves trading off different costs with different (opposing) cost structures. Ideally, firms make decisions that minimize their total costs. One common example of such a trade-off is that between inventory and transportation costs (see Figure 6).

Figure 6: Cost Conflict between Inventory and Transportation Costs[11]



In assuring that its customers obtain the goods they are supposed to when they are supposed to, a firm is subject to inventory costs. These costs include the (opportunity) cost of holding undelivered goods (stocks of goods large enough to ensure that there is always enough to satisfy customer orders), as well as storage costs themselves. Naturally, a firm would like to reduce its inventory costs. A good way to minimize these costs is to reduce the amount of time required for the goods to be delivered and to increase the reliability with which the goods arrive. This reduces the time spent, and therefore (opportunity) costs of, holding onto undelivered goods, as well as reducing storage and other in-transit costs. At the same time, improved transportation services (faster delivery times and improved reliability) cost more. In other words, reducing inventory costs involves increasing transportation costs (see Figure 6 for a graphical

[11] This example and as well as the graph based on example in Ballou (2004) Chapter 2.

representation of these trade-offs). The firm therefore trades off these different costs to arrive at the lowest combined cost for both of them. This theory is useful in developing expectations of many of the factors affecting carrier choice.

Applying this theory to develop *a priori* notions about the effect of shipment-type interactions led to the following reasoning and expectations. Both high-value and perishable goods are subject to high inventory costs. Perishable goods are subject to high inventory costs because they can easily go bad, but also because they often require specialized equipment (e.g. refrigerated warehouses). High-value goods have higher inventory costs simply because of their high value, but might also be subject to higher inventory costs as a result of security related costs. As a result of these higher inventory costs, one would expect that carrier choice would be less sensitive to transport cost as firms are willing to pay more to have them shipped more quickly to reduce inventory costs.

By-appointment shipments are often subject to important sanctions to ensure that they arrive when they are supposed to. For example, interviews with shippers revealed that it is not uncommon for them incur significant charges, or even have their shipments refused and sent back, if their deliveries do not arrive within 15 minutes of the scheduled arrival time. This is a particular component of inventory costs for by-appointment goods. As a result, by-appointment goods can be thought of as having higher inventory costs and thereby expected to be less sensitive to transportation costs.

A "total cost" trade-off perspective is not necessary to develop expectations about the effect of all of the shipment type interactions. In some cases it is possible just to consider inventory costs. As described above, high-value, perishable and by-appointment goods all have higher inventory costs. As a result, one would expect them to be more sensitive to other factors that also affect inventory costs. In particular, they were expected to be more sensitive to on-time reliability. In addition to on-time reliability, the higher inventory costs for high-value and perishable goods, led to the expectation that they both ought to be more sensitive to damage risk. In the case of high-value goods that would be a more likely target for theft, they were expected to be more sensitive to security risk as well.

Another type of shipment interaction tested was that between shipment distance and carrier attributes. Expectations about the effect of distance on carrier choice come from economic theory relating goods demand (and thereby transportation demand) to the proportion of final good price accounted for by transportation costs. In particular, it is straightforward (see Wilson (1980: Chapter 1)) to demonstrate that the price elasticity of transport demand is equivalent to:

$$\eta_T = \alpha \eta_D \tag{21}$$

Here, η_T is the price elasticity of transport demand and η_D is the price elasticity of any given good. α is the proportion (in percent) of a good's final price attributable to transportation costs. Since transportation costs increase with distance, the proportion of final price made up of transportation costs also increases with distance. As a result, the elasticity of transport demand should increase with distance. This was indeed the result that was expected from the interaction of distance with the carrier cost attribute.

With respect to the effect of the intermodal dummy on carrier choice, anecdotally, through telephone and in-person interviews, it seemed shippers thought that intermodal options became more interesting at longer distances. This seems likely to be related to the relationship between shipment distance and transportation cost discussed in the previous paragraph. That is, in general, "in the real world" rail and intermodal carriers are less expensive than road-only carriers. Since shippers should be expected to become more cost sensitive with distance, differences in price between intermodal and road-only carriers should become more important on longer, more expensive routes. If shippers assume rail carriers to be less expensive, one should expect the distance-intermodal interaction to be positive, i.e. of the opposite sign of the cost coefficient.

With respect to shipper attributes interacted with carrier attributes, these include the interaction of shipper size and geographical information with carrier attributes. For example, shipper size (represented by the number of employees) was interacted with carrier attributes. There were no *a priori* hypotheses about the effect that shipper size should have on carrier attribute coefficients. With respect to geographical characteristics, shipper distance from existing Expressway railheads (calculated as straight-line distance), whether or not the shipper was located between these railheads and whether or not the shipper was located in Ontario were interacted with the intermodal variable.

Distance from the shipper to existing railheads, and location between them were expected to have a negative effect on the likelihood of choosing an intermodal carrier. There was no expectation for the signs of the coefficients interacting carrier attributes with the Ontario locational dummy.

These 'direct' interaction terms also include the interaction of carrier attributes with a dummy variable for 3PLs to test whether 3PLs had different preferences for carrier attributes relative to other shippers. 3PLs are very understudied in the literature, particularly with respect to how their preferences might differ from other shippers in terms of carrier or mode choice. As a result, there were no *a priori* hypotheses about the signs that the direct 3PL variables would have.

A third type of variable includes interaction terms between the direct interaction terms described in the previous paragraph and 3PLs. The idea behind these variables was to test, for example, whether 3PLs would have different price-sensitivity for by-appointment shipments than other shippers. Again, there were no *a priori* hypotheses about the signs that these 3PL variables would have. The final global model is presented in Table 11 with an explanation of the units of measurement for the continuous variables found in Table 12.

6.2.3 Discussion/Interpretation of Results

Only the results of the random-effects model are presented in this section of the thesis. If the reader is interested in seeing how the random-effects model compares with the traditional CL, the results of the CL estimate of the same model can be found in Appendix 2.

Table 11: The Global Model with Shipment and Shipper-type Characteristics

Variable	Coefficient	% change in odds for increase in X		Std. Error	P-Value
		1% Increase	10% Increase		
Cost(ln)	-4.14000	-4.036	-32.604	0.563	0.000
Cost(ln)*Distance	-0.00220			0.000	0.000
Cost(ln)*By-Appointment	1.70000			0.363	0.000
Cost(ln)*High-Value	1.43000			0.370	0.000
Cost(ln)*High-Value*3PL	3.71000			1.030	0.000
		Odds multiplier for increase in X			
		1% Increase	10% Increase		
On-time Reliability	0.09730	1.102	2.646	0.010	0.000
On-time Reliability*Distance	-0.00003			0.000	0.000
On-time Reliability*By-appointment	0.04970			0.006	0.000
On-time Reliability*Perishable	0.05240			0.006	0.000
On-time Reliability*High-Value	0.01240			0.006	0.040
On-time Reliability*Employees	0.00006			0.000	0.000
Damage Risk	-0.39600	0.673	0.453	0.025	0.000
Damage Risk*3PL	0.22200			0.079	0.000
Damage Risk*Fragile	-0.21800			0.043	0.000
Security Risk	-0.10900	0.897		0.036	0.000
Intermodal	-0.81000	0.445		0.093	0.000
Intermodal*Distance	0.00017			0.000	0.050
Intermodal*Ontario Shipper	-0.29400			0.079	0.000
Intermodal*Shipper btw Railheads	-0.16900			0.072	0.020
Intermodal*3PL	-0.42800			0.134	0.000
ASC1	0.50200	1.652		0.0511	0.000
ASC2	0.54000	1.716		0.0487	0.000
Delta 1	0.68600			0.0578	0.000
Delta 2	0.62200			0.057	0.000
Log Likelihood	-5708				
Likelihood ratio test:	4128				
Adjusted rho-square:	0.262				
Observations	7074				

Discussion of the global model begins with an overview of the model and the carrier attribute coefficients. It continues afterwards with a thorough description of the interaction coefficients. Overall, the results are quite reasonable.

The model fits well with a pseudo R^2 of 0.26, and each of the direct carrier attribute coefficients is significant and has the right sign. Increases in cost, damage risk and security risk decrease the probability that a carrier is chosen. At the same time, an increase in on-time reliability also increases the probability that a carrier will be chosen.

Table 12: Units of Measurement for Continuous Variables

Cost: Natural logarithm of $CAD (Range: 4.9-7.6)
On-time Reliability: % of shipment on-time (Range: 85%-95%)
Damage Risk: % of shipments suffering from damage (Range: 0.5%-3%)
Security Risk: % of shipments suffering from theft (Range: 0.5%-1.5%)
Distance: km between shipment origin and destination (Range: 555-1,462)

6.2.3.1 Carrier Attribute Coefficients

With respect to cost, because the variable itself was in natural logarithms, the coefficient of -4.14 suggests that a 1% increase in cost would result in about a 4% decrease (third column) in the odds that a carrier would be chosen, and a 10% increase would decrease the odds by 33% (fourth column). The coefficient is in the range of other similar studies. In Fridstrom and Madslien's (2001) "shipment level" model they report an estimate of -2.21 (half the magnitude of my estimate), whereas Wigan et al. (2000) report coefficients from –0.049 to –0.298. The latter are based on nominal figures (i.e. dollars instead of the natural logarithm of dollars). When the model presented in Table 11 is run with cost in nominal terms, the coefficient on cost (-0.004) is much smaller than Wigan et al.'s cost coefficient. Regardless, this finding indicates shippers in the Corridor to be highly sensitive to carrier price differences.

Before continuing, it is worth mentioning how to interpret the coefficients of non-logarithmic explanatory variables. It is difficult to directly interpret the regression coefficients (the vector b) in output from a conditional logit regression analysis. This is because each coefficient refers to how much the natural logarithm of the odds, change with a unit change in the value of the associated independent variable.

The natural logarithm of the odds equals $\ln\left(\frac{p}{(1-p)}\right)$. As a result, it is more common to calculate $e^{b\Delta x}$ or the odds ratio, a term best thought of as an odds multiplier. For example if b=0.14, for a unit increase in x $e^{b\Delta x}$ = 1.15, the pre-existing odds of the numerator outcome occurring are multiplied by 1.15. This is the same as saying the odds of it happening increase by 15%. Note that this does not mean the probability of the numerator outcome is multiplied by 1.15. In order to calculate the change in probability, it is necessary to:

1. establish the pre-existing odds $\frac{p}{(1-p)}$,
2. multiply the pre-existing odds by the odds multiplier,
3. solve for the new value of p.

To illustrate by example, assume the pre-existing probability of the event of interest is 50%, and that the coefficient (b) of the explanatory variable x is 0.14. To solve for the new probability assuming a unit increase in the explanatory variable x...

1. $$\frac{p}{(1-p)}=1$$

2. $$\frac{p}{(1-p)}*1.15=1.15$$

3. $$p_{new}=0.53$$

Using these results, it is now more straightforward to interpret the non-logarithmic explanatory variable coefficients.

The coefficient of on-time reliability suggests a similarly strong effect on carrier choice as cost has. The coefficient of 0.097 suggests that if the on-time reliability for a company were to improve by 1%, the odds of choosing that carrier would improve by 10% and would increase more than two and a half times with an increase of 10%. In more intuitive terms, supposing the initial probability of a carrier being chosen were one half, a 10% increase in on-time reliability would improve its likelihood of being chosen to 70%. It is less straightforward to compare this coefficient with other studies, since other studies have tended to quantify on-time reliability in terms of percentage late as opposed to percentage on-time. That having been said, this seems a reasonable estimate and indicates extremely high sensitivity to on-time reliability in the choice of a carrier.

The coefficient on damage risk of -0.396 suggests an increase of 1% in damage risk would decrease the odds of choosing a carrier by a third. This would reduce a probability of 50% to approximately 40%. The coefficient is within the range of other studies with Fridstrom and Madslien and Wigan et al. reporting coefficients of -0.25 and ca. -500 respectively. The extremely large coefficient reported in Wigan et al. has probably to do with a stricter definition of damage risk.

While other studies have not reported on security risk, the coefficient reported here of -0.109 seems reasonable. An increase in 1% of security risk will reduce the odds of choosing a carrier by 10%. This would result in a decrease in probability of choosing a carrier with an initial probability of a third to a quarter.

The coefficients for the continuous variables in the model seem quite strong and reasonable. The most remarkable result, however, is the intermodal coefficient, given that it was not at all clear in interviews with shippers whether the fact that a carrier used intermodal services would affect their being chosen. It should be re-emphasized here, as mentioned in Section 6.2.2 that given business press commentary, as well as growing truck mode share that this result should perhaps not be surprising. At the same time, these results seemed striking for two reasons. The first is that the only shipper interviewed in survey development who believed knowledge of whether a shipment were intermodal might be important thought that this would be a positive factor. Second, while shippers assumed rail/intermodal service offerings to be weaker, they also assumed that these weaknesses were compensated through lower transportation costs with intermodal carriers. As a result, it was not clear that rail, in and of itself, all else equal, should have an important effect on carrier choice. The intermodal coefficient of -0.81 suggests that the odds of choosing a carrier that uses an intermodal carrier is more than halved. If for example the probability of choosing a particular carrier were one half, knowing that a carrier used intermodal services would reduce its probability of being used to a third.

Because other freight choice studies that have incorporated modal information by using an "alternative specific constant" approach (as opposed to having mode be a carrier characteristic as it is here) the results of the effect of mode on utility from other studies and the intermodal coefficient presented here are not strictly speaking the same. That having been said, it is worth mentioning some of these results, to give a sense of what other researchers have found. This is particularly interesting since the results have been variable in terms of whether rail has had a negative or positive effect on utility. For example, Jiang, Johnson and Calzada (1999) (an RP study) estimate an alternative specific constant for road relative to rail of 4.76, suggesting a very strong preference for road transportation. In the same study, however, they report a negative coefficient (-1.22) for intermodal transportation relative to rail, suggesting a preference for rail-only over intermodal transportation. Norojono and Young (2000) present a wide variety of estimates for alternative-specific constants of trucking relative to rail in Indonesia. These estimates range from a very negative (-35.773) for large trucks relative to rail to a positive estimate of 0.163 for small trucks relative to rail. As can be seen, while the effect on utility of the use of rail is quite variable, its effect in the present research certainly falls within the "ballpark" of what has been found in previous studies.

The coefficients ASC1 and ASC2 are the alternative specific constants. They represent the location of a particular alternative relative to the others. ASC1 is the alternative specific constant identifying the first (or left-most alternative in a choice task). ASC2 identifies the second, or middle, choice task. The inclusion of these constants amounts to testing for a choice task "position effect." In other words, including these constants tests whether the position of the alternatives (be they the first, second or third alternative) affects the probability of a particular alternative being chosen. The fact that ASC1 and ASC2 are statistically significant suggests that positioning matters.

Table 13: Shipment and Shipper 'Dummy' Interaction Terms

Cost Interactions	Coefficient	% change in odds for indicated increase in X	
		1% Increase	10% Increase
Cost(ln) only	-4.140	-4.036	-32.604
By-appointment	-2.440	-2.399	-20.750
High-value	-2.710	-2.661	-22.763
By-appointment, High-value	-1.010	-1.000	-9.178
High-value, 3PL	-0.430	-0.427	-4.015
By-appointment, High-value 3PL	1.270		
On-time Reliability Interactions	**Coefficient**	**% change in odds for indicated increase in X**	
		1% Increase	**10% Increase**
On-time Reliability only	0.097	1.102	2.646
By-appointment	0.147	1.158	4.349
Perishable	0.150	1.161	4.468
High-value	0.110	1.116	2.995
By-appointment, perishable	0.199	1.221	7.345
By-appointment, high-value	0.159	1.173	4.923
By-appointment, high-value, perishable	0.212	1.236	8.314
Damage Risk Interactions	**Coefficient**	**% change in odds for indicated increase in X**	
		1% Increase	**10% Increase**
Damage Risk only	-0.396	0.673	0.453
Damage Risk*Fragile	-0.614	0.541	0.293
Damage Risk*3PL	-0.174	0.840	0.706
Security Risk Interactions	**Coefficient**	**% change in odds for indicated increase in X**	
		1% Increase	
Security Risk only	-0.109	0.897	
Intermodal Dummy Interactions	**Coefficient**	**EXP(b)**	
Intermodal only	-0.810	0.445	
Ontario	-1.104	0.332	
Btw Railheads	-0.979	0.376	
3PL	-1.238	0.290	
Ontario btw Railheads	-1.273	0.280	
Ontario 3PL	-1.532	0.216	
3PL btw Railheads	-1.407	0.245	
Ontario 3PL btw Railhead	-1.701	0.183	

In particular, the fact that ASC1 and ASC2 were statistically significant with relatively large, positive coefficients suggests that respondents were more likely to choose the first and second alternative as compared to the third. In fact, the odds of choosing the first and second alternatives relative to the third were 65% and 71% higher, respectively.

The coefficients 'Delta1' and 'Delta2' are the standard errors of the error distribution (assumed to be normal) around the alternative specific constants (α in Equation 24 - here there are two because there are two ASCs). The fact that they are statistically significant simply confirms that it's appropriate to include random error components in the estimation.

In the final global model, in addition to the five carrier attribute variables, there were another 12 shipment and shipper interaction variables. These coefficients can be divided between those where the variables are interacted with the carrier attributes are dummy variables and those that are continuous. Table 13 shows the former.

6.2.3.2 Shipment and Shipper Interaction Coefficients

The first column identifies not only single carrier attributes, but also the relevant shipper-shipment 'dummy' interactions with a carrier attribute. The second column shows the value of the combined coefficient value of the first order variables and their interaction term.

The third and fourth columns show the implied effect of the coefficient values on the odds of choosing a carrier by changing the relevant attribute value by the amount shown in the column heading.

Consider the section labeled 'Cost Interactions.' The first line of this section shows the cost attribute coefficient. Columns three and four show that a 1% increase in cost would result in roughly a 4% decrease, and a 10% increase would result in a roughly 33% decrease in the odds of choosing a carrier - the same as reported in Table 11.

The second line of this section labeled 'by-appointment' shows what the cost coefficient is for by-appointment shipments. The value of this coefficient (-

2.440) is the sum of the Cost(ln) and Cost(ln)*By-Appointment shown in Table 11. The third column shows that a 1% increase in cost for a by-appointment shipment will reduce the odds of choosing a given carrier by around only 2.4%. The fourth column shows that a 10% increase in cost will reduce the odds of choosing a given carrier by 20%. In other words, by-appointment shipments are less cost-sensitive than other categories (not-by-appointment, low-value, not 3PLs) of shipment-shipper combinations. High-value shipments are also less price-sensitive than the base category shipments, but more price-sensitive than by-appointment shipments with a coefficient of -2.710. These results are consistent with *a priori* expectations as described in Section 6.2.2. 3PLs are even less price-sensitive for high-value shipments than are other end-shippers with a cost coefficient of only -0.430. Although the combined cost coefficient for high-value, by-appointment shipments by 3PLs is positive (1.270), which is at odds with common sense, it is not statistically significant from zero. This coefficient is, however, presented for completeness. With respect to other studies and what they have reported with respect to shipment characteristics and cost, Norojono and Young (2000) find that leather goods are less sensitive to cost with a coefficient of -1.799 as opposed to -4.068 for the other commodities considered in their study.

By-appointment shipments are more sensitive to on-time reliability with a coefficient of 0.147 as opposed to 0.097 for the base category (not-by-appointment, non-perishable, low-value shipments). This result also meets expectations. High-value and especially perishable shipments are also more sensitive to on-time reliability than the base category. The most on-time-sensitive shipments are by-appointment, high-value, perishable shipments with an on-time coefficient of 0.2, more than twice the coefficient of the base category. A 1% increase in on-time reliability for these shipments would result in a 22% increase in the odds of a given carrier being chosen. Another study that has reported results relating shipment characteristics with the effect on utility of on-time reliability is Fridstrom and Madslien (2001). They find that "comestibles"[12] are more sensitive to on-time reliability than are other shipments - a comparable result to the relation between perishable goods and on-time reliability presented here.

With respect to damage risk, results show, not surprisingly, that fragile goods are more sensitive to damage risk, and that 3PLs are less sensitive to damage risk than are other end-shippers. Norojono and Young (2000) report that leather is more sensitive to damage than the other commodities considered in their study. There are no significant shipment-shipper interactions with security risk.

Dummy interactions with the intermodal variable suggest that Ontario shippers, shippers located between the Expressway railheads and 3PLs are even more reticent about using intermodal transportation than other end-shippers. Their estimated coefficients are -1.104, -0.979 and -1.238 respectively. The most reticent shippers are 3PLs located in Ontario, between the Expressway railheads. They have an intermodal coefficient of -1.7. Knowing that a carrier will send a shipment intermodally reduces the shipper's odds of choosing that carrier by more than 80%! It should be noted that these results appear to represent the first attempt in the literature to estimate differences in mode or carrier choice between 3PLs and end-shippers.

Relatively intuitive explanations can be proposed for the reticence towards intermodal shipping by 3PLs and shippers located between the Expressway railheads. For the former, perhaps 3PLs, are more reluctant to use rail because reduced performance of shipments can result in the loss of a client. As a result any pre-conceived perception about rail performance would have a magnified rail-bias for them. For other end-shippers, reduced performance by an intermodal carrier might result simply in switching carriers. For the latter, their increased reluctance may be capturing intuition about the routing of their shipments. That is, for shippers located between the Expressway railheads, shipments between

[12] Although no definition of comestible is given in the Friedstrom and Madslien paper, it appears from the text that it is intended to mean "perishable."

Montreal and Toronto will necessarily 'back-track' at some point in their trip. Despite the fact that the routing of shipments should not interest end-shippers, this coefficient may be capturing this intuition. With respect to why Ontario shippers would be more reluctant than Quebec shippers, this remains a mystery.

Altogether, there are four continuous variable interactions, three relating to shipment distance and the other related to a firm's number of employees. The estimated coefficients themselves for these interactions are shown in the column labeled 'Coefficient' of Table 14 and are referred to as $CVIC$ below. While each of the coefficients is very small in absolute value terms (three of the four are zero to three decimal places), they become important over the range of values of the interacted variables. Table 14 shows the values of the combined carrier attribute and continuous variable interaction coefficients at different values of the interacted continuous variables. The values are calculated according to the following formula.

$$CC = CAC + CVIC * CV$$

The formula is explained by using the cost-distance interaction as an example. CC is the combined coefficient value (-5.24 for a 500 km shipment). CAC is the carrier attribute coefficient referred to in Table 11, Table 13 and Table 14 as the 'Cost only' coefficient of -4.14. $CVIC$ is the continuous variable interaction coefficient. It represents by how much CAC changes for each unit of the continuous variable. In this case it represents how much the cost-only coefficient changes when shipment distance increases by one kilometre (i.e. -0.0022).

As can be seen, as distance increases, shippers become more sensitive to cost, less sensitive to on-time reliability and less mistrustful of rail. In fact, at the longest shipment distance, and compared to the unadjusted coefficients, shippers are 80% more cost-sensitive, 40% less on-time sensitive and 30% less mistrustful of rail. With respect to the distance interacted intermodal variable, it suggests that the odds of choosing a carrier using intermodal services would be decreased by 40% for a shipment from Montreal to Chicago, as opposed to more than 50% suggested by the intermodal coefficient alone presented in Table 11 (-0.81).

Table 14: Shipment and Shipper Continuous Variable Interaction Terms

Distance Interactions				
Coefficient of Cost only	-4.140			
Coefficient of On-time Reliability Only	0.097			
Intermodal Coefficient only	-0.810			
		Shipment Distance (km)		
		500	**1000**	**1500**
	Coefficient	**Combined Coefficient Value at Different Shipment Distances**		
Cost(ln)*Distance	-0.00220	-5.240	-6.340	-7.440
On-time Reliability*Distance	-0.00003	0.084	0.071	0.057
Intermodal*Distance	0.00017	-0.726	-0.641	-0.557
Number-of-employee Interactions				
Coefficient of On-time Reliability only		0.097		
		Number of Employees		
		50	**775**	**1500**
	Coefficient	**Combined Coefficient Value with Different Numbers of Employees**		
On-time Reliability*Employees	0.00006	0.100	0.146	0.191

With respect to the size of the establishment (measured in number of employees), on-time reliability becomes even more important as establishment size increases. For an establishment with 1,400 employees (the largest in the survey), on-time reliability almost doubles, with a coefficient of 0.191 compared with the estimated simple coefficient on on-time reliability of 0.1. This result was unexpected, but might be explicable if it were the case that larger firms were more likely to send by-appointment shipments and thereby be more sensitive to on-time reliability. There is some evidence for this in this data set with a slight positive correlation between shipper size and the proportion of their shipments that were by-appointment.

In summary, it can be said that the main carrier attributes used in the model all have important explanatory power and that their importance changes in ways conforming to expectations when taking into consideration shipment and shipper attributes. Most importantly for this research, despite a reduced bias against intermodal shipping on longer shipment distances, there remains a strong unexplained bias against using rail for shipments in the Corridor.

It is indeed in this context that the model provides the most intriguing results. In particular, the coefficient estimate for carriers that use intermodal services implies that irrespective of other service attributes (cost, on-time reliability, etc.) there is a very strong bias against the use of rail. That is, even if a carrier had the same cost, on-time performance, etc. as another carrier, but used intermodal services, the odds of its being chosen would be halved. It is in this sense that the effect of this variable on carrier choice is considered unexplained – the intermodal variable identifies a difference in preferences for intermodal carriers, but it does explain why. Perhaps, given reports in the business press (see Section 6.2.2) and the attitudes of shippers towards rail (i.e. assumed weaker service performance requiring compensation in transportation charges) this should not be a surprising finding. However, it can only be interpreted as a bias, because the purpose of using a factorial design of attribute values is precisely to be able to extract the influence of variables separately, i.e., in theory, it cannot be claimed that it is because rail is often unreliable that there is such a strong negative coefficient for intermodal shipments, because the effect of on-time reliability should already be captured in the coefficient for on-time reliability. The fact that the attributes were presented in the way that they were in the survey ensures that other factors are at play in explaining the results.

Regardless of the degree to which the coefficient on the intermodal variable is or is not a surprise, these results suggest that rail needs to change its reputation or image among shippers. With the results of the global model presented, the development and presentation of the sub-models used in the simulations follows.

6.3 Selecting the Sub-models

The global model provided a broad understanding of the survey results, and in particular, those shipment and shipper characteristics that influenced carrier choice. This model did, however, include all observations and as a result, it was reasoned that such an aggregate model might hide some of the subtleties of the data. As a result, analysis was conducted to establish whether the data ought to be divided into subgroups and modeled separately.

A three-stage approach was adopted. The first was to establish *a priori* subgroups of the data that might need to be modeled separately. The second was to test statistically which subgroups ought not to be estimated together. The third, based on the second, was to establish which sets of subgroups should be modeled together.

The first stage was to establish potential subgroups *a priori.* As mentioned in Section 5.3, seventy-two different shipment categories were presented to the respondents in the contextual part of their questions. The categories were defined by shipment fragility, value, size, time-sensitivity and distance. For testing purposes, these 72 categories were reduced to 24 by incorporating the three distance characteristics of shipments (short, medium and long trips) into the explanatory variables by interacting trip distance with carrier attributes. An example of incorporating distance this way is the distance-price interaction variable described in the global model results. In addition to shipment types, it was of interest to see if different shipment types are treated differently by 3PLs. Hence 48 subgroups were tested to see if they should be modeled separately.

In the second stage, testing was conducted to see which of the subgroups had statistically different utility functions from the others, and hence should not be modeled together. These tests also made it possible to determine which subgroups didn't have significantly different utility functions from others and hence could be modeled together.

The above was accomplished using a version of the so-called Chow test (see for example Greene (2000: 287). It is an F-test of the joint insignificance of multiple variables identified with subsets of a population. The coefficients of these subset specific variables are allowed to vary independently from the coefficients used for the rest of the observations. These coefficients are allowed to vary independently from the rest by interacting the explanatory variables with a dummy variable identifying the subset of observations of interest. If all the explanatory variables of the model are interacted with the dummy variable identifying the subgroup, this amounts to testing whether the subgroup is statistically significantly different from the other observations. More precisely, it is testing whether, by allowing each of the explanatory variables to be estimated separately for the subgroup, there is a statistically significant increase in the explanatory power of the model. An example of using this method would be to test for the joint insignificance of variables interacted with a dummy variable indicating whether each respondent was a woman. If the test turned out to be statistically significant (i.e. the null hypothesis was rejected), it would amount to saying that there is a statistically significant increase in explanatory power by estimating a model for women independently from men, and therefore that separate models ought to be estimated for women and men. As this is a discrete choice analysis involving maximum likelihood estimation, instead of using an F-test the appropriate test is a likelihood-ratio test.

The procedure is relatively straightforward if there are only two subgroups of observations in a dataset, as in the case of testing for differences between men and women. It becomes more complicated as the number of subgroups increases. For example, suppose there are three subgroups in a dataset (groups 1, 2 and 3). Also suppose the explanatory variables were interacted with groups 2 and 3 separately, i.e. one set of explanatory variables interacted with a dummy variable for group 2 and another set with a dummy variable for group 3. A significant Chow test, jointly testing the variables interacted with group 2 would imply that the group 2 observations ought to be estimated separately from group 1. This would not, though, provide any information on whether group 2 should or should not be modeled with group 3. In order to establish this, it would be necessary to estimate a model with group 2 as the base category and to test for the joint insignificance of group 3 variables.

In other words, as the number of subgroups to be tested increases, so does the number of models that need to be estimated in order to test for differences between each of the different subgroups. In fact, if n is the number of subgroups in the data, then there need to be n-1 models estimated and $(n^2 - n)/2$ Chow tests calculated, with each of the n-1 models using a different subgroup as the 'base' group. In the example above, with 3 categories of observations, there would need to be 2 models estimated and 3 LR tests.

The first model would use group 1 as the base group and have two Chow tests to test whether groups 2 and 3 should be estimated separately from group 1. The second model would use group 2 as the base group and test whether group 3 should be estimated separately from group 2, thus resulting in 2 models estimated and 3 Chow tests.

As there were 48 different shipment-shipper categories, the initial idea was to test for differences between these 48 different subgroups. Very early in the analysis, it became clear there were far too few observations for each of the 24 shipment types by 3PLs to be able to test whether there were differences by shipment type and shipper group. As a result, the number of *a priori* subgroups was reduced to 24 shipment types.

An initial aggregate model was developed, testing down iteratively from a more to a less elaborate model, with insignificant variables being removed in each iteration. Because the purpose of developing this model was to test for different utility functions by subgroups of shipment types, information on shipment type was not included in the explanatory variables of this aggregate model. For example, whereas in the global model presented above, by-appointment shipments were interacted with on-time reliability, this was not done in this model so that differences between the subgroups could be tested. The resulting model is shown in Table 15.

Despite removing information about shipment type and 3PLs, most of the coefficients are quite similar to those in Table 11. The obvious exception is the coefficient on price-sensitivity which has decreased somewhat, but which is explicable because of the loss of the other interaction coefficients. The model is presented here for completeness since a relatively thorough interpretation was provided for the global model in Table 11.

A dummy variable for each of the 24 subgroups was then interacted with each of these variables and included in each of the models, except in those models where the given subgroup was the base subgroup. As one example, a dummy variable for the second subgroup (fragile, truckload, high-value, by-appointment shipments) was interacted with each of the variables, except in the second model where group 2 was the base group. For each of the models, Chow-tests for the joint insignificance of the variables interacted with a particular subgroup were calculated. The results of these tests are found in Appendix 1. The words "yes" and "no" in the table of Appendix 1 answer the question whether the omitted subgroup (identified by the rows) should be modeled separately from the subgroup identified by the columns.

Table 15: Global Model without Shipment Type Variables

Variable	Coefficient	Exp(b)	P-value
Cost(ln)	-2.520		0.000
Cost(ln)*Distance	-0.002		0.000
On-time Reliability	0.143	1.154	0.000
On-time Reliability*Distance	0.000	1.000	0.000
On-time Reliability*Employees	0.000	1.000	0.010
Damage Risk	-0.436	0.647	0.000
Security Risk	-0.113	0.893	0.000
Intermodal	-0.790	0.454	0.000
Intermodal*Distance	0.000	1.000	0.050
Intermodal*Ontario Shipper	-0.252	0.777	0.000
Intermodal*Shipper btw Railheads	-0.218	0.804	0.000
ASC1	0.495	1.640	0.000
ASC2	0.521	1.684	0.000
Delta1	0.642		0.000
Delta2	0.588		0.000
Log Likelihood	-5839		
Adjusted rho-square:	0.247		
Observations	7074		

Each of the 23 models included 264 variables and as a result, over 6,000 coefficients in total were estimated and 276 Chow-tests calculated. Because of the large number of regression coefficients estimated and LR-tests calculated, there is bound to be a considerable number of type-I errors. Hence , a statistical significance level of 1% instead of the usual 5% was used for the Chow-tests as recommended by Kennedy (1998: 76).

Table 16: Shipment Subgroups to be Modeled Separately

Shipment Subgroups
High-Value, By-Appointment, Not Perishable
High-Value, Perishable
Low-Value, By-Appointment
High-Value, Not By-Appointment, Not Perishable
Low-Value, Not By-Appointment

The third stage of subgroup determination was to examine which shipment groups (according to the LR-tests) should not be modeled together. This information, in combination with examination of the shipment groups themselves, allowed the determination of shipment groups that were intuitively acceptable as members of a given subgroup, and which could be modeled together. Five subgroups were identified by this process and are presented in Table 16 along with the original shipment groups in each.

6.4 Presentation of the Sub-models

Whereas the previous section described how the subgroups were determined, this next section presents the models estimated for each subgroup.

Based on the model in Table 15, models were determined for each of the 5 subgroups. That is, models with the variables in Table 15 were tested for each of the subgroups, and the final models were arrived at by testing down from this more general to the more specific models presented.

Table 17 summarizes the results for each of the five submodels, as well as for the global model in Table 15. A notable feature of these models is that they include only the five, and sometimes only four, carrier attributes. The reason for so few coefficients is that each of the subgroups has only a fraction of the observations of the global model, resulting in the insignificance of many variables due to the smaller number of degrees of freedom of the subgroup models. The models, however, show the main characteristics of the global model explained in Table 11.

Table 17: Summary of Subgroup Models

Variable	All Observations	High-value, By-appointment, Not Perishable*	High-value, Perishable	Low-value, By-appointment	High-value, Not By-appointment, Not Perishable**	Low-value Not By-appointment*
Cost(ln)	-2.520	-2.687	-4.00286	-4.375	-4.292	-2.392
Cost(ln)*Distance	-0.002					-0.004
On-time Reliability	0.143	0.133	0.181	0.143	0.083	0.089
On-time Reliability*Distance	0.000					
On-time Reliability*Employees	0.000					
Damage Risk	-0.436	-0.494	-0.265	-0.454	-0.549	-0.424
Security Risk	-0.113					
Intermodal	-0.790	-0.730	-0.719	-0.818	-0.560	-0.754
Intermodal*Distance	0.000					
Intermodal*Ontario Shipper	-0.252					
Intermodal*Shipper btw Railheads	-0.218		-0.507		-0.468	
ASC1	0.495	0.437	0.574	0.371	0.408	0.566
ASC2	0.521	0.461	0.558	0.415	0.502	0.614
Delta1	0.642	0.709	0.666	0.475	0.017	0.345
Delta2	0.588	0.195	0.456	0.520	0.398	0.159
Log Likelihood	-5839	-970	-893	-1522	-969	-1444
Adjusted rho-square:	0.247	0.220	0.319	0.256	0.203	0.239
Observations	7074	1141	1206	1873	1117	1737
*Delta2 not statistically significant						
*Delta1 and Delta2 not statistically significant						
NB - All other variables statistically significant at the 5% level						

When shipments are by-appointment and high-value, they tend to be less sensitive to price and more sensitive to on-time reliability. Perishable goods are also particularly sensitive to on-time reliability as high-value goods tend to be to damage risk. One notable feature of the models is the seemingly low absolute value of the price coefficient for low-value, not by-appointment goods. Previous reasoning suggests that this ought to be the most cost-sensitive category. In fact, when the interaction coefficient between distance and price in this model is taken into consideration, it results in a coefficient of -4.592, even for the shortest shipping route considered in the survey. As such, it is in fact the most price-sensitive category. It is also the least sensitive to on-time reliability.

The intermodal coefficient is relatively stable across subgroups, except for the high-value, not by-appointment, non-perishable subgroup. In this subgroup model, the intermodal coefficient is only -0.55. There is no obvious explanation for the low (in absolute terms) value of this coefficient.

This concludes the description of the econometric modeling and model development section. These five submodels were used to develop market-share and emissions simulations, the results of which are presented in Chapter 8. Before presenting the results in Chapter 8, however, it is necessary to explain the data, background and assumptions used in the simulations.

7 Market-share and Emissions Simulation: Data, Background and Assumptions

This chapter discusses some background to the market-share and CO_2 emissions simulations obtained using the models whose estimates were discussed in Chapter 6. It is necessary to explain the data used in the simulations, as well as a number of background assumptions made in the preparation of the data and the calculation of the simulations. The chapter is divided into four main sections: the Ontario Ministry of Transport (MTO) Commercial Vehicle Survey (CVS) trucking database, the definition of contestable truck trips, CO_2 emissions calculations, and the application of the CL models used in the simulations.

7.1 Trucking Data: the MTO Commercial Vehicle Survey 2001

In order to determine what the universe of contestable truck trips was, a record of existing trips was required. Luckily, the Ontario Ministry of Transportation (MTO) provided a sub-sample of its Commercial Vehicle Survey updated to the year 2002. The Ontario Commercial Vehicle survey was originally conducted as part of the Canadian National Roadside Survey (NRS), a national trucking survey coordinated by the Canadian Council of Motor Transport Administrators (CCMTA). The NRS was first conducted in 1999, and Ontario conducted follow-up surveys to its CVS producing results for the year 2002 (Haider 2006). The Ontario CVS is a very rich database of such high quality that it has been referred to anecdotally as one of the best trucking databases in the world.

The subset of the CVS provided by the MTO included trips originating in or destined for Southern Ontario, or using highways in Southern Ontario, including the Ontario part of the Corridor. As a result, it captured trips with one or both trip-ends in Southern Ontario, or with neither trip-end in Southern Ontario, but which traversed it. As a result, it captured trips such as Montreal - Toronto, Toronto - Windsor, but also Toronto - Chicago and even Montreal - Chicago. Hence it captured trips between all of the cities included in the analysis. Although the

Quebec Ministry of Transportation provided data from the Quebec equivalent of the MTO CVS, it didn't include truck trips between locations in Ontario, or between locations in Ontario and the US, and referred to 1999. Therefore the Ontario CVS data was used instead.

It provided considerable information on trip (e.g. geocoded origins and destinations, distance between origin and destination), shipment (by 4-digit SCTG[13] category), vehicle (e.g. configuration) and carrier (e.g. for-hire or private) characteristics. The geographical, shipment and carrier characteristics, as is described below, were the most important for the current analysis. The database itself contained records for 88,300 trips of which three quarters were by for-hire carriers (see Section 7.2.4) and 15% of which were LTL (see Section 7.2.3.1) trips.

7.2 Contestable Truck Trips

As discussed in Section 4.3, truck trips considered contestable by intermodal service were for-hire TL trips between major non-sameday origins and destinations in the Corridor where premium-intermodal service was believed to be realistically competitive. To be considered realistically competitive, a number of conditions needed to be satisfied for city pairs to be included. These conditions were:

1. each city in the pair needed to be a major origin and destination,
2. standard truck delivery times between the cities needed to be at least overnight,
3. rail infrastructure needed to exist that could realistically be used for freight transportation.

Based on these criteria, the major cities included in the analysis were Quebec City, Montreal, Toronto, Windsor and Chicago. All pairs of these cities were considered except for the city-pair Montreal - Quebec City. This pair was

[13] Standard Classification of Transported Goods

excluded because they are so close that the standard delivery schedule between these cities is sameday, with which rail cannot realistically compete.

While strictly speaking, Chicago is not in the Corridor, it was included in the analysis because it's a major origin and destination on the same trajectory as other trips considered, and is subject to standard delivery times from other Corridor origins. Detroit was not considered explicitly, but as will be seen later, trips between Detroit and other Corridor destinations were implicitly included in trips to and from Windsor.

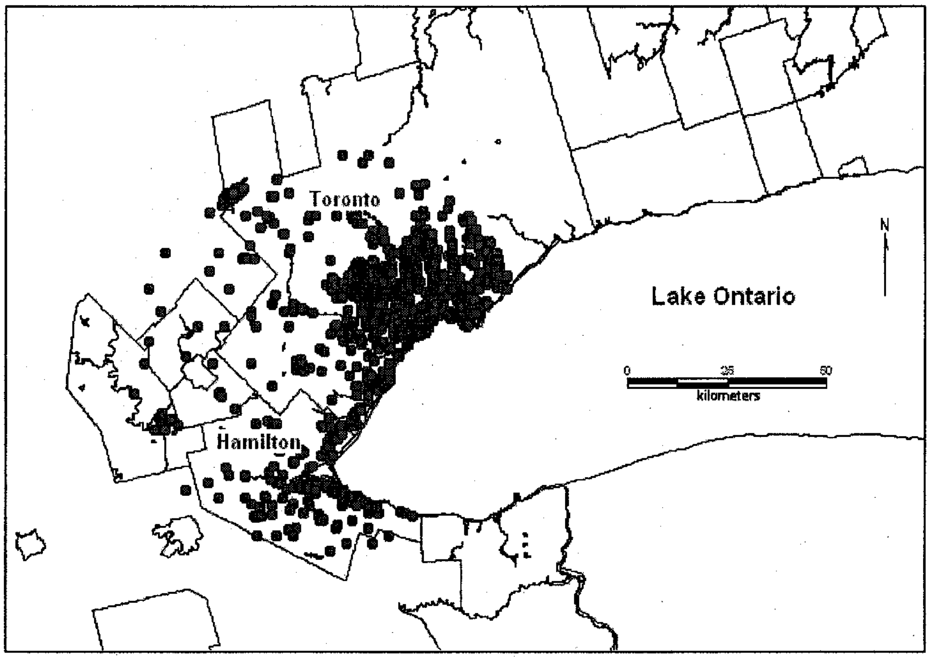
Finally, Ottawa was considered as a possible city to include in the analysis. While it is true that rail-lines do connect Ottawa to the main rail-lines of the Corridor, the lines themselves are not owned by the Class I freight carriers, but rather by Via Rail Canada (Railway Association of Canada 2004: Ontario Railways). The fact that neither Class I carrier has direct access (see below for more information on traffic contestability and infrastructure sharing), and the assumption that Via doesn't have sufficient infrastructure (rail yards, etc.) led to Ottawa not being included in the analysis.

7.2.1 Trip Origin- and Destination-Catchments

For a city-based analysis, it was necessary to define what city boundaries to use. One option would be to use CMA boundaries for example, but as railyards are often not central to CMAs, their boundaries were inappropriate for determining which shipments were contestable by an intermodal service using existing railyards in these metropolitan areas. For example, some locations in the Toronto CMA are 80 km from CP's Milton Expressway railyard. One would expect that the likelihood of a trailer being sent intermodally would decrease as the distance from the railyard to the shipment's origin and destination increased. Therefore it is more logical to define a city's potentially contestable freight traffic in terms of whether it is within a circular catchment area of a given radius around its railyard(s).[14]

[14] The term 'potentially contestable' is used here because geographical location is not the only criterion of contestability.

Figure 7: Trip Origins in the Toronto Expressway Railhead-Catchment [15]



Origins and destinations of each shipment in the database were mapped, and if they were within 50 km of a railhead in one of the cities of interest (see Figure 7 for an example showing shipment origins within the Toronto Expressway railhead-catchment) they were classified as originating in (or being destined for) the city in which the railyard was located. Table 18 lists the railyards included in the analysis, to what city they were assigned and to what company they belong. The latitude and longitude of railyards were determined using a combination of information from the railway company websites, GEOBASE rail network data,[16] and Google Maps.

The 50 km buffer was arrived at intuitively. The reasoning was that this would be about the longest distance that a truck could travel in end-of-the-day

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[15] Source of map layers: trip origins, MTO CVS; CMA boundaries, Statistics Canada Census 2001; provincial and state boundaries, MapInfo;.

[16] An online federal, provincial and territorial government initiative providing free geospatial data for Canada (www.geobase.ca).

traffic in Toronto or Montreal and still make it to the railhead in time to be loaded onto an Expressway-type service. Toronto and Montreal were used in this analysis because they are the most important locations, but also because they were the locations where road traffic congestion is most likely to place a constraint on catchment size. While other cities like Quebec City or Windsor might have larger potential catchments because of less road traffic, 50 km buffers from the railheads covered the vast majority of trip origins and destinations to these cities, in any case.

The MTO had data relating to truck trip lengths to and from the Toronto Expressway terminal. While they could not release this data, after internal analysis they confirmed that 50 km was a reasonable distance to be used as a buffer.

Table 18: Intermodal Railyards in the Cities Included in the Analysis

City	Railyard	Company
Chicago	Bensenville Intermodal	CP
Chicago	Markham Yard	CN
Windsor	Windsor Yard	CP
Windsor	Van de Water	CN
Toronto	Milton	CP
Toronto	MacMillan Yards (Vaughan)	CN
Montreal	Cote St. Luc	CP
Montreal	Taschereau	CN
Quebec City	Joffrey	CN

7.2.2 Incorporating Multiple Railyard Catchments

Except for Quebec City, all the cities considered have both CN *and* CP railyards. Moreover their railyards are close enough that their catchments overlap. As a result, were both companies to offer intermodal services they would compete for much the same potentially contestable traffic. Regardless of any overlap, estimating total potentially contestable traffic requires including the railway catchments of both railways.

While Expressway is the only current intermodal service competing directly with trucks in the Corridor, estimating the true potential of premium-intermodal services between the cities of interest requires the catchment areas of all railyards in the cities of interest to be considered. It might be thought that the railyards of the competing railways are close enough that a single joint catchment area could be defined as the union of the two. This would be feasible for cities like Montreal and Windsor, but not for Chicago and Toronto, where the CN and CP intermodal terminals are 45 and 37 kilometres apart, respectively.

Including multiple railyard catchments in a given city is not, in and of itself, very complicated. But complications arise when trying to define the potentially contestable traffic in cities with multiple catchments. The first is that a shipment whose origin and destination fall into both railyard catchments in both cities must not be double-counted as two potentially contestable trips.

The second complication is that the different railyards are operated by different companies and these companies do not generally share traffic.[17] It is very unlikely, for example, that CP would load a trailer onto one of its trains at its railyard in Toronto and deliver it to CN's railyard in another city. As a result, the addition of a second railyard catchment area in one city will only increase contestable traffic between a city-pair, if shipments in the new origin catchment are destined for the catchment of the *same* railroad company in the destination city. If not, this traffic will not be contestable. Clearly, this needs to be taken into consideration when establishing the amount of contestable traffic.

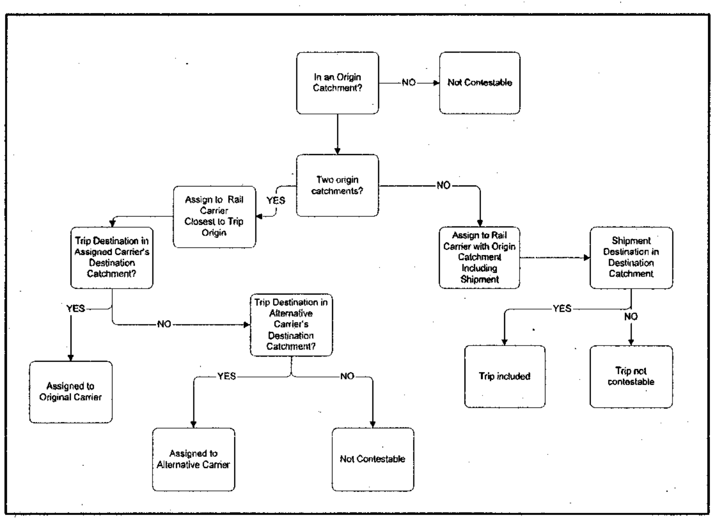
This complication does not arise for all trips. It depends on whether the shipment is one for which both companies could compete, i.e. shipments whose origins and destinations both lie within each company's catchment area. Shipments for which there is no inter-railroad competition have origins and destinations that fall only into the railyard catchments of one company. This would include, for example, a trip whose origin falls into CN's MacMillan Yard catchment and whose destination falls into CN's Taschereau Yard catchment, but not into CP's railyard catchments in Montreal and Toronto. It would also include any trips to or from Quebec City, since CP has no rail infrastructure to Quebec City and it is unlikely that CN and CP would share traffic.

[17] The recent agreement by CN and CP in British Columbia's lower mainland (see (Morton 2006)) and other 'co-production' agreements (see (Canadian National Railway 2000b) are some exceptions.

However, the complication in calculating potentially contestable traffic arises in situations where both companies might be able to compete. In order to avoid double-counting of contestable shipments, those falling into two rail catchments need to be assigned to one of the companies using a reasonable algorithm. The one adopted is illustrated in Figure 8.

The decision process for including trips as contestable and assigning them carriers was as follows. If the shipment origin was in only one catchment and its destination was in the catchment of the same company, the trip was considered contestable and assigned to that carrier. Otherwise, it was not considered contestable.

Figure 8: Decision Process for Assigning Traffic to Rail Carriers



If the shipment origin was in two railyard catchments, it was initially assigned to the carrier whose railyard was closest to the origin. If the destination was in the same carrier's railway catchment, the trip was assigned to the initial carrier and the trip was considered contestable. If, however, the destination didn't fall into the same carrier's railyard catchment, it was assigned to the other carrier. If the destination fell into that carrier's railway catchment, it was assigned to the second carrier and considered contestable. Otherwise the trip was not considered contestable.

The above method selected truck loads merely on the basis of their location relative to railyards. As described in Chapter 4, contestability is not only determined by location, but also by shipment and carrier characteristics. Specifically, only TL shipments by for-hire carriers are considered as contestable. The following sections describe how the number of trips was adjusted based on these characteristics.

7.2.3 Adjusting for Shipment and Carrier Characteristics

7.2.3.1 Removing LTL Trips

Since current intermodal service offerings are not particularly suitable for LTL traffic, these were removed as potentially contestable traffic. There is little easily available data on this, but luckily the CVS data contained enough information to identify LTL shipments. In particular, shipments were considered as LTL if they had more than one delivery destination, or if the shipment was identified as "LTL" or "LTL, Courier & Mail," etc. This resulted in the identification of 85% of the trips in the data as truckload shipments. This estimate is likely an upwardly biased estimate of the proportion of TL shipping, assuming not all truck drivers are aware of the nature of their shipment. For example, a trailer might be delivered to one destination where, unbeknownst to the driver, its load would then be cross-docked for final delivery elsewhere. Hence a delivery to one destination not identified as TL might indeed be LTL. The inverse, however, is unlikely.

7.2.4 Removing Private Carriers

Since the survey was of end-shippers, it can only be representative of shipments carried by for-hire carriers. As a result, only for-hire truck trips were considered to be contestable. A variable in the CVS data identified the trip as being done by for-hire or private carrier. Private carrier trips were removed. Roughly 90% of trips in the sample were by for-hire carriers.

7.2.5 Accounting for Existing Intermodal Traffic between Montreal and Toronto

In order to estimate the potential market-share for intermodal services it is necessary to know the total amount of truck traffic moving between the different city pairs. That is, the trucks on the roads and the trailers traveling by rail. This is not an issue for most of the city pairs considered, but is a consideration for the Montreal to Toronto corridor, where CP operates its Expressway service. However, getting access to the number of trailers traveling with Expressway is difficult. First, such trips are not covered in the CVS, or at least not the full extent of the trip. In other words, the CVS might capture trips from their origin to the Expressway terminals in Toronto, but it would not record it as a trip from Toronto to Montreal.

At the same time, there is no publicly available data for TOFC traffic between city pairs. As a result, CP was asked for this information. Due to its commercially sensitive nature, it was not made available. CP staff did, however, reveal that each train between Montreal and Toronto had a capacity of 105 trailers for a total overall daily capacity in both directions of 420 trailers. Using as a basis the catchments of the Expressway railyards and removing LTL trips (but not private carriers since Expressway moves both private and for-hire carriers), the total number of potentially contestable road-only trailer movements between Montreal and Toronto was calculated to be just below 1,600 per day. That is, these are current (2002) road-only trips having both their origins and destinations in the existing Expressway railyard catchments. Together, these two figures suggest an overall maximum market-share of ~20% for the Expressway service, i.e. 420/(1600+420). This figure (the estimated proportion of truck trips traveling with Expressway) was used as an adjustment factor to inflate the total number of contestable truck trips on this corridor.

Because the information provided by CP was imprecise, two different adjustment factors were used when undertaking simulations. These were based on two different assumptions about the capacity utilization of the CP trains: one low-, and one high- market-penetration rate. The high market-penetration rate

(~20%) was based on an assumption of 100% capacity-utilization of the CP trains, i.e. 420 trailers per day. The low market-penetration rate (~10%) was based on 50% capacity utilization. Neither of these market-penetration rates is believed to be more or less likely than the other, but was intended to represent upper and lower bounds of these rates.

7.2.6 Total Estimated Contestable Truck Traffic

Table 19 and Table 20 provide the results of the estimated number of contestable truck trips between the city-pairs considered.

Table 19: Estimated Daily Contestable Truck Trips in the Corridor (high Expressway market penetration)

Origin	Destination	Current Trailers per Day
Chicago	Montreal	22
Chicago	Quebec	1
Chicago	Toronto	207
Chicago	Windsor	26
Montreal	Chicago	33
Montreal	Toronto	1008
Montreal	Windsor	40
Quebec	Chicago	2
Quebec	Toronto	62
Quebec	Windsor	3
Toronto	Chicago	149
Toronto	Montreal	1051
Toronto	Quebec	47
Toronto	Windsor	1050
Windsor	Chicago	34
Windsor	Montreal	25
Windsor	Quebec	4
Windsor	Toronto	960
Total		4724

One result that might be surprising here is the large number of trips between Windsor and Toronto, more in fact than between Montreal and Toronto. The reason this figure is so high is that it reflects the many automobile industry shipments between Windsor and Toronto, as well as Detroit and Toronto.

7.2.7 Emissions Modeling

Once estimates for truck trips were developed, it was then possible to develop emissions estimates - both for existing truck trips, as well as for these trips, had they traveled intermodally. This essentially involved multiplying the distance of the trip by the appropriate (truck or train) emission factor, and multiplying daily emissions to arrive at annual estimates. Emissions estimates were made solely for the Canadian portion of trips since the focus of the research was Canadian transportation emissions.

Table 20: Estimated Daily Contestable Truck Trips in the Corridor (low Expressway market penetration)

Origin	Destination	Current Trailers per Day
Chicago	Montreal	22
Chicago	Quebec	1
Chicago	Toronto	207
Chicago	Windsor	26
Montreal	Chicago	33
Montreal	Toronto	914
Montreal	Windsor	40
Quebec	Chicago	2
Quebec	Toronto	62
Quebec	Windsor	3
Toronto	Chicago	149
Toronto	Montreal	953
Toronto	Quebec	47
Toronto	Windsor	1050
Windsor	Chicago	34
Windsor	Montreal	25
Windsor	Quebec	4
Windsor	Toronto	960
Total		**4531**

The CVS data included the distance of each of the trips (including distance covered in Canada), so calculating the emissions for each of the trips simply involved multiplying this distance by the trucking emission factor (see section below).

Estimates for what the emissions would have been had the trip gone intermodally were estimated by calculating the straight-line distance between the trip origin and origin railyard, as well as that between the destination railyard and the trip destination. While it would have been preferable to estimate these distances over a network, given the high correlation between road distance and straight-line distance in metropolitan areas with dense road networks, little benefit would have been derived from using network distances for the short distance local components of trips. These distances were then multiplied by the truck emissions factor. For the rail part of the journey, rail distances were compiled using the *Canadian Trackside Guide 2003* (The Bytown Railway Society 2003) and emissions calculated as the product of the rail distance by the rail emission factor (explained below).

7.2.7.1 The Truck Emission Factor

MOBILE6.2C was used to produce the truck-only CO_2 emissions factor in the analysis. MOBILE6.2C is the name given to the Canadian adaptation of the US Environmental Protection Agency's MOBILE62. Although, MOBILE6.2C is used internally at Environment Canada for mobile source emissions modeling (although not for CO_2), it has not been officially released. Despite the fact that it is not officially released, access was provided to the program for the current project. The descriptions of MOBILE6 and MOBILE6.2C come predominantly from USEPA (2003) and Taylor (2005), respectively.

The EPA MOBILE model was first developed in 1978. Since then it has been updated many times to reflect growing understanding of vehicle emissions, and to cover new emissions regulations and modeling needs. Although some updates were made in 1996 with the release of MOBILE5b, the 2003 MOBILE6 was the first major revision to MOBILE since MOBILE5a was released in 1993.

MOBILE in general is a model for estimating pollution from highway vehicles. MOBILE calculates emissions of hydrocarbons (HC), oxides of nitrogen (NOx), and carbon monoxide (CO) from passenger cars, motorcycles, light- and heavy-duty trucks. It also includes the ability to calculate CO_2 emissions. The model accounts for the emission impacts of factors such as changes in vehicle emission standards, changes in vehicle populations and activity, and variation in local conditions such as temperature, humidity and fuel quality.

MOBILE has been used to calculate current and future emission inventories of these emissions at the national and local level in the US. These inventories are used to make decisions about air pollution policy at the local, state and national level. Inventories based on MOBILE are also used to meet the federal Clean Air Act's State Implementation Plan (SIP) and transportation conformity requirements, and are sometimes used to meet requirements of the National Environmental Protection Act (NEPA). It has also been used commonly in the more formal literature with particularly relevant examples being from David Forkenbrock ((2001) and (1998)). MOBILE6.2 served as a base for the 2003 Canadian version, MOBILE6.2C. The Canadian model does not (except in specific cases) change the functionality of MOBILE6.2 or its commands. In effect, MOBILE6.2C uses input files and in some cases code modifications to adapt MOBILE6.2 to the Canadian context. For example, in the Canadian version default sulphur levels in gasoline were modified. As another example, different vehicle registration figures (representing vehicle fleet age) and mileage accumulation rates for vehicle categories were used in MOBILE6.2C.

As should be evident from the short description above, MOBILE6 and MOBILE6.2C are very elaborate programs that provide relatively fine-grained information by vehicle type, as well as by location. In particular, MOBILE6.2C produces CO_2 emission factors for up to eight different light- and heavy-duty vehicle classes for both gasoline and diesel vehicles. Moreover, it has been adapted to produce different estimates for four regions making up the Quebec-City Windsor Corridor (three in Southern Ontario and one in Southern Quebec).

For the purposes of this research, one vehicle emission rate was sought to represent emissions from intercity heavy-duty trucks operating in the Corridor. As a result, it was necessary to make some assumptions to combine the different emissions rates produced by MOBILE6.2C. With respect to vehicle type it was reasoned that the vast majority of the vehicles of interest (heavy-duty vehicles used for intercity trucking between major destinations of the corridor) would fall into the MOBILE6 classes 7, 8a and 8b.

These categories were used on the basis of the CVS database that included information on vehicle configuration, as well as on information about the MOBILE6 categories (see Figure 9 for visual representation of these categories).

Figure 9: Visual Representation of MOBILE6 Heavy-Duty Categories

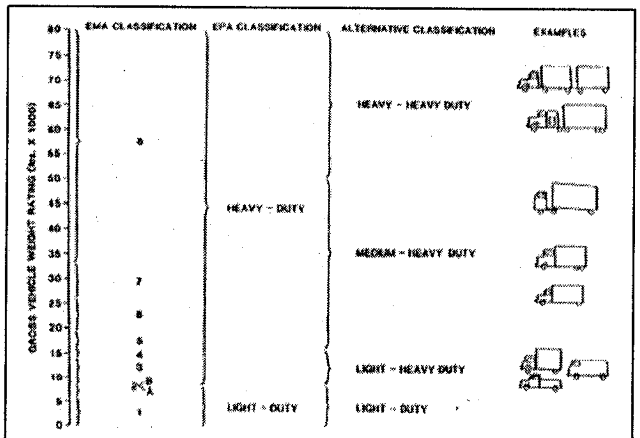


Image provided by the US EPA Office of Transportation and Air Quality

MOBILE6.2C contains information on the proportion of vehicle miles accumulated by each vehicle type per year, as well as the proportion of these vehicles for each of the four regions making up the Corridor. This information was used to calculate weighted averages of the emissions factors for each region, weighted by the proportion of each vehicle type registered in the region. A simple average of the CO_2 emission factors for each region was used to arrive at the final CO_2 emission factor. MOBILE6.2C produces emission factors in terms of grams of CO_2 per vehicle mile travelled. The resulting emission factor used was 935 g of CO_2 per kilometre. This is referred to as the truck emission factor (*tef*) below.

7.2.7.2 The Rail Emission Factor

While activity-based emission (emissions per tonne-km) rates for rail transportation are publicly available, the unit sought for this research was g/km per vehicle or trailer - a unit not publicly available. As a result, information on train fuel economy was obtained from Expressway staff. They reported that on the Montreal - Toronto run, their trains consumed 2,000 litres of diesel fuel over the 341 mile journey.

Naturally, derivation of a per-vehicle emission factor requires knowledge about the number of vehicles carried per train. As a result, two rail emission factors (*ref*) were used depending upon the assumed capacity-utilization of the Expressway trains. The *ref* was updated dynamically in the simulations when the capacity-utilization factor changed. The resulting *ref*s were 189 and 94 g/km per vehicle (trailer) for the low and high Expressway capacity utilization assumptions, respectively, which is between 10% and 20% of truck emissions. The mathematical formula for the rail emission factor (*ref*) is shown in Equation 26.

$$ref = \left(\frac{efe}{ec \times ecf} \right) \times 2{,}730\ g\ CO_2\ per\ litre\ of\ diesel\ fuel \qquad (26)^{18}$$

efe represents Expressway diesel fuel efficiency expressed as litres of diesel fuel consumed per kilometre travelled by an Expressway train, *ec* Expressway trailer capacity expressed in trailers per day and *ecf*, the Expressway capacity-utilization factor expressed as a proportion.

7.2.8 Current Emissions Estimates

Once current truck trips and kilometres had been estimated and emissions factors determined, it was possible to estimate current emissions. Equation 27 is the formula used to calculate aggregate truck emissions (tCO_2), the product of aggregate truck-only trailer-kilometres (*TKM*) and the truck emission factor (*tef*) in grams per trailer per kilometre (see Section 7.2.7.1).[19]

$$tCO_2 = TKM \times tef \qquad (27)$$

The calculation of intermodal emissions was slightly more complicated.

[18] The figure 2,730 g CO_2 per litre of diesel fuel comes from *Canada's Greenhouse Gas Inventory, 1990-2003* (Environment Canada 2005)

[19] *Aggregate* emissions and *aggregate* trailer-kms refer to the aggregates for each origin and destination pair.

Overall aggregate intermodal emissions (ICO_2) follow the same pattern as in Equation 27, namely:

$$ICO_2 = IKM \times ief \tag{28}$$

where IKM represents aggregate intermodal trailer kilometres and ief is the intermodal emission factor. The intermodal emission factor is the vehicle-trip-weighted average of the ratio between the emissions of current contestable truck-only trips (from the CVS) (tCO_2) and the emissions of those same trips had they traveled intermodally (iCO_2). This is expressed mathematically in Equation 29.

$$ief = \frac{\sum_i \left(\frac{iCO_{2i}}{tCO_{2i}} \right) \times cvs\exp_i}{\sum_i cvs\exp_i} \tag{29}$$

$cvsexp_i$ is the MTO CVS expansion factor associated with observation i of the database. iCO_{2i} represents the emissions associated with trip i of the MTO CVS, had that trip been transported intermodally. It was calculated as:

$$iCO_{2i} = taekm_i \times tef + rkm_i \times ref \tag{30}$$

The first part of the equation represents the emissions for the truck portion of the trip - $taekm_i$ is the truck access and egress distance to railyards. The second part of the equation represents emissions for the rail portion of the journey - rkm_i is the rail distance. The ief is more easily understood if broken into its component parts. First, the left-hand term in the denominator is the ratio of the estimated emissions of the i^{th} trip had it gone intermodally (iCO_2) and the estimated emissions had it gone road-only (tCO_2). As such tCO_2 is the estimated 'true' emissions from the trip. The combined term then gives a relative sense of how much less CO_2 would have been produced had the trip gone intermodally instead of by road-only. The second component of the expression is the $cvsexp_i$. As explained above, the $cvsexp_i$ is the expansion factor for the i^{th} trip in the CVS. For example, if the $cvsexp_i$ had a value of 2 for a given observation, it would mean that that observation represents two trips with the same characteristics "in the real world." As a result, the combined term calculates the relative emissions of intermodal to road-only trips and weights each of these ratios with the expansion factor. The fact that the entire expression is divided by the sum of all of the $cvsexp_i$ means that the resulting number is the weighted average of the ratio of intermodal to road-only trips across all the trips considered in the analysis.

Naturally, because of the effect on the rail emission factor of the Expressway capacity-utilization assumption, the intermodal emission factor (*ief*) was also dependent upon this assumption. That is, higher capacity-utilization resulted in a lower ratio since rail emissions per trailer were lower.

Emissions between Montreal and Toronto were the sum of aggregate truck-only and intermodal emissions. For all other city pairs, total emissions were only aggregate truck-only emissions. Table 21 and

Table 22 show the estimated 2002 emissions associated with truck and intermodal traffic between the city pairs considered.

Table 21: Estimated Annual CO_2 2002 (High Expressway Market Penetration)

Origin	Destination	Annual kg CO_2
Chicago	Montreal	6,614,794
Chicago	Quebec	463,698
Chicago	Toronto	22,144,109
Chicago	Windsor	58,841
Montreal	Chicago	9,698,445
Montreal	Toronto	148,046,804
Montreal	Windsor	12,320,726
Quebec	Chicago	762,239
Quebec	Toronto	17,024,093
Quebec	Windsor	1,270,232
Toronto	Chicago	15,955,939
Toronto	Montreal	150,995,708
Toronto	Quebec	13,043,730
Toronto	Windsor	120,572,662
Windsor	Chicago	365,244
Windsor	Montreal	7,514,868
Windsor	Quebec	1,411,363
Windsor	Toronto	111,524,453
Total		**639,787,947**

Both estimates yield overall emissions of roughly 0.64 Mt of CO_2, or roughly 2% of total road freight GHG emissions in Canada. This figure may seem surprisingly small, given how important these cities seem in terms of overall road transportation. It should, however, be kept in mind the large number of trips to and from each of these cities, but not between them that have been left out of the analysis. For example, while trips between Montreal and Toronto are included in the analysis, trips between Montreal and Kingston, Ontario, are not.

Table 22: Estimated Annual CO_2 2002 (Low Expressway Market Penetration)

Origin	Destination	Annual kg CO_2
Chicago	Montreal	6,614,794
Chicago	Quebec	463,698
Chicago	Toronto	22,144,109
Chicago	Windsor	58,841
Montreal	Chicago	9,698,445
Montreal	Toronto	146,458,820
Montreal	Windsor	12,320,726
Quebec	Chicago	762,239
Quebec	Toronto	17,024,093
Quebec	Windsor	1,270,232
Toronto	Chicago	15,955,939
Toronto	Montreal	149,376,094
Toronto	Quebec	13,043,730
Toronto	Windsor	120,572,662
Windsor	Chicago	365,244
Windsor	Montreal	7,514,868
Windsor	Quebec	1,411,363
Windsor	Toronto	111,524,453
Total		**636,580,350**

7.3 Implementing the Market-Share and Emissions Estimates

Once estimates of current trailer-kilometres and associated emissions were developed, it was possible to undertake the market-share and emissions simulations by applying each of the five carrier choice models described in Section 6.4 to the appropriate trips. For example, the High-Value-Perishable model was applied to those potentially contestable trips containing shipments of High-Value-Perishable goods. Applying the model refers simply to estimating the potential market-share for truck-only and intermodal traffic based on the estimated CL models and carrier and shipper attributes, as appropriate. The following subsections describe how the trips were segmented into the different shipment categories and how the carrier and shipper attributes used in models were derived.

7.3.1 The Determination of Shipment Categories

Shipment categories were defined using information from the CVS, as well as from the introductory part of the shipper survey. The CVS provided information on what was being shipped, as well as the value and weight of the shipment. The shipper survey provided information that permitted estimation of the proportion of shipments that are by-appointment. This proportion did not vary by shipment category.

The CVS identified individual shipments according to 4-digit SCTG code. This allowed goods to be classified as perishable or non-perishable with high accuracy.

Classification of goods into high- and low-value was also done based on the value per kilogram of shipments. Two different values were used to classify goods into high- and low-value shipments, one for perishable and another for non-perishable goods. Perishable goods worth more than $3/kg were considered as high-value and non-perishable goods worth more than $10.50/kg were considered high-value.

These determinations were somewhat arbitrary, but were based on the inspection of the CVS data and the value per kilogram of the different categories of shipped goods, and whether or not the categories were likely to be considered as high-value goods by shippers. For example, meat (which would seem to be a high-value good) was valued at $3.19/kg. For non-perishable goods, goods in the $10/kg range included articles such as lighting ballast, but above $10.50/kg began goods such as specialty tools.

Unfortunately, there was no information in the CVS about whether shipments were by-appointment. Luckily, however, survey respondents were asked to provide an estimate of the proportion of their shipments that were by-appointment. The average proportion of by-appointment shipments was 0.4, which was used to divide contestable, non-perishable (low- and high-value) trips, kilometres and emissions into by- and not-by-appointment categories.

To provide a sense for the relative importance of the shipment subgroups, the following table gives the proportion of trips shown in Table 19 that fall into the five shipment subgroups.

As can be seen trailer trips are dominated by low-value shipments that make up over 90% of trailer trips.

Table 23: Current Truck Trips by Shipment Subgroup

Subgroup	Trailer Trips	Proportion
High-Value, By-Appointment, Not Perishable	101	2%
High-Value, Perishable	58	1%
Low-Value, By-Appointment	1765	37%
High-Value, Not By-Appointment, Not Perishable	151	3%
Low-Value, Not By-Appointment	2648	56%
Total		**4724**

7.3.2 Carrier Attribute Values in the Simulations

Carrier attribute values used in the simulations were based on interviews conducted independently of the interviews conducted for survey development described in Section 5.2. In order to estimate appropriate attribute values, one hundred and fifty calls were made resulting in thirty interviews. These short interviews (2 to 5 minutes) involved asking shippers about the performance, in terms of their service attributes, of their carriers for both TL and LTL shipments. Respondents were also asked whether any of their carriers used premium-TOFC services and if so, how these carriers performed in terms of their service attributes. Of the thirty shippers interviewed, nine had used carriers employing premium-TOFC services. The attribute values obtained from the respondents were averaged and used as the attribute values for the truck-only and intermodal services in the simulations. These values, used in the simulation exercises, are shown in Table 24.

Table 24: Average Truck-only and Premium-Intermodal Carrier Attribute Values

	Truck-only		Premium-Intermodal	
	Average	Std. Deviation	Average	Std. Deviation
On-time Reliability	95.82	3.50	91.73	10.01
Damage Risk	1.42	2.57	1.89	2.87
Security Risk	0.33	0.54	0.17	0.41

With respect to price, this service attribute was calculated separately as described in 5.2. The degree to which Expressway services may be more or less expensive for a carrier is unclear since this information is of a particularly competitive nature. Nevertheless, discussions with Expressway staff led to the conclusion that the cost of a shipment for an end-shipper would be the same whether or not the carrier used Expressway or provided a truck-only service. Therefore the costs used in the exercise were the same for both types of carriage, and were based on TL prices between the cities of interest.

7.3.3 Shipper Attribute Values in the Simulations

The last remaining information required for the simulation calculations relates to whether the shipper was located between the two Expressway railyards. This was incorporated by using the proportion of shippers in the entire shipper population located between the two railyards. Shipper location was determined by geocoding postal codes in the Dun & Bradstreet database. Upon examining the shipper data, it was established that 57% of the shippers were located between these two railheads.

This concludes the discussion of the background and assumptions used to undertake the market-share and emissions simulations. The following chapter presents the results of the simulations.

8 Market-share and Emissions Simulation: Results

The market-share and CO_2 emissions simulation results are presented below. Results from 18 different scenarios are presented. They provide a range of estimates of the potential for CO_2 emissions reductions through freight mode shift towards intermodal transportation in the Corridor. The chapter begins with a description of the parameters defining the simulation scenarios. Each of the different scenarios is then presented.

To provide a clear understanding of the simulations, the results of the first several scenarios are provided in detail. The remaining scenario results are summarized in a less detailed manner. All of the results are summarized in Table 37 and Table 38. The results as a whole can be seen, more or less, on a continuum ranging from the current (or base case) situation to a "best case" scenario.

The different scenarios are defined by assumptions about four different parameters. Those parameters are:

- current market-share;
- intermodal service offerings (both geographic and logistic);
- cost differentials (as a proxy for differential taxes); and
- intermodal carrier attribute performance, and shipper perception of intermodal carriers.

At first, scenarios involving assumptions about one parameter at a time are presented to provide an understanding of the effects of the assumptions on overall results. Afterwards, more elaborate scenarios are presented where assumptions about more than one parameter are combined.

Simulation results are followed by some comments on why all of the simulated CO_2 emissions reductions may be slightly biased, and finally by a discussion of the overall potential for premium-intermodal services to reduce CO_2 emissions in the Corridor and in Canada.

8.1 Parameters Defining the Scenarios

As mentioned above, the parameters defining the different scenarios fall into four categories. The first of these categories is the current market-share assumption.

This assumption was described in passing in Section 7.2.5. There it was mentioned because of its importance in developing estimates of CO_2 emission factors as well as of current truck traffic between Montreal and Toronto. As may be recalled, accurate figures on the number of trucks using the Expressway service were not available. Hence two assumptions on current market-share of the Expressway service in the Montreal - Toronto corridor were used. These assumptions were, in effect, based on assumed capacity-utilization rates for the Expressway trains. With total capacity of the Expressway trains being 420 trailers per day, assumptions of 50% and 100% capacity-utilization were used. Use of the high-capacity-utilization assumption resulted in a higher current Expressway market-share, a higher estimated total number of trailers traveling in the Montreal - Toronto corridor, and a lower emissions factor (since more train-borne trailers were being transported for the same amount of fuel). The assumption used, be it high- or low-capacity utilization had an ambiguous effect on overall CO_2 emissions results.

The reason for this is straightforward. Higher capacity-utilization implied lower emissions per truck. At the same time, however, it also implied higher overall Expressway market-share. The result of the higher capacity-utilization was that the difference between current and simulated market share was lessened. In fact, while the simulated market share (based on the application of the five submodels) is just under 20%, current-market-share under the high capacity-utilization assumption is just *over* 20%. As a result, there is almost no difference between the emissions for the Montreal - Toronto corridor under the current and simulated market share, because roughly the same number of trailers is being transported intermodally in either case. Under the low capacity-utilization assumption, there is a smaller total number of trailers in the corridor, a larger unused capacity for trailers to be carried intermodally, but higher emissions per trailer. As a result, the high-capacity-utilization assumption will result in sometimes lower, sometimes higher simulated emissions.

The second set of assumptions is about intermodal service offerings. They can vary with respect to what city pairs offer the service. The current extent of Expressway service makes up one set of scenarios, and the other set includes all eight city pairs described in Section 7.2.

Service offerings are also varied logistically. As mentioned in Section 4.1.1.3, current Expressway service offerings are only suitable for TL shipping. Some of the simulation scenarios include LTL trips as contestable traffic, under the assumption that premium-intermodal services take a form where LTL shipping could realistically be attracted.

Under certain scenarios, the cost for truck-only carriers is allowed to be greater than for intermodal carriers. This is a proxy for what would happen, should there be taxes levied against trucks to encourage a shift to intermodal freight transportation. The model for the type of differential tax that might lead to such cost differences is the Swiss Heavy Vehicle Fuel Tax, described in greater detail below.

Finally, in some scenarios, intermodal carrier attributes are allowed to vary. In one set of simulations, the carrier attributes of truck-only and intermodal carriers are set to be the same. This amounts to asking what would happen if intermodal carriers could compete with the same performance as truck-only carriers. Some of the scenarios also include changes in the magnitude of the intermodal coefficient. One set of scenarios assumes that the intermodal coefficient is half of its estimated value, whereas others assume that it is zero. These assumptions amount to asking how market share would change if shippers were less mistrustful of rail for their shipments.

With this description of the parameter assumptions used in the different simulation scenarios, the results of the different simulations are now presented. The overall purpose of each of the simulations was to ask how CO_2 emissions would change if premium-intermodal services were able to reach their estimated market share potential. In the presentation of the first scenarios, information is provided on estimated current (2002) daily truck trips, daily truck-kms (kms covered by trucks) and annual CO_2 emissions. Truck trips were presented as a daily measure because it was thought that this was a more intuitive way to present the results. Simulated daily truck-only and intermodal trips, and the associated annual emissions are compared with current emissions.

8.2 The Current (or Base Case) Scenario

The first simulation presents an estimate of what emissions effects there would be if premium-intermodal services were able to reach the potential predicted by the models between Montreal and Toronto using Expressway as the model, i.e. only the CP railyard catchments are considered.

Table 25: Current Service - High Expressway Market Share

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	**Destination**	**Current Trailers**	**Current Trailer-KMs**	**Annual KG CO_2**	**Truck Only**	**Intermodal**	**Truck Only**	**Intermodal**
Montreal	Toronto	917	523,331	148,046,804	740	178	143,942,533	6,468,212
Toronto	Montreal	935	533,755	150,995,708	754	181	146,873,854	6,585,066
Total		1,852	1,057,087	299,042,511	1,493	359	290,816,387	13,053,279
							Grand Total	303,869,665
				Difference in Mt CO_2				-0.005
				% Change relative to current emissions				2%

With the high Expressway market share assumption, it is estimated that there are just below 1,900 trailers hauled between Montreal and Toronto per day resulting in 299 million kgs of CO_2 per year. Recall that the number of trailers is an estimate because the number of trailer trips from the MTO CVS has been adjusted upwards to include the number also carried by Expressway. What is interesting here, is that under the high market share assumption, there are actually more trailers carried by Expressway than is predicted as the maximum potential for premium-intermodal services in this corridor. As a result, the simulated outcome is for there to be fewer intermodal trips than at present, and thereby an increase in CO_2 emissions. However, the increase is extremely small (two percent) and this particular scenario is the only scenario where the simulation results in higher emissions.

Table 26: Current Service - Low Expressway Market Share

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	**Destination**	**Current Trailers**	**Current KM per Day**	**Annual KG CO_2**	**Truck Only**	**Intermodal**	**Truck Only**	**Intermodal**
Montreal	Toronto	821	468,324	146,458,820	662	159	128,812,886	8,954,624
Toronto	Montreal	837	477,653	149,376,094	675	162	131,436,099	9,116,397
Total		1,658	945,977	295,834,914	1,336	321	260,248,986	18,071,021
							Grand Total	278,320,007
				Difference in Mt CO_2				0.018
				% Change relative to current emissions				-0.06

Under the low market share assumption, it can be seen that there are roughly 1,700 estimated trailer trips on this same corridor and the slightly smaller figure of 296 million kg of CO_2 per year. In the simulation, it can be seen that the increase in market share from 10% to the 20% predicted by the models results in a small but unambiguous decrease in overall emissions. In particular, CO_2 emissions are simulated to decrease by 0.018 Mt per year representing a 6% decrease from current emissions. Here, it can be seen that the reduction in emissions due to the increase in the number of trailers traveling intermodally outweighs the higher CO_2 emissions factor resulting from the lower market share assumption. It is also possible to see that while the base-case predicts a significant potential for premium-intermodal services on this corridor, the overall potential to reduce emissions is very small. Naturally, in order to get a sense for the potential to reduce emissions for the entire Corridor, it is necessary to consider service offerings between additional city-pairs.

8.3 Expanding the Geographical Extent of Service Offerings

The inclusion of the other Corridor city pairs has a large impact on the results. In the high market share scenario the number of contestable truck trips, as well as current annual CO_2 emissions by these trucks more than doubles.

Table 27: Extended Service - High Expressway Market Share

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers per Day	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Chicago	Montreal	22	19,385	6,614,794	18	4	5,334,615	239,093
Chicago	Quebec	1	1,359	463,698	1	0	374,178	16,719
Chicago	Toronto	207	64,895	22,144,109	166	40	17,819,043	807,770
Chicago	Windsor	26	172	58,841	21	5	47,481	2,122
Montreal	Chicago	33	28,422	9,698,445	27	6	7,831,646	348,653
Montreal	Toronto	1,008	568,100	164,333,152	812	196	156,251,090	7,022,469
Montreal	Windsor	40	36,107	12,320,726	33	8	9,934,098	445,738
Quebec	Chicago	2	2,234	762,239	2	0	618,505	26,845
Quebec	Toronto	62	49,891	17,024,093	50	12	13,757,675	610,052
Quebec	Windsor	3	3,723	1,270,232	3	1	1,025,005	45,800
Toronto	Chicago	149	46,760	15,955,939	121	29	12,877,558	574,933
Toronto	Montreal	1,051	592,662	171,438,218	848	203	163,094,741	7,309,652
Toronto	Quebec	47	38,226	13,043,730	38	9	10,518,048	471,709
Toronto	Windsor	1,050	353,349	120,572,662	846	204	97,136,427	4,377,066
Windsor	Chicago	34	1,070	365,244	27	7	294,731	13,169
Windsor	Montreal	25	22,023	7,514,868	20	5	6,053,899	272,858
Windsor	Quebec	4	4,136	1,411,363	3	1	1,138,889	50,888
Windsor	Toronto	960	326,832	111,524,453	773	187	89,841,999	4,049,521
Total		4,724	2,159,346	676,516,805	3,807	916	593,949,628	26,685,056
							Grand Total	620,634,685
				Difference Mt CO_2				0.056
				% Change relative to current emissions				-0.08

One particularity to notice about this scenario is that the total number of trailer trips between Montreal and Toronto (truck-only and intermodal) in the simulation is larger than the number of trips in the base-case. The reason is that in the base-case, only trips within the CP Expressway railyard catchments were considered as contestable, whereas in the extended-service scenario, both CP and CN are assumed to offer premium-intermodal services.

Despite the doubling of the number of trips relative to the Montreal – Toronto corridor alone, the overall decrease in CO_2 emissions is only 0.06 Mt CO_2 per year. This is mostly due to the small decrease in emissions in the Montreal - Toronto corridor in the high market share scenario - recall Table 25 and Table 26 - i.e. the reductions come almost exclusively from the non-Montreal - Toronto trips.

Table 28: Extended Service - Low Expressway Market Share

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers per Day	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Chicago	Montreal	22	19,385	6,614,794	18	4	5,334,615	369,878
Chicago	Quebec	1	1,359	463,698	1	0	374,178	25,865
Chicago	Toronto	207	64,895	22,144,109	166	40	17,819,043	1,249,628
Chicago	Windsor	26	172	58,841	21	5	47,481	3,282
Montreal	Chicago	33	28,422	9,698,445	27	6	7,831,646	539,369
Montreal	Toronto	914	514,913	162,797,711	736	177	141,622,516	9,846,729
Montreal	Windsor	40	36,107	12,320,726	33	8	9,934,098	689,561
Quebec	Chicago	2	2,234	762,239	2	0	618,505	41,529
Quebec	Toronto	62	49,891	17,024,093	50	12	13,757,675	943,756
Quebec	Windsor	3	3,723	1,270,232	3	1	1,025,005	70,853
Toronto	Chicago	149	46,760	15,955,939	121	29	12,877,558	889,427
Toronto	Montreal	953	537,175	169,836,392	769	184	147,825,449	10,249,410
Toronto	Quebec	47	38,226	13,043,730	38	9	10,518,048	729,738
Toronto	Windsor	1,050	353,349	120,572,662	846	204	97,136,427	6,771,362
Windsor	Chicago	34	1,070	365,244	27	7	294,731	20,373
Windsor	Montreal	25	22,023	7,514,868	20	5	6,053,899	422,113
Windsor	Quebec	4	4,136	1,411,363	3	1	1,138,889	78,725
Windsor	Toronto	960	326,832	111,524,453	773	187	89,841,999	6,264,647
Total		4,531	2,050,673	673,379,538	3,652	879	564,051,761	39,206,245
							Grand Total	603,258,007
				Difference Mt CO_2				0.070
				% Change relative to current emissions				-0.10

In the "low market share, extended service" scenario, the number of contestable trailers and annual emissions more than double relative to the base case. Moreover, CO_2 emissions reductions almost double because of the decreases in truck-only traffic in the Montreal - Toronto corridor (recall Table 27), and between the other city-pairs. Nevertheless potential reductions remain relatively modest at 0.07 Mt CO_2 per year.

The scenarios so far have predicted the potential for emissions reductions, were premium-intermodal services with current service characteristics, current shipper perceptions of these services, and current performance introduced for the city-pairs in question. The following scenarios consider what would happen if the services, as well as the performance and shipper perceptions of premium-intermodal services were to change. We begin with what would happen if differential taxation of trucking changed the relative costs of truck-only and intermodal carriers.

8.4 Incorporating Differential Taxation - The Swiss Heavy Vehicle Fuel Tax

As a means to reduce freight transportation emissions, a differential tax to promote the use of rail is often considered. One country with a very aggressive tax designed to maintain and increase rail's share of traffic is Switzerland. As background, Switzerland has been concerned for a long time about the amount of transalpine road freight passing through Switzerland between Northern and Southern Europe. As a result, it has tried to encourage and maintain relatively high rail mode share for this traffic with approximately two-thirds of Swiss transalpine freight traffic moving by rail (Service d'information pour les transports publics 2004). Previously, rail's high share of freight traffic was facilitated by Swiss regulations limiting the size of heavy vehicles to 28 tonnes. This created a large incentive for transiting freight to be moved by rail to avoid the complications of having to comply with the 28 tonne limit.

However, the European Union began to pressure Switzerland on the use of its size regulations in the mid-1980's citing concerns that the legislation was intentionally discriminatory against non-Swiss carriers. In order to comply with European pressure to 'level the playing field' for non-Swiss carriers, while at the same time attempting to maintain rail's share of transalpine freight, the Swiss population approved, by a large majority, the *Distance-related Heavy Vehicle Fee,* or HVF, which came into effect in January, 2001. The fee is charged to trucks traveling in Switzerland, and is based upon truck payload and distance traveled in Switzerland. Different truck configurations are subject to different per tonne-km tariffs varying between CHF0.0142 and CHF0.02 (Swiss Francs) (Federal Office for Spatial Development 2002).

Table 29: Current Service - High Expressway Market-share (Trucks 10% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Montreal	Toronto	917	523,331	148,046,804	672	245	130,886,532	8,906,615
Toronto	Montreal	935	533,755	150,995,708	685	250	133,504,558	9,081,981
Total		1,852	1,057,087	299,042,511	1,358	495	264,391,090	17,988,596
							Grand Total	282,379,686
				Difference in Mt CO_2				0.017
				% Change relative to current emissions				-5.6%

Table 30: Current Service - Low Expressway Market-share (Trucks 10% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Montreal	Toronto	821	468,324	146,458,820	602	219	117,129,188	12,330,360
Toronto	Montreal	837	477,653	149,376,094	613	223	119,472,036	12,573,138
Total		1,658	945,977	295,834,914	1,215	443	236,601,224	24,903,498
							Grand Total	261,504,722
				Difference in Mt CO_2				0.034
				% Change relative to current emissions				-11.6%

The most appropriate tariff level in the Canadian context is CHF0.0142 for a truck with a 34-tonne payload and five axles. Calculations, including currency conversion were made to estimate how this tariff would translate in the Canadian context and it was estimated to amount to CAD$0.43 per kilometre for a 53- foot trailer.[20]

Ideally, one should be able to estimate what the effect of levying such a tax would be on shipping costs faced by the end-shipper, and then to estimate what the effect on market share would be using the models. Given the highly competitive nature of the road transportation sector in Canada and in the Corridor in particular, obtaining such commercial information is fraught with difficulties. However, and also because of the competitiveness of this sector, it's

[20] The tax is based on payload and not weight of the actual shipment.

likely that most of the costs associated with any such tariff applied in Canada would be passed on to the shipper. If a CAD$0.43 per kilometre tariff were applied, and if it were assumed that most of this would be passed on to the shipper, it would increase shipping costs by about a third.

Table 31: Extended Service - High Expressway Market-share (Trucks 10% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers per Day	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Chicago	Montreal	22	19,385	6,614,794	16	6	4,867,319	326,367
Chicago	Quebec	1	1,359	463,698	1	0	341,156	22,887
Chicago	Toronto	207	64,895	22,144,109	152	55	16,256,121	1,099,669
Chicago	Windsor	26	172	58,841	19	7	43,291	2,904
Montreal	Chicago	33	28,422	9,698,445	24	9	7,147,374	476,450
Montreal	Toronto	1,008	568,100	164,333,152	739	269	142,081,615	9,668,829
Montreal	Windsor	40	36,107	12,320,726	29	11	8,825,074	652,865
Quebec	Chicago	2	2,234	762,239	1	1	569,020	36,086
Quebec	Toronto	62	49,891	17,024,093	45	17	12,318,555	878,829
Quebec	Windsor	3	3,723	1,270,232	2	1	893,193	70,417
Toronto	Chicago	149	46,760	15,955,939	110	39	11,753,026	784,957
Toronto	Montreal	1,051	592,662	171,438,218	771	281	148,255,283	10,081,142
Toronto	Quebec	47	38,226	13,043,730	34	13	9,411,147	678,439
Toronto	Windsor	1,050	353,349	120,572,662	776	274	89,146,799	5,869,248
Windsor	Chicago	34	1,070	365,244	25	9	268,720	18,027
Windsor	Montreal	25	22,023	7,514,868	18	7	5,383,121	398,135
Windsor	Quebec	4	4,136	1,411,363	3	1	992,433	78,241
Windsor	Toronto	960	326,832	111,524,453	710	250	82,452,370	5,429,644
Total		4,724	2,159,346	676,516,805	3,474	1,250	541,005,617	36,573,139
							Grand Total	577,578,755
				Difference Mt CO_2				0.099
				% Change relative to current emissions				-14.6%

When using Stated Preference techniques, it is not recommended to estimate the effect of changes in attribute values outside the range provided to respondents. Since the largest difference in price between carriers shown to survey respondents was 20%, it would not be possible to estimate the effect of an HVF of the magnitude described above.

Table 32: Extended Service - Low Expressway Market-share (Trucks 10% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers per Day	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Chicago	Montreal	22	19,385	6,614,794	16	6	4,867,319	504,893
Chicago	Quebec	1	1,359	463,698	1	0	341,156	35,406
Chicago	Toronto	207	64,895	22,144,109	152	55	16,256,121	1,701,199
Chicago	Windsor	26	172	58,841	19	7	43,291	4,493
Montreal	Chicago	33	28,422	9,698,445	24	9	7,147,374	737,073
Montreal	Toronto	914	514,913	162,797,711	670	244	128,779,618	13,557,389
Montreal	Windsor	40	36,107	12,320,726	29	11	8,825,074	1,009,988
Quebec	Chicago	2	2,234	762,239	1	1	569,020	55,826
Quebec	Toronto	62	49,891	17,024,093	45	17	12,318,555	1,359,557
Quebec	Windsor	3	3,723	1,270,232	2	1	893,193	108,937
Toronto	Chicago	149	46,760	15,955,939	110	39	11,753,026	1,214,335
Toronto	Montreal	953	537,175	169,836,392	699	254	134,375,293	14,135,523
Toronto	Quebec	47	38,226	13,043,730	34	13	9,411,147	1,049,551
Toronto	Windsor	1,050	353,349	120,572,662	776	274	89,146,799	9,079,781
Windsor	Chicago	34	1,070	365,244	25	9	268,720	27,888
Windsor	Montreal	25	22,023	7,514,868	18	7	5,383,121	615,919
Windsor	Quebec	4	4,136	1,411,363	3	1	992,433	121,040
Windsor	Toronto	960	326,832	111,524,453	710	250	82,452,370	8,399,710
Total		4,531	2,050,673	673,379,538	3,333	1,198	513,823,631	53,718,509
							Grand Total	567,542,140
				Difference Mt CO_2				0.106
				% Change relative to current emissions				-15.7%

To show how such a tax might affect premium-intermodal market-share and emissions, two different simulation assumptions were used. The first assumes an HVF-like tariff resulting in a 10% increase in trucking costs faced by end-shippers, and the second a tariff resulting in a 20% increase.

As in the previous simulations, two existing premium-intermodal market shares for the Montreal - Toronto corridor are considered for each of the price increase scenarios. The results can be found in Tables 29 through 36. Tables 30 and 32 show that a 10% increase in truck-only carriers' costs relative to intermodal carriers reduces emissions by a maximum of 0.034 Mt and 0.011 Mt. Tables 33 through 36 show the simulation results under the assumption that truck-only services are 20% more expensive than intermodal services.

Table 33: Current Service - High Expressway Market-share (Trucks 20% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Montreal	Toronto	917	523,331	148,046,804	599	319	116,567,382	11,580,929
Toronto	Montreal	935	533,755	150,995,708	610	325	118,828,835	11,822,891
Total		1,852	1,057,087	299,042,511	1,209	643	235,396,217	23,403,820
							Grand Total	258,800,037
				Difference in Mt CO_2				0.040
				% Change relative to current emissions				-13.5%

Table 34: Current Service - Low Expressway Market-share (Trucks 20% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Montreal	Toronto	821	468,324	146,458,820	536	285	104,315,108	16,032,694
Toronto	Montreal	837	477,653	149,376,094	546	291	106,338,863	16,367,667
Total		1,658	945,977	295,834,914	1,082	576	210,653,971	32,400,361
							Grand Total	243,054,332
				Difference in Mt CO_2				0.053
				% Change relative to current emissions				-17.8%

Increasing the difference in costs between truck-only and intermodal carriers to 20% provides several interesting results. The first has to do with overall market share. In all the scenarios where truck-only carriers are 20% more expensive, the overall market share for intermodal carriers is roughly 36%.

This means that even with the largest possible differential in prices that can be used with these models in simulations, this difference alone cannot overcome the disadvantages that intermodal carriers face relative to truck-only carriers. If it could, one would expect that if intermodal carriers were 20% cheaper, they ought to have an estimated market share of 50%.

Table 35: Extended Service - High Expressway Market-share (Trucks 20% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	Destination	Current Trailers per Day	Current KM per Day	Annual KG CO_2	Truck Only	Intermodal	Truck Only	Intermodal
Chicago	Montreal	22	19,385	6,614,794	15	8	4,355,863	421,889
Chicago	Quebec	1	1,359	463,698	1	0	304,953	29,648
Chicago	Toronto	207	64,895	22,144,109	136	71	14,549,688	1,418,371
Chicago	Windsor	26	172	58,841	17	9	38,697	3,762
Montreal	Chicago	33	28,422	9,698,445	22	11	6,397,533	616,494
Montreal	Toronto	1,008	568,100	164,333,152	658	350	126,542,180	12,571,050
Montreal	Windsor	40	36,107	12,320,726	25	15	7,591,296	883,291
Quebec	Chicago	2	2,234	762,239	1	1	515,090	46,159
Quebec	Toronto	62	49,891	17,024,093	39	23	10,720,640	1,177,264
Quebec	Windsor	3	3,723	1,270,232	2	1	745,763	97,952
Toronto	Chicago	149	46,760	15,955,939	98	51	10,521,627	1,014,939
Toronto	Montreal	1,051	592,662	171,438,218	686	365	131,965,237	13,123,550
Toronto	Quebec	47	38,226	13,043,730	29	17	8,183,964	907,634
Toronto	Windsor	1,050	353,349	120,572,662	701	349	80,451,007	7,493,316
Windsor	Chicago	34	1,070	365,244	22	12	240,204	23,353
Windsor	Montreal	25	22,023	7,514,868	15	9	4,637,861	537,324
Windsor	Quebec	4	4,136	1,411,363	2	1	828,622	108,835
Windsor	Toronto	960	326,832	111,524,453	640	319	74,410,269	6,931,626
Total		4,724	2,159,346	676,516,805	3,109	1,614	483,000,494	47,406,459
							Grand Total	530,406,953
				Difference Mt CO_2				0.146
				% Change relative to current emissions				-21.6%

The second interesting result is that the maximum potential emission reductions under the current Expressway service is in the "low market share" scenario (from 0.04 to 0.05 Mt), whereas for the extended service scenario, it is the "high market share" scenario (from 0.146 to 0.145 Mt) that shows the largest reduction potential.

These 'reversed' results simply show the ambiguous effect of the capacity factor and thereby market share assumption as described in section 7.2.8. For the current Expressway offerings, the emissions reductions associated with the simulated increase of intermodal traffic in the "low market share" case has a larger (negative) effect on intermodal emissions than the (positive) effect of the lower capacity factor assumption (and resulting higher emissions factor). For the extended-service scenario, the opposite is true. Taken as a whole, however, it can be seen that maximum emission reductions are in the range of 0.15 Mt CO_2 per year.

Table 36: Extended Service - Low Expressway Market-share (Trucks 20% dearer)

					Simulated Trailers per Day		Simulated Annual KG CO_2	
Origin	**Destination**	**Current Trailers per Day**	**Current KM per Day**	**Annual KG CO_2**	**Truck Only**	**Intermodal**	**Truck Only**	**Intermodal**
Chicago	Montreal	22	19,385	6,614,794	15	8	4,355,863	652,666
Chicago	Quebec	1	1,359	463,698	1	0	304,953	45,866
Chicago	Toronto	207	64,895	22,144,109	136	71	14,549,688	2,194,233
Chicago	Windsor	26	172	58,841	17	9	38,697	5,820
Montreal	Chicago	33	28,422	9,698,445	22	11	6,397,533	953,723
Montreal	Toronto	914	514,913	162,797,711	596	317	114,695,020	17,626,810
Montreal	Windsor	40	36,107	12,320,726	25	15	7,591,296	1,366,460
Quebec	Chicago	2	2,234	762,239	1	1	515,090	71,408
Quebec	Toronto	62	49,891	17,024,093	39	23	10,720,640	1,821,238
Quebec	Windsor	3	3,723	1,270,232	2	1	745,763	151,533
Toronto	Chicago	149	46,760	15,955,939	98	51	10,521,627	1,570,119
Toronto	Montreal	953	537,175	169,836,392	622	331	119,610,358	18,401,512
Toronto	Quebec	47	38,226	13,043,730	29	17	8,183,964	1,404,118
Toronto	Windsor	1,050	353,349	120,572,662	701	349	80,451,007	11,592,230
Windsor	Chicago	34	1,070	365,244	22	12	240,204	36,127
Windsor	Montreal	25	22,023	7,514,868	15	9	4,637,861	831,245
Windsor	Quebec	4	4,136	1,411,363	2	1	828,622	168,369
Windsor	Toronto	960	326,832	111,524,453	640	319	74,410,269	10,723,290
Total		4,531	2,050,673	673,379,538	2,984	1,547	458,798,455	69,616,768
							Grand Total	528,415,224
				Difference Mt CO_2				0.145
				% Change relative to current emissions				-21.5%

While increasing road transport costs is one way to increase intermodal market-share, the following scenarios consider the effects of improving service performance and offerings for the city pairs of interest.

8.5 Improving Performance and Service Offerings

Having presented detailed results for the simulations, the rest of the simulation results are presented in summary form. Moreover, to facilitate comparison the new simulations are included in the same table as the summarized results of the simulations presented so far. The first three lines of Table 37 and Table 38 summarize the results presented so far. Six additional simulations for each of the high- and low-market-share assumptions are provided.

The "Intermodal Coefficient (50%)" and "Intermodal Coefficient=0" scenarios respectively reduce the size of the intermodal coefficient by 50% and eliminate it. These scenarios estimate how results would change if shippers became less mistrustful of intermodal shipping. In the "Intermodal Coefficient=0" scenario, shippers are assumed not to have any negative perception of intermodal shipping.

The scenarios with "Attribute Values the Same" in the title estimate what would happen if intermodal carriers were seen to perform as well as truck-only carriers in terms of carrier attributes, i.e. if they had the same on-time reliability, damage risk, etc. These scenarios are also combined with each other and with an assumption of LTL shipments being contestable.

The last of the scenarios is the most favourable to intermodal service. In it truck-only and intermodal carrier attributes are the same, truck-only carriers are 20% more expensive, there is no shipper bias against intermodal service, and service offerings allow LTL trailer movements to be contestable.

Three main conclusions can be drawn from this summary of the results. The first concerns the effect of the intermodal coefficient on overall results relative to cost differences. In particular, it was noted above that a 20% increase in cost for truck-only carriers could not overcome the combined disadvantages of intermodal attribute performance and shipper bias against intermodal carriers. However, when comparing the simulations where truck-only carriers are 20% more expensive with the "Intermodal Coefficient=0" simulations, it can be seen that the results are very close. This suggests that a 20% increase in cost comes very close to overcoming shipper bias against intermodal shipping - a potentially interesting policy implication.

Table 37: Emissions Simulation Summary - High Expressway Market Share

	Reductions in CO_2 (Mt) per Year	
Assumptions	**MTL - TO**	**Extended Service**
Current situation	-0.005	0.056
Trucks 10% dearer	0.017	0.099
Trucks 20% dearer	0.040	0.146
Intermodal Coefficient (50% of estimated value)	0.015	0.096
Intermodal Coefficient=0	0.038	0.144
Attribute Values the Same (Intermodal Coefficient (50%))	0.057	0.182
Attribute Values the Same (Intermodal Coefficient =0)	0.085	0.239
Attribute Values the Same (Intermodal Coefficient =0) and LTL	0.110	0.281
Attribute Values the Same (Intermodal Coefficient =0), LTL and Trucks 20% dearer	0.175	0.413

Second, the largest emissions reductions estimates, for both existing Expressway services as well as the expanded services involve the "high Expressway market share" assumption. The emission reduction effects of the lower intermodal emission factor are larger than the effects of the larger increase in intermodal traffic between Montreal and Toronto of high market share assumption.

Table 38: Emissions Simulation Summary - Low Expressway Market Share

	Reductions in CO_2 (Mt) per Year	
Assumptions	**MTL - TO**	**Extended Service**
Current situation	0.018	0.070
Trucks 10% dearer	0.034	0.106
Trucks 20% dearer	0.053	0.145
Intermodal Coefficient (50% of estimated value)	0.033	0.103
Intermodal Coefficient=0	0.051	0.143
Attribute Values the Same (Intermodal Coefficient (50%))	0.066	0.175
Attribute Values the Same (Intermodal Coefficient =0)	0.088	0.222
Attribute Values the Same (Intermodal Coefficient =0) and LTL	0.110	0.262
Attribute Values the Same (Intermodal Coefficient =0), LTL and Trucks 20% dearer	0.161	0.371

Third, and most importantly for this research, is the ultimate best-case scenario emissions reduction result, i.e. the potential reduction of 0.413 Mt. This result represents 40 percent of what the federal government was hoping to achieve from "further public-private collaboration to promote the use of intermodal freight opportunities and to increase the use of low-emission vehicles and modes."

8.6 Discussion of the Results

8.6.1 Why these Reduction Estimates Might be Too High

While some of the CO_2 reduction estimates might seem relatively substantial (0.413 Mt) compared to current emissions of 0.64Mt (2% of emissions from truck-only freight transportation in Canada), these figures need to be seen in context.

Firstly, there is a very wide range of estimated reductions from 0.413 Mt to as low as 0.018 Mt. Second, for the larger estimates (and in particular the "best case" scenario estimate), many assumptions are made, e.g. that intermodal services can enable carriers to provide "truck-only" service levels to their clients, that truck-only is 20% more expensive, etc. The estimated emissions reductions are therefore only as likely as these assumptions are reasonable.

Another element that might lead to overestimating potential reductions relates to the use of Stated Preference techniques. As described in Section 3.4, it is possible that using SP data 'uncalibrated' by RP data might result in the over-prediction of potential premium-intermodal market share. However, the base-case estimates of the current service offerings (with the high-market-share simulation predicting fewer intermodal trips than the high-market-share assumption itself) suggest that the SP model predictions by this analysis are at least "in the right ballpark" with respect to real-world market-shares. Moreover, given the seemingly negative perception held by shippers about intermodal transportation, these market share estimates might equally well be downwardly biased. This potential weakness does need, however, to be acknowledged.

A final factor that might lead to overestimating potential CO_2 reductions is the degree to which traffic considered contestable in the analysis, actually is so. In particular, the notion of contestable truck traffic needs to be nuanced by another factor – in reality just how common or *standard* are the types of shipments described in the survey? That is, how common are shipments requiring delivery in the morning, that involve pick-up the previous afternoon and that can be delivered to the railyard in time for train departure? To the extent that these standard conditions do not hold, predictions of total contestable traffic will be overestimated. For example, some shipments may require sameday delivery between Montreal and Toronto. These shipments, however, would not be contestable by premium-intermodal services, because these services are *de facto*, overnight. To get a more precise idea of the proportion of shipments that these average shipments represent would require further empirical work outside the scope of this research.

8.6.2 Why these Reduction Estimates Might be Too Low

While there are several factors that might upwardly bias the estimates of potential emissions reductions, there is at least one that would tend to bias them downwards. Because this was a survey of end-shippers, only for-hire truck movements were considered contestable. Hence trips by private carriers were left out. In the trips from the MTO CVS selected for this analysis, around 10% of truck movements between the city pairs of interest were private. To the extent that private carriers would use these services, emissions estimates would be biased downwards.

8.6.3 The Results on Balance

After this relatively thorough analysis of the results, what can be said about the potential for premium-intermodal services in the Corridor to reduce CO_2 emissions in Canada? Since this is not a feasibility analysis, it is beyond the scope of the research to judge to what extent the various assumptions made in the simulations are likely to be realistically achievable either for technical or for economic reasons. This research simply asks the question, what would happen if these assumptions held. Under them, the maximum estimated CO_2 emission reduction estimates are in the range of 0.413 Mt per year.

This represents a relatively small fraction of the total Canadian emissions or even of the amount the federal government was hoping to achieve from "further public-private collaboration to promote the use of intermodal freight opportunities and to increase the use of low-emission vehicles and modes." Nevertheless, it constitutes more than 50% of current CO_2 emissions from the truck trips considered contestable in this analysis. The fact that such a large proportional reduction seems at least possible, provides some hope for the potential for intermodal services to contribute to meaningful CO_2 reductions.

In particular, it is generally recognized that the potential for CO_2 reductions through the use of intermodal transportation is greatest for trips longer than 800 kms (see for example US EPA (2004)). Therefore, while potential reductions for city pair trips in the Corridor alone would not amount to 1 Mt, it is conceivable that measures allowing for these potential reductions to be met, in conjunction with the potential for reductions on other longer-haul city pairs (e.g. Toronto - Vancouver, Vancouver - Calgary) could reach 1 Mt. This is particularly pertinent given the fact that the total emissions considered in this analysis amount to only about 2% of total truck-related freight transportation. As discussed in Section 4.1.1.1, to evaluate the potential for reductions by using intermodal services on longer haul trips would require another survey outside of the scope of this work, but possibly within the scope of future research.

9 Avenues for Future Research

The results reported in this thesis suggest several avenues of potential follow-up and future research. This follow-up research falls into three categories: statistical approach, geographical scope and marketing research.

As mentioned in Section 5.2, one of the reasons for choosing to ask respondents to answer 18 stated choice questions was to leave the way open for conducting hierarchical Bayesian (HB) analysis. HB analysis is an advanced statistical method that can be used to try to understand individual level preferences in a context of responses from many different people in the same market (see Rossi, Allenby and McCullough (2005). In addition to HB analysis, there is also a great deal of potential to use this data to better understand mode switching behaviour through the use of random parameter analysis. This type of analysis is an extension of the error-components mixed-logit analysis presented in this thesis. In a random parameter approach, distributions on the model coefficients are also estimated (see Train (2003). Not only does this help to predict how market-share can change under differing scenarios, but it can also allow the researcher to ask by how much coefficients can vary over the population. In the current context, it would allow the researcher to ask the question whether all shippers have a negative bias against rail, or whether some of them might have a positive bias.

As alluded in Section 8.6.3, another dimension along which this research could be expanded would be geographical. The current research was restricted to the main city pairs of the Corridor because of resource constraints, combined with the fact that shipments over longer distances require a different type of survey. Incorporating shipments that go through the Corridor, but that originate in, or are destined to, locations far outside of the Corridor would provide a better sense of the true global potential for intermodal freight.

A third and final avenue for follow-up research would be in a qualitative or marketing research context. That is, while this research clearly reveals that shippers mistrust using rail for their shipments, it is not clear why. More qualitative, market research methods could certainly be used to shed light on this very interesting question.

10 Conclusions

The conclusions to be drawn from this thesis and this research are presented with respect to the thesis objectives outlined in the introduction.

10.1 Shippers' Utility Functions in the Quebec City - Windsor corridor

The global and shipment subgroup models of Chapter 6 provide a great deal of information about the utility functions of Corridor shippers in selecting carriers for their freight shipments. First, the models reveal that Corridor shipper utility is influenced in ways consistent with economic and logistics theory, previous applied research and common sense. That is, the odds of choosing a given carrier decrease with increases in cost, damage- and security risk, and increase with increases in on-time reliability. Moreover, these models all reveal that shippers have a strong bias against the use of rail for the transportation of their shipments.

Most of these findings are consistent with previous studies in terms of the effect on utility of these characteristics i.e. they are "right-sided," and their magnitudes are within the ranges of previous studies. At the same time, whereas the effect of rail in previous studies has been variable, in this study, rail has an unambiguous and strongly negative effect on utility. In addition to this, while the effects of carrier service attributes on carrier choice have been observed in other locations and reported elsewhere, the effect of shipment type on carrier choice has not been reported. As such, this research represents the first attempt to approach the question of freight mode choice in this way.

Also worth mentioning is the fact that while previous studies have not included security risk as an explanatory variable, the results of this research suggest that it should be included.

The global model presented in Chapter 6 also leads to the conclusion that shipper utility functions are affected by shipper characteristics. First, results reveal that 3PLs are less sensitive to cost and damage risk. At the same time, 3PLs have an even stronger bias against the use of rail than other end-shippers. This is perhaps due to the fact that fearing the loss of customers, 3PLs are more concerned with the negative perceptions of rail for shipping. Whereas 3PLs might lose a client from a problematic shipment with an intermodal carrier, other end-shippers might just change carriers. These results on the difference between 3PLs and other shippers represent the first to be publicly reported.

Second, larger shippers are more sensitive to on-time reliability than smaller shippers. Third, Ontario shippers and shippers located between the existing Expressway railheads are more biased against using rail than the rest of end-shippers in the Corridor. While it is difficult to speculate on why Ontario shippers might be more reticent to use intermodal carriers, there is at least one possible intuitive explanation for why shippers located between the Expressway railheads are more biased against intermodal shipping - i.e. because, for them, shipping intermodally between Montreal and Toronto would involve a shipment backtracking, they discount this as a viable alternative.

10.2 The Effect of Shipment Type on Shipper Utility

The global and shipment subgroup models of Chapter 6 reveal that the shipper's utility is also affected by shipment type. Shipper sensitivity to cost is reduced for high-value shipments, as well as for by-appointment shipments. At the same time, shipper sensitivity to cost increases with shipment distance. Shipper sensitivity to on-time reliability on the other hand is higher for perishable, high-value and by-appointment shipments, whereas it decreases with shipment distance. The disutility of damage risk increases if a shipment is fragile. Some of these results (particularly perishable items being more sensitive to on-time reliability) are consistent with previous findings, but most of the results have not been publicly reported before.

While the 'intermodal effect' on carrier choice is relatively constant across shipment types, bias against rail decreases as shipment distance increases. Moreover, analysis described in 6.3 reveals that differences in utility functions across shipment types are important enough that carrier choice is more appropriately modeled in five different subgroups than with all shipment types in the same model.

10.3 The Potential for Freight Mode Shift and Emissions Reductions

Finally, through the application of the five different submodels to the MTO CVS data under many different future scenarios, it was possible to establish estimates for the potential of premium-intermodal services to increase rail's mode share and reduce CO_2 emissions. The analyses revealed that expanding the geographical scope of intermodal service offerings (more destinations), improving shipper perceptions of intermodal transportation (smaller intermodal coefficient), and improving intermodal performance (so that it is comparable to truck-only carriers and would allow for LTL shipping) all would contribute to increasing intermodal transportation's potential to help reduce GHG emissions. Moreover, the analyses suggest that while a 20% increase in the cost of truck-only relative to intermodal carriers would be sufficient to overcome shipper bias towards intermodal, it would not be sufficient to overcome both shipper bias and the poorer perceived performance of intermodal carriers. Overall, the analyses suggest, that while premium-intermodal has the potential to capture significant market share between the city pairs considered, its potential to reduce CO_2 emissions is limited, with estimates varying between 0 and 0.413 Mt. While these figures may be disappointing for supporters of intermodal transportation as a means by which to reduce GHG emissions, it should be mentioned that the largest figure represents close to a 2/3rd reduction in current emissions for the trips considered - an impressive result.

At the same time it needs to be recognized that this analysis is based upon a relatively small number of Canadian city pairs. Therefore, while potential reductions for city pairs in the Corridor alone are limited, the inclusion in the analysis of other longer-haul city pairs could reveal quite different results.

More advanced statistical analysis (through the use of Hierarchical Bayesian or random parameter analysis) of this data, as well as marketing-type research investigating the causes for bias against rail in shipping and including other long-haul city pairs in an analysis similar to this one, are all interesting potential avenues of research to further understanding of the potential for intermodal transportation to contribute to GHG reductions in Canada.

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Appendices

Appendix 1: Results of Chow-Tests Used to Determine Sub-models

	Chi Square Test		DF=	8		Significance=		0.01																
Omitted Model	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	99	NO	YES	NO	YES	YES	NO	NO	YES	YES	NO	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO
2		99	NO	NO	NO	YES	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO
3			99	NO	NO	YES	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	NO	NO
4				99	YES	YES	NO	NO	NO	NO	NO	NO	YES	NO	NO	NO	YES	YES	NO	NO	YES	YES	NO	NO
5					99	NO	NO	NO	NO	NO	NO	NO	YES	YES	YES	NO	NO	NO	YES	YES	YES	YES	NO	YES
6						99	YES	YES	NO	YES	NO	NO	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	YES	YES
7							99	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
8								99	NO	NO	NO	NO	NO	NO	NO	NO	YES	NO	YES	NO	NO	NO	NO	NO
9									99	NO	NO	NO	YES	YES	NO	NO	NO	NO	YES	NO	YES	YES	NO	NO
10										99	NO	NO	YES	YES	NO	NO	YES	NO	YES	NO	YES	NO	NO	NO
11											99	NO	YES	YES	YES	YES	NO	NO	YES	YES	YES	YES	NO	YES
12												99	YES	YES	NO	NO	NO	NO	YES	YES	YES	YES	NO	NO
13													99	NO	NO	NO	YES	YES	YES	NO	YES	YES	YES	NO
14														99	NO	NO	YES	YES	NO	NO	YES	NO	NO	NO
15															99	NO	YES	YES	NO	NO	NO	NO	NO	NO
16																99	NO	NO	NO	NO	NO	NO	NO	NO
17																	99	NO	YES	YES	YES	YES	NO	NO
18																		99	YES	NO	YES	YES	NO	NO
19																			99	NO	NO	NO	NO	NO
20																				99	NO	NO	NO	NO
21																					99	NO	NO	NO
22																						99	NO	NO
23																							99	NO
24																								99

Appendix 2: Mixed vs. Traditional CL Models

Table 39: The Global Model Estimated with Standard CL

Variable	Coefficient	% change in odds for indicated increase in X		Std. Error	P-Value
		1% Increase	10% Increase		
Cost(ln)	-3.85153	-3.760	-30.725	0.536	0.000
Cost(ln)*Distance	-0.00211			0.000	0.000
Cost(ln)*By-Appointment	1.56558			0.345	0.000
Cost(ln)*High-Value	1.36181			0.352	0.000
Cost(ln)*High-Value*3PL	3.58256			0.971	0.000
		Odds multipler for indicated increase in X			
		1% Increase	10% Increase		
On-time Reliability	0.09200	1.096	2.509	0.009	0.000
On-time Reliability*Distance	-0.00003			0.000	0.001
On-time Reliability*By-appointment	0.04614			0.006	0.000
On-time Reliability*Perishable	0.04844			0.006	0.000
On-time Reliability*High-Value	0.01174			0.006	0.038
On-time Reliability*Employees	0.00006			0.000	0.008
Damage Risk	-0.37603	0.687	0.471	0.023	0.000
Damage Risk*3PL	0.20749			0.074	0.005
Damage Risk*Fragile	-0.19569			0.041	0.000
Security Risk	-0.10247	0.903		0.034	0.003
Intermodal	-0.76271	0.466		0.087	0.000
Intermodal*Distance	0.00017			0.000	0.036
Intermodal*Ontario Shipper	-0.26811			0.075	0.000
Intermodal*Shipper btw Railheads	-0.17068			0.068	0.012
Intermodal*3PL	-0.36005			0.126	0.004
ASC1	0.48085	1.617		0.036	0.000
ASC2	0.51486	1.673		0.035	0.000
Log Likelihood	-5769.65				
Likelihood ratio test:	4004				
Adjusted rho-square:	0.2576				
Observations	7074				
Units of Measurement of continuous variables:					
Cost: Natural logarithm of $CAD (Range: 4.9-7.6)					
On-time Reliability: % of shipment on-time (Range: 85%-95%)					
Damage Risk: % of shipments suffering from damage (Range: 0.5%-3%)					
Security Risk: % of shipments suffering from theft (Range: 0.5%-1.5%)					
Distance: km between shipment origin and destination (Range: 555-1,462)					

Table 40: Differences in Coefficient Estimates between Standard CL and Random Effects (Mixed-logit) Estimation

Variable	CL Coefficient	Mixed-logit Coefficient	Difference in Coefficients (CL-Mixed-logit)
Cost(ln)	-3.85153	-4.14000	0.28847
Cost(ln)*Distance	-0.00211	-0.00220	0.00009
Cost(ln)*By-Appointment	1.56558	1.70000	-0.13443
Cost(ln)*High-Value	1.36181	1.43000	-0.06819
Cost(ln)*High-Value*3PL	3.58256	3.71000	-0.12744
On-time Reliability	0.09200	0.09730	-0.00530
On-time Reliability*Distance	-0.00003	-0.00003	0.00000
On-time Reliability*By-appointment	0.04614	0.04970	-0.00356
On-time Reliability*Perishable	0.04844	0.05240	-0.00396
On-time Reliability*High-Value	0.01174	0.01240	-0.00066
On-time Reliability*Employees	0.00006	0.00006	-0.00001
Damage Risk	-0.37603	-0.39600	0.01997
Damage Risk*3PL	0.20749	0.22200	-0.01451
Damage Risk*Fragile	-0.19569	-0.21800	0.02231
Security Risk	-0.10247	-0.10900	0.00653
Intermodal	-0.76271	-0.81000	0.04729
Intermodal*Distance	0.00017	0.00017	0.00000
Intermodal*Ontario Shipper	-0.26811	-0.29400	0.02589
Intermodal*Shipper btw Railheads	-0.17068	-0.16900	-0.00168
Intermodal*3PL	-0.36005	-0.42800	0.06795
ASC1	0.48085	0.50200	-0.02115
ASC2	0.51486	0.54000	-0.02514

Appendix 3: Glossary

Term	Definition
3PL	Third party logistics company. Businesses that provide one or many of a variety of logistics-related services. Types of services can include public warehousing, contract warehousing, transportation management, distribution management, freight consolidation.
"by-appointment"	Shipments expected to be delivered at a precise time.
Carrier	Firm or corporation (trucking company, rail company, etc.) that moves a shipment from the shipper to the receiver.
COFC	(Container-on-flat-car). When a container is transported by rail.
Damage Risk	As described to survey participants: the probability (in percent) that a shipment will suffer from damage.
End-shipper	Shippers who hire other companies (carriers) to ship their goods. The are also referred to variously as 'hire and reward' shippers or shippers using for-hire carriers.
LTL	(Less-than-truckload) Shipments that do not make up a full truckload. An example is a shipment of a couple of pallets of merchandise.
On-time reliability	The probability (in percent) that a carrier will be on time when delivering a shipment.
Premium-TOFC	TOFC services that are scheduled, have short loading times, place a priority on on-time reliability and have ride quality comparable to trucks. Examples would be CP Expressway or CN RoadRailer.
Premium-intermodal	Intermodal service offerings that allow carriers to provide the same level of service to their clients as road-all-the-way trucking.
Private Carrier	Firm, or corporation which uses its own trucks to transport its own freight.
Receiver	Firm or corporation to whom a shipment is destined
Security Risk	As described to survey participants: the probability (in percent) that a shipment will suffer from theft.
Shipper	Firm or corporation that has a shipment that needs to be delivered.
TL	Truckload, shipments that fill a trailer.
TOFC	(Trailer-on-flat-car) When a truck trailer is transported on a rail flat car.