Estimation of Economic Impact of Freight Disruption due to Highway Closure

by

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B.S. Industrial & Operations Engineering
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Submitted to the Department of Civil and Environmental Engineering in partial fulfillment of the requirements for the degree of

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ABSTRACT

The main aim of this study is to provide a theoretical framework and methodology to estimate and analyze the economic impact of freight disruption due to highway closure. The costs in this study will be classified into three groups: private operating costs for carriers, logistics and scheduling costs, and indirect costs for the market. The resource saving method is used to measure private operating costs for carriers. The stated preference method and the logit model are used to measure logistics and scheduling costs. The input-output analysis is used to measure indirect costs for carriers. The recommended methodology can be used to the estimate economic impact of freight disruption due to highway closure. The framework can be used as a stepping stone for future research.

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Chapter 1. Introduction

1.1 Background

According to the American Trucking Associations (ATA), the U.S. economy heavily depends on commercial truck traffic. Billions of tons of almost every commodity which account for $671 billion of goods are transported by trucks. In the report, *When Trucks Stop, America Stops (2006)*, published by the ATA, several industries were interviewed to quantify the consequences of halting truck movement. In the food industry, with truck stoppage, shortage of commodities at grocery stores and supermarkets might lead to civil unrest. Drinkable water will run out in two to four weeks if there is a stoppage of purification chemicals to water supply plants. In the healthcare industry, truck traffic is relied on to deliver urgently needed medical supplies to save lives. Due to the trend of moving towards just-in-time inventory systems, hospitals may run out of stock if there are freight disruptions. In transportation, fuel is delivered by trucks. Without trucks, fuel supplies will run out in one or two days and other transportation modes such as air, rail and maritime transportation will be interrupted. For waste removal, more than 236 million tons of municipal or household waste is moved by trucks. Uncollected waste products create serious health and environmental consequences. In the retail sector, major retail chains in the U.S. have moved to a just-in-time inventory system, which may cause the disruptions of daily running of these stores. In manufacturing, a just-in-time inventory system may partially or totally shut down assembly lines in a few hours. In banking and finance, cash resources may be exhausted quickly and regular bank functions cannot be performed.

Even though one highway closure will not stop all trucks, rerouting and delay of shipments will also be likely to raise an enormous amount of losses, which will affect the local and national economy. The incident that happened in Washington State last year proves the importance of a healthy freight flow for both the state and nation.

I-5 Closure in Washington State

In December 2007, a heavy rain storm occurred in Washington State. One lane of I-5 in Chehalis was closed because of the dangerous flood level on December 3rd. A few hours later, the other lane was also closed. Thousands of trucks carrying freight had to take alternate routes or delay their trips. A 20-mile-long section of I-5 in Chehalis remained closed to all traffic while Washington State Department of Transportation (WSDOT) crews were working hard to get trucks turned around on I-5. There were few alternative routes to I-5 in Chehalis. The recommended detour route added 160 miles for trucks. On December 6, one lane of I-5 was reopened only for commercial trucks. The following day, I-5 was open for all traffic.

Even though I-5 was closed for just 3 days, it had a meaningful economic impact. According to WSDOT, one shipper recalled that he had to pay an expedited carrier $2500 per trip for each load, which typically costs around $300 to $500 per trip. Another carrier estimated an additional cost of $600 per truck per day due to the detour in fuel and driver wages. These are direct costs and do not cover spoiled goods, lost sales, disrupted production, etc. The purpose of this thesis is to better measure the economic impact of disruptions to a freight network such as the I-5 closure.

1.2 Object and Scope

The main aim of this study is to provide a theoretical framework and methodology to estimate and analyze the economic impact of freight disruption due to highway closure. The economic impact is not limited to just carriers. We also consider the impact on shippers and the market. By doing a thorough literature review to examine the existing models, we will select and modify a model with three different assessments: the direct loss for carriers, the direct loss for shippers and the indirect impact or ripple effect on the market and society including household, government etc.

In this study, a relatively short-term highway closure is examined. Shippers are able to reroute shipments to avoid the disruption area, which may cause a longer delivery time and higher transportation cost. If a highway closure lasts for a long period of time, shippers may alter their business models such as changing their inventory policy, reallocating their production sites, finding new suppliers, etc. Effects due to long-term highway closure will not be examined in this thesis. In addition, loss due to passenger travel disruption will not be included in this study.

1.3 Three Costs

Generally, the economic impact can be divided into three categories: private operating costs for carriers, logistics and scheduling costs, and indirect cost for the market. We discuss each in turn.

Private Operating Costs for Carriers

According to Forkenbrock (1999), operating costs are the direct expenses incurred from providing freight transportation services. Private operating costs include investments in capital facility which eventually wear out or depreciate and operating costs which are those closely associated with the amount of services. In this study, the private operating costs for carriers include additional salaries, wages, fringes, operating suppliers, tax and license fees, insurance fees, utilities fees, depreciation, office equipment, disposal of assets, and miscellaneous.

Logistics and Scheduling Costs

Logistics and scheduling costs are caused by delays of shipments to the distribution system. Alternatively speaking, they are caused by disruptions of synchronous activities. Synchronous activities are activities that are going to happen once shipments arrive in shippers' production system. Logistics and scheduling costs can be categorized into four types: additional logistics costs, costs of stocking, costs of spoiled goods, and costs of disruptions of just-in-time processing.

Indirect Costs for the Market

Indirect costs for the market are ripple effects of the private operating costs for carriers and logistics and scheduling costs. They are mainly caused by production disruptions from the shippers impacted by highway closure. Indirect costs for the market are lost revenues caused by shortage of supply to intermediate or final consumers. All three costs will be discussed in detail in Chapter 3.

A recent study conducted by Midwest Transportation Consortium notes that:

> *Initially, our team of researchers believed that we could develop a methodology to evaluate the benefits and costs of road closures. However, we discovered that the problem is more complex than it initially appeared. Although this report provides insights into the costs and benefits of road closure through case studies, it does not provide a methodology that can be used to determine under what conditions a road should be closed. The benefit side of the analysis focuses on the safety issues related to road closures and is covered in sufficient detail. However, the cost of a road closure is much more complex as it is concerned with the value of travel time and the value of travel time reliability.*

Synchronous activities complicate the cost estimation of a road closure. Interruption of synchronous activities creates problems for shippers because a failure to make a delivery on time may result in a cost penalty much greater than the shipment itself (Midwest Transportation Consortium 2005). Especially, nowadays, just-in-time processes are widely adopted. A one-hour delay may cause the shipper to shut down the whole assembly line. Costs due to disruptions in synchronous activities are a major component of the overall economic impact of freight disruptions. Examples of costs of disruptions of synchronous activities include:

- changing product sourcing,
- expediting product,
- double handling,
- disrupting manufacturing operation,
- shutting down a production line,

- hiring extra labor, and
- losing customers.

Synchronous activities will vary depending on the type of shipments and shippers' businesses.

1.4 Organization of the Thesis

This thesis will be organized into the following chapters. Chapter 1 introduces the importance and complexity of the problem. It also helps identify the issues related to the highway closures. Chapter 2 reviews past studies in the areas of disaster loss estimation methodologies, highway closure impact and the value of travel time in freight transport. Chapter 3 describes the analytic steps towards the final framework. A methodology to approach the economic estimation of freight disruption due to highway closure will be reviewed in detail. Theories supporting the methodology will also be discussed. Key elements of the general framework will be addressed. Finally, Chapter 4 summarizes the key findings and suggests areas for future improvement.

Chapter 2. Literature Review

2.1 Introduction

This chapter reviews various models and methodologies related to measuring the economic impact of freight interruption due to highway closure.

In a study conducted by the Cowlitz-Wahkiakum Council of Governments (CWCOG) in Washington State in 1997 to develop economic recovery strategies from the 1996 flood disaster, the costs due to the I-5 closure are categorized into three types: the delay costs related to the movement of goods and people along the route, the cost of delays in shipments on the distribution system, and the effects of late supplies of goods in the marketplace throughout the sales area served by I-5.

In their study, due to the complexity of the problem, only the delay costs related to the movement of goods and people along the route have been roughly estimated.

In a study quantifying the impacts of congestion on the costs of production for economic sectors, Weisbrod et al. (2001) identified three classes of costs and gave the definitions for each: direct travel (user) cost, including vehicle operating costs and value of time of driver and passengers, for all business-related travel; logistics and scheduling costs, including costs of stocking, perishability, and just-in-time processing; and market accessibility and scale, including loss of market scale economies and reduced access to specialized labor and materials because of congestion.

These two studies have similar classification for costs that we have adopted for this thesis. The remainder of the literature tends to cluster into three distinct areas: private operating costs for carriers, the value of travel time in freight transport, and economic impact following natural disasters. The remainder of this chapter will discuss each group.

2.2 Research on Private Operating Costs for Carriers

In the past studies, private costs for carriers include following categories: ownership, drivers, supplies, and back office.

Of course, not all past studies include all four types of costs, but most of the studies do. The most often omitted one is costs for back office operation, such as office rent, administrative costs, etc. For example, Waters et al. (1995) and Federal Highway Administration (1997) do not include these costs.

Past studies categorize costs based on different criteria: for example, lengths of haul, truck types and shipment types, etc. Waters et al. (1995) calculate the maximum values of time for several categories of trucks, based on their operating costs. Trucks are categorized by the type of freight carried and the number of axles. The operating costs include cost of ownership, hourly value of vehicle time and hourly value of driver time. Table 1 shows the summary value of commercial vehicles time savings in their study.

Table 1: Summary Value of Commercial Vehicle Time Savings: Heavy Vehicles

	Bulk Commodity				General/Dry Freight			
	2-axle gasoline	2-axle diesel	5-axle diesel	7-8 axle diesel	2-axle gasoline	2-axle diesel	5-axle diesel	7-8 axle diesel
% on road (1988)	5.80%	6.50%	15.90%	1.80%	13.50%	15.20%	37.20%	4.10%
General Assumptions								
Average cost of new truck/tractor	$75,140	$80,117	$97,980	$98,314	$43,250	$48,227	$97,980	$98,314
Average cost of new trailer			$46,805	$89,627			$30,574	$35,085
Annual repair cost of truck/tractor	$3,350	$3,997	$10,642	$11,018	$3,350	$3,997	$10,642	$11,018
Annual repair cost of trailer			$4,981	$6,189			$4,528	$4,981
Annual truck/tractor license fee	$396	$396	$1,404	$2,341	$396	$396	$1,404	$2,341
Annual trailer license fee			$21	$42			$21	$42
Annual Insurance cost truck/tractor & trailer	$3,393	$3,154	$5,930	$7,015	$5,456	$5,248	$6,523	$7,896
Average age of vehicle (years)	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
Depreciation per year	16%	16%	16%	16%	16%	16%	16%	16%
Depreciation due to time	40%	40%	40%	40%	40%	40%	40%	40%
Repair/maintenance due to time	20%	20%	20%	20%	20%	20%	20%	20%
Cost of money	12%	12%	12%	12%	12%	12%	12%	12%
Insurance cost due to time	15%	15%	15%	15%	15%	15%	15%	15%
Assumed annual hour	2,400	2,400	3,000	3,000	2,400	2,400	3,000	3,000
Cost of Ownership								
Truck/Tractor:								
Hourly repair cost	$0.28	$0.33	$0.71	$0.73	$0.28	$0.33	$0.71	$0.73
Hourly depreciation cost	$2.00	$2.14	$2.09	$2.10	$1.15	$1.29	$2.09	$2.10
Hourly interest cost	$2.25	$2.40	$2.35	$2.36	$1.30	$1.45	$2.35	$2.36
Hourly license cost	$0.17	$0.17	$0.47	$0.78	$0.17	$0.17	$0.47	$0.78
Trailer:								
Hourly repair cost			$0.33	$0.41			$0.30	$0.33
Hourly depreciation cost			$0.37	$0.72			$0.24	$0.28
Hourly interest cost			$0.97	$1.86			$0.64	$0.73
Hourly license cost			$0.01	$0.01			$0.01	$0.01

Table 1: Summary Value of Commercial Vehicle Time Savings: Heavy Vehicles

	Bulk Commodity				General/Dry Freight			
	2-axle gasoline	2-axle diesel	5-axle diesel	7-8 axle diesel	2-axle gasoline	2-axle diesel	5-axle diesel	7-8 axle diesel
Hourly insurance cost truck/tractor & trailer	$0.21	$0.24	$0.38	$0.47	$0.11	$0.13	$0.35	$0.37
Profit markup (5%)	$0.25	$0.26	$0.38	$0.47	$0.15	$0.17	$0.36	$0.38
GST + PST (7% each)	$0.72	$0.78	$1.13	$1.39	$0.44	$0.50	$1.05	$1.13
Hourly value of vehicle time	$5.88	$6.32	$9.19	$11.30	$3.60	$4.04	$8.57	$9.20
Cost of Driver								
Driver's hourly wage	$12.03	$12.03	$12.03	$12.13	$14.25	$14.25	$14.25	$14.91
Driver's wage burden	26%	26%	28%	30%	53%	53%	34%	42%
Driver's hourly wage burden	$3.13	$3.13	$3.37	$3.64	$7.55	$7.55	$4.85	$6.26
Hourly cost of driver	$15.16	$15.16	$15.40	$15.77	$21.81	$21.81	$19.10	$21.18
Hourly cost of helper	$0.76	$0.76	$0.77	$0.79	$1.09	$1.09	$0.96	$1.06
Profit markup (5%)	$0.80	$0.80	$0.81	$0.83	$1.15	$1.15	$1.00	$1.11
GST + PST (7% each)	$2.34	$2.34	$2.38	$2.43	$3.37	$3.37	$2.95	$3.27
Hourly value of driver time	$19.06	$19.06	$19.36	$19.82	$27.42	$27.42	$24.01	$26.62
Value of Time Savings								
Hourly value of vehicle time	$5.88	$6.32	$9.19	$11.30	$3.60	$4.04	$8.57	$9.20
Hourly value of driver time	$19.06	$19.06	$19.36	$19.82	$27.42	$27.42	$24.01	$26.62
Maximum value of time savings	$24.94	$25.38	$28.55	$31.12	$31.02	$31.46	$32.58	$35.82
Minimum value of time savings	$4.81	$4.81	$4.81	$4.85	$5.70	$5.70	$5.70	$5.96

All dollar figures in 1993 US $
Source: Waters et al. (1995), The Value of Commercial Vehicle Time Savings for the Evaluation of Highway Investments: a Resource Saving Approach

ATA (1995) compiles operating and financial data on truck load (TL) carriers. ATA data include nearly all Class I carriers and some of the Class II carriers in the United States. The TL carriers are categorized by length of haul. Table 2 shows the summary value of private operating costs of truckload general freight trucking.

Table 2: Private Operating Costs of Truckload General Freight Trucking (1994 Dollars)

Expense category	Length of haul			
	Under 250 miles	250 to 500 miles	Over 500 miles	All TL general freight carriers
Salaries	$47M	$80M	$30M	$426M
Wages	$298M	$359M	$1,940M	$2,596M
Fringes	$95M	$87M	$392M	$574M
Operating supplies	$158M	$276M	$1,285M	$1,719M
General supplies	$39M	$73M	$356M	$469M
Tax and license	$31M	$45M	$329M	$406M
Insurance	$41M	$60M	$316M	$417M
Utilities	$13M	$21M	$101M	$134M
Depreciation	$52M	$81M	$459M	$592M
Equipment rents	$322M	$689M	$2,656M	$3,667M
Office equipment	$5M	$15M	$45M	$66M
Disposal of assets	-$3M	-$9M	-$30M	-$42M
Miscellaneous	$14M	$28M	$73M	$115M
Total expenses	$1,112M	$1,806M	$8,220M	$11,139M
Highway miles operated (miles)	723M	1,367M	6,845M	8,936M
Ton-miles	5,253M	20,199M	106,833M	132,284M
Cost per mile	$1.54	$1.32	$1.20	$1.25
Cost per ton-mile	$0.21	$0.09	$0.08	$0.08
Average load (tons)	7.26	14.77	15.61	14.80

Source: ATA (1995, Summary Table III and V).

2.3 Research on Value of Travel Time in Freight Transport

Studies have been conducted in the congestion price area to measure the unit value of the average delay, but most of the studies focus on the value of travel time in passenger transport.

Zamparini et al. (2007) mention that there is an analytical equivalence of the value of travel time in passenger transport and in freight transport. A few studies adapted similar approaches of estimating the value of travel time in passenger to measure the value of travel time in freight transport.

Zamparini (2007) provides a comprehensive review of past research estimating the value of travel time in freight transport. In the summary, stated preference, where people are asked to state their choices, is more commonly used than revealed preference, the observed value from actual choice. Among all studies examined by Zamparini (2007), most cases estimate values using logit regression. Additionally, Weisbrod (2001) calculates reliability costs, which are defined as the unit value associated with an average level of delay, based on three different types of commodities since different types of commodities have drastically different impacts on shippers when dealing with shipment delay.

Previous research on the value of travel time in freight transport can be categorized according to modeling approach.

2.3.1 Modeling approaches

In order to estimate the value of travel time in freight transport, two phases of modeling should be considered. The first phase is the data collection stage and the second phase is the value estimation stage. Table 3 shows how the past studies are categorized by modeling in the data collection phase and the value estimation phase.

Table 3: Methodologies of Estimating the Value of Travel Time in Freight Transport by Road (in 1999 $US per Shipment per Hour)

Country	Author(s)	Data Collection Method	Value Estimation Method	Value of Travel time in Freight Transport
Finland	Kurri et al. (2000)	Stated preference	Logit	1.53
Sweden	Transek (1990)	Stated preference	Logit	2.25
Sweden	Widlert and Bradley (1992)	Stated preference	Logit	7
Sweden	Bergkvist and Johansson (1997)	Stated preference	Logit, WAD, bootstrap	3-7
Sweden	Bergkvist (2001)	Stated preference	Logit, neural networks	0-97
Norway	Fridstrom and Madslien (1994)	Stated preference	Box-Cox logit	0-69
Denmark	Fosgerau (1996)	Stated preference	Logit	31-71
Denmark	Jovicic (1998)	Stated preference and revealed preference	Hierarchical logit	1.69
Netherlands	McKinsey and Co. (1986)	Fuel cost, wage rates	Factor cost	24
Netherlands	NEA (1991)	Fuel cost, wage rates	Factor cost	26
Netherlands	De Jong et al. (1992)	Stated preference	Logit	43
Netherlands	De Jong et al. (1995)	Stated preference	Logit	40-43
Germany	De Jong et al. (1995)	Stated preference	Logit	33
Germany and Denmark	Fehmarn Belt Traffic Consortium (1999)	Stated preference and revealed preference	Logit	21
UK	De Jong et al. (1995)	Stated preference	Logit	36-48
France	De Jong et al. (1995)	Stated preference	Logit	34
Switzerland and Italy	Bolis and Maggi (2001)	Stated preference	Logit	10.78-19.4
US	Kawamura (2000)	Stated preference	Logit	23.4-26.8
Australia	Wigan et al. (2000)	Stated preference	Logit	0.33-0.20

Source: Adapted from De Jong (2000) and Bergkvist (2001)

In Table 3, 23 out of 27 studies use stated preference as their data collection method. In addition, two of the other four studies use both stated preference and revealed preference as their data collection method. Only two studies do not use the stated preference method. Obviously, the stated preference method is the dominant methodology among existing studies in estimating the value of travel time in freight transport. For the revealed preference method, all the relevant data has to be available and sufficient, which is hard to meet, while the stated preference method has no such requirement. In the next chapter, the theoretical framework of this thesis will be discussed. The next chapter will describe the general pros and cons of the stated preference method which serves to be an important component of the theoretical framework used in this thesis. How this method can be related to this highway closure study will also be discussed in detail.

In Table 3, for the value estimation stage, the logit model is popular among existing studies. Most often the logit model is used to analyze the choice data collected by the stated preference method.

In Table 3, past studies estimating the value of travel time in passenger and in freight transport due to congestion show there are huge variances on the value of travel time in freight transport due to congestion across multiple studies. One reason is that different studies use various different assumptions, sample sizes, geographical areas, and study times. Because of the complex nature of measuring the value of travel time in freight transport due to disruptions of synchronous activities, few accurate methods are available.

2.3.2 Selected Model

Kawamura (1999) also estimates the value of travel time in freight transport due to congestions by using both a stated preference method and a logit model. This study investigates the perceived value of commercial vehicle time in urban areas. Congestion price is based on the perceived value of commercial vehicle time. Kawamura (1999) designs a modified logit model and uses stated preference data for input. The theoretical foundation is that the perceived value is estimated based on the switch of choice in the stated preference question, which indicates the commercial vehicle operator's willingness to pay. For example, if a carrier is willing to pay $10 to save 10 minutes but is not willing to pay $12 to save 10 minutes, the value of time is estimated between $60 per hour to $70 per hour. Then, the model is applied to the SR91 (State Route 91) congestion pricing project in Southern California as a case study.

However, the model has a few weaknesses. First, the perceived value will change over time, so the survey should be designed to reflect the change of value at different stages. Second, the data, which only includes 70 truck operators' interviews in California, is not large enough to represent the whole population. Since the perceived value will vary largely across industries, it is necessary to collect enough data for each industry. Third, only the commercial vehicle operators were interviewed, so the perceived value only reflects their values; however, the reliability of shipments is more valuable for shippers than for carriers. Ignoring a large group of receivers cannot capture the whole value of commercial vehicle time.

2.4 Research on Estimating the Economic Impact following Natural Disasters

Research has been conducted to assess the economic impact following natural disasters. For example, Baade et al. (2007) evaluate the impact following Hurricane Katrina, Burrus et al. (2002) present a model to estimate the impact of low-intensity hurricanes, and Rose et al. (1996) develop an input-output model to evaluate the economic impact of electricity disruptions due to an earthquake.

2.4.1 Modeling Approaches

According to *The Impacts of Natural Disasters: A Framework for Loss Estimation* published by the National Research Council, direct losses result from the physical destruction of buildings, crops, and natural resources. Indirect losses represent the consequences of that destruction, such as temporary unemployment and business interruption. Impact or forecasting models for indirect losses of natural disasters include input-output impact models, computable general equilibrium models (CGE) and simultaneous equation econometric models.

According to Cochrane (2004), direct loss reflects damage to plants, equipment, and infrastructure plus loss of income as a direct result of that damage. Indirect loss is everything else. Cochrane (2004) categorizes six ways which include linear programming, survey, econometric model, input-output model, computable general equilibrium model, and hybrid model to estimate indirect damage and criticizes each approach. For linear programming, it is questionable whether scarce resources will be distributed in an optimized way after the disaster. It is doubtable that survey represents group decision. Econometric model is derived from historical trading pattern so it may not capture the nature of supply shocks. Input-output model may not work when faced with a sudden and uneven shock to a region's productive capacity. Computable general equilibrium model can work under uneven supply shock with price change while in the real world, relative price change is conspicuously lacking. Many assumptions about substitutions may be not valid. Hybrid model can apply to the uneven supply situation, but inputs are user defined, which could be challenged.

2.4.2 Selected Models

Sohn et al. (2003) and Kunnumkal (2002) both use transportation network models as one component in their models. In this highway closure study, an input-output model is selected to estimate economic losses of freight disruptions due to highway closure. (Reasons for selecting the model will be discussed in the next chapter). Burrus et al. (2002) are selected because they utilize an input-output model to estimate the local economic impact of low-intensity hurricanes.

Sohn et al. (2003) estimate two aspects of costs: (1) cost associated with final demand loss and (2) transportation cost increase. Two factors influencing final demand are the network disruption ratio and resiliency of economic sectors. The bottlenecks which are bridges on each link are identified. The disruption ratios on the bridges are aggregated for the disruption on the link. Then all the disruption ratios on links are aggregated at a zonal level to be used in the final demand loss function. Three factors are considered for resilience of economic sectors. The higher the proportion of intrazonal flow is, the higher the resiliency will be. The higher the usage is, the lower the resiliency will be. The longer the distance is, the lower the resiliency will be. The integrated commodity flow model (ICFM) is used to estimate the increased cost of transportation. The model consists of two components: a multi-regional input-output model and a commodity flow model. An optimization algorithm is applied to measure the transportation cost increase. The objective function is to minimize total cost in the system, which includes the network assignment costs, intraregional travel costs and interregional flow distribution costs. ICFM is run once before the disruption as a reference. After the earthquake, the network capacity is adjusted to reflect the damages. The model is run again. The difference between the two runs is the transportation cost increase.

The model developed by Sohn et al. (2003) combines the transportation network disruption and economic input-output model. Not only is the highway system in the model, but the railway network is also integrated into the transportation network. However, other alternative minor roads are ignored. The economic model doesn't consider the damage on the regional production system. Moreover, the recovery process is not modeled.

Kunnumkal (2002), based on the one developed by Gupta (2001), develops a macroscopic methodology to estimate social-economic loss at the national level following a major earthquake. Kunnumkal (2002) defines socio-economic losses as direct losses due to building, contents, bridge and pavement damage, and indirect losses due to reduced productions, reduced consumptions and increased transportation costs. The model has five different components: the network model, the attenuation model, the fragility model, the loss-of-function and recovery model, and the input-output model.

Kunnumkal (2002) divides the U.S. into 152 analysis regions around the nodes of the road network. The analysis regions are formed by aggregating counties around the closest highway node. Kunnumkal (2002) also groups similar industries into 13 economic sectors. Time after the earthquake is separated into several recovery periods. The local ground motion intensity is associated with the initial damage level of each infrastructure. For each recovery period, the production levels of the economic sectors are calculated based on the damage level of the infrastructure. If a commodity cannot be shipped out due to transportation interruption, the production level for that commodity is then reduced so as to meet the network constraint. The indirect losses due to such reduced production are finally calculated for that recovery period. This process is repeated across recovery time periods using the updated production levels and network constraints from the previous ones. All these are repeated until the damage level of all elements go back to their pre-earthquake stage.

Very few papers such as Kunnumkal (2002) address the economic loss at the national level. Moreover, the recovery process is explicitly demonstrated in the model, which is very useful to understand the evolution of losses over time. However, the model has a few weaknesses. The model's transportation network does not include minor alternative routes. The methodology is deterministic and does not address uncertainty. The indirect losses at the national level may not represent local indirect losses well. The model doesn't take local mitigation or recovery capability into consideration.

Burrus et al. (2002) examine industry-specific business interruption losses and indirect and induced economic loss from three low-intensity hurricanes striking Wilmington, N.C.: Bertha (July 12, 1996), Fran (September 5, 1996) and Bonnie (August 26, 1998). Taking a similar approach through estimating business closure times as Cho et al. (1999), Burrus et al. (2002) use business interruption times to estimate business interruption losses. A survey was conducted in 1999 to quantify the business interruption times. Then, business interruption times were measured by full-day equivalents loss (FDEL) to standardize the inputs. Business interruption losses to output (BILO) are calculated by multiplying FDEL by average daily revenue per industry obtained from IMPLAN, an input-output database. BILO can only capture the direct economic loss for the region. Burrus et al. (2002) define indirect impacts as the reductions in regional economic output due to reduced purchases by businesses suffering direct impacts. Burrus et al. (2002) also calculate induced impacts, which are reductions in regional output due to reductions in household spending caused by temporary reductions in household income. By inputting BILO, which is the direct impact into IMPLAN software, IMPLAN estimates direct impacts on regional employment and business taxes, indirect impacts and induced impacts across industries. The methodology is simple and easy to understand. Just like other input-output models, however, IMPLAN fails to capture the uneven shocks and uncertainty. Moreover, survey-based methodology may create bias if the sample is not random.

2.5 Conclusion

Past research findings are summarized as the following:

Very few papers address the estimation of costs due to road closure. Among these papers mentioned in this literature review, three types of costs are identified for road closure: (1) private operating costs for carriers, (2) logistics and scheduling costs, and (3) indirect costs for the market. However, past researchers fail to generate a standard approach to estimate these three costs because of the complex nature of the problem. Thus, these costs are examined in their respective areas: private operating costs, value of travel time in freight transport, and economic impact following natural disasters.

For research on private operating costs, a resource saving method is widely used for cost estimation. Among past research, different components are included in each model, which therefore lead to various final results.

For research on value of travel time in freight transport, the stated preference method is widely used for data collection, and the logit model is widely adopted for value estimation. Not all delays are valued equally; Values of travel time in freight transport vary across different time periods after highway closure. The perceived values of shipments to shippers in different industries are also diverse.

For research on economic impact following natural disasters, several methodologies are used in past research. Each economic impact estimation methodology has its unique advantages and disadvantages. Selection of a methodology depends on specifications of a particular study. There is no consensus that one methodology is superior to the rest.

The best model for each research area is selected and the reason for selection of the model is discussed in the next chapter in detail. Since all these models are not created for estimating economic impact of freight disruption due to highway closure, each selected methodology will then be adjusted accordingly to best fit the overall model.

Chapter 3. Theoretical Framework and Methodology

3.1 Overview

This chapter discusses the theoretical framework and methodology for estimating economic impacts of freight disruptions due to highway closure. The costs in this study will be classified into the following three groups: private operating costs for carriers, logistics and scheduling costs, and indirect costs for the market.

3.2 Private Operating Costs for Carriers

After a local Department of Transportation announces the closure of a highway, all vehicles will be directed to take a detour. The detour will cause truck drivers additional time and additional driving mileage to avoid the disrupted area. The additional time and driving mileage will cause carrier companies to spend extra money on resources, such as trucks, drivers, equipments, supplies, etc.

We use the resource saving method, which is based on the marginal cost associated with unit time increase, to the approximate private operating costs for carriers for one mile. A per-mile private operating cost of $1.25, estimated by ATA (1994) in Table 2 (Chapter 2), will be used in this study. This value includes not only the operating costs for truck drivers but also operating costs for truck companies.

The unit cost data is from 1994, so the corresponding inflation adjustment should be made. Moreover, if there is more recent and accurate data available, the more recent data should be substituted for the 1994's unit cost. Because of time limitation, the unit cost of private operating cost for carriers is not calculated and is borrowed from the result of ATA (1995). However, in future research, in order to reflect the uniqueness of each study and have more accurate results, the components of unit value of private operating costs for carriers should be revisited and the unit of private operating costs for carriers should be recalculated for that particular study.

3.2.1 Assumptions

Several assumptions are made in the present project. First, truck drivers are assumed to have perfect information of duration of the highway closure and additional time to take the detour. Thus, all truck drivers will make decisions whether to take the detour based on minimum time losses associated with private operating costs for carriers. Second, shippers will not cancel their shipments. All trucks will take the detour or wait for the reopening of the highway. Third, delay of shipments on the detour route is not included in this study. Fourth, only one detour is considered. Fifth, traffic volume is not affected by other factors. Sixth, highway closure information is available immediately. There is no gap between the decision making and action taking.

3.2.2 Methodology

The private operating cost for carriers is the most direct and easiest to obtain among the three costs caused by freight disruptions due to highway closure. Additional driving mileage is converted to additional driving time by taking the detour instead of the original route. The final time loss is equal to the maximum of waiting time and additional driving time. The final private operating cost is generated by multiplying the final time loss by the unit value of private operating cost.

The detailed process for estimating the private operating cost consists of the following steps:

Step 1: Collect the data for traffic on the detour route and the closed highway:

v_{dn}: average speed of vehicles on the detour route d during normal days

D_d: distance of the detour route, d.

D_c: distance of the part of the closed highway, c, which overlaps with the detour route

v_{dc}: average speed of vehicles on the detour during closure time

q: total number of vehicles impacted by the highway closure. This number can only be estimation. q can be obtained by counting the traffic volumes passing by the automatic traffic recorders (ATRs) located on the open segments closest to the closed part of highway. q can be also obtained by using the average traffic volumes of the closed highway for the same duration of highway closure during normal days.

P: percentage of commercial vehicles over all vehicles on the closed highway during normal days. This number can be obtained from the Freight Analysis Framework (FAF)[1].

[1] Source: http://ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm

Step 2: Calculate the additional time by taking the detour, T_d:

$$T_d = \max(0,\ {}^{D_d}/_{v_{dc}} - {}^{D_c}/_{v_{dn}}) \qquad \text{Equation 1}$$

Step 3: Calculate the final time loss by comparing the additional time of taking the detour with the waiting time without taking the detour. Based on the assumption that the duration of the closure is known, truck drivers will make decisions on whether to stay or to take the detour. If the duration of closure is shorter than the additional time of taking the detour, truck drivers will wait for the reopening of the closed highway and will not take the detour.

$$T = \min(T_d, T_w) \qquad \text{Equation 2}$$

where:

T_w: waiting time for the reopening of the highway

T : final time loss

Step 4: Calculate the cost for the time loss for one vehicle. Since the unit value of private operating costs, $1.25, is per-mile based, it needs to be translated to a unit of per-hour based.

$$C_{vehicle} = T * c * v \qquad \text{Equation 3}$$

where:

$C_{vehicle}$: cost of the time loss for one vehicle

c: unit cost of the private operating cost, a per-mile operating cost of $1.25 (Chapter 2 Table 2)

v: average speed of commercial vehicles nationwide

Step 5: Calculate the total private operating costs for carriers for all impacted commercial vehicles.

$$C_{Transportation} = C_{vehicle} * q * P \qquad \text{Equation 4}$$

where:

$C_{Transportation}$: total cost of private operating costs for carriers for all impacted commercial vehicles

If the duration of the closure is long, the duration could be segmented into several smaller time periods. Costs for each time period can be calculated by using the methodology above. If the distance of the detour is long, the detour route can also be separated into several shorter detour segments. Higher resolution can generate more accurate private operating costs for carriers.

It should be noted that there are several assumptions made for the methodology. In order to get more accurate estimations for private operating costs for carriers, these assumptions should be revisited and corresponding changes of the methodology should be made based on specific requirements of a given project. One assumption is that every truck driver has perfect information of the duration of the highway closure. In reality, however, only a certain percentage of drivers have exact information. Final time losses of these drivers can be calculated based on the model used in this thesis. For the rest of the drivers who do not have information regarding the duration of highway closure, they probably wait for a certain time period before deciding to take the detour. The length of the time period is the maximum duration for which a single driver is willing to wait. If the highway is still closed after their expected waiting time, these drivers will take the detour. Otherwise, they will continue the trip until the closed segment to reopen. In this case, final time losses should be the weighted average of final time losses of truck drivers who have full information of highway closure duration and those who do not. Equation 2 should be modified as:

$$T = K \times \min(T_d, T_w) + (1 - K) \times \{T_w \times f(x) + (T_e + T_d) \times [1 - f(x)]\}$$

$$f(x) = \begin{cases} 1, & x < T_e \\ 0, & x \geq T_e \end{cases} \qquad \text{Equation 5}$$

where:

T_e: expected waiting time for a commercial vehicle driver

K: percentage of commercial vehicle drivers who know the duration of the highway closure.

3.3 Logistics and Scheduling Cost

Logistics and scheduling costs are caused by disruptions of synchronous activities. The delay of the shipment may result in a loss that is far more than the value of the shipment itself. Most of the studies estimating the value of travel time in freight transport apply discrete choice model to get the unit value of average delay due to congestion. According to Ben-Akiva et al. (1985), a discrete choice model is a math function which predicts individuals' preference on utilities of various competing alternatives. The discrete choice theory is, again, used in this study to estimate the value of travel time in freight transport from the start of the delay due to the highway closure.

3.3.1 Value of Travel Time in Freight Transport

The concept of estimating the value of travel time in freight transport is based on a firm's willingness to pay with notice of the delay situation. The method measures the exchange rate between time and money firms are willing to pay (Kawamura 1999).

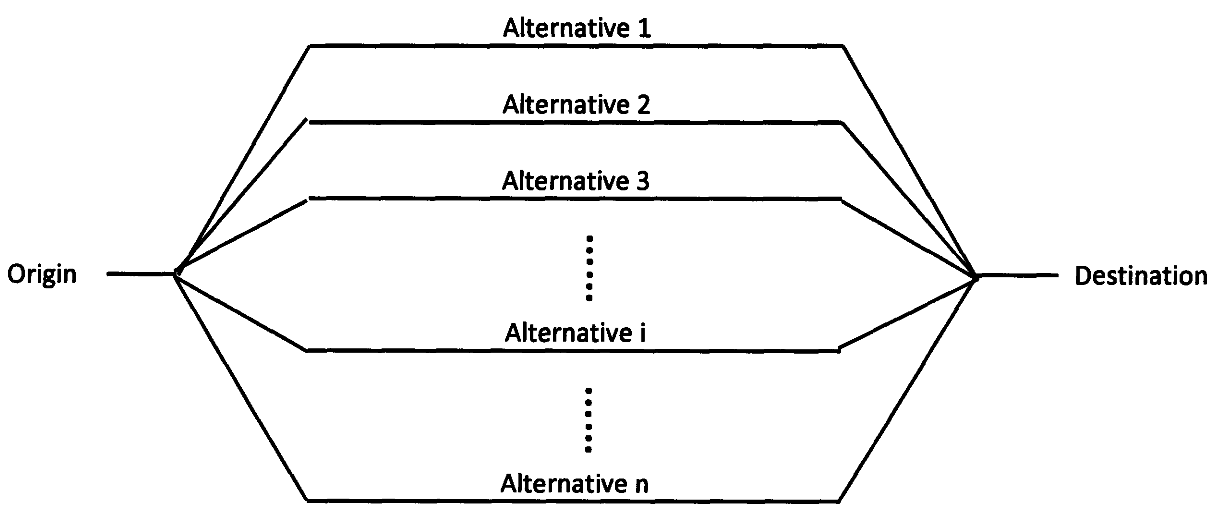

Figure 1: Alternatives Routes of One Origin-Destination Pair for the Stated Preference Method

In Figure 1, each alternative is associated with a unique travel cost and a unique travel time. By selecting the perceived the best option, respondents will reveal their willingness to pay with the notion of the delay due to highway closure. There are two ways to collect data to reveal the willingness to pay from respondents: revealed preference method and stated preference method.

3.3.2 Revealed Preference versus Stated Preference

Revealed preference methods take the actual behavior of individuals into account. All the studies of revealed preference methods are based on the data collected by observing the real behavior of individuals making a choice. On the other side, a stated preference method is a simulated situation where individuals make decisions based on what they think they will do.

Actually, there are very restrictive rules for using revealed preference methods. First, all the alternative routes have to be available for users to select. Second, real choices must exist among all alternative routes. Third, all the relevant data to measure parameters of all alternative routes has to be available and sufficient.

In reality, these conditions are hard to meet. On the other hand, stated preference methods have the following advantages compared to revealed preference methods: First, stated preference methods require less time to collect data than revealed preference methods. Second, survey questions can be designed to eliminate the correlations in stated preference methods. Third, survey questions can be designed to explore a large range of trade-offs.

Consequently, most researchers select stated preference methods to estimate the value of travel time. However, stated preference methods also show weaknesses: first, survey sample cannot represent a whole population very accurately. Second, stated preference methods might create bias. Third, most surveys are answered by transportation managers. They may not have the knowledge on the loss from disruptions of synchronous activities across the whole organization.

Because stated preference methods are conducted under hypothetical scenarios, respondents may not consider consequences as fully as they would in a real situation. However, carefully designed surveys may minimize some biases to a certain degree.

In this study, no actual data was obtained to conduct the revealed preference method, and the stated preference method has more advantages than the revealed preference method. The stated preference method is therefore selected to estimate the value of travel time in freight transport from the start of the delay due to highway closure.

3.3.3 Survey

Stated preference methods have weaknesses as mentioned above. In order to estimate the value of travel time in freight transport from the start of the delay due to highway closure as accurately as possible, surveys could be well designed to minimize inaccuracy.

The following requirements of surveys have to be met to estimate the value of travel time in freight transport. First, respondents should be the ones who plan the day-to-day operations of the truck fleet and know about the relationship between delays and productivity losses. Second, some relevant information has to be collected, such as commodity type, shipment value, industry type, company size, fleet characteristics, etc.

Researchers should explain various scenarios clearly to respondents. Respondents are asked to make a choice on route selection under the knowledge that the shipment is delayed in a certain time period after a highway closure. For past studies, respondents have been mostly carriers. Since logistics and scheduling costs are major losses for shippers, surveys should target shippers instead of carriers for this study. However, some carriers also need to be surveyed to obtain the losses by carriers due to synchronous activities occurring on carrier side. This loss cannot be captured by private operation costs for carriers.

According to the Midwest Transportation Consortium, the unit cost of travel time in freight transport declines over time. The relationship between relative cost of one hour of delay and hours of advanced notification of a delay is shown in Figure 2.

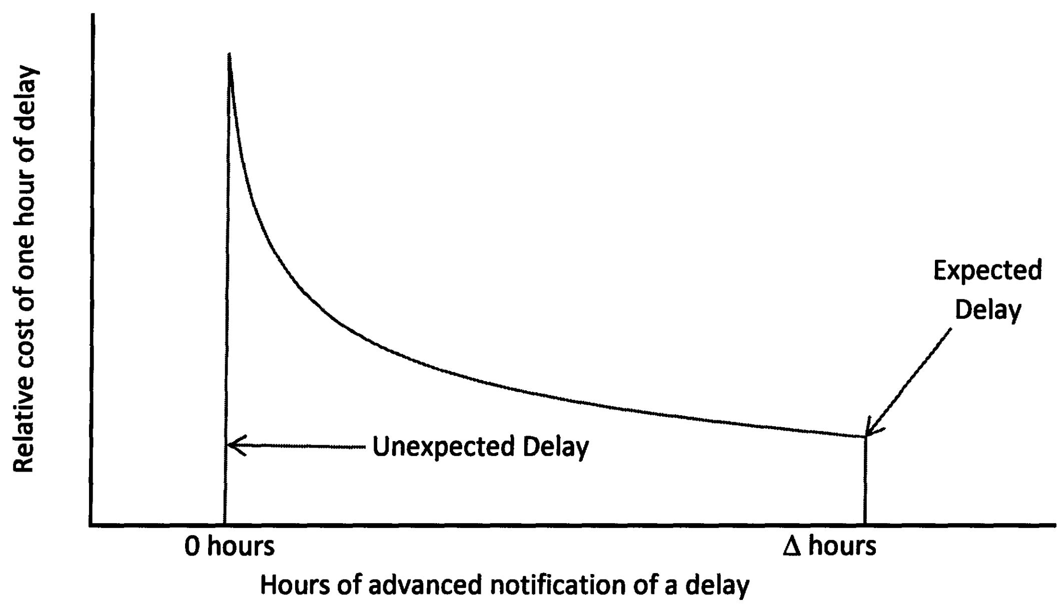

Figure 2: Relative Cost of a Delay

Freight delay costs consist of two parts: expected delay and unexpected delay. With advanced warning of a delay (expected delay), carriers and shippers have a greater ability to adjust and accommodate a delay. Without advanced warning of a delay (unexpected delay), carriers and shippers have the least opportunity to adjust synchronous activities, therefore generating the highest costs. As shown in Figure 2, unexpected delays will eventually be transformed into expected delays with advancement of warning. The relative cost of an unexpected delay is much greater than the cost of an expected delay in freight. The reason is that with the notice of delay, shippers may take actions to minimize losses caused by the delay. Figure 2 also indicates that the value of travel time in freight travel varies in different time periods after highway closure.

Perceived values of shipments to shippers in different industries are also quite diverse. These underline the need to differentiate the commodities in estimating the impact of a highway closure to a variety of industries. Commodities can be categorized based on the methodology provided by the North America Industry Classification System (NAICS). The aggregation level of the commodity type depends on the specification of different projects. Table 4 shows all commodities aggregated to 16 sector levels by NAICS.

Table 4: Sector Report for 2006 Annual Commodity.

Sector Code	Sector Descripton
01	Agriculture, forestry, fishing, and hunting
02	Mining
03	Utilities
04	Construction
05	Manufacturing
06	Wholesale trade
07	Retail trade
08	Transportation and warehousing
09	Information
10	Finance, insurance, real estate, rental, and leasing
11	Professional and business services
12	Educational services, health care, and social assistance
13	Arts, entertainment, recreation, accommodation, and food services
14	Other services, except government
15	Government
16	Other
NIPA	National income and product accounts (NIPA) reconciliation item
S002	Scrap, used and secondhand goods
V001	Compensation of employees
V002	Taxes on production and imports, less subsidies
V003	Gross operating surplus

Source: www.bea.gov

Based on the reasons discussed above, the classification of commodity types and time periods after highway closure should be reflected in the survey. The survey should draw enough samples to represent each industry/commodity. Respondents also need to be asked to make decisions under various delay stages. Combining the facts that the value of travel time in freight travel may vary in different time periods after highway closure and by different commodity type, final results for the unit value of travel time in freight transport should look like the following:

Table 5: Unit Value of Travel Time in Freight Transport

	Time Period 1 (0 hr - 3 hr)*	Time Period 2 (4 hr - 7 hr)	Time Period 3 (8 hr - 11 hr)	Time Period 4 (12 hr - 15 hr)	Time Period 5 (16 hr - 19 hr)	Time Period 6 (20 hr - 23 hr)	....
Industry 1	C^1_1	C^2_1	C^3_1	C^4_1	C^5_1	C^6_1	
Industry 2	C^1_2	C^2_2	C^3_2	C^4_2	C^5_2	C^6_2	
Industry 3	C^1_3	C^2_3	C^3_3	C^4_3	C^5_3	C^6_3	
Industry 4	C^1_4	C^2_4	C^3_4	C^4_4	C^5_4	C^6_4	
Industry 5	C^1_5	C^2_5	C^3_5	C^4_5	C^5_5	C^6_5	
Industry 6	C^1_6	C^2_6	C^3_6	C^4_6	C^5_6	C^6_6	
⋮							⋱

where:

C_i^j: average unit value of travel time in freight transport for one commercial vehicle carrying commodity i at time period j.

*Duration of each time period should be obtained from a pilot study before a full-scale survey.

3.3.4 Logit Model

Logit models have been widely adapted to estimate the value of travel time in passenger transport. In recent decades, researchers have started applying logit models to estimate the value of travel time in freight transport (Chapter 2 Table 3).

The utility function is a mathematic expression assigning a value to all alternatives. After collecting the data by using stated preference methods, the utility function for individual j for choosing alternative i can be defined as following:

$$U_{ij} = \alpha C_{ij} + \gamma T_{ij} + \varepsilon_{ij} \qquad \text{Equation 6}$$

where:

C_{ij}: loss associated with alternative *i* for an individual *j*.

T_{ij}: travel time for alternative *i* for an individual *j*.

ε_{ij}: unobserved stochastic portion of the utility with alternative *i* for an individual *j*.

α: marginal utility of cost; parameter for cost

γ: marginal utility of time; parameter for time

The observable portion is $\alpha C_{ij} + \gamma T_{ij}$. ε_{ij} is the unobserved stochastic portion of the utility function and is a random variable. ε_{in} may be caused by unobserved attributes, taste variations, measurement errors, imperfect information, and proxy variables resulting from the imperfect relationship between the attributes and the alternatives (Ben-Akiva and Lerman, 1985). ε_{ij} is identically and independently distributed (IID) with Gumbel distribution. α and γ can be obtained through applying a maximum likelihood method. Currently, several software packages are available to estimate α and γ.

The value of travel time in freight transport from the start of the delay is the ratio between the marginal utility of cost, α, and the marginal utility of time, γ.

$$\text{Value of Time} = \frac{\alpha}{\gamma} \qquad \text{Equation 7}$$

Logit models are based on the assumption that ε is independent and identically distributed, which means all alternatives are not overlapped and independent to each other.

3.3.5 Methodology

The methodology can be summarized in the following steps.

Step 1: Design a logit model. Depending on the detail and sophistication level required, researchers should design the logit model to reflect the key characteristics of their studies. Equation 6 is a basic logit model and it can be one of the options to estimate the value of travel time in freight transport due to highway closure.

Step 2: Design a survey by using stated preference methods. The survey has to be carefully designed to meet the specific scope of the project. Good design can eliminate a certain degree of bias. Each scenario should be carefully worded to avoid any confusion. The value of travel time in freight transport varies based on time periods from the start of the delay and commodity types. The survey should be designed to reflect these characteristics. A sample of questionnaires for measuring the value of travel time in freight transport designed by Kawamura (1999) can be used as a reference in future research.

Step 3: Decide on proper sample selection criteria based on the scope of the project. Sample selection should be representative for the population studied in the project.

Step 4: Analyze the data collected by the survey to ensure the quality of all data. Before analyzing the collected data, the erroneous data should be discarded. The characteristics of the data can be compared with characteristics of the population studied. If there exists a deviation, a further investigation needs to be launched to test the quality of overall data. For example, the distribution of the data could be compared with the distribution of the population to verify the trustworthiness of the data. Each deviation should be carefully examined and explained in order to avoid corrupted data.

Step 5: Apply a maximum likelihood method to estimate parameters for the logit model. If the logit model (Equation 6) is selected, α and γ should be estimated. There are several commercial and open source software packages available for the parameters' estimation, such as SAS, R, NLOGIT etc.

Step 6: Generate the unit value of travel time in freight transport. For the logit model used in this study, Equation 7 is the unit value of travel time in freight transport. The unit value of travel time in freight transport for different commodities and for different time periods from the start of the delay should be collected separated. The final results of the unit value of travel time in freight transport should look like those in Table 5. If the study time is limited, researchers can use results from past studies. For example, Weisbrod et al. (2001) stratified the shipments into three commodities by eight sector levels. However, that might not accurately reflect delays due to highway closure for one particular study.

Step 7: Calculate the total value of travel time in freight transport from the start of the delay for each commodity based on the following equation. The total value of travel time in freight transport from the start of the delay for one particular industry is the logistics and scheduling cost for that industry.

$$C_i = \left(\sum_{j=0}^{n} C_i^j \; T_j \right) \times q \times P \times P_i \qquad \text{Equation 8}$$

where:

C_i: total value of travel time in freight transport for all impacted commercial vehicles carrying commodity *i*

C_i^j: average unit value of travel time in freight transport for one commercial vehicle carrying commodity *i* at time period *j*

T_j: duration of time period *j*

n: average number of time periods a commercial vehicle will have from the start of the delay due to highway closure

q: total number of vehicles impacted by the highway closure

P: percentage of commercial vehicles over all vehicles on the closed highway during normal days

P_i: percentage of commercial vehicles carrying commodity *i* over all commercial vehicles on the closed highway during normal days. This number can be obtained from the Freight Analysis Framework (FAF).

The final logistics and scheduling cost, C_i, is the input for the indirect cost for the market. Each highway closure case can use this methodology to calculate the logistics and scheduling cost, but certain adjustments should be made before applying the method. There is still room for improvements for future research.

3.4 Indirect Costs for the Market

Indirect costs for the market are ones that are physically and/or temporally removed from the disruption (usually termed a "direct effect" or "direct impact"). These costs are passed along to the market by carriers and shippers, in the form of private operating costs for carriers and logistics and scheduling costs. Any direct losses of shippers and carriers through the disruption of regular services will generally affect a much wider market. For example, Industry B's final product takes Industry A's output as one of its ingredients. If a temporary shortage of raw materials on Industry A's side due to highway closure, the output of Industry A cannot be delivered to Industry B as scheduled. The output of Industry B will be influenced because of a lack of output from Industry A. Moreover, if Industry B also serves Industry C, Industry D and so on, at the end, the whole market could be affected due to ripple effects of the single, simple highway closure. Even though some industries might not send their products by that highway, they could still be affected through ripple effects.

As mentioned in Chapter 2, there are several research methodologies for measuring this inter-industry relationship to estimate economic impacts following natural disasters. The input-output model is selected in this study to measure economic impacts of freight disruptions due to highway closure. The reasons can be summarized as follows. First, an input-output model is the simplest in terms of construction and implementation among those which can estimate economic impacts following natural disasters. Second, the input-output model efficiently provides a comprehensive set of economic impact estimates when short-run disruptions are being analyzed. (It serves as the basis for many complex models that integrate economic with demographic and fiscal responses to economic events.) Third, the input-output model can measure any economic impacts, no matter what geographical scale is used. Fourth, the input-output model can measure any economic impacts, regardless of the source of disruption. Fifth, due to the popularity of the model, data collection is relatively easier, and software and databases of the input-output model have been developed (e.g., IMPLAN, the Southern California Planning Model, HAZUS, Regional Econometric I-O Model, Dendrinos-Sonis Model, etc.). Thus, there is broad range of economic impact studies that have been carried out using the input-output modeling technique.

3.4.1 Input-Output Model

In order to explain the mechanism of input-output analysis, current relationships among industries should first be explored. Input-output tables are the tools that provide the details of these relationships. (The following explanation of an input-output model is taken from Polenske et al. (1993), Miernyk (1965), and Miller et al. (1985))

3.4.1.1 Input-Output Table

As commonly developed, input-output tables are constructed as annual accounts measuring the transaction flows of goods and services between each and every industry. In addition to transactions between producers and final consumers (e.g., households, public agencies, export markets, inventories, and investors), they also include intermediate transactions between producers as goods and services are combined for sale to final users within an economic area. The economic area can be defined as a nation, a state, a county, etc. Choice of area depends on the scope of a given research study. Industries can be aggregated to a general level, such as manufacturing, and they can also be disaggregated to a more detailed level, such as steel nails. Level of aggregation depends on the details of a particular study. Table 6 is an example of an input-output accounting table using numerical data, and Table 7 is the same input-output table using symbolic data.

Table 6: Seven-Sector Industry Input-Output Table, U.S. 1987 ($1982 Million)

Producing Sector	Purchasing Sector 1	2	3	4	5	6	7	Final Demand	Total Output
1	51,949	80	1,415	91,220	4,619	11,187	348	35,684	196,502
2	369	18,346	4,969	170,920	1,008	51,499	3,646	(27,477)	223,280
3	1,534	470	826	20,018	12,473	66,388	11,115	381,933	494,756
4	36,752	15,700	176,203	865,110	79,418	211,830	8,678	1,016,471	2,410,163
5	10,360	4,342	56,747	150,767	66,123	71,618	5,260	693,175	1,058,392
6	14,936	20,698	47,070	180,771	172,066	468,030	15,100	1,347,464	2,266,136
7	451	1,035	1,645	25,133	16,832	30,492	2,062	398,453	476,103
Value Added	80,150	162,611	205,881	906,224	705,852	1,355,091	429,895	0*	3,845,702
Total Outlays	196,502	223,280	494,756	2,410,163	1,058,392	2,266,136	476,103	3,845,702	10,971,032

* No Data Provided

Source: INTRO-IO: Introduction to Input-Output Accounting and Modeling

Table 7: Seven-Sector Industry Input-Output Table

	Processing Sector 1	2	3	4	5	6	7	*Final Demand*	Total Output
1	z_{11}	z_{12}	z_{13}	z_{14}	z_{15}	z_{16}	z_{17}	Y_1	X_1
2	z_{21}	z_{22}	z_{23}	z_{24}	z_{25}	z_{26}	z_{27}	Y_2	X_2
3	z_{31}	z_{32}	z_{33}	z_{34}	z_{35}	z_{36}	z_{37}	Y_3	X_3
4	z_{41}	z_{42}	z_{43}	z_{44}	z_{45}	z_{46}	z_{47}	Y_4	X_4
5	z_{51}	z_{52}	z_{53}	z_{54}	z_{55}	z_{56}	z_{57}	Y_5	X_5
6	z_{61}	z_{62}	z_{63}	z_{64}	z_{65}	z_{66}	z_{67}	Y_6	X_6
7	z_{71}	z_{72}	z_{73}	z_{74}	z_{75}	z_{76}	z_{77}	Y_7	X_7
Value Added	W_1	W_2	W_3	W_4	W_5	W_6	W_7	W_Y	W
Total Outlays	X_1	X_2	X_3	X_4	X_5	X_6	X_7	Y	X

All data in the table can be obtained from commercial software packages such as IMPLAN, REMI, RIMS. In Table 7, z_{ij} represents the symbolic flow of monetary value (i.e. value of transactions) from each Industry i (shown in the row headings) to each Industry j (shown in the column heading). Industry i is the supplier and Industry j is the customer. When viewed in columnar form, we see the purchases made by each Industry j from each and every Industry i.

In Table 6 and Table 7, in addition to purchases among industries, there are other economic activities shown for the region. For example, final consumers, companies for private investment purposes, governments and external entities can also purchase products from the region. Purchases of this type are called *final demand.* Moreover, in order to produce a product, in addition to intermediate inputs, several other inputs are often needed, including labor, consumed capital resources, compensation to business owners, and tax payments. All these are termed *value added.* When a full accounting for value added and final demand is made, the input-output accounts generate estimates of the gross regional product and income, two commonly used gauges of economic activity that are often used to describe national-level economic performance. The inter-industry intermediate transactions are identified as occurring in *the processing sector* in this table.

With the final demand of Industry i denoted as Y_i and the total output of Industry i denoted as X_i, each row of the processing sector in Table 7 can be presented as

$$X_i = \sum_j Z_{ij} + Y_i \quad \forall\, i \qquad \text{Equation 9}$$

In general, all processing sector data can be obtained by surveying industries to get the monetary value of input *from* the industries as suppliers and output *to* the industries as customers. A national set of these accounting data prepared annually by the Bureau of Economic Analysis at the U.S. Department of Commerce prepared as part of the national income and products accounts. In addition, commercial software such as IMPLAN, REMI, RIMS also contain these data (or transformations based on these data) for inter-industry transactions.

3.4.1.2 Direct-Input Coefficient Table

After obtaining the input-output table, the flow of input from Industry *i* to Industry *j*, z_{ij}, is divided by the total output of Industry *j*, X_j. The result is the ratio of input to output, which is denoted as a_{ij}:

$$a_{ij}=\frac{z_{ij}}{X_j} \qquad \text{Equation 10}$$

This ratio is called direct input coefficient. It measures the amount directly purchased from Industry *i* per dollar's worth of output of Industry *j*. This is a fixed relationship, which is one basic assumption of an input-output model. Polenske et al. (1993) states that, in an input-output model, there are constant returns to scale among productions. Thus, a_{ij} is a fixed number during the period of study. With $a_{ij}=\frac{z_{ij}}{X_j}$, Equation 10, can be rewritten as:

$$X_i = \sum_j a_{ij} X_j + Y_i \quad \forall\, i \qquad \text{Equation 11}$$

The direct input coefficients table is calculated from Table 6:

Table 8 Direct-Input Coefficient Table (Direct Input per Unit of Output)

	1	2	3	4	5	6	7
1	0.264	0.000	0.003	0.038	0.004	0.005	0.001
2	0.002	0.082	0.010	0.071	0.001	0.023	0.008
3	0.008	0.002	0.002	0.008	0.012	0.029	0.023
4	0.187	0.070	0.356	0.359	0.075	0.093	0.018
5	0.053	0.019	0.115	0.063	0.062	0.032	0.011
6	0.076	0.093	0.095	0.075	0.163	0.207	0.032
7	0.002	0.005	0.005	0.010	0.016	0.013	0.004
Value Added	0.408	0.728	0.728	0.376	0.667	0.598	0.903
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000

Source: Calculated from Table 6 as the direct input from a given industry divided by the total output of the industry that is purchasing the input

Table 8 shows the amount that each industry purchases directly, first round, from other industries to produce one dollar's worth of the product of each industry based on the interrelationships of industries in Table 6.

3.4.1.3 Direct and Indirect Coefficients Table

The direct coefficient table only measures the first round effect of change of one dollar's worth of output. As mentioned before, there are ripple effects after the first round impact. Another table can be derived to reflect the direct and indirect change of output. It is called the direct and indirect coefficient table.

In order to obtain the direct and indirect coefficient table, some transformations have to be made. After grouping all Xs to the left side of the equations, Equation 11 can be rewritten as:

$$X_i - \sum_j a_{ij} X_j = Y_i \quad \forall\, i \qquad \text{Equation 12}$$

After grouping the same X together, Equation 12 can be rearranged as:

$$(1 - a_{11})X_1 - a_{12}X_2 - \dots - a_{1i}X_i - \dots - a_{1n}X_n = Y_1$$

$$- a_{12}X_1 + (1 - a_{22})X_2 - \dots - a_{2i}X_i - \dots - a_{2n}X_n = Y_2$$

$$\vdots$$

$$- a_{i1}X_1 - a_{i2}X_2 - \dots + (1 - a_{ii})X_i - \dots - a_{in}X_n = Y_i$$

$$\vdots$$

$$- a_{n1}X_1 - a_{n2}X_2 - \dots - a_{ni}X_i - \dots + (1 + a_{nn})X_n = Y_{1n}$$

Equation 13

In matrix terms,

$$A = \begin{bmatrix} a_{11} \; a_{12} & \cdots & a_{1i} \; \dots & a_{1n} \\ \vdots & \ddots & \vdots & \\ \vdots & & \vdots & \\ a_{n1} \; a_{n2} & \cdots & a_{ni} \; \dots & a_{nn} \end{bmatrix}$$

Equation 14

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix}$$

Equation 15

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix}$$

Equation 16

Based on the matrix terms above, Equation 13 can be rewritten as:

$$(I - A)X = Y$$

Equation 17

In order to generate the direct and indirect impact on X, Equation 17 should be rearranged to represent X in matrix terms:

$$X = (I - A)^{-1}Y \qquad \text{Equation 18}$$

where $(I - A)^{-1}$is termed Leontief inverse, also named the total requirements matrix[2].

The direct and indirect coefficient table, which is derived from Table 6, is shown below:

Table 9 Direct and Indirect Coefficient Table (Direct and Indirect Input per Unit of Final Demand)

	1	2	3	4	5	6	7
1	1.386	0.010	0.039	0.088	0.018	0.021	0.005
2	0.045	1.106	0.067	0.134	0.022	0.051	0.014
3	0.023	0.009	1.017	0.023	0.022	0.042	0.026
4	0.467	0.157	0.639	1.660	0.185	0.235	0.056
5	0.120	0.040	0.179	0.129	1.092	0.067	0.021
6	0.210	0.155	0.231	0.211	0.249	1.310	0.055
7	0.013	0.010	0.016	0.023	0.023	0.022	1.006

Source: Calculated from Table 6 using only the seven-sector direct-input coefficients by inverting the (*I-A*) matrix.

This table includes not only the first round effect but also the second, the third ... infinite rounds of effects.

Table 9 shows that in order to produce each dollar's worth of output of the industry at the left, the direct and indirect amount of products have to be produced by the industry at the top.

[2] This transformation is named for Wassily Leotief, the economist who applied economic accounting data to the study of economic structure and structural change. Dr. Leontief was recognized for his work in this field with the Nobel Price for Economics in 1973.

3.4.2 Assumptions

Several assumptions are made in the present project. First, all industries operate with constant returns to scale, meaning that no economics of scale can be achieved through altering the level of output in this model. Second, since highway closure times are generally short (i.e., less than a year), so during the period of study, the technology of one industry will not change significantly, which means inputs from one industry to another industry are in fixed proportions. Third, since the study time is short, the supply shortage will drive the demand temporarily down for this period. The reduction of supply is equal to the reduction of demand. Uneven shock of production capacity is not considered. Fourth, since the study time is short, the impact will not change the price of products.

3.4.3 Methodology

For this highway closure case, shippers receiving commodities through the closed highway represent companies in their corresponding industries. Carriers carrying commodities on the closed highway represent companies in the transportation industry. The amount of losses for shippers and losses for carriers will be passed down to other industries in the market through inter-industry connections. The input-output model is used to estimate indirect costs of the market based on inter-industry relationships by inputting direct losses for shippers and carriers which represent their corresponding industries.

The methodology can be summarized in the following steps:

Step 1: Obtain the total loss for carriers from private operating costs for carriers as the total direct loss of the transportation industry. The direct loss of the transportation industry can be treated as demand reduction for the transportation industry in the input-output model because the transportation industry can be viewed as an intermediate consumer for other industries. Under the assumption that the impacted time period is short, the reduction of supply is equal to the reduction of demand for that period. The total private operating cost for carriers, $C_{Transportation}$, is used as an input to the input-output model, $\Delta Y_{transportation}$, which describes the reduction of demand.

$$\Delta Y_{transportation} = C_{Transportation} \qquad \text{Equation 19}$$

where:

$C_{Transportation}$: total cost of private operating costs for carriers for all impacted commercial vehicles

Step 2: Obtain the total loss for the industry by adding all logistics and scheduling costs for all companies in that industry. Like the situation explained in Step 1, the loss for the industry can be treated as the demand loss for that industry in the input-output model because each industry can be viewed as an intermediate consumer for other industries. Moreover, since the impacted time period is short, the reduction of supply is assumed to be equal to the reduction of demand. The total value of travel time in freight transport for all impacted commercial vehicles carrying commodity i, C_i, is used as an input to the input-output model, ΔY_i, which describes the reduction of demand for commodity i.

$$\Delta Y_i = C_i \qquad \text{Equation 20}$$

where:

C_i = total value of travel time in freight transport for all impacted commercial vehicles carrying commodity i

Step 3: Obtain the change of final demands, ΔY, by combining the results from Step 1 and 2 to get the column matrix of final reductions on demand Y.

$$\Delta Y = \begin{bmatrix} \Delta Y_1 \\ \Delta Y_2 \\ \vdots \\ \Delta Y_n \end{bmatrix} \qquad \text{Equation 21}$$

Step 4: Apply Leontief's inverse to generate direct and indirect costs for each industry, X_i. In matrix terms, it shows:

$$X = (I - A)^{-1} Y \qquad \text{Equation 22}$$

$$X = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_n \end{bmatrix} \qquad \text{Equation 23}$$

Step 5: Calculate direct and indirect costs for the market by summing up all direct and indirect costs for each industry.

$$C_{direct\&indirect} = \sum X_i \qquad \text{Equation 24}$$

where:

$C_{direct\&indirect}$: direct and indirect costs for the market

Step 6: Calculate indirect costs of the market by subtracting private operating costs for carriers, and logistics and scheduling costs.

$$C_{indirect} = C_{direct\&indirect} - \sum Y_i \qquad \text{Equation 25}$$

where:

$C_{indirect}$: indirect costs of the market

In the real world, conditions after a highway closure will not exactly follow the assumptions mentioned in this chapter, so economic impact cannot be estimated very accurately. However, the input-output model can bring extra insights and rough ideas of economic impacts due to highway closure on the market of an affected region.

Chapter 4. Conclusions

4.1 Overview

The goal of this study is to provide a theoretical framework and a methodology to estimate and analyze economic impacts of freight disruptions due to highway closure. Based on the past studies on three areas, private operating costs for carriers, the value of travel time in freight transport, and estimation of economic impacts following natural disasters, a model is developed with three different assessments: private operating costs for carriers, logistics and scheduling costs, and indirect costs for the market.

A resource saving method is selected to measure private operating costs for carriers. A stated preference method is selected for collecting data, and a logit model is selected to estimate the perceived value of travel time in freight transport due to highway closure from the start of the delay. The value of travel time in freight transport may vary in different time periods after a highway closure and by different commodity types. Indirect costs for the market are calculated by an input-output model.

4.2 Model Improvements and Future Research

Since the model consists of three assessments, we will discuss the weaknesses and improvements for each component.

4.2.1 Private Operating Costs for Carriers

In this study, we assume that all traffic flows run in a closed transportation network, which only includes the closed highway and the detour route. In reality, it is not necessary for truck drivers to take the detour route recommended by the Department of Transportation. More than one option will be available for truck drivers to avoid disrupted areas. Shippers might even cancel the shipments. Everything happens in a totally-open transportation network. There are some models available to measure the larger and more complex transportation network. Kim et al. (2001) use an optimization-based model to simulate traffic flows after an earthquake. The transportation model developed by Kim et al. (2001) is represented by routes and links in the U.S. interstate highway system and the railway system. An integrated commodity flow model combined with a multi-regional input–output model is applied to estimate commodity flows between regions at the minimum cost. Moreover, Dalziell et al. (2001) use the SATURN computer model, which is designed based on traffic assignment algorithm to estimate traffic flows within the network. In the model, a traveler takes the route with the minimum cost. When some routes are closed, the traveler has to reselect routes, which will exceed the original cost before the road closure. Moreover, the number of trips is related to the cost. The reduced amount of travel will be calculated by using the elastic assignment procedure in the SATURN program when the cost of travel increases. More advanced optimization-based models like these two could be adapted to estimate the traffic flow after highway closure and private operating costs for carriers in future research.

In this study, we assume the information dose not lag behind the action. Actually, information is very important for responding quickly to highway closure. As mentioned in Chapter 1, with advanced warning, unexpected delays with much higher costs will be quickly transformed to expected delays with lower costs. Good warning and alert systems can save carriers and shippers losses. In future research, the relationship of losses and information availability should be examined. Information availability should be the priority in risk management practices for Departments of Transportation to minimize the losses caused by highway closure.

4.2.2 Logistics and Scheduling Costs

Logistics and scheduling costs are the most difficult costs to estimate. A stated preference method is selected to roughly estimate losses of freight disruptions due to highway closure. Since stated preference techniques are survey-based methods, there always are biases or imperfect knowledge from respondents. Revealed preference methods can be used together with stated preference methods to minimize the bias from surveys in future research. For example, data for transportation mode choices can be obtained. Future research can explore the relationship between transportation mode choices and the value of travel time in freight transport. The logit model used in this study is based on the assumption that ε, the unobserved stochastic portion of the utility function, is independent and identically distributed, which means all alternatives are not overlapped and independent to each other. However, in reality, this is not the case. A random coefficient logit model does not exhibit the independence of irrelevant alternatives property. The random coefficient logit model can be substituted for this logit model for future research. Other more advanced logit models can also be explored in the future to estimate the value of travel time in freight transport from the start of the delay. In addition, some statistical models, such as econometric models, are being used to estimate economic impacts following natural disasters. The relationships between losses of companies and highway closure could be explored in a statistical perspective in future research.

4.2.3 Indirect Costs for the Market

Like other models used by economists, an input-output model has its weaknesses. For example, in the real world, inputs from one industry to another industry are not in the fixed proportion. Input and output of one industry are not in linear relationship. Reduction of demand is not equal to reduction of supply. Prices for products might change because of the equilibrium of supply and demand. As discussed in Chapter 2, some more advanced models have been adapted to estimate economic impacts following natural disasters. Some of these models can make up for the weaknesses of an input-output model. For example, GEC can capture the price change, and it also takes consideration of uneven changes for supply and demand. These models can be explored in future research to estimate the economic impact of freight disruptions due to highway closure.

Even though the final model cannot capture all the details, the approach may become a stepping stone for the future research estimating economic impact of freight transport due to highway closure.

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