Decision Making Process and Factors Affecting Truck Routing

by

Yichen Sun

B.Eng., Hong Kong University of Science and Technology (2011)

Submitted to the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degree of

Master of Science in Transportation

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2013

Author ....
Department of Civil and Environmental Engineering
May 13, 2013

Certified by ....
Moshe E. Ben-Akiva
Edmund K. Turner Professor of Civil and Environmental Engineering
Thesis Supervisor

Certified by ....
Tomer Toledo
Associate Professor, TIIT, Technion - Israel Institute of Technology
Thesis Supervisor

Accepted by ....
Heidi M. Nepf
Chair, Departmental Committee for Graduate Students

Decision Making Process and Factors Affecting Truck Routing

by

Yichen Sun

Submitted to the Department of Civil and Environmental Engineering
on May 13, 2013, in partial fulfillment of the
requirements for the degree of
Master of Science in Transportation

Abstract

This research studies the decision-making process and the factors that affect truck routing. The data collection involved intercept interviews with truck drivers at three rest area and truck stops along major highways in North America. The computerized survey solicited information on truck routing decisions, the identity of the decision-makers, the factors that affect routing and sources of information consulted in making these decisions. Stated Preferences (SP) experiments were conducted, where drivers' choice behaviour between two hypothetical scenarios were observed and modeled. 252 drivers completed the survey, yielding 1121 valid SP observations.

This data was used to study the identity of routing decision makers for various driver segments and the sources of information used both in pre-trip planning and en-route. A random effects logit model was estimated using the SP data. The results show that there are significant differences in the route choice decision-making process among various driver segments, and that these decisions are affected by multiple factors beyond travel time and cost. These factors include shipping and driver employment terms, such as the method of calculation of pay and bearing of fuel costs and tolls.

Thesis Supervisor: Moshe E. Ben-Akiva
Title: Edmund K. Turner Professor of Civil and Environmental Engineering

Thesis Supervisor: Tomer Toledo
Title: Associate Professor, Technion - Israel Institute of Technology

Acknowledgments

First and foremost, it is with immense gratitude that I acknowledge the support and help from my advisors: Professor Moshe Ben-Akiva and Professor Tomer Toledo, both of whom continually and convincingly conveyed the spirit of hardworking and drive for perfection. I appreciate their knowledge, experiences, and guidance that made my stay at MIT such a challenging, unique, and rewarding experience.

I am indebted to all the professors who have instructed me through the courses Ive taken at MIT: Professor Cynthia Barnhart, Professor Carolina Osorio, Professor Amedeo Odoni, Professor Arnold Barnett, Professor George Kocur, Professor Anna Mikusheva, Professor Victor Chernozhukov, and Professor Christopher Zegras.

I want to thank many colleagues and friends, without whom this thesis would have remained a dream. Thanks to Katherine Rosa and Eunice Kim for your administrative support and friendship. Thanks to Joan, Jorge, Erika for your efforts and help during this research project.

Many, many heartfelt thanks also go to my friends who have always been there. I feel motivated and encouraged every time we meet or talk online.

Last but not least, I want to take this opportunity to thank my parents, Aoming Sun and Aihua Han, who taught me honesty, esteem, and independence. I thank you for your unconditional love, for the innate gift that I inherit in learning language, music, engineering, and cooking, and for the everyday phone calls that you made, since I left home at 15. No word can describe how lucky I feel to have parents like you. I love you.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

1.1 Motivation

The 117 million households, 7.4 million business establishments and 89,500 governmental units in the USA generate an enormous demand for efficient movement of freight [25]. The movement of freight shipment tonnage increased by 20% from 1993 to 2002, and is projected to increase by 65-70% by 2020 [23]. Trucks are the dominant mode of freight transportation in the US. In 2002, trucks moved 64% of freight by value, 58% by weight, and 32% by ton-miles [16]. Trucks are expected to haul 75% of the freight tonnage by 2020 [22] and 68% of the value by 2040 [28]. In 2009, trucks carried freight at a value of 9.5 billion dollars, which is about 65% of the value of freight transported by all modes.

In 2009, there were 10.6 million heavy trucks registered in the US [15]. The number of commercial trucks in the US increased by 56% between 1980 and 2008. In 2008, they accounted for 4.2% of all vehicles. But, they accumulated 10% of the total highway miles driven [28]. The total annual highway miles driven by trucks have increased by 109% between 1980 and 2008. This increase is higher compared to that of all vehicles, which is 96% for the same period [25].

The highway transportation system has not grown at a similar rate. Its total route length has increased by only 5% between 1980 and 2008 [28]. This results in increased congestion and the delays, environmental impacts, deterioration of safety and increased energy consumption that it brings about. In recent years, government agencies, constrained by budget availability, have increasingly turned to the development of private or private-public partnership (PPP) toll roads. These already account for about 30-40% of the new access-controlled road developments in the US. These numbers are expected to further increase in the next decade [57].

Understanding the behavior of road users is critical in order to develop measures to improve the performance of transportation networks. However, while there have been numerous studies of the relevant passenger travel behaviors, the research on truck routing choices is limited.

Toll road operation is the subject of on-going debates among decision-makers and in the public, and is a useful example to demonstrate the need to better understand truck routing behavior. Heavy trucks are critically important for toll roads because of their importance in generating revenue. Bain and Polacovic [8] found that trucks account for 10% of traffic flow on toll roads, but generate 25% of the revenue. In many cases, the use of toll roads, after they opened, was lower than originally forecasted, with an over-estimation of traffic by 20-30% in the first five years of operation. Government agencies risk not only the loss of revenue-sharing income but also additional costs to fulfill risk-sharing guarantees made to the developers. Furthermore, the trucking industry has been a strong opponent to toll roads on grounds such as fairness and double taxation [70], and forecasting errors for truck traffic were larger compared to those for light vehicles [59]. This uncertainty, often over-forecasting flows and revenue, contributes to increased risks in the development of toll roads. Thus, better understanding of trucks route choices is important to improve toll road use forecasts. It may also help road operators design measures that would make toll roads more attractive to trucks.

This research intends to study the decision-making process and to identify the key factors that affect truck route choice, in particular the choice between free and toll road alternatives. A comprehensive survey was designed for this purpose, where the actual routing decision-making procedure, the characteristics of different entities, and the attributes of the trip and routes were acquired. An SP experiment was administered at the same time. At last, a binary choice model was developed based on a combination of the SP data and the specifics of the actual trip, to investigate drivers choice between free and tolled alternatives.

1.2 Thesis organization

This thesis is organized as follows.

Chapter 2 reviews the background information relevant to this study. It gives an overview of the trucking industry, by examining the existing conditions of its key entities, the shipment and the shipper, the carrier, the driver and the truck, relations among entities, service terms, employment terms, trip and route attributes, and government regulations. It also provides an overview of the toll roads in North America.

Chapter 3 reviews studies related to truck routing choice behavior. The literature was broadly divided into two types: commercial Value of Time studies, and general studies that also consider other factors.

Chapter 4 describes the survey scheme and survey administration to acquire data on the decision-making process related to truck routing and the factors that affect it. Broadly speaking, two types of data were collected from 4 road intercept interviews. The first part collected information on the actual routing decision-making procedure, the characteristics of different entities and their relationships, and the attributes of the trip and routes. The second part was a Stated Preferences experiment where two hypothetical route alternatives were presented in each of the two scenarios.

Chapter 5 discusses analysis for data collected in part 1 of the survey. This chapter provides summary statistics and analysis of the responses regarding drivers actual experiences, not hypothetical SP choices. The analysis refers to several aspects, including the sample composition, the employment terms, route decision-making process, information sources, and other factors.

Chapter 6 develops a route choice model based on part 2 of the survey: the SP experiment. In this experiment each participant was asked to make a choice between two route alternatives. The alternatives were defined by the attributes of road type, travel time and distance, frequency of unexpected delays and toll-related attributes: the cost, method of payment (ETC or cash) and bearer of toll costs.

Chapter 7 concludes the thesis by summarizing the objective, approach, and findings of this research. It also lists the limitations of this study, and suggests directions for future research.

Chapter 2

Trucking Industry Overview

2.1 Key Entities

We identify four key entities in the trucking industry: Shippers, Carriers, Drivers, and Brokers or Logistics providers. These entities and the relations among them are shown in Figure 2-1. The arcs in the figure indicate that there exists an interaction between two entities. For example, both shippers and carriers may deal with third party brokers to help arrange the shipment to be shipped. The Service Terms specify the contractual relation between Shippers and Carriers, either directly or through third parties. Similarly, the Employment Terms are defined by the contract between Carriers and Drivers.

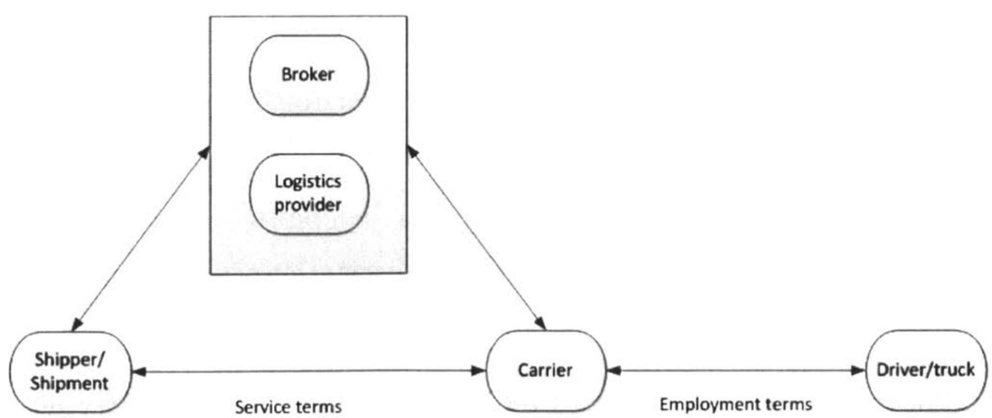

Figure 2-1: Different entities in the trucking industry and the relations among them

The shipper is the party responsible for initiating a shipment. It is usually, but not always, the sender the person or company who is the supplier or owner of the commodities shipped. However, in some cases, the receiver of a shipment may act as the shipper and deal directly with logistics providers or carriers. This may occur, for example, when large companies receive products from small businesses. The identity of the shipper is determined in the contracts between senders and receivers.

The carrier is the person or company that undertakes, in a contract of carriage, to perform or to procure the performance of carriage, which is to move the shipment from one point to another [49].

A driver is the person who operates the truck. In 2009, the trucking industry employed a total of 2.75 million drivers: 1.55 million heavy truck drivers, 835,000 light and delivery truck drivers and 363,000 drivers/salespersons [28]. Most commonly one driver operated a truck alone, but sometimes a team of two or more drivers operate the truck in alternating fashion. Owner-operator drivers can be self-employed independent contractors, which act themselves as carriers and contract with shipper directly.

Freight brokers and logistics providers are transportation intermediaries. A broker is an independent contractor paid to arrange motor carrier transportation. Freight brokers work on behalf of a carrier or a shipper. They utilize for-hire carriers to provide the actual truck transportation without actually providing it themselves. Brokers are paid commissions, either as a percentage of the freight charges or as a lump sum amount per container, depending on the carrier and/or trade lane.

In the context of truck shipping, a logistics provider (or 3rd party logistics provider - 3PL) plays a similar role to that of a broker. However, more generally, it provides a wider range of services compared to a broker. It typically handles not only truck shipping, but also other logistics service, such as multi-modal transportation, warehousing, cross-docking, packaging, inventory management and freight forwarding.

Table 2.1 below summarizes statistics regarding the size of the industry and quantities for the key entities.

In the following, we discuss these four entities and their characteristics in further detail and examine the inter-relations among them as defined in the main contractual terms.

Table 2.1: Key entities market size and trends

Entity	Size	Annual change	Source
Shipments:			
Weights	12,490 million Ton (2010)	1.0% (2002-10)	FHWA 2007 [23], 2011c [28]
Value	$10,515 billion (2010)	2.2% (2002-10)	FHWA 2007 [23], 2011c, [28]
Carriers:			
Companies	512,180 (2010)	1.8% (2009-10)	FMCSA 2011b [33]
Trucks	11.0 million (2009), 1.9 million tractors (2008)	1.5% (2000-08)	FHWA 2010b [25], 2011c [28]
Drivers	2.75 million (2009)	-0.9% (2000-09)	FHWA 2011c [28]
Broker/3PL:			
Revenue	$127.3 billion (2010)	8.4% (2000-10)	Armstrong Associates 2011 [1]

2.2 The Shipment and the Shipper

Table 2.2 summarizes the main characteristics of shipments. Although some shippers may initiate different types of shipments, they are generally characterized to a large extent by the shipments they make. In 2010, the total tonnage shipped by trucks was 12,490 million ton, including 12,309 million ton domestic and 181 million ton import or export shipments [28].

Table 2.2: Shipper and shipment characteristics

Attribute	Typical values
Size	Truckload, Less than truckload, Parcel
Special service	Temperature control, Oversize/overweight, Hazmat
Industry	Forest, Metal, Electronics, Food, Agriculture
Commodity type	Building material, Textile, Machinery, Mineral, Food, Agriculture, Animal products, Wood, Metals, Transportation, Chemical, Miscellaneous
Cargo value	Bulk, Average value, High value
Origin and destination	Locations and facility types

The most definitive characteristic of the shipment is its size. To a large extent, it also defines the types of carrier that will be used and the shipping terms. The three shipment sizes are Truckload (TL), Less-Than-Truckload (LTL) and parcel/express.

A TL shipment has the quantity of freight required to fill a truck, or at a minimum, the amount required to qualify for a truckload rate [26]. It is usually moved from one sender to one receiver without having to make an intermittent stop to sort the load in a terminal. Typical load sizes are 10,000 pounds or more and the distances covered are usually more than 500 miles for long haul carriers and between 200 and 500 miles for medium or regional haulers [60].

LTL shipments have loads that by themselves are not sufficient to fill a container or to meet the truckload requirements [26]. LTL shippers account for around 14% of the total number of shippers in the US trucking sector [66]. Load sizes for LTL shipments are generally in the order of 500 to 2,000 pounds. LTL shipments are transported in containers or trailers loaded with cargo from more than one shipper. The shipments are typically picked-up by a truck in a specific service area or along a regional route and transported to a terminal. At the terminal, the shipments are sorted and consolidated on other trucks that deliver them onward to their final destinations, again with a truck servicing a specific area or corridor. The operation of LTL service dictates that routing choice is limited.

As noted above, carriers are also defined to a large extent by the shipment sizes they transport. The operations of these two types of services differ significantly. The cost structure of LTL carriers is more complex than that of a TL carrier. LTL carrier typically have higher fixed and operating costs, which include increased overhead costs that stem from the handling of many smaller shipments, additional labor costs for dock personnel at terminals, and the costs of maintaining the terminal areas [60].

Parcel shipments are small packages, usually less than 100 pounds. Parcel carriers make door-to-door deliveries of these shipments. These carriers operate within specific delivery timeframes that ensure on-time delivery based on the customers specifications. Parcel service commonly uses light trucks or vans.

In addition to their size, some shipments may require specific truck equipment or treatment while being transported. These are defined as special service shipments. Special services include the transportation of chemicals or hazardous materials (hazmat), oversize/overweight loads and shipments that require temperature control (either refrigeration or heating). These services require special equipment, and often additional permits for the commodities being transported as well as additional training and licensing for drivers. Thus, both the fixed and marginal costs of special service carriers are higher compared to standard service carriers. Hazardous materials transported by all modes account for $ 1,448 billion in value, 2,024 million in tons, and 472 billion ton-miles. Trucks move 58% in value of all hazardous materials shipped within the U.S, totaling 1,091 million tons of hazardous materials, which are nearly 10% of all truck shipments by weight [25].

The commodity being transported is characterized by the closely related attributes of the shipper/shipments industry, the commodity type and the cargo value. The top 10 shipment commodities, by weight, are comprised entirely of bulk products and account for 65% of total tonnage but only 16% of the value of goods moved in 2007. The top 10 commodities by value accounted for 58% of total value and only 18% of all weight. The leading commodities by weight include gravel, cereal grains, and coal. The leading commodities by value are time-sensitive goods, including machinery, electronics, and motorized vehicles [25].

These commodity attributes affect the shipping terms and the logistics strategies, such as the delivery schedule and window. For example, delivery schedules and windows for perishable agriculture and food items are expected to be shorter and tighter compared to those for other commodities. These attributes, and in particular the cargo value, may also affect the level of control that carriers exercise over the trucks' locations while en-route.

Finally, the origin and destination points of the shipment are obviously the basis for any routing decisions. They do not only dictate the trip end points, but also define the length of the trip, and through that, in most cases, the freight charges. This also determines the potential value of different routing alternatives that trade-off travel time, travel distance and costs.

Table 2.3 presents summary statistics and figures for US shipments and their make up with respect to the characteristics discussed above.

Table 2.3: Statistics of shipment and their characteristics

Characteristic	Statistics	Source
Mode:		
Value	Trucks 71%, parcel/courier 13%, rail 4%, all other 12% (2007)	
Weight	Trucks 70%, parcel/courier 0.3%, rail 15%, all other 15% (2007)	Margreta et al 2009[50]
Ton-miles	Trucks 40%, parcel/courier 0.8%, rail 40%, all other 19% (2007)	
Type	TL 86%, LTL 14% (NA)	Truckinfo 2011[66]
Hazmat:		
% of all truck shipments	Value 10%, Tons 14%, ton-miles 8% (2007)	Margreta et al. 2009[50], BTS 2010[15]
Truck % of all hazmats	Value 58%, Tons 54%, Ton-miles: 32% (2007)	
Commodities/industries:		
Weight	Manufactured 24%, food 11%, wood 8%, minerals 6%, agriculture 5%, all others 25%, empty 21% (2002)	FHWA 2011c[28]

2.3 The Carrier

Table 2.4 summarizes the main characteristics of carriers. These entities may operate either as for-hire or as private carriers.

Table 2.4: Carrier characteristics

Attribute	Typical values
Carrier type	For hire, Private
Service Type	Shipment size: TL, LTL, Parcel Time constraint: Standard, Expedited, Express Special service: Temperature control, Oversize/overweight, Hazmat
Service area	Local, Regional, National, International
Fleet size	Small (<5), Medium (5-50), Large (>50)

A for-hire carrier provides transportation services to the public on a fee basis. Thus, they transport goods that they do not own. For-hire carriers may be further classified by the level of access to service: Common carriers are required to serve the general public on demand, at reasonable rates and without discrimination; Contract carriers make arrangements with certain customers to transport only their shipments and are not accessible to the general public. Owner-Operator driver are a type of for-hire carriers.

A private carrier is a not-for-hire carrier contracted to or owned by a shipper. It operates primarily to transport goods for that shipper and does not offer services to the general public. Private carriers are not required to obtain an operating authority from the Federal Motor Carrier Safety Administration.

The Federal Motor Carrier Safety Administration maintains a registry of motor carriers. At the end of 2010, the registration records included 378,293 for-hire carriers, 620,784 private carriers and 154,719 other interstate motor carriers [5].

The service type that a carrier provides is defined by the shipment sizes it handles, the time schedules and special services it offers. Carriers are classified by the shipment sizes they cater for: TL, LTL or parcel. USCB (2004) [67] estimated that TL was 78% of the miles for medium and heavy truck and LTL 22% in 2002. By revenue, [18] estimated that the TL share was 69% and LTL 31% in 2007.

The distinction between TL and LTL carriers is becoming less clear in recent years, as carriers, in particular larger ones, tend to operate both types of service. In terms of service times, expedited (faster) and express (fastest) services provide higher priority service compared to standard delivery.

Carriers may also provide service for shipments that require special treatment, such as hazardous materials (hazmat), oversized/overweight loads or shipments that require temperature control. Carriers specializing in these services would provide the necessary equipment. They would also obtain the needed carrier permits and have drivers with the correct qualifications and licenses.

The geographic area they serve may also characterize carriers. They may provide local service within a metropolitan area or a state, offer regional service covering several states (e.g. New England, Southwest), offer national service throughout the lower 48 states or also provide border-crossing service, and so access international locations in Canada and/or Mexico. The size of the area that a carrier serves would affect the regularity of the trips that trucks make, and consequently the level of familiarity of dispatchers and drivers with the routes for specific trips. In 2002, 51% of truck miles were driven within a range of 100 miles, 25% within 101-500 miles and 22% over 500 miles. 67% of truck miles were driven solely within the origin state and 33% also in other states [28].

Carrier companies differ widely in the fleet sizes they operate. The largest carriers operate thousands of trucks. At the other extreme, a very large number of independent truckers operate one (or a few) trucks, as owner-operators. The operations practices of these carriers differ significantly. Generally, large carriers are able to develop sophisticated tools and methods to control their trucks and optimize their performance. Small carriers do not usually have the administrative and financial resources to invest in such practices. The vast majority of for hire trucking companies are small businesses. In 2010, 90% operated 6 or fewer trucks, 7% operated 7 to 20 trucks and only 3% operated more than 20 trucks [5]. Consequently, the trucking industry is highly fragmented, resulting in intense competition, both in terms of price and service, and low profit margins. [6] estimated that the average marginal cost per mile in the industry was $1.45 in 2009. Using an empirically derived estimate of the average industry operational speed of 40 miles per hour, ATRI estimated the hourly marginal cost was $58 in 2009. Fuel and driver wages (excluding benefits) constituted 58% of the average operating cost.

Table 2.5 presents summary statistics and shares for US carriers and their characteristics discussed above.

2.4 The Driver and the Truck

There were 3.2 million truck drivers and driver/sales jobs in the US in 2008. Of these, 56% were heavy truck and tractor-trailer drivers; 31% were light or delivery service truck drivers; and the remaining 13% were driver/sales workers. There are about 2 million tractor trailers in the US [13]. Table 2.6 summarizes the main characteristics of the drivers and the trucks they operate.

Truck drivers may be owner-operators or employed as hired drivers. Owner-operators (O-O) are drivers that own the trucks they drive. These drivers typically also run the day-to-day operations of their small business. It is estimated that 8% of the 3.2 million truck drivers in the US are self-employed. Of these, a significant number are owner-operators

Table 2.5: Statistics of carriers and their characteristics

Characteristic	Statistics	Source
Carrier Type		ATA 2011 [5]
Carriers	For hire 32%, private 53%, other 15% (2010)	
Value	For hire 59%, private 41% (2010)	
Shipment size		USCB 2004 2007 [67],[18]
Trucks	TL 70%, LTL 30% (2002)	
Miles	TL 78%, LTL 22% (2002)	
Revenue	TL 69%, LTL 31% (2007)	
Service area		FHWA 2011c[28]
Trucks	100 miles or less 80%, 101-500 miles 10%, 501 miles of more 7%. Within one state 89% (2002)	
Miles	100 miles or less 51%, 101-500 miles 25%, 501 miles or more 22%. Within one state 67% (2002)	
Fleet size		ATA 2011 [5]
Trucks	1-6 90%, 7-20 7%, 21 or more 3% (2010)	

[12]. Owner operators owned 6% of the medium and heavy trucks in the US in 2002 and drove 9% of the miles [67]. Owner-operators can enter into a lease agreement with a larger carrier or shipper and haul freight for them or operate under their own authority to become self-employed independent contractors and haul free-lance. In contrast, hired drivers work for carrier companies under an employment contract and do not have any ownership of the truck.

Table 2.6: Driver and truck characterstics

Attribute	Typical values
Driver type	Owner-operator, hired driver
Driving arrangement	Single, Single with sleeper berth, Team
Truck type	Number of axles (2 7+) Single unit, Single trailer, Multi trailers
Trailer type	Semi-trailer, Full trailer Box, Flatbed, Tank, Dump, Concrete mixer, Auto transporter, Log, Intermodal chassis, Towing vehicle

The driving arrangement is closely related to the Hours-Of-Service (HOS) regulations, which will be discussed below in Chapter 2.4. The most common situation is that of a single driver operating a truck. However, the HOS regulations limit the number of hours that a driver may drive continuously, and so the usage of the truck is limited with a single driver. In order to allow continuous movement of the truck, in particular for long-haul trips, driver teams may be used. These teams of two drivers travel together and alternate in operating the truck. This allows almost continuous operations of the truck and supports faster delivery times. Trucks driven by teams must be equipped with sleeper berths in order to allow the team member not driving to get the rest mandated in the regulations. Single drivers may also use trucks with sleeper berths. In 2002, 17% of the medium and heavy trucks in the US were equipped with sleeper. But, these trucks travelled 44% of the miles [67]. The HOS regulations allow more flexibility in this case and so facilitate more efficient utilization of the truck.

Freight trucks are characterized by the configuration of the truck and trailer(s), the corresponding numbers of axels that they have and by the type of trailer. A single unit truck is a vehicle in which the cargo carrying capability is integral to the body of the vehicle. A truck tractor is a power-unit that hauls semi-trailer or trailer units. The truck tractor itself does not have any cargo carrying capability without attached trailers. Both single units and truck tractors can be attached to a single trailer or to multi trailers (double or triple). The total number of axles on the truck configuration includes those of the truck and any trailers. It can range from 2 or 3 axles for a single unit or bobtail (truck tractor without a trailer) to 7 or more for units with three trailers. In most cases, tolls and road charges are determined by the number of axles in the vehicle. Figure 2-2 shows the various vehicle configurations of tractors and trailers.

Trailers also have different types and bodies. A semi-trailer is trailer without a front axle. Therefore, part of its weight is supported by the truck tractor. A full-trailer has both front and rear axles, and so supports its own weights. It is pulled using a drawbar. There are many trailer body types, as shown in Figure 2-3. The most common ones are van/box bodies. Other trailer bodies are tailored for specific types of commodities (e.g. tanks, concrete mixer, auto transporters, logs) and/or loading and unloading methods (e.g. dumps, intermodal chassis).

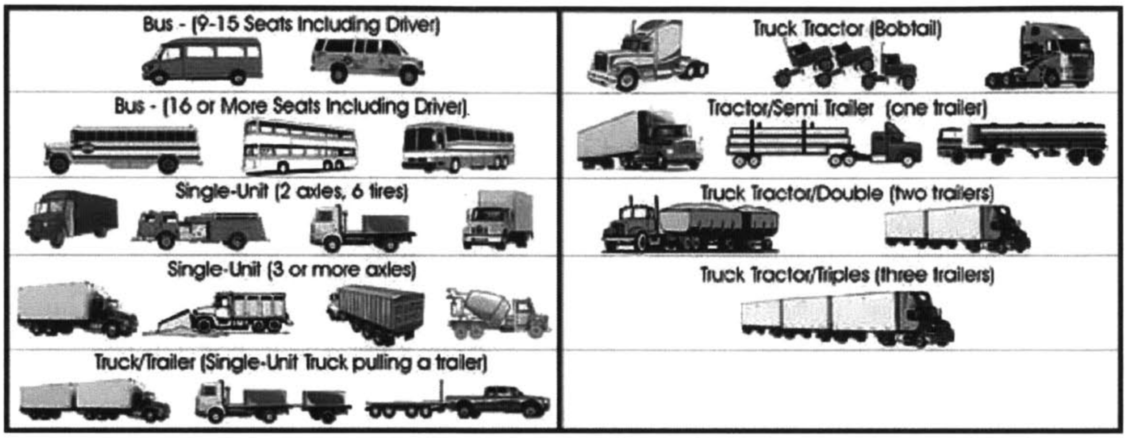

Figure 2-2: Different truck vehicle configurations (Source: FMCSA 2011a [32])

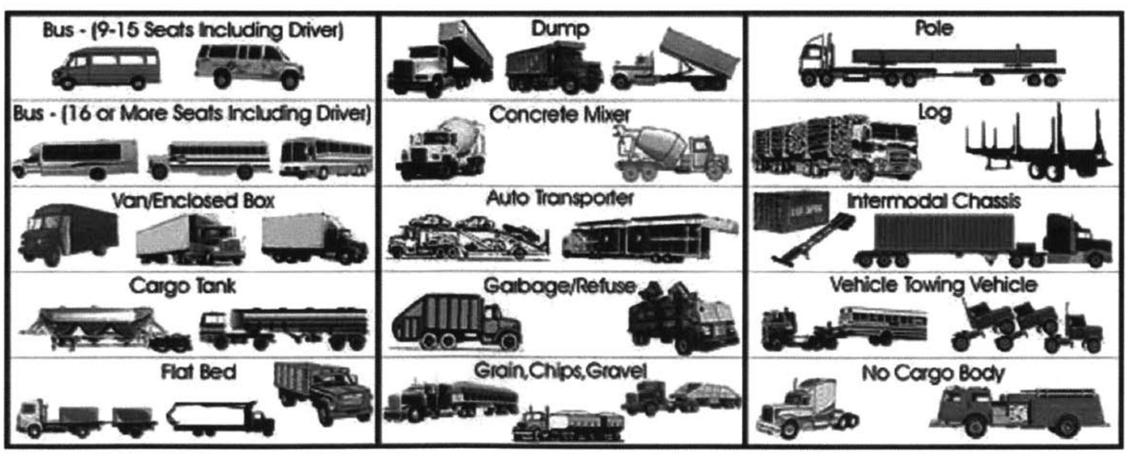

Figure 2-3: Different trailer types (Source: FMCSA 2011a [32])

In terms of ownership, carriers may haul trailers that are their own property or ones that belong to the shippers.

Table 2.7 presents summary statistics and shares for US carriers and their characteristics discussed above.

2.5 Relations among Entities

Two types of contracts, as shown in Figure 2-1, determine the relationships between the various entities involves in the freight industry: the service agreement between the shipper and the carrier (either directly or through a third party), and the employment agreement between the carrier and the driver. We now discuss the terms of these two contracts.

2.6 Service Terms (Shipper/Carrier)

The main terms of the service contract are the service type, its delivery schedule and the associated charges. These attributes are summarized in Table 2.8.

The payment structure for the shipping includes both basic freight charges and accessorial and miscellaneous surcharges that are negotiates between the shipper and carrier. Surcharges may include, as separate line items on freight bills, fuel surcharges, congestion and insurance surcharges, in-transit stop-off/drop charges, as well as detention charges.

Typically, carriers quote a basic freight charge rate to the shipper based on the origin and destination of the trip, the specific commodities being transported and their general value, the pick-up and delivery schedule and any other specific service requirements. The basic charge typically includes the basic cost of fuel and in most cases also road charges and tolls.

The most common additional charge is the fuel surcharge. ATA [5] estimated that combination trucks consumed 48 billion gallons of fuel in 2010. This accounts for 16% of all the fuel purchased in the US. The fuel surcharge is intended to address the risk that stems from the volatility in fuel prices. Fuel surcharges are specified in terms of cost per mile. To calculate the surcharge, first, the difference between the actual price of a gallon of Diesel

Table 2.7: Statistics of drivers and trucks and their characteristics

Characteristic	Statistics	Source
Drivers	2.75 million Heavy trucks 56%, light trucks 30%, driver/sales 13% (2009)	FHWA 2011c [28]
Driver type: Trucks Miles	 O-O 6% (2002) O-O 9% (2002)	USCB 2004 [67]
Driving arrangement Sleeper berth	 Trucks 17%, trick miles 44% (2002)	USCB 2004 [67]
Trucks Type Axles **Truck miles** Type Axles	6.2 million medium and heavy trucks (2004) 8.5 million medium and heavy trucks (2005) Single unit 74%, tractors 26% (2002) 2 - 60%, 3 - 11%, 4 - 5%, 5 or more 24% (2002) 145 billion medium and heavy truck miles (2002) Single unit: 38%, tractors 62% (2002) 2 26%, 3 6%, 4 9% 5 or more 58% (2002)	ATA 2007 [4] FMCSA 2007a [29] USCB 2004 [67]
Configuration Trucks Truck miles	 No trailer 50% SU+1 trailer 29%, tractor+1 trailer 19%, tractor+2 or 3 trailers 1% (2002) No trailer 20% SU+1 trailer 42%, tractor+1 trailer 36%, tractor+2 or 3 trailers 2% (2002)	USCB 2004 [67]
Trailer types Trucks Truck miles	5.6 million trailers (2008) Van 29%, flatbed 17%, dump 14%, tank 6%, refrigerated 4% (2002) Van 45%, flatbed 12%, dump 8%, tank 7%, refrigerated 9% (2002)	ATA 2011[5] USCB 2004 [67]

Table 2.8: Carrier service terms

Attribute	Typical values
Charges	Basic Freight Charges Surcharges (Fuel, Congestion, Insurance) Detention, Stop-off/drops Tolls
Service type	Standard, Expedited, Express
Delivery schedule	Time: Same day, Overnight, 1, 2, 3, 4+ days. Delivery Window: Date, By time (9AM, Noon, 5PM), Exact Pickup Window
Late penalties	In pay or other form

and a base price that is covered within the freight charge is calculated. The actual price of fuel is determined by national or regional average highway fuel prices that are published weekly by the US Department of Energy (DOE). This cost per gallon is translated to a cost per mile, based on a pre-defined fuel consumption performance standard. Note also that, if governmental restrictions prescribe specific routes to be used or avoided for the shipment, the surcharge will be applied to the additional mileage required to complete the delivery [2].

Another surcharge form are congestion surcharges, which account for the fact that some regions experience excessive traffic congestion that are not accounted for in the basic freight charges. Congestion charges are typically applied to shipments originating or intended to sea ports, border crossings and the New York City and Los Angeles areas. The NYC surcharge also captures the high truck tolls in this area. The insurance surcharge protects carriers against unexpected spikes in insurance premiums by allowing additional charges when the premium increases by more than a pre-specified amount compared to its level at the time the contract is signed. Tolls are commonly included in the freight charges and not billed separately.

Detention charges apply when a tractor truck and/or a trailer spend excessive time for loading or unloading. These charges are calculated on a per-hour basis. They are applied to the time spent loading or unloading beyond a pre-specified allowed time (e.g. 2 hours). In-transit stop-off/drop charges are paid when the shipper requests that the shipment will stop for partial loading/unlading or other purposes at an intermediate stop. The charge includes two parts: a per-mile charge for the additional distance traveled in order to make the stop, and a per-hour charge for the time the truck spends at the stop.

The types of service offered by carriers in terms of delivery speed are standard, expedited and express, in increasing order of delivery speed. These services are associated with delivery schedules that are defined by the time of delivery, both in terms of the delivery day and the time of day, and by the length of the delivery time window. The time to deliver may be overnight or within a certain number of days. The delivery window may be a full day on a particular date (or a few days) or may be defined as deliver by time, which specifies the latest delivery time within the day (e.g. by the beginning (9AM) or the end (5PM) of the business day). Alternatively, an exact window of delivery time (e.g. between 2PM and 4PM) may be specified. Similarly, the pickup schedule defines the time frame in which the carrier will pick the shipment up. Two recent surveys collected information on delivery windows. Table 2.9 presents the distribution of delivery windows found in these studies. Delivery windows vary greatly, and seem to depend on the type of operations, the commodity and the length of the trip.

Table 2.9: Delivery window distribution

		Zhou et al. 2009 [75]	Miao et al. 2011 [52]	
Sample size		2023	44	69
Geographic area		Texas	Texas	Wisconsin
Delivery window	< 1 hour	6%		
	1-3 hours	8%	34%	43%
	3-6/3-5 hours (Zhou/Miao)	8%	9%	20%
	6-12/5-12 hours (Zhou/Miao)	6%	20%	16%
	12-24 hours	9%		
	1-3 days	42%	36%	20%
	4-6 days	15%		
	> 1 week	6%		

2.7 Employment Terms (Carrier/Driver)

The main terms of drivers' employment contracts are the compensation basis, additional compensation circumstances and surcharges and penalties. These attributes are summarized in Table 2.10.

Hired drivers for carrier companies are typically not paid a flat rate, but based on some measure of performance. Long-haul drivers are most commonly paid by the mile, with bonus opportunities available based on performance measures such on-time delivery and fuel consumption [13]. The per-mile rate can vary greatly among carriers. They may depend on the type of truck driven, the cargo hauled, the area of service covered, and special services provided, such as trucking hazardous materials and increase with experience and seniority. In many cases, drivers are not paid at all or only paid a reduced rate for return trips unless they carry another load. The average estimate is that drivers earn 30.3 cents/mile. The estimated yearly income for a driver is $32,000, with O-Os making slightly more[66].

Table 2.10: Driver employment terms

Attribute	**Typical values**
Compensation basis	Miles, Hours, Freight charges/value, Load weight, Fixed
Surcharges	Fuel, Congestion, toll
Additional compensation	Stops Detention Loads/unloads
Late penalties	In pay or other form

The method of calculation of mileage between the pick-up and delivery points for pay purposes is pre-specified in the employment contract. Most commonly the calculation is based on book or practical miles or on hub miles. Book or practical miles are derived from various software and books that list standardized distances between points, such as the Household Goods (HHG) Miles Guide or the PC*MILER software. Compensation by hub miles uses the actual travel distance measured in the odometer. To restrict drivers ability to unnecessary inflate their mileage, carriers may limit mileage not to exceed the practical miles by more than 5-10%.

Some long-haul drivers, especially owner-operators, are paid a fraction of the freight charges [13]. This fraction may depend on the particular type of cargo. Other, less common payment methods calculate the compensation based on the load weight/value or as a fixed sum per load or working day. Line-haul and local delivery drivers are often paid by hours, with extra pay for working overtime. Table 2.11 presents results of surveys that collected information on drivers' compensation methods. The differences among the statistics shown are large. This may be partly explained by differences in the populations of drivers surveyed in these studies, such as the fraction of O-Os and for-hire drivers and of TL and LTL operations. Mullett and Poole [54] summarize the common pay methods in various segments of the industry, but do not provide any statistics. They report that drivers for TL and intercity LTL carriers are commonly paid by the mile, O-Os are paid by the mile or a percentage of the freight charges. Local LTL drivers, delivery and parcel/express drivers are paid by the hours. Private fleet drivers are paid a mix of hourly and by the mile.

Table 2.11: Driver compensation method distribution

		Kawamura 2000 [46]	Zhou et al. 2009 [75]	Miao et al. 2011[52]	
Sample size		985	2023	45	69
Geographic area		California	Texas	Texas	Wisconsin
Pay method	Miles	NA	45%	67%	52%
	Hours	64%	1%	NA	NA
	Load	NA	21%	13%	13%
	Freight charges	NA	30%	16%	23%
	Other	36%	2%	4%	12%

Owner-operators (O-O) leasing to a larger carrier may be working either under a gross lease or a net lease contract. With a gross lease contract, the O-O is responsible for most truck related expenses, such as fuel, road taxes, licenses, permits and insurance. The carrier would reimburse the driver surcharges that are calculated similar to the way the carrier charges the shipper as described in the service terms discussion above. With a net lease contract, the O-O is only responsible for the costs directly related to the truck: lease payments, insurance and maintenance costs. All other costs (fuel, road charges and tolls, licensing and freight insurance) are paid by the carrier. This contract type lowers the initial operating costs for the driver, and so lowers barriers of entry to the O-O market [74]. Zhou et al.[75], which surveyed 2023 truckers in Texas, collected information about the toll cost responsibility. 75% of drivers indicated that they pay themselves and only 25% reported that their company pays the tolls. However, the authors indicate that the results may be biased as a result of unclear phrasing of the question. Mullett and Poole [54] suggest that most commonly carriers pay for tolls in all segments of the industry (TL, LTL, delivery, parcel/express and private fleets), except O-Os, who usually pay themselves. However, they do not provide any relevant statistics.

The terms for additional pay for detention and stops are similar to those that the carrier charges the shipper. In addition, drivers are paid if they participate in loading/ unloading the shipment at the end points.

Penalties may be imposed on unjustified late deliveries. These may be in direct monetary term or more indirect through refusal of shipments or lose of future work. Zhou et al. [75], in the survey mentioned above, also collected information on late penalties. However, the responses mix together penalties to the driver and to the carrier. 51% of drivers indicated penalties in the form of late delivery fines or a need to refund fees. 36% indicated the risk of losing the shipping contract, 30% indicted the risk of the shipment being refused, 13% were concerned about losing their jobs and 22% indicated no late penalties at all.

2.8 Trip and Route attributes

The characteristics of the various entities involved in trucking, and the contractual terms discussed above provide a general description of the industry. However, specific trips may have specific attributes that are relevant for routing decisions. Table 2.12 summarizes these attributes.

Trips may be inter-city involving substantial highway travel, or intra-city occurring mostly within the metropolitan area. A closely related attribute is the trip length, measure in terms of travel time or distance. The values presented in Table 2.12 represent classifications that have been used in various surveys. The 11 hours boundary in the classification of travel times stems from the maximum driving time within one day allowed by the hours-of-operations (HOS) regulations (see Chapter 2.9). Private fleets commonly undertake local and regional hauls, whereas for-hire carriers or O-Os usually handle longer hauls [70].

Trips may have single loading/unloading locations or multiple ones at either tor both trip ends. Multiple loading/unloading points constrain the alternative routes the truck may realistically take. The pick-up and delivery locations may be facilities of the shipper, consolidation centers, where freight is sorted and consolidated or terminals at sea ports, airports, rail stations or border crossings. Depending on the type of trip end locations drivers and carriers may have different expectations in terms of the amount of time they will spend loading/unloading. Together with the definition of the delivery schedule and window for the specific trip, this may affect the value they place on differences in travel time or arrival times that result from selecting various routes.

Table 2.12: Trip-specific attributes

Attribute	**Typical values**
Trip type	Intercity, intra-city
Trip length	Local, Short, Medium, Long Distance: <50, 50-200, 200-500, >500 miles Time: <2, 2-5, 5-11, >11 hours
Trip ends	Shipper, Consolidation centers/terminals Single, Multiple
Delivery window	<3, 3-5, 5-12, >12 hours
Routing decision maker	Driver, Carrier, Shipper/logistics provider

Finally, the entity actually making the routing decisions may differ for specific trips. In some cases, shippers or logistics providers dictate a specific route to the carriers they hire. More commonly, and in particular when payment is pre-defined (e.g. based on book or practical miles), shippers tend not to get involved in the route selection. With some carriers (generally, larger and more sophisticated ones) dispatchers assign routes and communicate them to their drivers. Drivers may have some flexibility to augment their routes. Other carriers (especially smaller ones and O-Os) allow drivers to choose their own routes.

Table 2.13 presents summary statistics and shares for the freight trips and their characteristics discussed above.

2.9 Government Regulations

The Federal Motor Carrier Safety Administration (FMCSA) regulates safety-related aspects of trucking. Carriers that operate and trips that take place wholly within a single state are subject to state (not federal) regulations. In most cases, these are similar to those implemented by FMCSA. Two regulations that are relevant for truck scheduling and routing are the hours-of-service regulations (HOS) and the establishment of designated, preferred, and restricted routes for Hazardous Materials. In this chapter, we describe the details of these regulations.

Table 2.13: Statistics of trips and their characteristics

Characteristic	**Statistics**	**Source**
Trip length		
Trucks	50 miles or less 65%, 51-100 miles 15%, 101-200 miles 5%, 201-500 miles 5% 501 miles or more 7%, off road 3% (2002)	USCB 2004 [67]
Miles	50 miles or less 35%, 51-100 miles 16%, 101-200 miles 10%, 201-500 miles 15% 501 miles or more 22%, off road 2% (2002)	FMCSA
Body Type	Single-unit: 12,200 annual miles per truck, truck-tractors: 63,400 annual miles per truck. (2002)	2007b [30]
Truck Type	50 miles or less: 71% of medium trucks, 77% of light-heavy trucks, 56% of heavy trucks 51 miles or more: 29% of Medium trucks, 23% of light-heavy trucks, 44% of heavy trucks	
	Sample of 45 drivers in Texas (2010) Driver 44% dispatcher/manager 53%, shipper 2%	Miao et al. 2011 [52]
Route choice decision-maker	Sample of 66 drivers in Wisconsin (2010) Driver 36% dispatcher/manager 55% shipper 3%, other 6%	Kawamura 1999 [45]
	Sample of 2023 drivers in Texas (2008) Driver 85% dispatcher/Manager 12%, other 3%	Zhou et al. 2009[75]
Trip ends	Quebec - Ontario destinations: warehouse/distribution center 24%, retail outlet 10%, truck/rail terminal 23%, manufacturer 10%, other 33% Ontario - Quebec destinations: warehouse/distribution center 22%, retail outlet 24%, truck/rail terminal 14%, manufacturer 12%, other 28%	McLean 2000 [51]

2.9.1 Hours-of-Service

The Hours-of-Service regulations limit the amount of hours that commercial motor vehicle (CMV) drivers may drive.

The regulations limit driving to a 14-hour duty period. This period cannot be prolonged even if the driver takes some off-duty time within it. Once a driver has reached the end of the 14-hour period, he/she cannot drive again until completing an off-duty period of at least 10 consecutive hours. A sleeper berth provision allows a driver in a truck that has one to spend some or all of the 10 off-duty hours in the berth. A driver may also take time off in the berth during a duty period. If this time off is at least 8 consecutive hours it will not count towards the 14-hours duty period, and so allow the driver to postpone the end of the 14-hours duty period.

Within a 14-hours duty period, the driver may actually drive up to 11 hours. There is no restriction on how many of these hours can be consecutive. The driver may work in the remaining time within the duty period (or even beyond it), but cannot drive until completing a 10-hour off-duty period.

In addition to the duty period regulations, the HOS regulations forbids driving after the driver has reached a limit of 60 on-duty hours (all work, not only driving) within 7 consecutive days or after the driver has reached a limit of 70 on-duty hours (all work) within 8 consecutive days. The count of on-duty hours may be restarted if the driver has been off-duty for a period of at least 34 consecutive hours.

The HOS regulations are defined on rolling time periods (and not on set calendar days or weeks). They impose strict constraints on truckers' schedules and may affect the potential use and value of time that they derive from travel time savings related to improved routing. The regulations also force careful planning of travel routes and itinerary to allow completing activities such as searching for parking places within the driving periods. This consideration is especially important around urban areas, where there is often shortage of truck parking spaces.

2.9.2 Routes for hazardous materials

The Federal Motor Carrier Safety Administration [31] provides a list of designated, preferred, restricted and recommended routes for different classes of hazardous materials. Prescribed (or designated) routes must be used by hazmat trucks. Preferred or recommended routes must be used by trucks carrying specific classes of hazmat. Similarly, restricted routes may not be used by all hazmat trucks or by trucks carrying specific classes of hazmat.

In many areas, especially around metropolitan centers, these regulations greatly reduce or completely eliminate routing alternatives for the relevant truck traffic.

2.10 Toll roads in North America

The National Highway System contains approximately 160,000 miles of roadway important to the US economy, defense and mobility. Toll roads constitute 5,210 (2,902 rural toll road miles and 2,308 urban toll road miles) miles within this system, which amount to only 3% of its length. However, travel on toll roads has been growing steadily. In 2008, the total mileage driven on toll roads was about 220 million vehicle miles, which is about 7% of the total highway vehicle-miles traveled. This figure represents an average annual increase of 4% since 1993. Furthermore, this rate of increase is roughly double that of other roadway types within the highway system [24] [27].

Perez and Lockwood [57] argue that toll roads currently play an increasingly important role in the development of the highway system. In the 1990's 30-40% of new highway miles were the result of toll road development. Based on analysis of on-going toll road projects at various stages of development, the authors estimated that the rate of toll road development doubled in the 2000's. About half of the toll road projects since 1991 involve public-private partnerships (PPPs) through which a private entity is responsible for the toll road development, operations, and in some cases finance and operations. In 2006, the development of new toll road projects concentrated in several states including Texas (38 on-going toll projects), Florida (29), Colorado (12), Virginia (13) and California (10).

The development of toll roads offers potential improvements to the transportation system that would otherwise not be realized due to budget constraints. Munroe et al. [55] evaluated the economic benefits of toll roads in Orange County, CA. They concluded that these toll roads result in substantial savings, to both users and non-users. The annual savings were valued at $182 million for travel timesaving, and $7 million due to reduced fuel consumption. Campbell [19] compared the safety performance of toll road to that of non-toll freeways. He found that toll facilities provide improved safety performance. This is attributed mainly to better road conditions and to faster crash response and clearance. The toll collection method has further effect on safety with toll roads operating electronic toll collection being safer than other toll roads.

Heavy vehicles are a significant factor determining the performance of toll roads, both in terms of revenue generation and the ability to reduce congestion on alternative routes. Various incentives have been studied as means to attract trucks to toll facilities. Zhou et al. [75] interviewed individuals in the industry, including shippers, carriers and drivers. They found that O-Os were the least likely to use toll roads because of the difficulty in passing the cost of the toll on to their customers. In contrast, private fleets were the most likely to evaluate the potential benefits of a toll route and use it if it is beneficial. In addition they conducted a survey of over 2,000 truck drivers in Texas aiming to identify incentives that may motivate them to use the SH-130 by pass to Austin. They found that that small carriers and O-Os strongly prefer the non-toll routes. The incentives that most appealed to truck drivers were off-peak discounts, and a free trip after a number of paid trips.

Several attempts to attract heavy vehicles to toll roads have been made, in most cases with disappointing results. In 2001, the Port Authority of New York New Jersey (PANYNJ) introduced time-of-day pricing in the six bridges connecting the two states as part of a price increase measure aimed to reduce congestion during peak hours. The plan included discounts to EZPass users in off-peak and night periods. However, Ozbay et al. [56] and Holguin-Veras et al. [41] [42] found that the differential price had only a small impact on travel patterns. Only 20% of carriers reported making changes in their operations in response to the pricing changes. 10% reported increased use of EZPass, but only 6% reported changing their routes, and 0.5% changing the time of their travel to off-peak periods. Private carriers showed more flexibility in making changes in their operations, which the authors attribute to the higher willingness on part of their customers (within the same company) to accept these changes.

In 1996, Floridas Turnpike lowered its toll rate by 33% to attract trucks from the parallel free alternative I-95. However, no change in the demand was observed, as trucks preferred the shortest I-95 paths. CRSPE [20] reported on a survey conducted in Lee County that found 37% of trucks never adjusted routes or times to obtain toll discounts. The reasons cited for this behavior were being customer-driven and not having viable option. A study in Georgia showed that delivery times based on shipper or manufacturer requirements were not likely to be rescheduled because of tolls, and that this pressure from shippers to deliver at times convenient to them forced carriers to make trips during peak hours [63]. Earlier studies also showed very low elasticities of truck demand to changes in toll rates: -0.086 in Massachusetts [17], -0.09 in New Jersey [69] and -0.15 in Ohio [75]. These elasticities are much smaller than those observed for passenger traffic, and indicate that only very large toll rate decreases may attract truck drivers to toll roads. In another direction, Zhou et al. [75] report that an increase in the speed limit for heavy trucks on the Ohio Turnpike from 55 mph to 65 mph in 2004, resulted in a 10% increase in truck traffic.

2.11 Summary

The existing conditions of trucking industry were examined from Chapter 2.1 to 2.9. Given the complexity of the industry in terms of the many players and different formats of their contractual relationships, toll road operations offer a good example to demonstrate the need to better understand truck routing behavior, as well as to probe into the highly heterogeneous structure of trucking industry. This leads to the discussion of truck route choice, which affects and results from the interactions among all key entities in the trucking industry. It is also directly relevant to toll roads as the day-to-day operations involve truck drivers behavioral decisions between tolled and non-tolled roads.

Chapter 3

Truck Route Choice Studies

This chapter provides a summary on studies related to trucking route choice behavior. The impact of truck route decisions comes as a result from the interactions among shipper, driver, and road provider, and from their evaluations of route attributes such as travel time and delays. Therefore, to study the factors affecting truck route choices is crucial to understand the industry as a whole, and to help manage risks for toll road operations.

The relevant literature may be broadly divided into two types of studies:

1. Commercial value of time (VOT) studies, which mostly consider the tradeoff between travel time and cost.

2. General studies of truck route choice that also consider the effects of other factors, such as shipper and shipment characteristics, service terms, delay magnitude and frequency, and so on. In this context, we also briefly review studies of passenger traffic route choice that directly addressed revealed preferences between toll and free routes.

3.1 Value of Time studies

A number of studies focused on measuring VOT. VOTs are useful for evaluating the potential impacts of a variety of measures and policies and assessing the demand for services, including the use of toll roads.

Truck VOT studies typically employed stated preference (SP) data collection techniques as an efficient way to design and control hypothetical situations. The survey questions were designed as a set of ratings, rankings, choices or matching between alternatives described by attributes set to particular levels. In some cases, background information that was collected ahead of the SP experiment was used to customize the SP questions to the respondents, and so to increase the realism of the scenarios presented to them [34]. Adaptive Stated Preference (ASP) takes the questionnaire customization process one step further, by adjusting attribute levels in later stages of the experiment in light of the responses to earlier scenarios [34]. Typically, these background questions related to some of the aspects that have been discussed in Chapter 2, including the characteristics of:

- Shipper and shipment (e.g., size, special service, commodity type)
- Carrier (e.g., type, service type, service area)
- Driver and truck (e.g., driver type, number of axles, trailer type)
- Service terms (e.g., toll bearer, delivery schedule, driver compensation basis)
- Trip and route (e.g., trip length, delivery window, routing decision maker)

Table 3.1 presents a summary of VOT studies, the data collection approaches they used, and their main findings. We next discuss these in further details. It should be noted that VOT values reported here are not directly comparable, as they are not adjusted to any specific year.

Zamparini and Reggiani [73] conducted meta-analysis of 46 previous studies on truck VOT from 22 different countries in Europe and North America. The mean VOT they found was $20/hour with a standard deviation of $13/hour, which represents a coefficient of variation of 0.66. Some of the differences among the VOT in the various studies could be explained by the geographic location of the study, the national GDP of the country where it was conducted and the mode of shipping (5 out of the studies addressed rail transport).

Smalkoski and Levinson [65] used an adaptive SP approach to collect data on VOT of carriers in Minnesota. They first sent participants by mail-in questionnaires soliciting background information about the carrier and its typical service. This data was used to tailor an SP experiment to the particular circumstances of the specific carrier. This survey was administered using a computer in a face-to-face interview. They found statistically significant higher VOT for for-hire carriers compared to private fleets ($60/hour and $42/hour, respectively). They also found a wide range of VOT, from $21/hour to $78/hour, depending on the type of facility being served. Although the authors do not offer any explanation for these differences, they may be capturing the effect of various operational factors, such as differences in commodity types and values, delivery schedules and importance of on-time delivery.

Bergkvist [10] used a database of SP responses from 277 shippers in Sweden to estimate VOT. They segmented the sample by the geographic location of the company in the north or south of the country, by the type of carrier they use (for-hire or private) and by the trip length. They found that the VOT is much higher, by an order of magnitude, for short trips (less than 3 hours) compared to longer ones, and for private carriers compared to for-hire ones. They also found some differences in VOT between the regions and depending on the type of commodity being shipped.

de Jong [38] reported on an adaptive SP experiment with carriers in the UK. The computerized interviews were conducted face-to-face and involved two types of scenarios that involved the trade-off among travel time, travel cost and the risk of unexpected delays. The scenarios were presented in either an abstract way or using a route choice settings. The paper does not report on the results pertaining to the delay risk variable. VOT are segmented by the carrier type, private or for hire. However, there is a large difference (by a factor of 2) in the VOT for for-hire carriers between the abstract and route choice scenarios. As a result, VOT are lower for private fleets compared to for-hire carriers in the abstract scenarios, but higher in the route choice scenarios.

Ismail et al. [37] studied the VOT of delays at US-Canada border crossings in the context of willingness to pay for passes for faster service at the facility. They contacted carriers that operate across the border and presented them with an adaptive SP survey that included binary questions on their willingness to pay specific fees to expedite their service time at the border crossing. The response rate was very low, with only 15 participants that completed the SP part. Thus, the results they present are not reliable or meaningful.

Wynter [71] analyzed the variability in VOT among carriers in France. She conducted an SP survey of 408 fleet managers that included information about the commodity type they serve and their typical travel distance. A lognormal distribution was found to fit the data well, with a coefficient of variation of 0.69. She also found that the mean VOT increases linearly with the trip length and varies considerably among various commodity types.

Kawamura [46] also analyzed the variability in VOT among carriers. He estimated truck VOT using ASP data collected in California. Data collection began with face-to-face interviews with decision-makers in trucking companies. The respondents were asked about their choices in scenarios that included travel on a congestion-priced freeway segment in which they could choose between free and toll lanes with various combinations of tolls ranging from $1 to $10, and time savings between 5 and 15 minutes. A follow-up survey was conducted to obtain more accurate VOT with scenarios that were tailored to each respondent based on the VOT ranges they indicated in the interviews. The follow-up survey was administered by mail or through face-to-face interview. In addition, he asked respondents about the characteristics of the trucking company, including fleet size and characteristics, type of service, cargo type and value, and management strategy. The author used a binary random coefficient logit formulation to estimate VOT and its distribution. He used a lognormal distribution of VOT and estimated its mean at $23/hour. He also found wide variability in the VOT with a standard variation of $32/hour. Kawamura also segmented the data by carrier type, shipment size, and the method of driver compensation. He found differences in the VOT means and distributions among the various segments: for-hire trucks had higher average VOT compared to private fleets. Carriers that paid drivers hourly wages had higher VOT compared to those that paid commissions or fixed salaries.

Miao et al. [52] recognized the importance of the specific conditions relative to the delivery schedule and included them in their SP survey. They conducted both roadside intercepts with truckers at truck stops in Texas and Wisconsin, and telephone/mail interviews with fleet managers and dispatchers. The surveys in both cases consisted of two parts: collection of background information and an SP experiment. The background information collected the carrier type, route length, typical cargo type, number of truck axles, trip length in terms of hours, drivers compensation basis, frequency of changing route to avoid congestion, delivery window, and who the route decision makers and toll bearers were. The questionnaire addressed to fleet managers and dispatchers solicited similar information about the typical operations of the fleet. Respondents were then presented with two hypothetical scenarios that described a trip in which they are either running late by 30 minutes or are on time for their scheduled delivery. They were asked about the amount of toll they were willing to pay in order to save time, so that they will be less late, on time or ahead of time. Figure 3-1 shows an example of the options presented to the drivers.

You are running <u>30 minutes late</u>. Please select the maximum you are willing to pay for each scenario:

Arrival Time: 15 minutes late				Arrival Time: On time				Arrival Time: 15 minutes early			
$30	$20	$13	Other	$50	$35	$20	Other	$68	$45	$23	Other

Figure 3-1: SP questions example (Source: Miao et al. 2011 [52])

The authors used an ordered logit model formulation to estimate the coefficients of travel time and travel cost and through these estimate VOT. They found VOTs that ranged from $26/hour to $68/hour, depending on the geographic location (higher values in Wisconsin) and on the relations to the scheduled delivery (higher values for trips running late). In addition, they estimated VOTs for specific segments in the population, based on the characteristics of the driver compensation basis, carrier type, who pays the toll, and trip length. In these estimates, they only used the data from the scenario in which the driver is running 30 minutes late. They found that drivers that are paying the tolls themselves were less willing to use toll roads. Drivers paid by miles perceived higher VOT than the others, and private carriers perceived a higher VOT when compared with owner-operators and for-hire drivers.

The results of the studies described above, especially for specific segments, are based in some cases on relatively small sample sizes. However, they still show high variability in VOT, both when it is modeled explicitly and when it is demonstrated through segmentation of the market based on the situation and on the characteristics of the shipment, trip, carrier and driver. These results seem to indicate that these factors have a substantial effect on truck route choice and that VOT is not the only determinant of these decisions. The use of a single, or at most two, attributes in segmenting the population fails to capture the effects of multiple characteristics and the potential for interaction effects. Furthermore, only a single study incorporates a factor that accounts for the specific situation considered for a specific trip (being late or on-time with respect to the delivery schedule). All other studies reviewed consider segmentations that are based only on the characteristics of the shipment, carrier or trip.

Table 3.1: Summary of VOT studies-a

Authors	Survey type	Survey administration	Participant, Sample size	Segmentations	Main findings and remarks
Bergkvist (2001)[10]	SP	Interviews	277 shippers	Trip length Carrier type Commodity type Location	Higher VOT for shorter trips and for private carriers
de Jong (2000)[38]	SP-choice	Face-to-face computerized interviews	Carriers, sample size not reported	Carrier type	Scenarios include risk of unexpected delay.
Ismail et al. (2009)[37]	SP-choice	Mail-in	15 carriers	Fleet size Cargo value Crossing frequency	VOT for delay at border crossings. Sample too small
Kawamura (2000)[46]	SP-choice	On-site interview, mail follow-up	70 carriers route decision-makers	Carrier type Shipment size Compensation basis	High variability in VOT (mean $23, std. $32)

Table 3.2: Summary of VOT studies-b

Authors	**Survey type**	**Survey administration**	**Participant, Sample size**	**Segmentations**	**Main findings and remarks**
Miao et al. (2011)[52]	SP-matching	Truck stop intercepts	47 drivers in TX 64 in WI	Compensation basis Carrier/Driver type Toll bearer Trip length	Wide range of VOT ($26-$68/hr) depends on segments and schedule delay
Smalkoski, Levinson (2005)[65]	SP choice	Computerized interview	Carriers, sample size not reported	Carrier type Trip end facility	Mean VOT $50/hr. Range of $21-78/hr
Wynter (1995)[71]	SP choice	On-site interview	408 carriers	Trip length Commodity type	High variability in VOT (COV=0.69) in general and between segment. VOT increases with distance
Zamparini, Reggiani (2007) [73]	Meta analysis		46 previous studies in 22 countries		Mean VOT $20/hr, COV=0.66 depends on location and GDP

3.2 Truck route choice studies

VOT studies are very limited in that they only consider travel time and cost and ignore the effects of any other factors. However, the wide range of freight VOTs across studies or within one study for various segmentations suggest that other factors affect routing decisions. This chapter discusses more general studies of truck route choice that directly linked route choices to other factors beyond the tradeoff between time and cost. These factors include the characteristics of the market entities (drivers, carriers and shippers) and their interactions represented by contract terms, as well as route attributes such as the frequency and magnitude of delays, tolls and their method of collection. Unlike VOT studies which mainly used survey data, a great diversity of methods emerged in truck route choice studies.

Table 3.3 summarizes some current route choice studies and their results.

Table 3.3: Summary of route and service choice studies-a

Authors	**Survey type**	**Survey administration**	**Participant, Sample size**	**Variables**	**Main findings and remarks**
Bolis and Maggi (2001)[14]	SP-rating	Computerized on-site interviews	22 shippers	Cost, travel time, service frequency, flexibility, percent late	All factors except flexibility significant in overall model. High willingness to pay for on-time performance and flexibility with just -in-time
Danielis et al. (2005) [21]	SP-several forms	Computerized on-site interviews	65 logistics managers for manufacturers	Cost, travel time, risk of delay, risk of damage	All factors are significant. Value of delay higher than VOT. High reliability value for just-in-time. Large variability among industries
de Jong et al. (2004)[39]	RP and SP	Computerized on-site interviews	135 shippers, 59 carriers	Cost, travel time, service frequency, percent late, percent damaged	All variables significant in model. Did not use RP data in final models

Table 3.4: Summary of route and service choice studies-b

Authors	**Survey type**	**Survey administration**	**Participant, Sample size**	**Variables**	**Main findings and remarks**
Fowkes, Whiteing 2006 [35]	SP-rating	Computerized on-site interviews	49 shippers	Cost, latest departure time, expected and 98th percentile arrival times	Simple regression was used. VOT lower than value of delay. Variability among industries
Hunt, Abraham (2004)[43]	SP-rating	Driver intercepts, on-site interviews with managers	101 drivers, 141 carriers	Travel time, toll cost and method of payment, road type, probability and magnitude of delays	Route choices with toll and free alternatives. All variables except toll payment methods were significant. Value of delays higher than VOT
Hyodo, Hagino (2010) [44]	RP	Routes reported in traffic permit application	24,497 truck routes	Toll, travel time, properties of the road links	Estimated generalized cost model for shortest path assignment. Trucks tend towards links with 4 or more lanes and weight/height designations

Table 3.5: Summary of route and service choice studies-c

Authors	Survey type	Survey administration	Participant, Sample size	Variables	Main findings and remarks
Jovicic (1998) [40]	RP and SP-choice	Data derived from 3 previous projects	1012 respondents, 847 ship with trucks	Cost, travel time, service frequency, % late, % damaged, schedule flexibility, info availability	RP and SP combined. All variables significant. Cost and travel time are most important. Flexibility and info availability least important. Values of attributes higher for high value shipments.
Knorring et al. (2005) [47]	RP	In-truck GPS data collection	9053 trips in 10 OD pairs with a choice of CBD or bypass routes	Distance, travel time	Willingness to trade a 1% increase in travel distance for a speed gain of 0.4 mph.

Table 3.6: Summary of route and service choice studies-d

Authors	**Survey type**	**Survey administration**	**Participant, Sample size**	**Variables**	**Main findings and remarks**
Kurri et al. (2000)[48]	SP-choice	Computerized on-site interviews	103 transport managers for manufacturers	Cost, travel time, frequency and magnitude of unexpected delays	Value of delay much higher than VOT. High variability of both among industries
Prozzi et al. (2009)[60]	-	Web-based questionnaire	112 carriers	Reasons for using or avoiding toll roads. Incentives that may affect usage	Main reasons to use toll roads were reduced congestion and time savings. Main reasons not to were price and irrelevant locations. Discounts and refunds are incentives with highest potential to increase usage.

Table 3.7: Summary of route and service choice studies-e

Authors	Survey type	Survey administration	Participant, Sample size	Variables	Main findings and remarks
Qin et al. (2009)[61]	RP	Loop detector data on highway with active work zone and diversion routes	15-minute data at 8 locations on 3 routes, sample size not reported	Traffic flow characteristics, travel information	Route choices affected by time of day, total traffic flow and the % of trucks.
Small et al. (1999)[64]	SP-choice	Initial phone interview, mail-in experiment	20 carriers	Cost, mean and distribution of travel time	Late schedule delay explain route choice better than travel time variability and even mean travel time
Austroads (2003) [7]	SP-choice	Face-to-face interviews	43 senior managers for shippers	Cost, travel time, % late, % damaged. Longhaul and metro TL and LTL segments	All variables significant. Higher VOT for metro shipments.

Table 3.8: Summary of route and service choice studies-f

Authors	Survey type	Survey administration	Participant, Sample size	Variables	Main findings and remarks
Wood (2011)[70]	SP-choice	Face-to-face interviews and web-based survey	Drivers, carriers and shippers: 661 web-based. Face-to-face sample size not reported	Toll, travel time and distance	Willingness to pay tolls mostly no difference among employment type, service type, years of experience, annual mileage, typical trip length, (intra-)urban trips or current toll road usage level. Substantial negative perceptions to tollroads.
Zhou et al. (2009) [75]	SP-rating	Web-based and paper survey	2023 drivers	Various incentives to use toll roads	Biggest incentives are those related to discounts on tolls and fuel, and to road services and quality.

Several researchers studied the choice of routes or shipping service made by shippers. In addition to travel time and cost, these studies accounted for the effect of travel time reliability captured by the frequency and magnitude of delays, or by the risk of late delivery. In the context of shipping services, the risk of damage to the goods in transit was also considered. Most of these studies still employ SP methods. One such study was conducted in Finland by Kurri et al. [48], who identified unexpected travel delays as an important variable in addition to the expected travel time and cost. They developed an SP experiment in which respondents were presented with 12 to 15 pairwise comparisons of shipping service alternatives that were defined by the attributes of cost, travel time and fraction and magnitude of unexpected delays. The survey was administered through on-site interviews with 103 transport managers in manufacturing companies. In their analysis, the authors used a logit model for the service choice. However, they do not present the model estimate. Instead, they calculated VOT and value of delays for the entire sample and segmented by the commodity industry. The results showed that the reliability of travel times is a more valued factor compared to the travel time itself, as values of delay are larger by an order of magnitude compared to VOT. Furthermore, VOT and value of demand vary by a factor of 4 and 78, respectively among the various industries with the highest values obtained for daily goods and the lowest for the forest industry.

Small et al. [64] conducted a survey of 20 carriers in California in which respondents were presented with 6 scenarios in which they asked to choose between two alternative routes. The routes were characterized by three factors: the travel time, cost and the distribution of arrival times relative to the delivery schedule. The results showed that carriers were sensitive to late schedule delays, i.e., the expected late time for late trips, but not to early schedule delays. When accounting for the schedule delay, the travel time itself was not significant in predicting route choices. Furthermore, other functional forms of variables that aimed to capture the effect of travel time uncertainty, namely the travel time standard deviation and coefficient of variation (COV) were not significant in the model when used instead of the schedule delay. While the results are based on a relatively small sample, they clearly indicate the importance carriers place on on-time delivery performance.

Danielis et al. [21] studied the choice of carrier service by shippers. They interviewed 65 logistics managers for Italian manufacturing firms. The SP experiment they used consisted of several part requiring respondents to choose and rank alternatives as well as to determine unacceptable attribute levels. Alternatives were defined by cost, travel time, risk of delay and risk of damage or loss of the shipment. The different parts of the experiment were analyzed separately. Overall, all these attributes were significant in the model. The value of eliminating an hour of delay was 30%-50% higher than that of an hour travel time saving. VOT varied widely with the industry segment. However, the authors do not report the numbers of observations in each segment, which may be very small. Further analysis showed that VOT is lower for long-haul trips, over 12 hours and that the value of reliability is much higher for just-in-time shipments.

Austroads [7] conducted a similar study in Australia. They conducted face-to-face interviews with 43 senior managers for shippers using LTL carriers and TL carriers both in urban and inter-urban trips. Respondents were asked to make pairwise choices of carriers based on the attributes of cost, travel time and percentages of late deliveries and shipments damaged in transit. All these variables were significant in the binary logit models they developed. The found that VOT are higher for trips within the metropolitan area, but the willingness to pay for on-time delivery and for reductions in damaged shipments is higher for long-haul trips.

Fowkes and Whiteing [35] conducted a VOT study which also accounted for reliability. They asked 49 shippers to rate three carrier services compared to a base one, which was based on actual shipments. The attributes considered in the alternatives were the cost, latest departure time, expected arrival time and 98th percentile of the arrival time. Rail alternatives were also considered. The authors used simple regression models, which are inappropriate for the (bounded) collected data, to evaluate VOT and value of delay for various industry segments and for express service. The results showed that the value of delays is higher than the VOT for most segments. Both VOT and value of delays were highest for express shipments and lowest for bulk and coal shipments.

Bolis and Maggi [14] also studied the choice of carrier service by shippers. They interviewed 22 Italian and Swiss shippers. The SP experiment they used involved rating of carrier service alternatives against a benchmark. The alternatives were defined by their cost, travel time, on-time delivery percentages, frequency of service, and flexibility in terms of notice time to the carrier. The experiment also included rail options. With the exception of the service flexibility all attributes were significant in the model with travel time and cost being the most important. However, shippers that are involved in just-in-time operations, place much higher value on on-time performance and flexibility compared to other companies. They also found differences in the values of the attributes between Italian and Swiss companies.

de Jong et al. [39] developed models of shipping service choice for shippers and carriers. They collected both revealed preference (RP) and SP data from 135 shippers and 59 carriers in the Netherlands. Respondents were presented with up to 16 SP scenarios in which they chosen between two alternatives. The presented attributes were cost, travel time, the frequency of service and the fractions of late deliveries and shipments damages in transit. Attribute values were based on those observed in the RP choice. Ultimately, the authors chose to only use the SP data in their analysis. They found that all these factors are significant in explaining service choices. They also develop separate models for shipments of raw material and finished products and containers, and account for differences between low and high value shipments. They find that the value of on-time delivery is higher for finished products and containers compared to raw materials.

Jovicic [40] also combined RP and SP data on shippers' service choice. They used data from three previous studies in Denmark. The alternatives presented to respondents included similar attributes as in most other studies in this area: cost, travel time, risk of delays and damage to the shipment and frequency of service. In addition, the schedule flexibility and availability of an information system were also used. The analysis also included other modes of shipping. The results are presented separately for low-value and high-value shipments. The definition is based on the shipment industry. All the variables listed above were significant in the law-value shipping model, and all but the flexibility and information availability in the high-value shipping model. The most important variables were cost and travel time, with the risks of delays and damage and the service frequency being of secondary importance.

The studies discussed above mainly addressed the choice of carrier service. In the context of route choice in the presence of toll alternatives, Hunt and Abraham [43] conducted an

SP experiment in which respondents were asked to rank four route alternatives. These alternatives were defined by the travel time, toll cost, method of payment (with or without stopping at a booth), the primary road type (freeway or surface street), and the probability and magnitude of delays. Participants included 101 truck drivers and 141 managers in carriers in Montreal, Canada. Two sets of scenarios were used in the experiment for short-haul (less than 20 minutes long) and long haul trips. Respondents were assigned to either of these two sets, based on the travel times they reported for a recently completed trip. However, in the model they developed, the authors did not distinguish between observations of short and long haul trips or between the choices of drivers and managers. The authors found that, except toll collection method, all the attributes they considered had significant effects on route choices. The effect of delays was very large with the value of delay being greater than the VOT.

A few studies relied on other types of data. Knorring et al. [47] used global positioning systems (GPS) to record the movements of about 250,000 trucks over 13 days. From these data they extracted the actual route choices for ten specific origin-destination pairs in the US. These OD pairs are characterized by providing long-haul truckers a choice between a route passing through the CBD of a metropolitan area and a bypass route. The final data set included 9053 truck route choices. None of the routes used involved tolls. No additional information was available about the shipments or drivers. The model they developed captures the trade-off between speed and travel distance. The results showed that drivers are willing to trade an increase of their travel distance by 1% for a gain in speed of 0.4 mph.

This study exemplifies the great potential of the use of GPS data, which is available in large quantities from in-truck navigation systems. However, it also shows the need to complement the location data with additional information related to the attributes of the trip and the constraints imposed by the shipment schedule and other factors.

Hyodo and Hagino [44] hypothesize that trucks use shortest paths with respect to some generalized cost functions. They estimate these functions with records of 24,497 marine container truck trips to/from the Tokyo and Yokohama ports. These records were obtained from the computerized system that truckers use to apply for (mandatory) traffic permits. They find that in addition to the effect of tolls and travel times, truckers tend to prefer routes comprised of links that have at least two lanes in each direction and that have either height or weight designations.

Qin et al. [61] studied the impact of advisory information in the context of work zones on truck route diversion choices. The data was collected for a work zone on I-39/90, a major truck corridor in the Midwest. Loop detector data was collected on the highway with active work zone and on alternative diversion routes allowing estimating the fractions of truckers selecting each alternative. Contrary to their a-priori expectations the advisory information provided did not have a significant effect on route choices. Variables that explained route choices were the time of day (truckers tended to use diversions more in day trips compared to night trips), the total traffic flow approaching the work zone (trucks used diversions more when flows were higher) and the percentage of trucks in the traffic flow (trucks tended to use diversions less when this fraction was higher). The authors do not offer plausible interpretations for these results, which may be capturing the effects of other underlying factors. While their results do not provide evidence to support this argument, the authors raise the point that truckers route choices should be affected also by the conditions they are faced with, in this case expressed by the information they receive through the advisory message signs.

Zhou et al. [75] studied the effects of various incentives on the use of toll roads. They conducted an SP survey in Texas with a focus on the choice between the tolled State Highway 130 (SH-130) and the free I-35. 2023 drivers participated in the survey that was administered both online and by paper. Participants were first asked to rate 20 different incentives. The highest rated incentives were those related to various discounts on tolls and fuel, road services available on the toll road (truck stops, parking, repair facilities) and the toll road design (shoulders, signing, lighting and ramps). In addition, choice experiments in which the respondents were asked to choose between the toll and free alternatives in scenarios that involved price-related incentives were administered to 187 of the participants. The results showed the potential appeal of these incentives and in particular off-peak and plan discounts.

Wood [70] studied the factors that affect toll road usage. They collected data from drivers, carriers and shippers through face-to-face interviews and web-based surveys. The researchers distributed their survey through industry associations, including the Council of

Supply Chain Management Professionals (CSCMP), American Trucking Association (ATA), Owner-operator Independent Drivers Association (OOIDA), National Private Truck Council (NPTC) and Truckload Carriers Association (TCA), through trucking community forums and blogs and at truck shows and industry meetings. The SP experiment involved simple scenarios in which respondents were asked to state their willingness to pay various toll levels to save time in situations of travel on a long-distance turnpike, a CBD bypass, and a tolled bridge. In the analysis, the author attempted to detect the characteristics of drivers, carriers and shippers that affected their willingness to pay tolls. In most cases, only familiarity with the type of scenarios described in the questions was associated with an increased willingness to pay tolls. In addition to the SP experiment, the survey collected data on attitudes and perception of the participants towards tolls. Overall they find strong objection to tolls that are perceived as too expensive and aimed as a taxation mechanism. The participants also did not see toll roads as useful to them in helping comply with HOS regulations, improve on-time performance or safety. Participants also exhibited a strong perception that the use of toll roads poses an administrative burden to them.

Prozzi et al. [60] conducted a web-based survey of 112 carriers in Texas on their use of toll roads in the state. Truck toll road users were mostly private carriers (33%), followed by TL (28%) and LTL (15%). The majority of the non-users of Texas toll roads were TL carriers. Respondents were asked to list their main reasons for using or not using toll roads. The main reasons provided to use toll roads were time savings (39%) and reduced congestion (30%), with some respondents also noting better quality of toll roads (8%), safer travel (6%) and shorter distances (5%). The main reasons to avoid toll roads were that they were not relevant for their trips (35%), price (35%) and also inability to recover tolls from shippers (9%) and weights/oversize restrictions (7%). Non-toll users were also asked about the potential impact of various incentives on their use of toll roads. The incentives with the highest potential to increase toll road use were monetary ones: providing discounts for monthly plans or off-peak travel or refund for fuel taxes and improved availability of truck stops and services.

Also in the area of passenger traffic, there have not been many studies that addressed the impact of toll facilities on route choice. The only study we are aware of in this context is that of Ramming [62]. The author used RP observations of travelers in the Boston area to develop route choice models. The final model specifications explicitly include dummy variables for three toll facilities in the Boston area: a toll road and two toll bridges. The estimated parameter values were negative for the toll road and positive for the two toll bridges. This result suggests that the toll facility dummy variables may also be capturing the prominence of these facilities in the network and delays that may occur at toll collection booths. Other variables included in the model were free flow times, delays (interacted with drivers' income), road types, shortest paths in terms of distance and travel time and latent variables of network knowledge.

3.3 Summary

The focus of most of the literature reviewed above is on VOT, namely on the variables cost and travel time. While these are consistently important determinants of trucks' route choices, they are not the only important ones. Several of the studies that considered the risk of delays have demonstrated the importance of this factor, which can be directly linked to on-time delivery. These studies found that the value of delays, at least for some segments of the industry, is higher than VOT. Several other factors, characteristics of the shipment and carrier and of the trip, have also been linked to route choices in the literature. Shipment and carrier attributes include the commodity or industry type, cargo type and value, the carrier type and its fleet size. Trip and driver attributes include the driver's compensation basis, the entity that bears toll costs, the trip length and the type of facilities being served. These results, together with the high variability in VOT estimated in the literature, seem to suggest that route choices are complex and affected by the specifics of the trip in question. The availability and use of information was considered in two studies [40],[61]. Neither of these found it to be an important factor. Modern trucks and truck operators already use sophisticated tracking and navigation systems, and so additional information from external sources may not have a large effect on trucking operations. Truck route choice is also made in a tightly regulated and constrained environment. Government HOS and road use regulation and contractual requirements on delivery times and windows limit the options that truckers face. On-time delivery is also the main service attribute by which carriers and drivers are evaluated. However, these situational constraints have not been integrated in the models reported in the literature. The study of Miao et al. [52] is the exception in this respect. It considered situations in which the delivery is on time or behind schedule and found large differences in the willingness to pay for time savings in these two situations. Another indication to the importance of the delivery schedule is the high VOT found for express and just-in-time services. Other constraints that have not been accounted for in existing models, but may impact routing decisions are related to the availability of road services including parking facilities and gas stations along the various routes. There is a shortage of truck parking in the US, especially around urban areas. Truck stops, gas stations and repair shops are important facilitators of trucking activity. Many carriers have discount agreements with specific chains and so have strong preferences to routes that enable them to get the services they need. Finally, the HOS regulations may substantially affect truck scheduling and routing. As suggested by Wood [70], it is plausible that the time savings that may be obtained by using toll roads are meaningful when this time can be used to add a paying trip within the allowed work shift. There have been attempts in the literature to optimize scheduling under the HOS and labor constraints (e.g., Xu et al. 2003 [72], Portugal et al. 2006[58], Min 2011[53]). However, to the best of our knowledge, no studies have considered the effects of HOS regulations on routing. The contractual shipping terms have also not received much attention in existing literature. Miao et al. [52] and Kawamura [46] both found that the driver's compensation basis affects their choices. Miao et al. [52] also found that the willingness to use toll roads depends on who ultimately bears this cost. However, there may be other terms that affect routing, such as late delivery penalties, the delivery schedule and window, the involvement of hazardous materials, fuel surcharges, the driving arrangement and so on.

Finally, most of the studies in the literature used SP data. As demonstrated by Knorring et al. [47] data from truck tracking devices, commonly using GPS, can be obtained in large quantities and high quality. These data provide much more reliable and rich information on the routes truckers use in real-world situations. However, as discussed above, the routing information by itself is not sufficient to understand routing behavior. It needs to be complemented with other information on the shipment, trip and situational constraints.

Chapter 4

Experimental Design and Data Collection

Chapter 3 summarizes existing studies on truck route choices, where very few have addressed the complexity and heterogeneity of the industry, and others based their approaches on flawed assumptions. Many determinants of truck route choices have been studied in separate studies, while no one has come up with a comprehensive approach that aims at collecting information about the entities, the specifics of the trips, as well as the external resources that may be affecting the decision-making process.

This survey was designed to provide a comprehensive look at all factors, many of which were identified by existing studies which to date have not provided a holistic view. The importance of truck demand forecasting, the complexity of the industry, together with the lack of research attention, motivated this new data collection design.

Data on the decision-making process related to truck routing and the factors that affect it, was collected using a computerized survey. In the processes of learning the relevant factors and behaviors, three different versions of questionnaires were administered at four points in time and in different locations. Following each of the first two data collection exercises, the questionnaires were revised based on the results and feedback that were obtained. In addition two on-line versions of the survey were developed: one oriented at truck drivers and the other at personnel at trucking companies and other entities. This chapter presents an overview of the information that was solicited within these surveys.

The questionnaires included two parts. The first part collected information on the routing decision making for the shipment they were transporting at the time of the interview. In addition, information on the driver and carrier characteristics, the contractual or employment terms for the driver (i.e. basis for calculation of compensation and terms related to the costs of fuel and tolls) was collected. The questionnaires for the first parts are available in Appendix. The second part included a Stated Preferences (SP) experiment. Respondents were asked to choose between two hypothetical route alternatives.

4.1 Data Collection

The background information was solicited on the characteristics of the driver, the carrier and the current shipment, as well as on the process of the route decision-making, the entities (drivers, carriers, shippers) that are involved in it and the relevant aspects of the relations between them.

Table 4.1: Background information collected in the survey

Information category	**Data collected**
Carrier and current shipment	Private fleet/for hire carrier TL/LTL Commodity type transported Specialized services (e.g., hazmat, temperature controlled) Electronic toll tag availability
Driver	Owner-operator/hired driver Years of experience
Employment terms	Method of pay calculation (e.g., by mile, hour, percentage of load) Bearer of fuel costs Bearer of toll costs Penalties for late delivery Metrics for driver performance evaluation
Truck routing	Identity of decision maker Flexibility to make changes en-route Sources of information used in planning and en-route Factors affecting route choices

Table 4.1 summarizes the information items that were solicited in this part.

The basic characteristics of the driver, carrier and shipment were collected based on the main classifications developed in the previous report. In addition, information on the availability of electronic toll tags was solicited as a factor that may affect the choice of use of toll roads. The information related to the employment terms, that define the relations between drivers and carriers or shippers includes the basis for calculation of pay, the bearers of fuel costs and tolls, penalties for late deliveries, and metrics used by carriers and shippers to evaluate the performance of drivers. It is expected that these arrangements affect the importance that routing decision makers place on various factors and risks in making these decisions. For example, if drivers make routing decisions, it is plausible that they would be less willing to use toll roads when they personally bear the tolls as opposed to when these are fully paid by the carrier or shipper.

Participants were also asked to explain the routing decision making process. Specifically, they were asked on the identity of the decision maker, their ability to change routes while on their way for various reasons, the sources of information they use in planning their routes and to change routes while they are on their way. Finally, they were explicitly asked to report factors that are considered in making route choices.

4.2 Stated Preferences (SP) Experiment

The SP experiment presented respondents with hypothetical route choice scenarios. In each case, they were asked to state which route they would choose from two alternatives that differed in the values of several factors, among them the attributes of toll or free road, the travel times and distances.

The SP questions were developed around two typical scenarios in which toll roads exist:

- Bypass scenario: A choice between an urban freeway passing through the downtown of a metropolitan area and a bypass alternative, which has longer distance, but less congested and so may be faster. The bypass may also be tolled.
- Turnpike scenario: For a long section of a trip passing through a rural area, a choice

between a tolled highway and a free parallel road, which offers a lower design level (e.g. includes signalized intersections).

With both scenarios the questions were set in the context of a future trip with the same origin, destination and delivery (or pick-up) schedules as the one the drivers were transporting at the time of the interview.

The attributes considered in the design of the questions and their values in each scenario are presented in Table 4.2. These values were chosen based on the results in the literature review and on inputs from the first survey conducted in Texas that did not include the SP part. Examples of questions from the two scenarios are shown in Figure 4-1 and Figure 4-2.

A design with 40 cases in ten blocks of four cases was developed using the AlgDesign package in R [68]. This procedure uses Fedorov's algorithm applied to a randomly selected subset of the possible set of candidate cases to obtain the D-optimal design and blocking. Each respondent was randomly assigned with one block for each scenario. Thus, each respondent was presented with a total of eight cases.

Table 4.2: Factors and their levels in the SP experiment

Scenario	Factors	Levels
Bypass	Difference in travel distance (miles)	5, 10, 15, 20
	Difference in expected travel time (min.)	0, 10, 20, 30
	Frequency of delays that exceed	0, 1, 1, 2 (bypass - v1)
		0, 1, 2, 4 (bypass - v2)
	30 min (in 10 trips)*	0, 2, 4, 6 (downtown -v2)
	Toll amount ($)	0, 5, 10, 15
	Toll payment method	Cash, Electronic
	Toll bearer	Driver, Other
	Toll reimbursement method (if applicable)	Pre-paid, Reimbursed
Turnpike	Difference in travel distance (miles)	-20, -10, 0, 10, 20
	Difference in expected travel time (min.)	0, 15, 30, 45, 60
	Toll amount ($)	10, 15, 20, 25, 30
	Toll payment method	Cash, Electronic
	Toll bearer	Driver, Other
	Toll reimbursement method (if applicable)	Pre-paid, Reimbursed
	Free road type	2 lane undivided, 4 lane divided

* In the first version of the SP experiment, drivers were asked to report delay probabilities that they have experienced for the downtown route and to use these in their SP responses.

They were only given the values for the bypass alternatives. Later, they were given values for both alternatives.

In the following questions, consider a future trip with the same origin, destination and delivery (or pick-up) schedule as the current leg of your trip. Suppose that for a part of it, passing through an urban area, there are two alternative Interstate routes: The first route passes through the center of the urban area. The second route bypasses the urban area. In each case, please select the route you would choose

The two routes have the following attributes:
The travel distance is 10 miles longer on the bypass route
The travel time is 20 minutes less on the bypass route
Delays that exceed 30 minutes occur on 0 in 10 trips on the urban route
Delays that exceed 30 minutes occur on 4 in 10 trips on the bypass route
There is no toll on the urban route
There is a toll of 15 USD on the bypass route
You have an electronic toll tag, and the cost will be reimbursed by the company or shipper

Which route will you choose?
- ☐ **Urban route**
- ☐ **Bypass route**

Figure 4-1: Example of bypass scenario question

In the following questions, consider a future trip with the same origin, destination and delivery (or pick-up) schedule as the current leg of your trip. Suppose that for a part of it, a section of 100 miles passing in a rural area, there are two alternative routes. The first route uses a a toll road. The second route uses a free road. In each case, please select the route you would choose.

The toll route is a 4-lane divided Interstate highway
The free route is a 2-lane undivided US highway with at grade intersections
The travel distance is 20 miles shorter on the toll route
The travel times on the two routes are the same
The toll charge is 25 USD
You have an electronic toll tag, and you are responsible for the toll cost

Which route will you choose?
- ☐ **Toll route**
- ☐ **Free route**

Figure 4-2: Example of turnpike scenario question

4.3 Survey Administration

The surveys were implemented on Apple iPad tablets using the iSurvey software application [36]. It was administered to drivers at rest areas and truck stops on three highway corridors:

- I-35 near Salado, North of Austin, Texas;
- Ontario Highway 401 near Ayr, west of Toronto, Canada
- Lake Station on the west end of the Indiana Toll Road

These locations are shown in Figure 4-3, Figure 4-4 and Figure 4-5, respectively.

In the Texas location the survey was conducted twice - first, on February 21th and 22nd 2012, and later on June 11th and 12th 2012. The February survey was the first one to take place in the project and served as a pilot. 92 responses were collected. These included only the items within the data collection, and not any SP experiments. In the May survey, 26 responses were collected. These included also the SP experiments. The questionnaire for this survey was identical to the one used in Indiana. The interviews were conducted in a state-owned roadside rest area on I-35 North of Austin. I-35 is a free highway. It is about 15 miles north of the interchange with SH-130, the toll road bypassing the Austin city center. This rest area had parking areas allotted for buses, trucks, and recreational vehicles. The facilities at the rest stop included vending machines, pay telephones and restrooms. There were no food outlets, convenience stores or gas services in this location. Therefore during the daytime the numbers of truckers stopping were relatively small. These drivers usually only stopped for short periods of time. Drivers showed up more frequently in the afternoon, to use the facility for overnight parking. These drivers were also more willing to participate in the survey. The rest areas were located on both sides of the road. The interviews were conducted one day on each direction.

The survey in Toronto was conducted at a truck stop off Ontario Highway 401. This location is about 40 miles west of the interchange of highways 401 and 407, which is the toll road in the Toronto metropolitan area. The facility offered a fuel stations, convenience store, restaurant and a truck washing service. The survey was held on April 17th through 19th 2012. Most drivers were interviewed while refueling their trucks. In some cases this meant that they became impatient and tended to leave once their vehicles were ready. Overall, 53 responses were collected. In addition to the above, this may be attributed to lower truck flows in the facility and to bad weather conditions.

The survey in Indiana took place from May 22nd through 24th 2012. It was conducted in a service area (travel plaza) southeast of Chicago on the Indiana Toll Road. Facilities in this location included three fast food restaurants, a convenience store, a fuel station, restrooms, and vending machines. Most of the drivers were interviewed while using the food facilities, and tended to generally be more willing to participate. As in Texas, the interviews were conducted in facilities on both sides of the road. A total of 81 responses were collected in these three days.

Overall, a total 252 responses were obtained in all locations with 1121 valid SP observations.

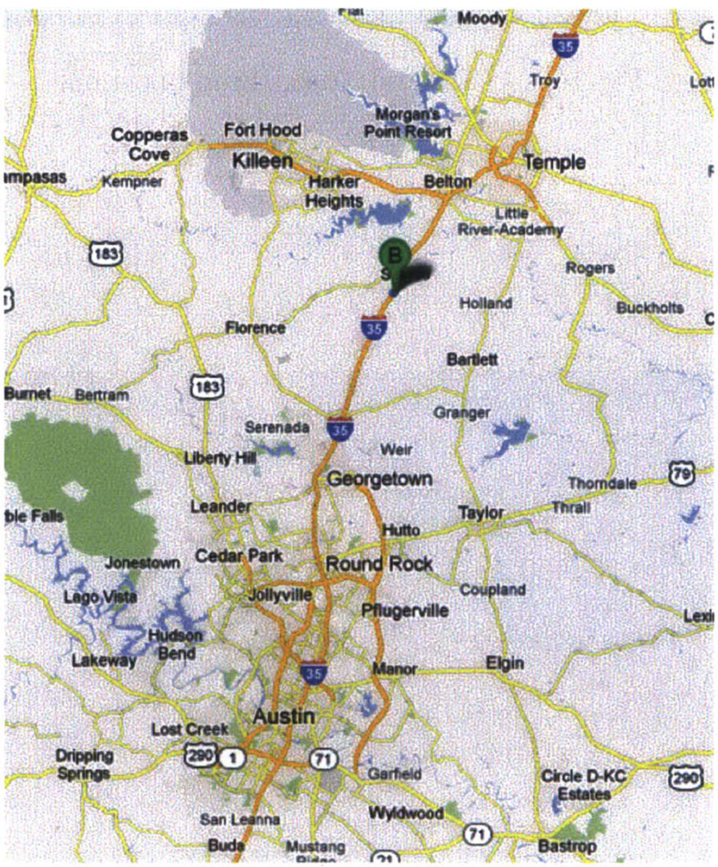

Figure 4-3: Texas Rest Area Location

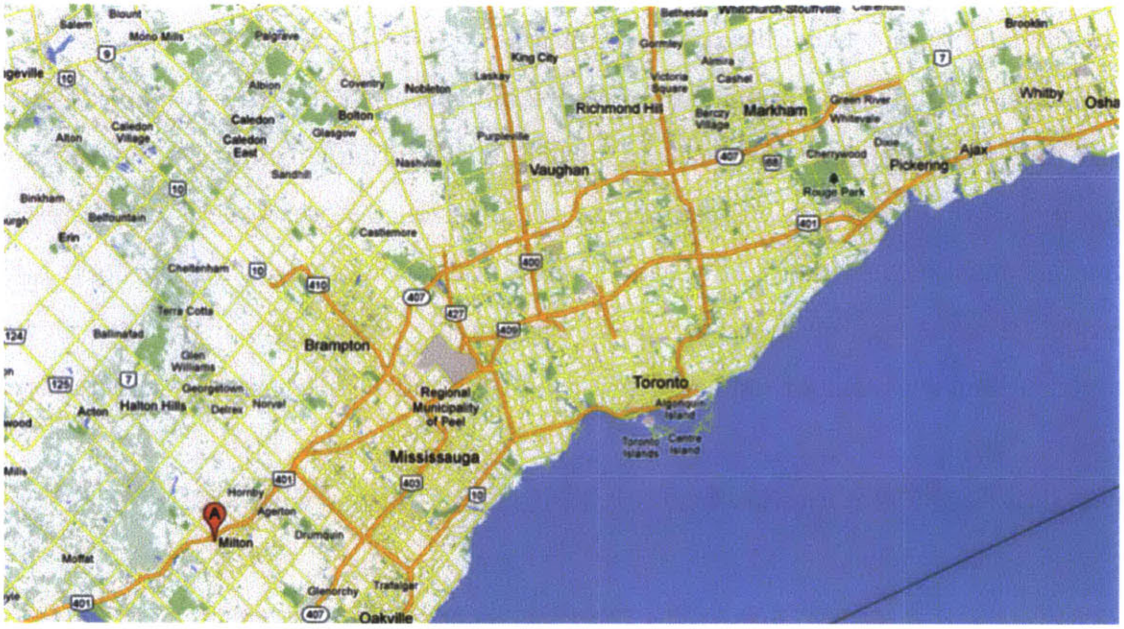

Figure 4-4: Toronto Trucks Stop Location

Figure 4-5: Indiana Truck Stop Location

Chapter 5

Dataset Statistics

This chapter provide summary statistics and analysis of the responses obtained in the surveys described in the previous chapter. The analysis refers to several aspects:

- The composition of the sample in terms of the types of drivers, carriers and shipments they transported.
- The employment terms for the drivers that may be relevant to their routing.
- The route decision-making process pre-trip and en-route.
- Sources of information used in planning the route and to learn about conditions that may prompt changes in routing.
- Factors that affect routing decisions
- Availability of electronic toll tags

The results presented below are derived from the responses in all three locations. For some items, there were differences (questions were added) between the questionnaires used. Therefore, the sample sizes relevant to each analysis differ. The collected data set includes responses from 252 drivers (118 in Texas, 53 in Ontario and 81 in Indiana).

5.1 Sample Composition

The sample makeup in terms of the characteristics of the driver and the shipment transported are presented in Table 5.1.

Table 5.1: Driver and shipment characteristics

	Characteristic	**Overall** (N=252)
Driver type	Hired-Company	56%
	Hired-Private	19%
	OO-Leased	19%
	OO-Own	6%
Years of experience	Less than 1	4%
	1 to 2	6%
	3 to 5	9%
	5 to 10	16%
	Over 10	63%
	Not Answered	2%
Shipment type	TL	78%
	LTL	10%
	Others	12%
Specialized Service	None	72%
	Hazmat	5%
	Wide	2%
	Temp. control	16%
	Others	5%

Most truck drivers that participated in the surveys, 75% overall, were hired drivers. Within those, the larger share was of drivers for for-hire carriers and the rest were drivers for private fleets. This result differs from government statistics that suggest a reverse split. The difference may be explained by differences in the utilization of trucks and in their levels of usage of truck stops. It may also be a result of incomplete responses and understanding of the specific question. In particular in Toronto, the distinction between for-hire carriers and private fleets was not made clear. Therefore the results for these two groups are shown together. In addition, 19% of drivers are owner-operators (OO) that lease their services to a larger carrier or shipper. The remaining 6% are OO working under their own authority as self-employed independent contractors and haul free-lance. This share is consistent with figures published by the Census Bureau [67]

Drivers levels of experience may affect their familiarity with the road network and their willingness to use alternatives routes. 63% of drivers had been driving for over 10 years, and only 10% had less than 3 years of experience. This result is consistent with reports that warn from the aging of the truck drivers' population in the US, and of shortage of new drivers. [3]

78% of shipments transported by the trucks when interviewed were TL. This is a bit higher compared to industry estimates that 60% of trucks are in TL service and that they drive 72% of the mileage [67]. Of the rest, 10% were LTL shipments and 12% were parcels, empty trips or others. The lower-than-expected share of LTL shipments may be because these trips tend to be shorter and so may less frequent users of truck stops and rest areas.

Most trips (72%) did not involve any special shipping service. 16% involved temperature control and 5% involved shipment of Hazmats. These numbers compare well with estimates that refrigerated vans are used in 9% of the truck-miles [67] and that Hazmats constitute 8% of the ton-miles [25] driven in the US.

5.2 Employment terms

Some aspects of the drivers employment terms, especially those related to compensation and bearing of various costs, may affect routing decisions. The employment terms for the overall sample and for the hired and OO segments are summarized in Table 5.2.

The majority of drivers are paid a fixed amount for a specific trip, which does not depend on their routing. Most commonly, drivers are paid by book miles. The only two payment calculation methods in which that relate to the actual travel time and distance are drivers paid by hours (12%) and to lesser extent drivers paid by actual miles (12%). Some hired drivers are paid by actual miles or by hours (14% and 15%, respectively). These methods are less frequent for OOs (3% and 6%, respectively). The terms are very different for hired drivers and OOs with respect to fuel and toll costs. For 92% of hired drivers, but only 5% of OOs, the company is responsible for fuel costs. The situation with respect to toll is similar. 89% of hired driers, but only 24% of OOs reported that their company is fully responsible for tolls. OOs are also less likely compared to hired drivers (50% and 68%, respectively) to have electronic toll collection (ETC) tags.

Table 5.2: Employment terms by driver type

	Characteristic	Overall (N=252)	Hired (N=192)	OO (N=64)
Pay calculation method	Book miles	47%	48%	38%
	Actual miles	12%	14%	6%
	Hours	12%	15%	3%
	Others	29%	23%	53%
Bearer of fuel costs	Company	69%	92%	5%
	Driver - partially	15%	2%	54%
	Driver	16%	7%	41%
Bearer of toll costs	Company	74%	89%	24%
	Driver - partially	2%	68%	50%
	Driver	16%	5%	14%
	Other/no answer	8%	3%	56%
Electronic toll tag	With tag	65%	68%	50%
	Without tag	35%	32%	50%

5.3 Routing Decision-Maker

In identifying the routing decision makers, a distinction was made between pre-trip route planning and en-route adjustments. In the route planning phase, drivers may be assigned a route or choose on their own. An assigned route may be mandatory, or a recommended one that they can ask for approval to change or freely choose another one. Drivers that choose their routes may be required to do so from a set of pre-approved alternatives, get their chosen route approved, or be to make their own choice. En-route drivers may not be allowed to change routes at all, may ask and be assigned a new route, or they may change their route on their own freely or after getting approval for the change.

Table 5.3 shows the distribution of responses for both planning and en-route decision-making for the overall sample and various segments within it.

The majority of drivers report that they are responsible for routing decisions. At the planning stage 65% of drivers were free to choose their own routes. Only 16% were assigned a route that they had to follow. While en-route, drivers have even more flexibility to change their routes. 84% reported that they could change their routes freely. Only 2% cannot change at all or will be reassigned a route by their company. This result indicates that drivers have substantial responsibility in managing their routes. OOs, almost always, decide their own routes, both at the planning stage and en-route. In contrast, only 53% of hired drivers freely choose their own routes. The rest experience different levels of supervision, with 21% taking required follow routes assigned to them. Still, 96% of hired drivers can change their routes while driving, either freely (80%) or after obtaining approval. Drivers carrying LTL shipment play lesser roles in deciding routes. Only 50% of LTL drivers choose their own route freely, compared to 65% of TL drivers. At the other extreme, 25% of LTL drivers must follow an assigned route, as opposed to only 16% of TL drivers. While the sample size for LTL is rather small, these patterns are consistent in all decision-making options. Similarly, 85% of TL drivers may change their route freely while driving, compared to only 75% of LTL drivers.

Table 5.3: Planning and en-route routing decision-making by driver and shipment type

		Overall (N=153)	**Driver type** **Hired** (N=114)	**OO** (N=39)	**Shipment type** **TL** (N=119)	**LTL** (N=16)
Planning	Assigned - must follow	16%	20%	5%	16%	25%
	Assigned - approval	2%	3%	0%	1%	6%
	Assigned - freely	8%	11%	0%	9%	13%
	Choose - alternatives	7%	10%	0%	7%	6%
	Choose - approval	2%	3%	0%	2%	0%
	Choose - freely	65%	54%	95%	65%	50%
En-route	Not allowed	3%	3%	0%	1%	6%
	Reassigned	1%	1%	0%	1%	0%
	Approval	12%	16%	0%	13%	19%
	Freely	85%	80%	100%	85%	75%

Table 5.4 shows the routing decision-makers for various driver segments in terms of the bearer of fuel and toll costs and the method of pay calculation. Drivers may be fully, partially or not at all responsible for the cost of fuel and tolls. Drivers that are fully or partially (e.g. receive surcharges) responsible for fuel costs overwhelmingly have the right to choose routes on their own. Drivers that are not responsible for fuel costs at all are more restricted in their

routing: only 53% chose their routes freely; 20% were assigned routes that they must follow; 81% can change their route while driving. A similar pattern is observed for toll costs. 89% of drivers that are fully or partially responsible for tolls select their own routes, and 100% can freely change their routes while driving. In contrast, when drivers are not responsible for tolls, only 57% in pre-trip and 82% en-route chose routes freely. As for drivers payment method, the category that combined payment options that are unrelated to routing (i.e. fixed amounts or depending on the load weight, value or the freight charges) had the highest level of freedom in choosing routes (81% pre-trip and 91% en-route). Drivers paid by hours, whose pay depends the most on routing decision had the least flexibility in making decisions (47% and 71% for pre-trip and en-route, respectively).

Table 5.4: Planning and en-route routing decision making by employment terms

	Driver pays fuel			**Driver pays tolls**			**Pay method**			
	No (N=118)	Partly (N=23)	Yes (N=18)	No (N=32)	Partly (N=4)	Yes (N=24)	Book miles (N=66)	Actual miles (N=20)	Hours (N=17)	Others (N=53)
Planning										
Assigned - must follow	20%	9%	6%	12%	0%	8%	21%	20%	23%	9%
Assigned - approval	3%	0%	0%	3%	0%	0%	1%	0%	12%	0%
Assigned - freely	12%	0%	0%	16%	0%	4%	18%	5%	6%	0%
Choose - alternatives	9%	0%	0%	6%	0%	0%	5%	15%	12%	6%
Choose - approval	3%	0%	0%	0%	0%	0%	2%	0%	0%	4%
Choose - freely	53%	91%	94%	63%	100%	88%	53%	60%	47%	81%
En-route										
Not allowed	3%	0%	0%	3%	0%	0%	2%	5%	6%	2%
Reassigned	1%	0%	0%	0%	0%	0%	1%	0%	0%	0%
Approval	15%	4%	0%	9%	0%	0%	14%	10%	23%	7%
Freely	81%	96%	100%	88%	100%	100%	83%	85%	71%	91%

Table 5.5: Planning and en-route routing decision making by Specialized services

	Hazmat (N=7)	**Temperature controlled** (N=22)	**None** (N=100)
Planning			
Assigned - must follow	0%	14%	19%
Assigned - approval	14%	5%	1%
Assigned - freely	14%	9%	7%
Choose - alternatives	0%	0%	9%
Choose - approval	14%	5%	2%
Choose - freely	57%	68%	62%
En-route			
Not allowed	0%	0%	3%
Reassigned	0%	5%	0%
Approval	29%	14%	12%
Freely	71%	82%	85%

5.4 Sources of Information

Information about the sources of information that drivers use when planning their routes and the way they learn about delays on their routes while driving was also collected. Drivers were asked to rate the frequency at which they use various information sources on a 5-point scale. The results are presented in Table 5.6. Drivers mainly base routing choice on their own prior experience. All drivers indicated that they rely on it at least half the time. Maps and navigation systems are also useful sources (62% and 65%, respectively use it at least half the time). En-route, other drivers are the most frequent source of information (72% use it at least half of the time). The company is not perceived as a significant source of information at any stage. Only 27% and 18% receive information from it at least half of the time, pre-trip and en-route, respectively.

Table 5.6: Sources of information used in making routing decisions

	Never 1	Seldom 2	Half 3	Usually 4	Always 5	Avg.	Std.
Planning							
Prior experience (N=11)	0%	0%	9%	73%	18%	4.1	0.5
Navigation (N=58)	26%	9%	20%	21%	24%	3.1	1.5
Map (N=58)	29%	9%	17%	21%	24%	3	1.6
Other drivers (N=11)	18%	46%	9%	27%	0%	2.5	1.1
En-route							
Company (N=11)	37%	36%	18%	0%	9%	2.1	1.2
Navigation (N=146)	53%	7%	6%	13%	21%	2.4	1.7
Highway Ratio (N=146)	40%	8%	15%	20%	17%	2.7	1.6
Other drivers (N=148)	21%	7%	16%	28%	28%	3.3	1.5
Company (N=149)	67%	15%	8%	6%	4%	1.7	1.1
No info (N=149)	21%	21%	23%	22%	13%	2.9	1.3

Table 5.7: Factors that affect routing decisions

	Never 1	**Seldom** 2	**Half** 3	**Usually** 4	**Always** 5	**Avg.**	**Std.**
Predictable travel time (N=57)	9%	7%	9%	24%	51%	4	1.3
Parking (N=58)	12%	7%	17%	17%	47%	3.8	1.4
Fuel Stations (N=58)	7%	5%	10%	16%	62%	4.2	1.2
Fuel Consumption (N=11)	46%	27%	27%	0%	0%	1.8	0.8

5.5 Factors affecting route choices

Respondents were also asked about the frequency at which several factors affect their routing decisions. Four factors were considered: travel time predictability, availability of parking locations, fuel stations that the driver can use and the effect on fuel consumption. The results are presented in Table 5.7. Drivers were most concerned with having fuel stations that they could use (88% at least half the time), followed by having predictable travel times (84%) and by being able to find truck parking (81%). In contrast, the effect of the route on fuel consumption did not factor in their responses. None of the respondents stated that they consider it usually or always.

5.6 Electionic toll collection tags

Finally, the questionnaires also collected information on the availability of ETC tags in the truck, which is expected to affect the use of toll roads. The results are presented in Table 5.8. Overall 64% of trucks were equipped with an ETC tag. As can be expected, penetration rates were lower for OOs, who often need to cover the costs themselves. Surprisingly, they were also lower for LTL shipments. This may reflect shorter haul trips or more regular service areas, which may allow drivers better familiarity with non-toll alternatives. In terms of toll bearers, the ETC penetration rate is highest (75%) when the company bears the toll cost either directly or through reimbursement. It is lowest (33%) when the driver is responsible for the toll cost. Note that the sample sizes for the cases that the driver is partially reimbursed or for other arrangements are very low and therefore the sample penetration rates for these are not meaningful. They are reported only for completeness. Nevertheless, the low sample sizes do indicate that these are uncommon employment terms.

Table 5.8: ETC penetration rates for various segments in the sample

	Group	**ETC tag penetration rate**	**Sample size(N)**
	Entire sample	64%	160
Driver type	Hired drivers	68%	120
	OO	50%	40
Shipment type	TL	71%	120
	LTL	44%	16
Toll bearer	Company	75%	123
	Driver partially	50%	4
	Driver	33%	24
	Others	50%	6

Chapter 6

Route Choice Model

All the surveys conducted after the first one in Texas also included a stated preference (SP) experiment. In this experiment each participant was asked to make a choice between two route alternatives. The alternatives were presented in the context of trips that are similar to the current trip they were interviewed in (similar pick-up and load-off locations, schedule and employment terms). The alternatives were defined by the attributes of road type, travel time and distance, frequency of unexpected delays and toll-related attributes: the cost, method of payment (ETC or cash) and bearer of toll costs. Examples of these choice scenarios were presented in Figure 4-1 and Figure 4-2 for scenarios of an urban bypass and a rural highway, respectively.

The reliability of the SP data is generally considered lower compared to that of revealed preferences (RP observation of choices made in the real-world) due to the hypothetical nature of the choice, the lack of implications (e.g. the costs associated with the various choices are not actually incurred) and the simplified presentation of the problem, which leads respondents to ignore some factors and situational constraints. Nevertheless, it is useful in order to get an initial idea about the key factors that affect route choices and about the trade-offs among them. This knowledge will be useful in designing the RP data collection that will be conducted later within the project. It will also help refine SP questionnaires that will be used together with the RP in order to enlarge the sample and increase the range of situations considered.

This chapter describes the route choice model that was developed using the collected SP data and presents the estimation results.

6.1 Model Framework

Figure 6-1 provides a conceptual framework for the route choice model. Explanatory variables include characteristics for the driver and carrier as well as employment terms. The other types of explanatory variables are attributes of the shipment and attributes of the alternative routes. Both the driver and carrier attempt to minimize cost to arrive at an optimal routing choice.

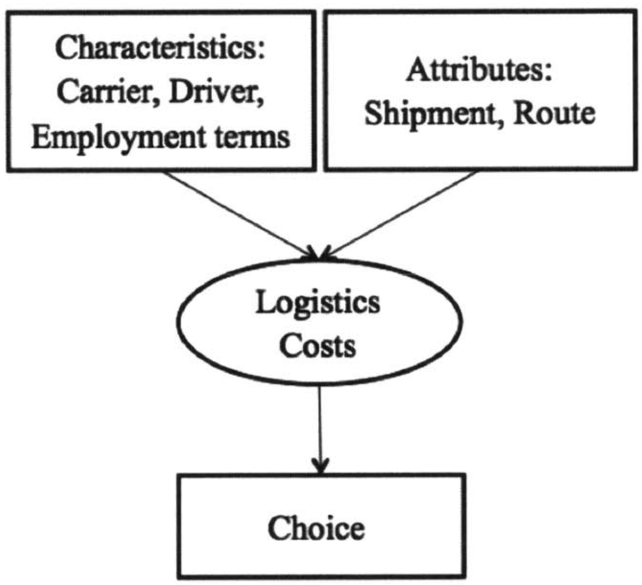

Figure 6-1: Conceptual Framework of truck routing decision-making process

The model was designed to predict the choice of routes by truckers. A binary choice model was used. The dependent variable is a discrete indicator for the chosen alternative. Each alternative in each experiment is associated with a utility function that depends on the attributes of that alternative and the characteristics of the decision-maker. The utilities also include an error term that captured the effects of unobserved variables and measurement errors. In order to make the route choice model applicable to trips that differ from the ones that were used to estimate the model, the utility specifications are generic (i.e. do not include any parameters that are specific to an alternative). Thus, the utility functions are given by:

$$U_{int} = V_{int}(X_{int}, \beta_n) + \epsilon_{int} \tag{6.1}$$

Where, U_{int} is the utility of alternative (route) i to individual n in choice experiment t. V_{int} is the systematic part of the utility function. X_{int} and β_n are the explanatory variables in the utility function and the corresponding parameters, respectively. ϵ_{int} is a generic error term. The error terms are assumed to be independently and identically drawn from a Gumbel distribution. The model assumes that drivers would choose the alternative with the highest utility. Under these assumptions, the predicted probability that driver n chooses route i in scenario t is given by:

$$P_{int}(i|\beta_n) = \frac{exp(V_{int}(X_{int}, \beta_n))}{\sum_{j=1}^{J} exp(V_{jnt}(X_{jnt}, \beta_n))} \tag{6.2}$$

Where, $P_{nt}(i|\beta_n)$ is the probability of choosing alternative i. J is the set of all alternatives considered by the driver. In these experiments, J={1,2}.

Note that the parameters are defined as individual-specific. That is, they are assumed to vary across drivers, but to be constant in all the experiments conducted with the same driver. This is done in order to capture the heterogeneity in tastes within the driver population. Ignoring taste heterogeneity can lead to inconsistent estimates of the model parameter, and affect the model's prediction power [9]. In the model estimation, the number of responses from each driver is small (up to 8) and therefore does not allow directly estimating a set of parameters for each individual. Instead, a random coefficients approach is used and the distributions of these parameters in the population are estimated.

In the current model, two coefficients are assumed to be distributed in the population: the coefficients of the toll amount and of a toll dummy (which takes value of 1 if the road is tolled and 0 otherwise). The coefficients will be formally defined below. Both are assumed to follow log-normal distributions (in order to ensure that their coefficients are always negative indicating that drivers prefer lower or no tolls to higher tolls). These distributions are not assumed to be independent of each other, as both coefficients represent the attitudes of drivers towards tolls. Therefore, their joint distribution is given by:

$$ln\left(\begin{bmatrix}\beta_{Toll,n}\\ \beta_{TollD,n}\end{bmatrix}\right) \sim \left(\begin{bmatrix}\beta_{Toll}\\ \beta_{TollD}\end{bmatrix}, \begin{bmatrix}\sigma^2_{\beta_{Toll}} & \sigma_{\beta_{TollD},\beta_{Toll}}\\ \sigma_{\beta_{Toll},\beta_{TollD}} & \sigma^2_{\beta_{TollD}}\end{bmatrix}\right) \tag{6.3}$$

Where $\beta_{Toll,n}$ and $\beta_{TollD,n}$ are the coefficients of toll amount and toll dummy for individual n, respectively. β_{Toll} and β_{TollD} are the corresponding mean parameters of the lognormal distributions. $\sigma^2_{\beta_{Toll}}$, $\sigma^2_{\beta_{TollD}}$ and $\sigma_{\beta_{TollD},\beta_{Toll}}$ are the standard deviations and covariance parameters of the joint log-normal distribution. These last five parameters characterize the heterogeneity in the population. These are the parameters that are actually estimated in the model. In addition, an individual specific error term ϵ_n is added to all alternatives in all the experiment that were presented by the same individual. This error term captures unobserved similarities and preferences for the individual across alternatives and experiments.

6.2 Model Specification

Table 6.1 lists the variables used in the specification of the final model that was estimated. The main three variables that we are interested in the trade-offs between them are the travel time, cost, and frequency of delays. The travel cost considered is the direct toll cost. The model also captures the effect of the use of a toll road, regardless of the toll cost, and whether or not the driver is responsible for the toll cost. The frequency of unexpected delays is also interacted with other characteristics of the driver and shipment in order to capture the different sensitivities to delays for various groups. The variables retained in the final model are the method of calculation for the driver pay and whether or not the shipment is temperature controlled.

Thus, the utility functions are specified with the following functional form:

$$\begin{aligned} U_{int} =&\beta_{downtown} + \beta_{free} + \beta_{time}Time_{int} + \beta_{toll,n}Toll_{int}+\\ &\beta_{tollD,n}TollDummy_{int}(1+\beta_{tollcompany}TollCompany_{int})+\\ &\beta_{delay}Delay_{int}(1+\beta_{delayHourly}DelayHourly_{int}+\\ &\beta_{delayTemp}DelayTemp_{int}) + \alpha_i\epsilon_n + \epsilon_{int}\end{aligned} \tag{6.4}$$

Table 6.1: Definitions of variables used in the estimated model

Variables	**Definition**
Dependent	
Y	Choice indicator: 1 for the chosen alterative, 0 otherwise
Independent	
Downtown	Downtown constant: 1 if downtown route in urban bypass scenario, 0 otherwise
Free	Free route constant: 1 if free route in rural turnpike scenario, 0 otherwise
Time	Travel time (hours)
Toll	Toll amount (2012 US$)
TollDummy	Toll road dummy: 1 if the route involves tolls, 0 otherwise
Delay	Number of trips with delays that exceed 30 minutes (out of 10 trips)
TollCompany	Toll road payment by company: 1 if company is responsible for the toll cost, 0 otherwise
DelayHourly	Number of trips with delays that exceed 30 minutes (out of 10 trips) if driver is paid by the hour, 0 otherwise
DelayTemp	Number of trips with delays that exceed 30 minutes (out of 10 trips) if shipment is temperature controlled, 0 otherwise

The models were estimated with the BIOGEME software for estimation of discrete choice models [11]. The method of simulated maximum likelihood as used with 5000 Halton draws.

6.3 Estimation Results

The model estimation results are presented in Table 6.2.

Overall, the estimated values of the parameters are in agreement with prior expectations. As expected, the signs for the coefficients of travel time, tolls and delays are all negative. These imply that increases in the values of these variables for a specific route alternative reduce the utility of that route and the probability that it will be chosen.

The constants in the model capture the preference of drivers to the specific types of routes described in the two experiment scenarios. In both cases they imply preference to higher quality and level of service roads. The constant for the downtown route in the urban bypass scenario is negative. This implies that, everything else being equal, drivers prefer the bypass route to the downtown route. Similarly, the negative constant for the free route in the rural highway alternative implies that, everything else being equal (including zero tolls), drivers prefer the toll route.

The coefficients of the toll cost and the toll dummy variables were estimated as random parameter with log-normal distributions. The estimated distribution of the toll cost parameters is given by:

$ln\beta_{toll,n} \sim N(\beta_{toll}, \sigma^2_{\beta_{toll}}) = N(-4.56, 1.53^2)$

The mean parameter value is:

$\beta_{Toll,n} = -exp(-4.56 + 1.53^2/2) = -0.0337$

The median parameter value is:

$\beta_{Toll,n} = -exp(-4.56) = -0.0105$

The mode parameter value is:

$\beta_{Toll,n} = -exp(-4.56 - 1.53^2) = -0.00101$

Similarly, the estimated distribution of the toll dummy parameters is given by:

$ln\beta_{tollD,n} \sim N(\beta_{TollD}, \sigma^2_{\beta_{TollD}}) = N(-0.565, 0.43^2)$

The mean parameter value is:

$\beta_{TollD,n} = -exp(-0.565 + 0.43^2/2) = -0.623$

The median parameter value is:

$\beta_{TollD,n} = -exp(-0.565) = -0.568$

The mode parameter value is:

$\beta_{TollD,n} = -exp(-0.565 - 0.43^2) = -0.472$

The toll dummy variable is also interacted with a dummy variable for the case that the company (and not the driver) is responsible for the toll cost. The estimate value for this variable is -1.08. This means that the negative impact of the toll road on the route choice when the driver is responsible for the toll cost is reversed when the company is responsible for the toll cost.

Other characteristics of the shipment and employment terms were interacted with the delay variable. The compensation for drivers that are paid by hours may increase when they experience delays on their trips. The estimation results show this effect, as they were much less sensitive to the risk of delays on the route. In contrast, drivers that were transporting temperature-controlled goods, were more sensitive to travel delays. This may reflect the higher time-sensitivity that may be associated with these shipments (often perishable) or the higher energy costs of keeping the required temperatures.

The estimated parameter values suggest significant trade-offs among travel time, the use of toll roads, toll costs and the frequency of delays. The estimation of random toll coefficients leads to a distribution of toll values of time. The VOT for the mean toll coefficient is 30 \$/hr. This value is consistent with figures reported in the literature. However, the range of VOT is wide with values from 30 \$/hr and 235 \$/hr between the first and third quintiles. This wide range reflects two extreme attitudes of drivers that were observed in the sample. On one extreme, one group stated that they will not use toll roads in any case. At the other extreme, drivers stated that they will always use the fastest route disregarding any tolls they may incur.

The wide range of attitudes towards toll roads is also apparent when considering the toll road dummy variable. This variable captures the attitude towards using the toll road itself, regardless of the toll amount. Drivers that pay for the tolls themselves, at the 25th percentile of the distribution would be willing to accept a 29 minutes additional travel time in order to avoid a toll road (before considering the toll cost itself). Drivers at the 75th percentile would be willing to accept additional 52 minutes of travel time to avoid the toll road. As noted above, this behavior is reversed when the driver is not responsible for the toll costs. In this case drivers are willing to incur additional travel times between 2 minutes (25th percentile) and 4 minutes (75th percentile) in order to use the toll road.

Two characteristics of the shipment and employment terms were found to affect the disutility associated with the risk of unexpected delays: drivers that are paid by the hour favor delays compared to other drivers. Drivers that transport temperature controlled shipments are more sensitive to the risk of delays. Other drivers are insensitive to delays, willing to trade-off only 2 minutes of travel time for a 10% reduction in the risk of delays that exceed 30 minutes. Drivers paid by hours are willing to accept 7 minutes longer travel times in order increase their risk of travel delay by 10%. While this result is not expected, it should be noted that the pay for these drivers increases when they are delayed in traffic. In contrast, drivers with temperature-controlled shipments are willing to increase their travel times by

16 minutes to reduce their risk of delays by 10%. This may reflect higher time sensitivity of these goods (perishables) and the additional energy cost for refrigeration associated with travel delays.

Table 6.2: Estimation results

Parameters	Estimated values	t-statistics
Downtown	-1.29	-5.9
Free	-0.965	-2.79
Time	-0.874	-2.84
Toll - mean	-4.56	-5.26
Toll standard deviation	1.53	2.37
Toll dummy	-0.565	-0.98
Toll dummy standard deviation	0.43	1.31
Toll dummy company	-1.08	-19.4
Delay	-0.0227	-0.67
Delay hourly pay	0.123	3.07
Delay temperature controlled	-0.204	-1.85
$\alpha_{downtown}$	0.976	4.11
α_{free}	1.13	4.65
$\sigma_{toll,tollD}$	-2.11	-2.62
Model Summary		
Number of observations:	1121	
Number of individuals:	143	
Number of Halton draws:	5000	
Final log-likelihood:	-630.86	
Rho-square:	0.188	
Adjusted rho-square:	0.17	

6.4 Demonstration

The choice between the toll bypass and free downtown routes is used in order to demonstrate the effects of the tolls on route choices. Figure 6-2 shows the estimated probabilities of choice of the tolled bypass as a function of the toll amount for drivers in the 1st, 2nd and 3rd quartiles of the probability distribution, for the cases that the driver or the company is responsible for tolls. The figure is based on an assumption of equal travel times and delay frequencies in the two routes.

For drivers that are responsible for tolls, the introduction of tolls (at toll value zero) sharply reduces the probability that they will choose the toll road. This captures their preference to avoid toll roads. In contrast, when drivers are not responsible for the toll cost, the introduction of tolls does not affect their route choices. Further increases in the toll amounts negatively affect the probability of toll road choice in all cases.

The figure also shows the wide variability in drivers preferences towards the toll road. The choice probabilities are much lower for drivers that are responsible for the toll cost. But, even within the same segment, and in particular for drivers who are responsible for the toll cost, there are very large differences in the toll road choice probabilities between drivers in the 1st and 3rd quartiles of the distribution (e.g. between probabilities of 0.03 and 0.62 for \$50 tolls).

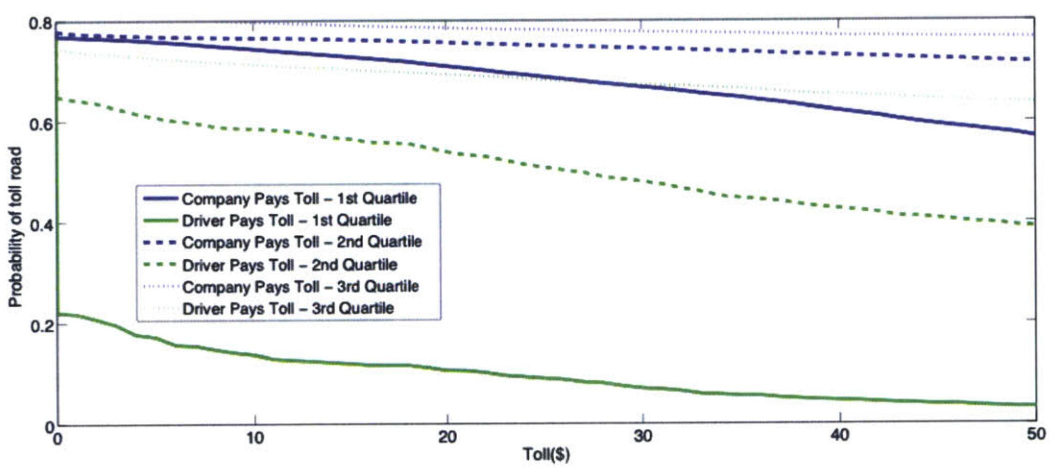

Figure 6-2: Effects of Tolls

The price elasticity of toll bypass is demonstrated in Figure 6-3. The percentage change in probability of choosing the toll bypass given 1 % change in the current toll level, is expressed as a function of toll amount. Similarly, drivers in the 1st, 2nd and 3rd quartiles of the probability distribution of toll coefficient are demonstrated respectively, for the cases that either the driver or the company is responsible for tolls.

It is clear that toll level has larger impact on driver's decision of choosing toll road, as toll becomes higher and higher. The impact is always negative. This is true either the driver pays or not. Therefore, even if drivers did not demonstrate clear adversion to the introduction of toll in the case where they were not responsible for it, toll still negatively affects their perception of the choice.

That being said, it is also observed that the price elasticity of the case when company is paying, is almost always smaller than that of the case when driver is paying. The offset between each pair of lines is the effect that captured by the dummy denoting company paying tolls.

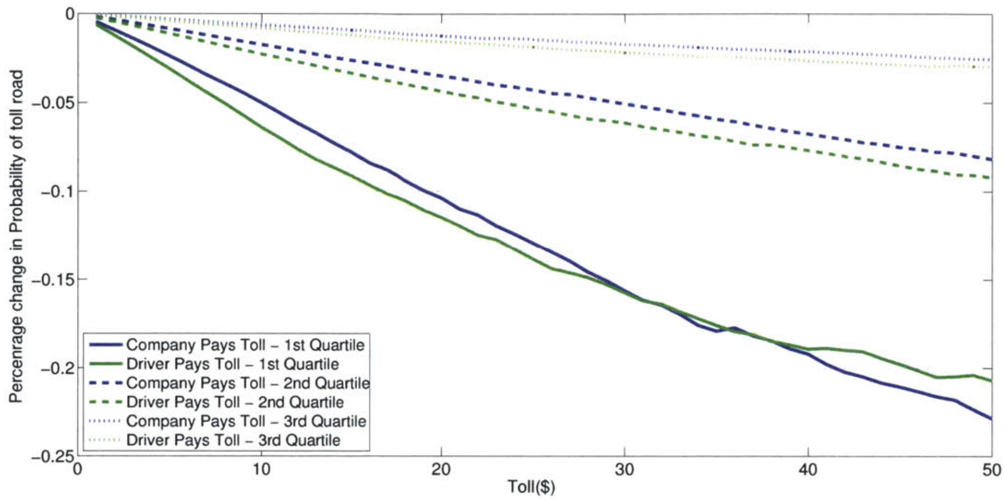

Figure 6-3: Price elasticity of Toll road demand

Next, the willingness to pay (WTP) for travel time savings and for delay reduction are plotted. Figure 6-4 shows the WTP to reduce travel time or Value of Time. Since the existing literature mostly treated VOT as a constant for any given population, in any circumstances. However in any real population, this value differs widely from individual to individual, and depends on circumstances of any particular trip. Therefore, here the VOT is treated as a random variate among a given truck driver population that is described statictically in terms of its perception of toll levels, i.e. $\beta_t oll$. The distribution of the toll coefficient is simulated to get 50,000 virtual observations. Each observation is then used to calculate a unique value of time. Then the VOTs are ordered and plotted as a ranked set of data, with the ith percentile spliting the lowest i % occurence of the simulated data.

The distribution of VOT is skewed to the left, shape of which mimics a beta distribution of $\alpha = 4.5$, and $\beta = 0.45$. The mean VOT is 30 \$ /hour, as mentioned above, however, the extremely large variance was observed and captured in a random distribution. In real terms, the large variance could be explained by driver's strong aversion to tolls when he/she is responsibel for the toll cost, and indifference to tolls when he/she is not responsible. Other explanatory factors, such as drivers' evaluation of the tradeoff between safety and (generalized) cost.

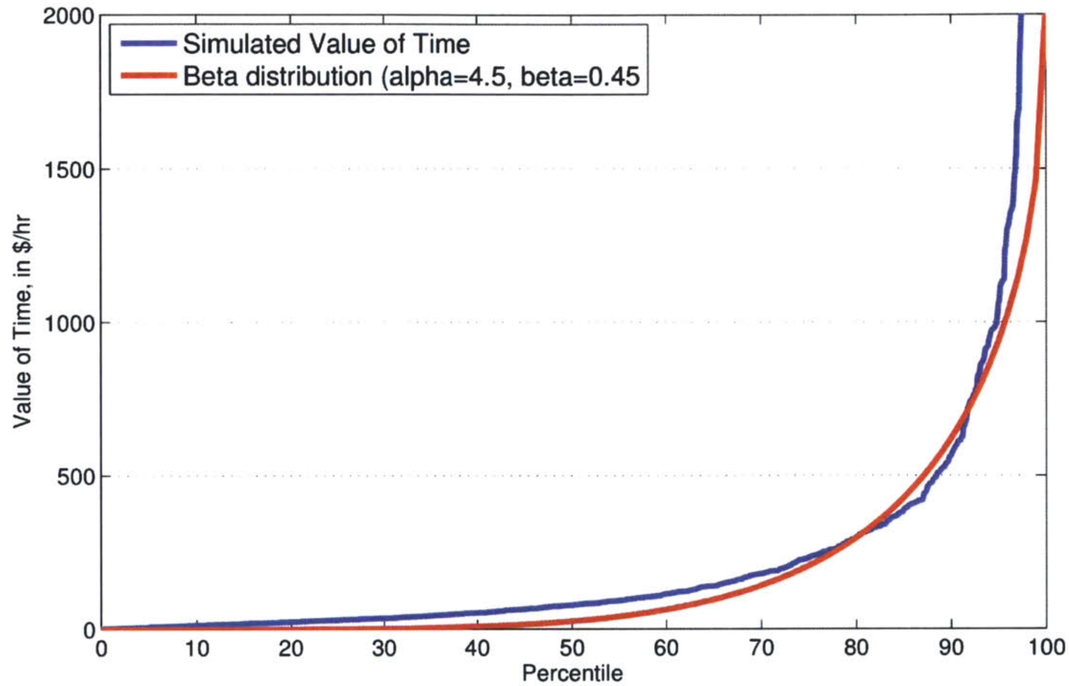

Figure 6-4: Value of Time, in $/hour

At last, drivers' willingness to pay for one unit of delay reduction is demonstrated in Figure 6-5. The willingness to pay is expressed as the extra amount of tolls one is willing to pay in order to reduce the delay risk. Again, 50,000 virtual observations have been simulated based on the distribution of toll coefficient. The horizontal axis represents a typical truck driver at a certain percentile of the population's toll coefficient distribution, and the vertical axis represents how much this virtual driver will be willing to pay for one unit of delay risk reduction. Note that since delay is specified as the number of delay trips out of 10 trips, one unit of delay risk is equivalent to 10 % reduction in delay probability.

The WTP profile is plotted for three cases: when driver is paid by hours (and not hauling temperature-controlled goods), when the driver is hauling temperature-controlled shipments (but not paid hourly), and when neither happens (other drivers). It is shown that the majority of "other drivers" are indifferent to delay, while hourly-paid drivers show clear interests in getting more delays, and drivers transporting temperature-controlled are more adverse to delay risks. This is consistent with the findings in Section 6.3.

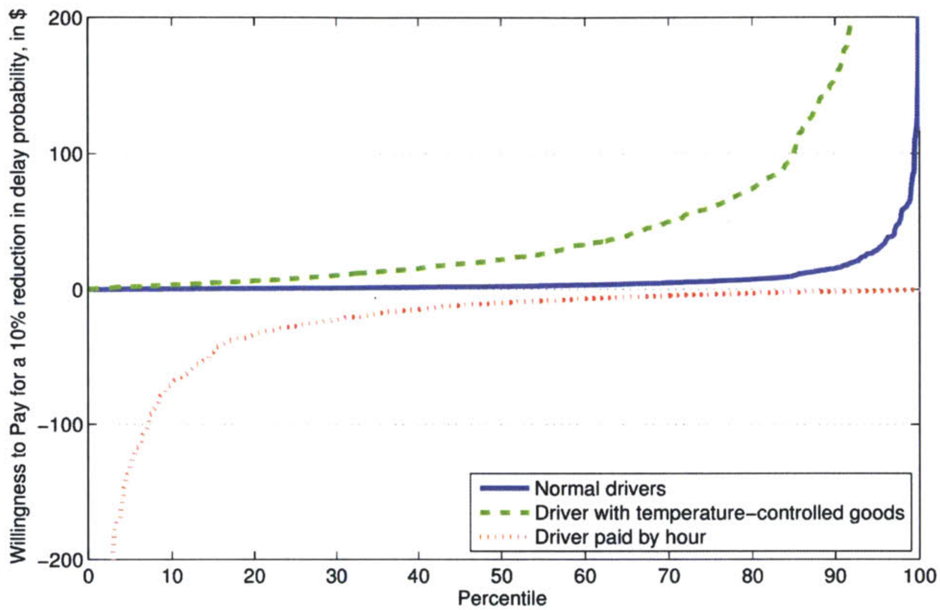

Figure 6-5: Willingness to pay for a 10 % reduction in delay probability

Chapter 7

Conclusion

7.1 Research Summary

This research studies the characteristics and considerations involved in truckers routing decision-making. Building on existing literature, this study designed survey questionnaires inquiring truck route choice decision-making process and the factors affecting truck route choice.

The questionnaires included two parts. The first part collected background information on the characteristics of the driver, the carrier and the current shipment, as well as on the process of the route decision-making, the entities (drivers, carriers, shippers) that are involved in pre-trip and en-route decision-making, and the relevant aspects of the relations between them. The basic characteristics of the driver, carrier and shipment were collected based on the main classifications developed in the trucking industry overview. The second part of the questionnaire was an SP experiment. Respondents were asked to choose between two hypothetical alternatives in two typical scenarios: urban and rural. The alternatives differed in the values of tolls, travel times, delay chances, distances, and so on.

Using data collected in intercept interviews with truck driver, statistics were developed to identify the routing decision makers, along with the impacts of employment terms, information sources, electronic toll collection tags on the decision-making process.

The second part of the questionnaire contributed to a route choice model to quantify the effects of the factors that explain these choices. In developing the model, the trade-offs between three variables were of interest: travel time, cost, and delay frequency. Direct toll cost, and a toll dummy representing the existence of toll represented the cost. The model also captures effects of whether the driver is responsible for the toll cost. Interactive terms were used to capture the different sensitivities to delays for various groups.

7.2 Research Contributions

This thesis draws on ideas from SP approach to itemize, prioritize, group, and quantify the determinants that affect the decision-making process and the truck route choice behavior from roadside intercept interviews. Building on the complex structure of trucking industry, the design of this questionnaire was greatly enhanced by integrating key ideas from existing studies.

Beyond the findings of existing literature, the results of this study explicitly showed the decision-making process in both pre-trip and en-route phases, and showed that in most cases the driver was the decision-maker before setting out on the road. This is especially the case for OOs and for drivers that are responsible, even if partly, for the cost of fuel and tolls. This finding contradicts the assumptions that most existing studies of truck routing are based on, for example: shippers and shipment schedules dictate routing decisions while drivers do not have a decision-making role in routing.

Furthermore, the sources of information that drivers consult in making routing decisions are explicitly investigated. Truckers receive little support from their companies especially regarding re-routing decisions due to en-route incidents. Rather than sticking to prefixed routing decisions or relying on traditional media access such as highway or CB radio, drivers rely largely on navigation systems that provide precise, flexible, quicker and even real-time routing suggestions.

Having identified drivers role in the decision-making process, the study continued in examining the factors that those decision-makers look out for, in addition to travel cost, time, and delay that most conventional approaches focused on. The study also added dimensions by examining and quantifying how drivers perceptions of these road attributes change due to the their characteristics.

Specifically, a model based on the SP data is presented, and its properties are discussed and demonstrated. Estimation results of the model show that there are significant differences in the route choice decision making process among various driver segments, and that these decisions are affected by factors that include shipping and driver employment terms, such as the method of calculation of pay and bearing of toll costs. Even with an average VOT of 30 $/hour, an extremely large variance was observed, which essentially represents drivers strong preference to avoid toll roads when the driver is responsible for the cost, but indifference to tolls when the driver is not responsible for the cost. These findings suggest that simple VOT studies that have been used as a basis to predict truck route choices and flows, and in particular in the context of toll roads, are not adequate.

In general, this study has made a noteworthy contribution in developing a comprehensive survey methodology so as to adequately address the segments of the transportation system that contribute to freight transportation from pre-trip phase to delivery point. Given the limited truck data available, this study expanded the current research span for trucking performance measures by explicitly outlining the determinants that were previously neglected, demonstrated the importance of the freight system and the extent of system problems which are highly different from passenger car transportation, and proved that the dynamics of trucking industry is indeed complex, yet not intractable.

7.3 Ongoing Revealed Preferences Research

It has to be noted that the current results are based on SP data that represent simplified situations and decision protocols. It is therefore easy for bias to arise from various aspects: survey participants might be indifferent to the experimental task, there might be omissions of situational constraints, incomplete descriptions of alternatives, as well as cognitive incongruity with actual behavior. Therefore, the logical next step is to employ Revealed Preferences experiment to study the choice behavior in real settings, so as to ensure cognitively congruency with actual behavior.

This ongoing experiment is intended to collect RP data on route choice of freight trucks. The trucks will be equipped with GPS loggers that continuously collect location and movement data, and transmit this information through wireless networks to an application server at MIT in real-time. This piece of information will be complemented by questionnaires on the project website that are directly dedicated to each truck driver participant.

At the application server, algorithms to match observations to road segments on a GIS database map and to identify locations of stops that the trucks made on their routes are applied. The processed information will be shown to participants using dedicated personal webpages. The drivers will be asked to log in to these webpages to validate and correct the information on their movement and to add additional information that could not be inferred from the location information (e.g. pick-up and delivery schedules for loads, tolls and their methods of pay). Figure 7-1 shows a screenshot of the web interface.

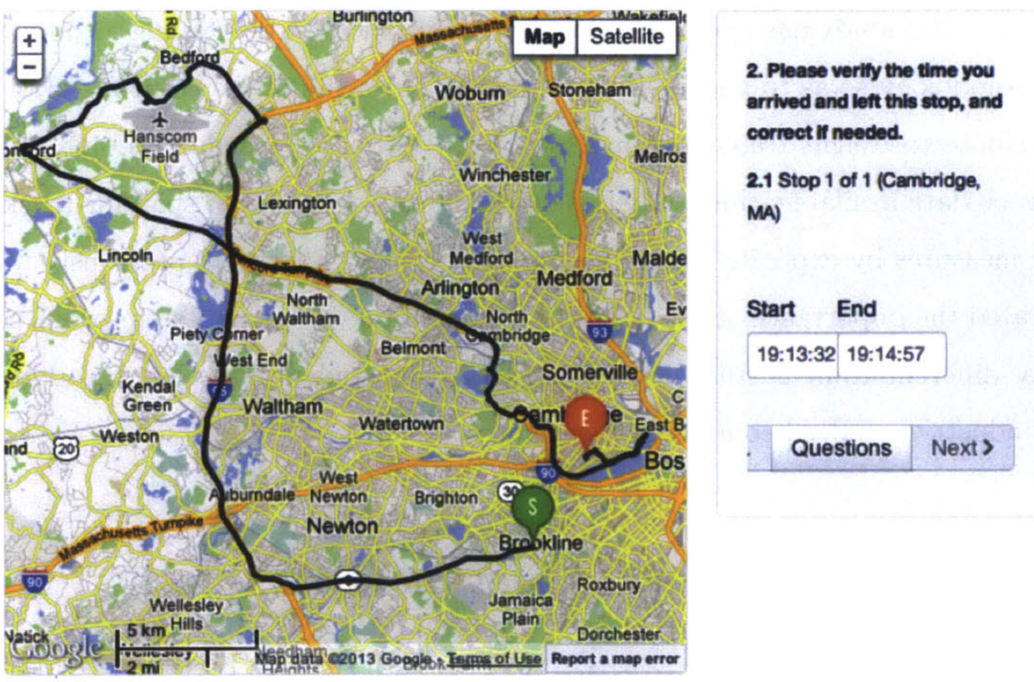

Figure 7-1: Effects of Tolls

The experiment steps are described below. Survey participants will be recruited according to pre-defined quotas that base on three criteria: the geographic location, the driver type, and the availability of ETC in the trucks driven by participants. Geographic locations will be the same three regions where the existing SP data were collected. The driver type criterion is defined by their responsibility of toll costs.

Once participants have been recruited they will be invited by email to register on the project webpage at: http://truckers.mit.edu. After registration, a GPS logger will be sent to the participant.

After logger is installed and starts broadcasting location data, the participant will be able to see their movement information using the web interface. By the end of each day drivers will be asked to access these data, validate and correct them as needed and respond to various questions regarding stops and travel segments

At the end of the GPS data collection period, drivers will be asked to complete a final exit survey. This survey will include an additional route choice SP experiment that would be tailored to the characteristics of the drivers and the trips they make. The survey will be conducted through the interface of the personal webpages as well.

Currently, the first round of 38 trucking companies has been recruited by telephone through a market research firm, 21 out of which have successfully registered at the project website. GPS logger devices have been delivered to those companies, and many of them have started transmitting data back to the server at MIT.

7.4 Future Research Directions

The research presented in this thesis focused on modeling with SP data for route choice behavior. There is a lot of scope for work to be done in the future. Some of those ideas are described below.

- **Refining the route choice model**

  The current route choice model could be evaluated and refined by applying to generalized dataset. Data could be generalized to larger scales so as to test model flexibility. Geographical locations could also be encoded into the model, when RP data is available. In addition, the RP dataset to be collect from current phase could be combined with existing SP data so as to benefit from strengths, correct for weaknesses, and improve model efficiency.

- **Generalization of the behavior choice model**

The proposed model looks into choice behavior in the specific setting of either rural or urban scenario, where only two hypothetical alternatives are available. However in reality, the complex road network provides more options than could be properly represented in a multinomial discrete model. Therefore, generic (i.e. unbranded or unlabelled) choice models could be developed .

- **Expansion of survey questionnaire**

  Information such as whom to consult and factors being considered while making routing or re-routing decisions has been acquired and analyzed empirically. While participants have clearly acknowledged the importance of parking safety, and the difficulty of observing the Hour-of-Service regulation, the current questionnaire did not give full attention to those concerns. It is therefore worthwhile to expand the questionnaire by soliciting more detailed information in these aspects.

- **Incorporating other key entities**

  The current model looks into the choice of routes of truck drivers. The application can be extended to generate choice experiments for trucking company dispatchers and shippers, since in many cases they are the decision-makers, rather than drivers themselves.

- **Modeling the decision-maker identities**

  The current model is based on routing choices, while the decision-making process was only qualitatively discussed. It therefore makes sense to quantify the decision-making process by developing logit or decision-tree models. The process could be characterized by the identity of decision-maker, OO, and ETC user.

- **Real-time traffic forecasting**

  Finally, the existing map-matching algorithms have already linked Google Maps API to vehicle locations and movements. Therefore, one will be able to predict real-time truck traffic in areas associated with both RP and SP experiments once a final model has been developed and test to confirm.

Appendix A

Survey Questionnaires

The Intelligent Transportation Systems Lab at the Massachusetts Institute of Technology is conducting research about future highways that better serve the needs of trucks. Therefore, we seek information about the preferences and constraints that affect how trucks' routes are selected. The information you give will be combined with other data already available to provide better predictions of trucks' use of highways. The survey will only take a few minutes. Thank you for participating.

A.1 Texas - February 2012

A.2 Toronto - April 2012

A.3 Indiana - May 2012

Figure A-1: Texas Questionnaire

THE FOLLOWING QUESTIONS RELATE TO YOUR CURRENT TRIP

1. **Who is the truck operator?**

☐ Hired driver with a for-hire trucking carrier
☐ Owner operator under own operating authority
☐ Owner operator leased to a carrier
☐ Hired driver for a private fleet
☐ Other, please specify: ______________________________

2. **What is the shipment type?**

☐ Truckload ☐ Less-than-truckload ☐ Parcel/express
☐ Empty ☐ Other, please specify: ____________________

3. **Where did you pick the load up?** If multiple locations, select the location you picked up the largest percentage of shipment weight.

Location name: ______________________________

City: ____________________ State: ____________________

What type of facility is this location?
☐ Customer facility ☐ Warehouse/distribution center ☐ Port
☐ Rail facility ☐ Border crossing ☐ Airport
☐ Other, please specify: ______________________________

4. **When did you pick the load up?** If multiple locations, select the location you picked the largest percentage of shipment weight.

Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

5. **When you picked the load up, how much driving time was left on your hours of operations log?**

Hours:_____ Minutes:_____

6. Where will you deliver the load? If multiple locations, select the location you will deliver the largest percentage of shipment weight.

Location name: ____________________________________

City: __________________ State: ____________________

What type of facility is this location?

☐ Customer facility ☐ Warehouse/distribution center ☐ Port
☐ Rail facility ☐ Border crossing ☐ Airport
☐ Other, please specify: ____________________________________

7. What are the earliest and latest delivery times for the load? If multiple locations, select the location you will deliver the largest percentage of shipment weight.

Earliest delivery

Date: ____/____ (Month / Day) Time: ____/____ (Hour / Minute) AM / PM

Latest delivery

Date: ____/____ (Month / Day) Time: ____/____ (Hour / Minute) AM / PM

8. Who decided the route for this trip?

☐ Driver ☐ Dispatcher/carrier ☐ Shipper/logistics provider
☐ Other, please specify: ____________________________________

9. What is your route for this trip? List the main roads and intersections/interchanges in the order they are used.

____
____
____
____
____

10. For trips with similar origins and destinations, in what percentage have you used this route?

____% of trips

11. What are alternative routes that you have used for trips with similar origins and destinations? List the main roads and intersections/interchanges in the order they are used.

Alternative 1

____

____

____

____

____

Percentage of trips you have used this route: _____% of trips

Alternative 2

____

____

____

____

____

Percentage of trips you have used this route: _____% of trips

12. If you made the routing decision for this trip, what are the main factors you considered when selecting the chosen route?

____

____

____

____

____

13. Do you have the authority to change the route while driving?

☐ Yes ☐ No

14. If you make routing decisions, which of the following factors do you consider when making these choices?

Travel distance	☐ No	☐ Yes
Travel time	☐ No	☐ Yes
Travel time reliability	☐ No	☐ Yes
Congestion (stop-and-go traffic)	☐ No	☐ Yes
Tolls and road charges	☐ No	☐ Yes
Weather conditions	☐ No	☐ Yes
Road classes (interstate, state highway)	☐ No	☐ Yes
Road conditions (grade, curves, pavement))	☐ No	☐ Yes
Road services (truck/rest stops, gas stations)	☐ No	☐ Yes
Insurance constraints	☐ No	☐ Yes
Road use restrictions	☐ No	☐ Yes
Other	☐ No	☐ Yes, please specify:

____

____

____

15. If you make routing decisions, which of the following sources of information do you use when making these choices?

Own prior experience	☐ No	☐ Yes
Navigation system	☐ No	☐ Yes
Map	☐ No	☐ Yes
Dispatcher	☐ No	☐ Yes
Other drivers	☐ No	☐ Yes
Internet/cellular,	☐ No	☐ Yes, Please specify:______________

____

Other	☐ No	☐ Yes, please specify:______________

____

16. What is the basis for the calculation of your compensation for this trip?

☐ Book miles ☐ Actual miles ☐ Hours

☐ Freight charges ☐ Load weight ☐ Fixed amount

Other, please specify:______________________________________

17. Do you get reimbursed for fuel costs?

☐ No ☐ Yes, in full ☐ Yes, fuel surcharges

Please specify the reimbursement terms

____

____

18. Do you get reimbursed for tolls and road charges?

☐ No ☐ Yes, in full ☐ Yes, partially

Please specify the reimbursement terms

____

____

19. Do you incur penalties for early/late delivery?

☐ No ☐ Yes, please specify:____________________________

____

____

20. What is the truck configuration for this trip?

☐ Single unit only ☐ Single unit with a trailer

☐ Tractor only (Bobtail) ☐ Tractor and 1 trailer

☐ Tractor and 2 trailers ☐ Tractor and 3 trailers

☐ Other, please specify: ____________________________

21. How many axles does the vehicle, including trailers, have?

☐ 2 ☐ 3 ☐ 4 ☐ 5

☐ 6 ☐ 7 or more

22. What is the cargo body type for this trip?

☐ Van/Enclosed box ☐ Tank ☐ Flatbed

☐ Dump ☐ Concrete mixer ☐ Auto transporter

☐ Log ☐ Intermodal chassis ☐ Towing vehicle

☐ None ☐ Other, please specify: ____________________

23. What are any service specializations for this trip, if any?

☒ None ☐ Hazardous material ☐ Wide loads

☐ Temperature controlled ☐ Expedited/express

☐ Other, please specify:________________________________

24. What is the driving arrangement for this trip?

☐ Single ☐ Single with sleeper berth ☐ Team

25. What type of cargo do you carry? If more than one type, select type that make up largest percentage of shipment weight.

☐ Agriculture ☐ Animal products ☐ Food

☐ Mineral products ☐ Chemical/petroleum ☐ Wood

☐ Textiles ☐ Metals ☐ Building material

☐ Machinery/Electronics ☐ Transportation ☐ Miscellaneous

☐ Other, please specify:________________ ☐ Don't know

26. What is the total weight or volume of the cargo onboard?

Quantity:__________ ☐ Pounds ☐ Gallons

☐ Empty ☐ Don't know

Figure A-2: Toronto Questionnaire

27. What is the total value of the cargo onboard?

$ __________ ☐ Don't know

28. How many years have you been working as a truck driver?

☐ Less than 1 ☐ 1-2 ☐ 3-5 ☐ 5-10 ☐ Over 10

29. What are the metrics used to evaluate your work performance? Please select all that applies

☐ On-time performance ☐ Miles traveled per day ☐ Load transported per day

☐ Customer satisfaction ☐ Operating speed ☐ Fuel consumption

☐ Other, please specify: ____

____

30. Do you have any other comments about truck routing and the factors that affect it that you think may be relevant to our research?

____

____

____

The information you provided will help develop a follow-up experiment. In this experiment we will use in-truck GPS technology to collect information about travel routes. You will be able to see your own trip routes on a secure personal webpage, where you will also be asked to respond to additional questions and provide details on your trips. You will be compensated for your effort.

The results of this study may be published, but identifiable personal information or information about your company will not be shared with others or published. Your participation in this study is voluntary. You may withdraw from the study at any time with no penalty.

Would you consider participating in this experiment?

☐ No ☐ Yes, please provide contact information:

Name:____

Phone:____

Email:____

Company:____

Mailing address:____

Would you need to get authorization to participate?

☐ No ☐ Yes, please provide contact information for the person in charge:

Name:____

Phone:____

Email:____

Company:____

Mailing address:____

THE FOLLOWING QUESTIONS RELATE TO THE CURRENT LEG OF YOUR TRIP

1. Which of the following best describes you?
- ☐ Hired driver with a for-hire trucking carrier
- ☐ Owner operator under own operating authority
- ☐ Owner operator leased to a carrier
- ☐ Hired driver for a private fleet
- ☐ Other, please specify: ____

2. What is the shipment type?

☐ Truckload ☐ Less-than-truckload ☐ Parcel/express

☐ Empty ☐ Other, please specify: ______________________

3. Where did you start the current leg of your trip (picked up or delivered a load)? If multiple locations, use the last one.

City: __________________ State: ____________________

4. When did you start the current leg of your trip (picked up or delivered a load)? If multiple locations, use the last one.

Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

5. When you started the current leg of your trip, how many driving hours did you already have on your hours of service log?

Hours:_____ Minutes:_____

6. What is the next stop on your current trip (to deliver or pick up a load)?

City: __________________ State: ____________________

7. How many driving hours does the current leg of your trip take from origin to destination?

Hours:_____ Minutes:_____

8. How frequently do you take trips with similar origin and destinations (loaded or empty)?

☐ At least once a week

☐ 1 – 3 times a month

☐ Less than once a month

9. Suppose that you made this trip 10 times on the same route and same time of day, in how many trips would you estimate that you would experience delay that would exceed 30 minutes?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

10. Which one of the following best describes the schedule for your next delivery (or pick-up)?

☐ Appointment:

From: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

To: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Deliver by time:

Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Delivery window:

Earliest: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

Latest: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Other, please specify:____

11. What is your route for the current leg of this trip? List the main roads and intersections on your way

____
____
____
____
____

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you use this route?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you miss or need to reschedule the delivery time?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

12. What is an alternative route that you have used for similar trips? List the main roads and intersections on your way. In particular, mention alternative in the Chicago area.

____
____
____
____
____

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you use this route?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

13. How is the route for the current leg of your trip decided?

☐ I get a route that I must follow
☐ I get a route but can ask for approval to use another one
☐ I get a route but free to choose my own
☐ I choose a route among pre-approved alternatives
☐ I choose a route and need to get it approved
☐ I choose a route freely on my own
☐ Other, please specify:_______________________________________

14. Suppose that there is information available about delays on your route (due to congestion, work zone, accident), which of the following best describes how your route may change?

☐ No change is possible at all
☐ My company/dispatcher will contact me and assign a new route
☐ I can request and will be assigned a new route
☐ I can change my route, but need to get approval from the company/dispatcher
☐ I am free to change the route on my own
☐ Other, please specify: ______________________________

15. What is the basis for the calculation of your compensation for this trip?

☐ Book miles ☐ Actual miles ☐ Hours
☐ Freight charges ☐ Load weight or value ☐ Fixed amount
☐ Other, please specify: ______________________________

16. Which one of the following best describes how fuel costs are handled?

☐ The cost is charged directly to the company
☐ I pay and will later be fully reimbursed by my company
☐ I pay and will later be partially reimbursed (only surcharges)
☐ I pay and will not be reimbursed at all
☐ Other, please specify: ______________________________

17. Is your truck equipped with electronic toll tags?

☐ No
☐ Yes, please specify for which system (e.g., EZPass, SunPass): ______________

18. Which one of the following best describes how tolls and road charges are handled?

☐ The cost is charged directly to the company
☐ I pay and will later be fully reimbursed by my company
☐ I pay and will later be partially reimbursed
☐ I pay and will not be reimbursed at all
☐ Other, please specify: ______________________________

19. Do you incur penalties for late delivery?

☐ No
☐ Yes, please specify: ______________________________

20. How strongly do you agree or disagree with the following statements?

- My company monitors my whereabouts closely when I'm on the road

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- Being on time for delivery is very important to me

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- It is difficult for me to deliver on time with the delivery schedules I get

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- My company routinely evaluates my fuel consumption

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- It is difficult for me to plan my route without consulting a map or navigation system

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I rely on the navigation system to route me to my destination

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I only learn about congestion on my route when I get to it

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- My company/dispatcher inform me about delays on my route

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I learn about delays on my route from other drivers

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I rely on radio and navigation services for traffic information

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I will always prefer to use interstate or Canadian 400-series highways

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I always plan ahead in order to find a good place to park overnight

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I make sure to have fuel stations that I can use when I plan my route

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- It is important to me to be able to predict my travel times in advance

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

- I will never use a toll road if I don't have to

☐ Strongly Disagree ☐ Somewhat Disagree ☐ Neutral
☐ Somewhat Agree ☐ Strongly Agree

21. How many years have you been working as a truck driver?

☐ Less than 1 ☐ 1-2 ☐ 3-5 ☐ 5-10 ☐ Over 10

22. What is the truck configuration for the current leg of your trip?

☐ Single unit only ☐ Single unit with a trailer
☐ Tractor only (Bobtail) ☐ Tractor and 1 trailer
☐ Tractor and 2 trailers ☐ Tractor and 3 trailers
☐ Other, please specify: ____________________

23. What type of cargo do you carry in the current leg of your trip? If more than one type, select the type that make up largest percentage of shipment weight.

☐ Agriculture ☐ Animal products ☐ Food
☐ Mineral products ☐ Chemical/petroleum ☐ Wood
☐ Textiles ☐ Metals ☐ Building material
☐ Machinery/Electronics ☐ Transportation ☐ Miscellaneous
☐ Other, please specify: __________ ☐ Don't know

24. What are any service specializations for this trip, if any?

☐ None ☐ Hazardous material ☐ Wide loads
☐ Temperature controlled ☐ Expedited/express
☐ Other, please specify: ____________________

25. Do you have any other comments about truck routing that may be relevant?
___
___
___

The information you provided will help develop a follow-up experiment. In this experiment we will use in-truck GPS technology to collect information about travel routes. You will be able to see your own trip routes on a secure personal webpage, where you will also be asked to respond to additional questions and provide details on your trips. You will be compensated for your effort.

The results of this study may be published, but identifiable personal information or information about your company will not be shared with others or published. Your participation in this study is voluntary. You may withdraw from the study at any time with no penalty.

Would you consider participating in this experiment?

☐ No ☐ Yes, please provide contact information:

Name:___

Phone:___

Email:___

Company:___

Mailing address:___

Would you need to get authorization to participate?

☐ No ☐ Yes, please provide contact information for the person in charge:

Name:___

Phone:___

Email:___

Company:___

Mailing address:___

Figure A-3: Indiana Questionnaire

THE FOLLOWING QUESTIONS RELATE TO THE CURRENT LEG OF YOUR TRIP

1. **Which of the following best describes you?**
- ☐ Hired driver with a for-hire trucking carrier
- ☐ Owner operator under own operating authority
- ☐ Owner operator leased to a carrier
- ☐ Hired driver for a private fleet
- ☐ Other, please specify: ______________________________

1. **What is the shipment type?**
- ☐ Truckload ☐ Less-than-truckload ☐ Parcel/express
- ☐ Empty ☐ Other, please specify: ______________________

2. **Where did you start the current leg of your trip (picked up or delivered a load)?** If multiple locations, use the last one.

City: ____________________ State: ______________________

3. **When did you start the current leg of your trip (picked up or delivered a load)?** If multiple locations, use the last one.

Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

4. **When you started the current leg of your trip, how many driving hours did you ALREADY have on your hours of service log?**

Hours:_____ Minutes:_____

5. **What is the next stop on your current trip (to deliver or pick up a load)?**

City: ____________________ State: ______________________

6. **How many driving hours does the current leg of your trip take from origin to destination?**

Hours:_____ Minutes:_____

7. How frequently do you take trips with similar origin and destinations (loaded or empty)?
☐ At least once a week
☐ 1 – 3 times a month
☐ Less than once a month

8. Suppose that you made this trip 10 times on the same route and same time of day, in how many trips would you estimate that you would experience delay that would exceed 30 minutes?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

9. Which one of the following best describes the schedule for your next delivery (or pick-up)?
☐ Appointment:

From: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

To: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Deliver by time:

Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Delivery window:

Earliest: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

Latest: Date: _____/_____ (Month / Day) Time:_____/_____ (Hour / Minute) AM / PM

☐ Other, please specify:____

10. What is your route for the current leg of this trip? List the main roads and intersections on your way

____
____
____
____
____

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you use this route?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you miss or need to reschedule the delivery time?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

11. What is an alternative route that you have used for similar trips? List the main roads and intersections on your way. In particular, mention alternative in the Chicago area.

____
____
____
____
____

In the last 10 trips that you have made with similar origins and destinations and at the same time of day, in how many trips did you use this route?

☐ 0	☐ 1	☐ 2	☐ 3
☐ 4	☐ 5	☐ 6	☐ 7
☐ 8	☐ 9	☐ 10	

12. How is the route for the current leg of your trip decided?

☐ I get a route that I must follow
☐ I get a route but can ask for approval to use another one
☐ I get a route but free to choose my own
☐ I choose a route among pre-approved alternatives
☐ I choose a route and need to get it approved
☐ I choose a route freely on my own
☐ Other, please specify:____

The information you provided will help develop a follow-up experiment. In this experiment we will use in-truck GPS technology to collect information about travel routes. You will be able to see your own trip routes on a secure personal webpage, where you will also be asked to respond to additional questions and provide details on your trips. You will be compensated for your effort.

The results of this study may be published, but identifiable personal information or information about your company will not be shared with others or published. Your participation in this study is voluntary. You may withdraw from the study at any time with no penalty.

Would you consider participating in this experiment?

☐ No ☐ Yes, please provide contact information:

Name:____________________

Phone:____________________

Email:____________________

Company:____________________

Mailing address:____________________

Would you need to get authorization to participate?

☐ No ☐ Yes, please provide contact information for the person in charge:

Name:____________________

Phone:____________________

Email:____________________

Company:____________________

Mailing address:____________________

Bibliography

[1] Armstrong Associates (2011), Full Stride 2010 3PL Market analysis and 2011 Predictions, Armstrong Associates, Stounghton WI.

[2] ATA (2004), Model Truckload Motor Carrier/Shipper Agreement with Commentaries, American Trucking Association, Arlington VA.

[3] ATA (2005), Global Insight Inc., The U.S. Truck Driver Shortage: Analysis and Forecasts, Report Submitted to American Trucking Association, Arlington VA, 2005.

[4] ATA (2007), Standard Trucking and Transportation Statistics (STATS) Sample, American Trucking Association, Arlington VA.

[5] ATA (2011), American Trucking Trends 2011. American Trucking Research institute, Arlington VA.

[6] ATRI (2011), An Analysis of the Operational Costs of Trucking, 2011 Update. American Transportation Research Institute, Arlington VA.

[7] Austroads (2003), Economic Evaluation of Road Investment Proposals: Valuing Travel Time Savings for Freight, Publication No. APR230/03, Austroads Publication No. APR230/03 Sydney, Australia.

[8] Bain R. and L. Polakovic. Traffic Forecasting Risk Study 2005: Through Ramp-Up and Beyond. Standard & Poors, London UK, 2005.

[9] Ben-Akiva M., Bolduc D. and Park J.Q. (2008), Discrete Choice Analysis of Shippers Preferences, in Recent Developments in Transport Modeling: Lessons for the Freight Sector, Emerald Group, UK, pp. 135-155.

[10] Bergkvist E. (2001), Freight Transportation: Valuation of Time and Forecasting of Flows, Umea Economic Studies 549, Umea University, Sweden.

[11] Bierlaire M. (2003), BIOGEME: A Free Package for the Estimation of Discrete Choice Models, Proceedings of the 3rd Swiss Transportation Research Conference, Ascona, Switzerland.

[12] BLS (2010), Occupational Employment and Wages, May 2010: 53-3033 Light Truck or Delivery Services Drivers, 53-3032 Heavy and Tractor-Trailer Truck Drivers. Bureau of Labor Statistics.

[13] BLS (2011), Occupational Outlook Handbook, 2010-11 Edition, Truck Drivers and Driver/Sales Workers, Bureau of Labor Statistics, US Department of Labor, Washington DC.

[14] Bolis S. and Maggi R. (2001), Evidence on Shippers' Transport and Logistics Choice, in Proceedings of the 1st Swiss Transport Research Conference, Ascona, Switzerland.

[15] BTS (2010), State Transportation Statistics 2010, Bureau of Transportation Statistics, US Department of Transportation, Washington DC.

[16] BTS (2011), Freight Data and Statistics, Bureau of Transportation Statistics, US Department of Transportation, Washington DC.

[17] Burris M.W. (2003), The Toll-Price Component of Travel Demand Elasticity, International Journal of Transport Economics 30, pp. 4559.

[18] USCB (2007), 2007 Economic Census, US Census Bureau, Washington DC.

[19] Campbell J. (2008), Toll vs. Nontoll: Toll Facilities are Safer, Tollway Winter 2008, pp. 55-63.

[20] CRSPE (2004), 2004 Survey Report as Part of the Expansion of Variable Pricing to Heavy Vehicle Project, CRSPE, Inc., Fort Myers, FL.

[21] Danielis R., Marcucci E. and Rotaris L., (2005), Logistics Managers Stated Preferences for Freight Service Attributes, Transportation Research Part E 41, pp. 201-215.

[22] FHWA (2005), Freight Facts and Figures 2005, Federal Highway Administration US Department of Transportation, Washington DC.

[23] FHWA (2007), Financing Freight Improvements, Federal Highway Administration, US Department of Transportation, Washington DC.

[24] FHWA (2010a), Our Nations Highways: 2010, Federal Highway Administration, US Department of Transportation, Washington DC.

[25] FHWA (2010b), US 2010 Freight Facts and Figures, Federal Highway Administration, US Department of Transportation, Washington DC.

[26] FHWA (2011a), Freight Glossary and Acronyms, Federal Highway Administration, US Department of Transportation, Washington DC.

[27] FHWA (2011b), Toll Facilities in the United States: Bridges, Roads, Tunnels, Ferries, Federal Highway Administration Publication No. FHWA-PL-11-032, Department of Transportation, Washington DC.

[28] FHWA (2011c), US 2011 Freight Facts and Figures, Federal Highway Administration, US Department of Transportation, Washington DC.

[29] FMCSA (2007a), Commercial Motor Vehicle Facts, Federal Motor Carrier Safety Administration (FMCSA) and Motor Carrier Management Information System (MCMIS).

[30] FMCSA (2007b), Development and Evaluation of Alternative Concepts for Wireless Roadside Truck and Bus Safety Inspections, Federal Motor Carrier Safety Administration, US Department of Transportation, Washington DC.

[31] FMCSA (2009), Current List of Designated, Preferred and Restricted Routes, Federal Motor Carrier Safety Administration, US Department of Transportation, Washington DC.

[32] FMCSA (2011a), FMCSA Crash Data Collection Resource, Federal Motor Carrier Safety Administration, US Department of Transportation, Washington DC.

[33] FMCSA (2011b), Commercial Motor Vehicle Facts Novermber 2011, Federal Motor Carrier Safety Administration (FMCSA).

[34] Fowkes A.S. and Shinghal N. (2002), The Leeds Adaptive Stated Preference Methodology, Institute of Transport Studies, University of Leeds, Working paper 558.

[35] Fowkes, A.S. and Whiteing A. (2006), The Value of Freight Travel Time savings and Reliability improvements Recent Evidence from Great Britain, in Proceedings of the European Transport Conference 2006.

[36] iSurvey iPad Survey App Software, Version 2.8.0, 2012.

[37] Ismail K., Sayed T. and Lim C. (2009), A Study of the Commercial Value of Time for Operation at Border Crossings, in Proceedings of the 2009 annual Conference of the Transportation Association of Canada, Vancouver BC.

[38] Jong G. de (2000), Value of Freight Travel Time Savings, in D.A. hensher and K.J. Button (eds.), Handbook of Transport Modelling (Second Edition), Elsevier, New York, pp. 553-564.

[39] Jong G. de, Bakker S., Pieters M. and Donselaar P.W., (2004), New Values of Time and Reliability in Freight Transport in the Netherlands, in Proceedings of the European Transport Conference 2004.

[40] Jovicic G. (1998), Application of Models based on Stated and Revealed Preference Data for Forecasting Danish International Freight Transport, in Proceedings of the Annual Transport Conference at Aalborg University.

[41] Holgun-Veras, J., Ozbay K. and Cerreno A. (2005), Evaluation Study of Port Authority of New York and New Jerseys Time of Day Pricing Initiative, Final report prepared for the New Jersey Department of Transportation.

[42] Holgun-Veras, J.H., Wang Q., Xu N., Ozbay K., Cetin M. and Polimeni J. (2006), Impacts of Time of Day Pricing on the Behavior of Freight Carriers

in a Congested Urban Area: Implications to Road Pricing. Transportation Research Part A 40, pp. 744-766.

[43] Hunt J.D. and Abraham J.E. (2004), Stated Response Examination of Factors Influencing Commercial Movement Route Choice Behavior, in Proceedings of the 8th International Conference on Applications of Advanced Technologies in Transportation Engineering, Beijing, China, pp. 72-77.

[44] Hyodo T. and Hagino Y. (2010), Modeling Truck Route Choice Behavior by Traffic Electronic Application Data, paper presented at the Transportation Research Board SHRP 2 Symposium: Innovations in Freight Demand Modeling and Data, Washington DC.

[45] Kawamura K. (1999), Commercial Vehicle Value of Time and Perceived Benefit of Congestion Pricing, PhD dissertation, University of California, Berkeley.

[46] Kawamura K. (2000), Perceived Value of Time for Truck Operators, Transportation Research Record 1725, pp. 31-36.

[47] Knorring J.H, He R. and Kornhauser, A.L. (2005), Analysis of Route Choice Decisions by Long-Haul Truck Drivers, Transportation Research Record 1923, pp. 46-60.

[48] Kurri J., Sirkia A. and Mikola J. (2000), Value of Time in Freight Transport in Finland, Transportation Research Record 1725, pp.26-30.

[49] MARAD (2008) Glossary of Shipping Terms, Maritime Administration, US Department of Transportation, Washington DC.

[50] Margreta M., Ford C. and Dipo M. A. (2009), U.S. Freight on the Move: Highlights from the 2007 Commodity Flow Survey Preliminary Data. RITA Bureau of Transportation Statistics Special Report, US Department of Transportation, Washington DC.

[51] McLean (2000), 1999/2000 Interprovincial Roadside Truck Survey Report, McLean Transportation Engineering Consultants, Canada.

[52] Miao Q, Wang B.X. and Adams T.M. (2011), Assessing the Value of Delay to Truckers and Carriers, Final Report CFIRE 03-15 and UTCM 09-00-45, University Transportation Research Program.

[53] Min H. (2011), Combined Truck Routing and Driver Scheduling Problems under Hours of Service Regulations. Report UTUTC-SC-1, University of Toledo University Transportation center.

[54] Mullett R. and Poole B. (2006), Road Pricing and Trucking: Framing the Issues, Tollways Winter 2006.

[55] Munroe T., Schmidt R. and Westwind M. (2006), Economic Benefits of Toll Roads Operated by the Transportation Corridor Agencies, report prepared by LECG, Emeryville, CA.

[56] Ozbay K., Yanmaz-Tuzel O. and Holguin-Veras J. (2006), Evaluation of Time-of-Day Pricing Initiative on Car and Truck Traffic: Port Authority of New York and New Jersey. Transportation Research Record 1960, pp. 48-56.

[57] Perez B. and Lockwood S. (2006), Current Toll Road Activity in the U.S.- A Survey and Analysis, Federal Highway Administration US Department of Transportation, Washington DC.

[58] Portugal R., Ramalhinko H. and Paixal J.P., (2006), Driver Scheduling Problem Modeling, Working Paper, Universida of Lisboa, Portugal.

[59] Prozzi J., K. Flanagan, L., Loftus-Otway, B. Porterfield, K. Persad, J.A. Prozzi, and C.M. Walton. (2010) Toll Roads: What We Know About Forecasting Usage and the Characteristics of Texas Users. TxDOT Project 0-6044, Texas Department of Transportation, Austin TX.

[60] Prozzi J., Rutzen B. and Robertson C. (2009), Characteristics of the Truck Users and Non-Users of Texas Toll Roads, Report FHWA/TX-10/0-6044-2 Volume 2, US Department of Transportation, Washington DC.

[61] Qin X., Han J. and Wang B.X. (2009), Advanced Traveler Information Impact on Truck Route Choice, in Proceedings of ICCTP 2009: Critical Issues in Transportation Systems Planning, Development, and Management, pp. 1934-1945.

[62] Ramming, M. S. (2002), Network Knowledge and Route Choice, MS Thesis, Massachusetts Institute of Technology, Cambridge MA.

[63] Short J.B. (2007) Survey of Motor Carrier Opinions on Potential Optional Truck-Only Toll Lanes on Atlanta Interstate Highways. Preprints of the 86th Annual Meeting of the Transportation Research Board, Washington DC.

[64] Small K.A., Noland R., Chu X. and Lewis D. (1999), Valuation of Travel Time Savings and Predictability in Congested conditions for Highway User Cost Estimation, NCHRP Report 431, US Department of Transportation, Washington DC.

[65] Smalkoski B. and Levinson D. (2005), Value of Time for Commercial Vehicle Operators, Journal of the Transportation Research Forum 44, pp. 89-102.

[66] Truckinfo (2011), Trucking Statistics, Truckinfo.net.

[67] USCB (2004), 2002 Economic Census: Vehicle Inventory and Use Survey, U.S. Census Bureau, Washington DC.

[68] Wheeler R.E. AlgDesign. The R project for statistical computing, 2004.

[69] Wilbur Smith (1995). Potential for Variable Pricing of Toll Facilities, Wilbur Smith Associates report to Federal Highway Administration, US Department of Transportation, Washington DC.

[70] Wood H.P. (2011), Truck Tolling: Understanding Industry Tradeoffs When Using or Avoiding Toll Facilities, Final Report NCFRP Project 19 and NCHRP Project 19-09, US Department of Transportation, Washington DC.

[71] Wynter L.M. (1995), Stated Preference Survey for Calculating Values of Time of Road Freight Transport in France, Transportation Research Record 1477, pp. 1-6.

[72] Xu H., Chen Z.L., Rajagopal S., and Arunapuram, S. (2003), Solving a Practical Pickup and Delivery Problem, Transportation Science 37, pp. 347-364

[73] Zamparini L. and Reggiani A. (2007), Freight Transport and the Value of Travel Time Savings: a Meta-Analysis of Empirical Studies, Transport Reviews 27, pp. 621-636.

[74] Zellman M. (2011), Salary of a Truck Driver Owner Operator, eHow Money

[75] Zhou L., Burris M.W., Baker R.T. and Geiselbrecht T. (2009), Impact of Incentives on Toll Road Use by Trucks, Transportation Research Record 2115, pp. 84-93.