

# Towards Understanding the Impacts of Congestion Pricing on Urban Trucking

by

Janine M. Waliszewski

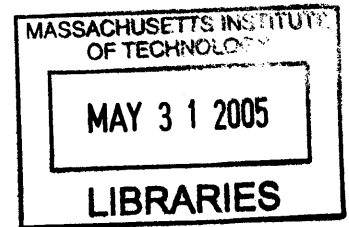
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**BARKER**



*To Bobak, Clarice, and Andrea*



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## **Abstract**

Understanding policy impacts on freight is essential for planners who have overlooked this transport group in the past and must evaluate new congestion alleviation policies with respect to regional economic and social goals. Since urban areas are limited in infrastructure expansion and travel demand continues to rise, congestion pricing is a potentially compelling policy alternative. This thesis focuses on measuring the impacts of congestion pricing policies on urban freight.

We differentiate from prior studies which measure the impacts *of* urban freight and present tools to measure the impacts *on* urban freight according to three stakeholder groups: shippers, carriers, and the public sector. We recognize that the impacts *of* urban freight may be the motivators for policy change or project implementation and the continued study of these impacts is critical to the public sector who aims to minimize externalities of increasing truck traffic (and is also an urban freight stakeholder); however, we suggest that the impacts that these projects or policies have *on* freight is particularly important given the economic value associated with goods movement.

For each of these stakeholder groups, we evaluate their goals, enumerate the possible responses to the scheme, and provide tools to quantify the impacts. First, we summarize the experiences of urban freight in other congestion pricing schemes and review several implementation decisions from the perspective of freight stakeholders. Second, we characterize possible freight responses to transportation improvement policies. Third, we expand previous freight impact analyses by quantifying the first-order impacts of the scheme for each stakeholder group. Finally, we propose additional research extensions related to analyzing the higher-order impacts of freight and using the methods here as a means to introduce public- and private-sector collaboration.

**Thesis Supervisor: Joseph M. Sussman**

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# Chapter 1

## Introduction

Understanding policy impacts on freight is essential for planners who have overlooked this transport group in the past and must comprehensively evaluate new congestion alleviation policies with respect to regional economic and social goals. Since urban areas are limited in infrastructure expansion and travel demand continues to rise, congestion pricing is a compelling policy alternative. Providing tools to measure the impacts on urban freight can help planners more effectively determine if congestion pricing is an applicable policy for their region. This thesis focuses on measuring the impacts of congestion pricing policies on urban freight.

This chapter defines the motivation for our work and summarizes the content of this thesis. In section 1.1, we discuss the intensifying problem of urban congestion and how freight both contributes and is affected by this congestion. Then, in section 1.2 we identify how planners are incorporating freight into urban transport planning. Section 1.3 identifies congestion pricing as a policy of interest for dealing with congestion in an economic and social context. Finally, we present a framework for evaluating freight projects and policies in 1.4 and in section 1.5 we introduce our application of these methods for evaluating the congestion pricing impacts on freight. Section 1.6 gives an overview of the chapters that follow.

### **1.1 Urban congestion and freight traffic**

This section combined with the next address three interconnected issues: (1) congestion is already a major problem, continues to grow, and has economic and social costs associated with it; (2) trucks are a large and growing part of congestion (and are affected by it as well); and (3) planning

agencies do not currently have the tools to evaluate the impacts of congestion-alleviation policy alternatives on freight.

### **1.1.1 Urban congestion**

The combination of limited infrastructure and growing travel demand in large and growing cities leads to congestion. The average American household owns 1.8 cars, and every year they drive them more (EIA 2002)—both navigating suburban developments and on longer trips to work in expanding urban areas. Those who argue that this congestion is actually a sign of a productive region are correct in some sense, but they do not account for the fact that users of the system do not pay the full costs of their travel. For example, because one more person in traffic makes every one else's travel time slower and contributes emissions to surrounding neighborhoods and urban air sheds, many trips impose costs on others exceeding the value of their own trip costs. These costs on others are called external costs, or externalities.<sup>1</sup> By not having to pay the full value of each trip, transportation is under-priced and motorists tend to overuse the system. The losses from highly congested, or overused, roadways include wasted time and fuel which translate to losses in economic productivity and environmental degradation. The Federal Highway Agency's Office of Operations best summarizes the congestion problem for us:

Demand for highway travel by Americans continues to grow as population increases, particularly in metropolitan areas. Construction of new highway capacity to accommodate this growth in travel has not kept pace. Between 1980 and 1999, route miles of highways increased 1.5 percent while vehicle miles of travel increased 76 percent. The Texas Transportation Institute estimates that, in 2000, the 75 largest metropolitan areas experienced 3.6 billion vehicle-hours of delay, resulting in 21.6 billion liters (5.7 billion gallons) in wasted fuel and \$67.5 billion in lost productivity. And traffic volumes are projected to continue to grow. The volume of freight movement alone is forecast to nearly double by 2020. Congestion is largely thought of as a big city problem, but delays are becoming increasingly common in small cities and some rural areas as well (FHWA 2005).

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<sup>1</sup> Specifically, we refer to what economists call 'technological externalities' as externalities. Pecuniary externalities, or transfers, are not directly considered here, but we do present further applications which include them in Chapter 5.

### **1.1.2 Urban freight**

Confined to the same infrastructure, freight travel must compete with passenger trips. Even in locations with heavy rail access and usage, trucks remain the primary carrier for delivering goods to urban locations: tomatoes are delivered to markets, clothing to shopping malls, and raw materials to industrial sites, all demanding a high degree of reliability. Moreover, the cost of congestion to freight travel is higher than for passengers. The value of time (VOT) for passengers is generally assumed to be a fraction of the occupant's salary, whereas the VOT for truck trips reflects the inventory costs of the goods being carried. The Texas Transportation Institute (TTI) suggests that the value of time for commercial vehicles is more than five times higher than for passengers: \$71.01 per commercial-vehicle hour versus \$13.45 per passenger hour (TTI 2005). Meanwhile, the costs of congestion and poor reliability must be built into supply chains. Congestion-related impacts constrain efficiency, and may add further costs for shippers.

Freight traffic is vulnerable to the costs of this congestion especially since urban goods movements are a response to consumer demands (called a 'derived demand') and therefore are not easily diverted or deterred. At the same time, transportation and warehousing accounts for approximately 11 percent of our national gross domestic product (BTS 2003), so productivity losses in freight can have a large overall effect on the economy. Freight movements are closely associated with national, regional, and local economic stability and growth.

Not surprisingly, truck traffic in the United States has grown significantly over the last few decades and is projected to continue in the future. "Since 1970, truck travel in the United States, as measured in [vehicle miles traveled (VMT)], has increased 216 percent, whereas the population has only increased by 33 percent and overall vehicle travel (total VMT) has increased by 137 percent. Meanwhile, highway system capacity (measured in lane-miles of freeways and arterial roadways) has increased by 18 percent since 1980" (Douglas 2003, p. 1). As mentioned above, the forecasts for freight continue to grow as well.

Global, national, and local trends which account for the past increases in truck volumes are still valid today. Therefore, barring a radical change in the way that logistics and supply chains function, an increase in freight forecasts are valid. Globally, recent advancements and increases in globalization are expected to continue, and are supported by multimodal transport and containerization. Nationally, deregulation in the 1980's brought low prices and increased productivity into the trucking market which persists today. Also, despite security increases, open border policies such as NAFTA make truck movements even more prevalent. Global and national trends mean that intercity freight volumes increase, but ultimately, many of these

shipments end up in urban locations, where the consumer awaits. Locally, just-in-time manufacturing processes and declining inventories at retail stores both require smaller, more frequent deliveries. These trends are relevant, support demand forecasts, and therefore give compelling reasons for urban transport planners to mitigate impacts on freight in future policy and project evaluations.

## **1.2 Freight planning tools**

Metropolitan areas recognize the need for freight planning; however, they generally lack the tools to do so. The tools have been slow to develop for a few reasons: (1) the importance of freight was not recognized until the 1990s, decades after the passenger transportation planning process was standardized, (2) the supply chain and logistics processes which determine freight traffic volumes and patterns are complex, and (3) since freight only accounts for a small percentage of total vehicle traffic volumes, policymakers do not earn as much political capital with freight congestion remedies as they would with passenger congestion alleviation. Therefore, improvements for freight trips are usually by-products of general or passenger congestion remedies.

The late development and modeling of freight transport flows is partially due to the complexities of urban freight travel. First, as opposed to passenger motorists with simple decisions about whether to travel based on trip purposes, the timing, routing, and frequency of freight trips depend on multiple decision makers within a larger supply chain. Since this process is not well understood in the public sector, developing tools to explain travel patterns is difficult. In the last several years, the steep development curve in freight modeling suggests that the field has not yet reached maturity. Additionally, planners rarely measure the isolated impacts of freight travel and truck flow data is not often available.

Similar to forecasting urban freight demand with models, urban planners recognize the need for measuring the impacts of policies on urban freight, but have not implemented uniform evaluation criteria. Some resources are devoted to understanding impacts on intercity and national freight flows, but urban areas lag in the tools and resources for implementation. These types of evaluation tools are critical for helping policymakers address freight needs and prioritize projects. According to Kawamura and Seetharaman (2005)

It is recognized by the MPOs that freight planning should be incorporated at the comprehensive plan level and that piecemeal planning may not be the way to do this. This is supported by the fact that all the long-range plans reviewed at least refer to goods movement in the objective statements. However, in reality, there

is no evidence that recommended performance measures for the freight oriented objectives were used to prioritize projects... Even if adequate performance measures existed...they were not applied, probably because of technical reasons such as lack of data and forecasting models. If freight projects are to be given a serious consideration for funding, their benefits must be quantified so that they are comparable against other projects.

Because congestion is increasing, truck volumes are growing, and trucks are increasingly affected by congestion, methods to quantify the impacts on freight are timely and essential.

### **1.3 Congestion pricing as an applicable policy**

A wide range of both state and metropolitan planning organizations reported in 2002 that “the most serious and widespread challenge” to increasing truck traffic today is “congested urban highways and intercity streets” (Douglas 2003, p. 9). We are not surprised by this survey data, given the economic importance of urban goods movement and the stifling costs of congestion. Several types of strategies are available for responding to this congestion, many of which provide additional benefits such as reducing truck-idling time and concomitant emissions.

One strategy rarely implemented is congestion pricing. Although charging people to drive on roadways that once were “free” is reasonable to economists (who measure the cost of travel imposed on others), pricing is difficult for citizens to accept. This makes policy implementation a difficult choice for policymakers.

However, congestion pricing is a unique strategy tool both specifically for freight planning, but also as a passenger congestion mitigation tool that could have large impacts on freight travel. On the one hand, trucks paying additional costs to travel on the roadway will be reluctant to absorb the fess and may change their routing patterns or trip timing. On the other hand, congestion pricing is such a potentially strong policy for passenger congestion alleviation, that by reducing auto trips it would greatly reduce the costs of congestion to trucks by providing travel time savings and increased reliability. This in turn could lead to reductions in fleet size or further optimization of supply chains. Additionally, charging road users the marginal costs of their trips ensures that each trip made exceeds the external social costs generated by the trip.

A sense of momentum related to congestion pricing exists since London demonstrated that the policy can be both feasible and effective in a Western democracy with its 2003 implementation. For example, cities such as San Francisco and New York have identified congestion pricing as a policy alternative (Nyberg 2005, Kennedy 2003, respectively) and opinion pieces from Los Angeles to Boston advocate that local politicians give it more consideration

(Richmond 2005, Sheffi 2005, respectively). Given the difficulties in political feasibility and implementation that often accompany congestion pricing, providing tools to policymakers can help them identify critical data needs, estimate impacts, and determine ways in which urban truck traffic may respond to a pricing scheme.

## **1.4 Evaluating projects and policies**

Given the importance of freight for economic growth and the need to better understand the impacts of transport policies on freight, we provide tools evaluating urban transport policies from the perspective of freight stakeholders. Considering each freight stakeholder separately captures the complexity in freight flows, and we believe that by understanding the role of freight stakeholders, we can more effectively weigh the impacts of freight policy alternatives or projects.

We are aware of few efforts which analyze policy impacts related to urban freight. Kawamura summarizes current Metropolitan Planning Organizations' (MPO) efforts of measurement as "an ad-hoc adoption of passenger demand forecasting models... [in which] the accuracy and sensitivity attained by such techniques is obviously not adequate for evaluating the costs and benefits of proposed freight projects" (2003c, p.1). After performing a survey of 28 states and 8 MPOs, Douglas reiterates the same idea, saying

The most critical need for further research is to help increase the number and scope of the published sources that quantitatively document the effectiveness of various truck-related roadway improvements or management strategies in improving safety, reducing congestion, and increasing productivity. To conduct an effective evaluation of project costs and benefits the transportation professional needs documented, quantitative evidence of the potential benefits of a strategy (2003, p.31).

We differentiate from prior studies that focus on measuring the impacts *of* urban freight and present tools to measure the impacts *on* urban freight. We recognize that the impacts *of* urban freight may be the motivators for policy change or project implementation and the continued study of these impacts is critical to the public sector who aims to minimize externalities of increasing truck traffic (and is also an urban freight stakeholder); however, we suggest that the impacts that these projects or policies have *on* freight is particularly important given the economic value associated with goods movement. We measure the policy impacts on freight according to each of the three urban-freight stakeholder groups: shippers, carriers, and the public sector.

We define the ways in which freight decision makers may respond to transport policies and quantify the magnitude of such changes. By measuring impacts according to urban freight

stakeholder groups, we break away from the traditional pattern of adopting methods developed for passenger planning to address the goals of the freight community.

## **1.5 Analyzing congestion pricing impacts on freight stakeholders**

Given the recent interest of congestion pricing in several urban areas and its effectiveness for mitigating transport externalities, providing specific tools to policymakers for evaluating the impacts of congestion pricing on freight is both timely and appropriate. Therefore, we outline our evaluation based on stakeholders and define the tools to measure the impacts on freight for a congestion pricing policy alternative.

After we summarize responses to international congestion pricing applications, we discuss several implementation decisions from the freight perspective to provide additional insight to a policy maker unfamiliar with the freight process. Then, we discuss the likely freight responses and quantify the impacts to the policy implementation. Although empirical evidence suggests that freight receives benefits from pricing strategies, we do not attempt to generalize these results. Instead, we hope to outline which variables make congestion pricing favorable for trucks and provide tools to policymakers to measure these impacts while evaluating a congestion pricing scheme in their region.

## **1.6 Thesis organization**

This thesis closely follows the outline of the introduction chapter and moves us toward understanding the impacts of congestion pricing on freight. In Chapter 2, we provide background on urban goods movement and its inclusion in the transportation planning process. In Chapter 3, we identify congestion pricing as an increasingly important policy tool. We introduce the background and economics of congestion pricing, and review available data about the impacts on freight from current implementations. Chapters 2 and 3 together serve as a literature review to frame our understanding of both freight traffic and congestion pricing. Chapter 4 describes the possible freight responses to transport polices, and offers tools to measure impacts on each stakeholder according to their goals. In Chapter 5 we conclude and suggest next steps for future research.





## **Chapter 2**

# **Transport planning and urban freight**

“Urban freight transport is more than any other type of traffic, the subject of local, regional, and national policies in different policy fields, such as transportation planning, environmental planning, and economic planning” (Visser et al. 1999, pg. 3). Since urban freight is performed primarily by the private sector and infrastructure planning is performed by the public sector, the needs of each must be balanced. Later in this thesis, we present congestion pricing as a policy alternative for such balance. First, we provide background on goods movement and the transport planning process. In Section 2.1 we address several characteristics of the urban truck travel. Then in Section 2.2, we discuss the role of transportation planners. Finally, in Section 3.3, we identify the challenges presented by increasing truck volumes and summarize policy alternatives.

### **2.1 Characteristics of urban trucks**

We find that transport planners are unfamiliar with urban trucks patterns since they are not surveyed as often as passenger flows: are they delivering goods or performing a service? What are their typical trip patterns? These are critical questions to ask when developing transport policy. Therefore, this section presents key characteristics of urban truck transport. First, we briefly identify who these trucks are and comment on their travel patterns. Next, we describe the trends which contribute to the rising share of urban truck traffic, and lastly we identify key stakeholders.

#### **2.1.1 Who are they? What are they doing?**

Commercial vehicles in urban areas include the traditional goods movement truck traffic and service trips. Traditional goods movement trips include package and mail delivery, freight

distribution and urban warehouse deliveries, and goods transported to construction sites. These types of trips, especially distribution and delivery trips are our primary focus, since they are a large portion of freight traffic and because they are poorly understood in the planning process. Service trips include those by safety, utility, and public service vehicles, and business and personal service trips (Cambridge Systematics, et al. 2003, p. E-2). This includes the cable repair van or garbage collection service. In many cases though, these trips behave like passenger trips, making them difficult to distinguish. Often, commercial vehicles for service trips resemble passenger vehicles, whereas trucks associated with urban goods movement are typically heavier and larger. Throughout this thesis, we use the terms 'freight' and 'goods movement' loosely to refer to *truck* trips in an urban area that are subject to differing traffic regulations than autos.

Our typical truck trip is a commodity flow or delivery which moves between a shipper (origin) and receiver (destination). First, the shipper chooses between for-hire service and a privately-owned truck (operated exclusively by the company) to carry their products. With a private fleet, no intermediaries are involved and the product is delivered directly. On the other hand, for-hire delivery may be managed by a freight-forwarder who coordinates delivery, or the shipper may hire a trucking company directly to take their goods. In either case, if the shipment volume equals an entire truckload (TL), it will likely be delivered directly as such. If the volume is less than a full truckload (LTL), carriers often consolidate shipments en route. Depending on the length of haul and other product deliveries, an LTL shipment may be carried by multiple vehicles between origin and destination, depending on the consolidation and redistribution of the shipment over the trip. Several mode choices exist for long-haul shipments; however, for our urban application, we do not consider modal options besides truck (but carriers can still chose between carriers). In Chapter 4, we continue this discussion by explaining the role of urban freight within the supply chain.

### **2.1.2 Typical distribution and trip patterns**

The characteristics of urban goods movement provide an understanding of both fleet distribution and travel trip patterns. The most valuable data is by specific urban area, although only a fraction of metropolitan areas have devoted resources to procuring this data, even though intercity freight transportation is well-documented.<sup>2</sup> For example, the 2002 Transit Cooperative Research Report (TCRP) *Characteristics of Urban Travel Demand* (Reno et al. 2002, p. 36) presents freight

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<sup>2</sup> For example, publicly available Commodity Flow Survey and Federal Analysis Framework, and privately produced Reebie commodity flow data all quantify national and/or international intercity freight flows.

summary characteristics dating from 1959 to 1975 because more recent data was not available. Fortunately, urban freight data collection is becoming more common; a recent Federal Highway Administration (FHWA) initiative provided funds to summarize the most recent data from urban areas at a national level (as part of a larger scale effort to document current freight modeling practices) (Cambridge Systematics et al. 2004). This section reviews urban truck aggregate characteristics across several cities.

Overall, truck travel has grown significantly over the past several decades and is expected to continue. Since 1970, truck vehicle miles traveled (VMT) has increased 216 percent (while roadway capacity expanded only 33 percent) and planners expect increases of another 87 percent domestically and 107 percent internationally between 1998 and 2020 (Douglas 2003, p. 3). These growth statistics emphasize the importance of freight transportation planning in the future.

Aggregate data over several urban areas helps explain what this transportation looks like. Surveys in 13 urban areas in the United States (specifically including both goods movement and service vehicles), indicate that good movement has the following characteristics:

- Average fleet size equals 190,000 trucks, or 53.5 trucks per 1000 people;
- Average trip length equals 45.6 miles;
- Average annual VMT equals 4.57 million;
- Average percentage of total passenger VMT equals 9.6 percent;
- Average percent of trips by time period for AM peak, PM peak and off peak, respectively equals 31, 11, and 58 percent; and
- Total VMT across all urban areas in the United States equals 380 million, and over 85 percent of this travel occurs on interstates or expressways (Cambridge Systematics et al. 2003, pp. 4-2 – 4-14).

The most valuable data is by specific urban area. By 1996, at least 23 cities or metropolitan areas had already completed freight surveys and another 7 had surveys in progress or planned for the near future (Cambridge Systematics et al. 1996, Appendix M).

### **2.1.3 Influences on urban freight**

As noted in Chapter 1, many factors influence the volume urban freight flows; this section reviews recent trends which contribute to further growth. Many of these factors, such as the transition to just-in-time manufacturing are common and well-documented. Yet, Czerniak et al. (2002) provide a comprehensive summary of the most recent global, national, and local

influencing factors in their Transportation Research Board ‘Millennium’ paper<sup>3</sup> which we summarize here.

Globally, increased international multimodal shipping and containerization have led to efficiencies encouraging more global supply chain activity. Implementing practices like just-in-time manufacturing, while influencing the frequency of shipments at the local level, has also led to changes in delivery cycles that increase traffic flows at national and global geographies. Nationally, federal deregulation policies in 1978 and 1980 have increased competition, inducing more efficient practices in several freight transport modes. These efficiencies result in lower costs, improved services, and wider geographic coverage. Also, the implementation of the North America Free Trade Agreement (NAFTA) lowered trade barriers between the United States, Mexico and Canada, and increased traffic at border crossing by facilitating import and export activities.

Locally, factors such as shopping patterns, urban form, and congestion contribute to freight movements as well. Online shopping with at-home delivery and the location of larger retailers near residential areas has increased noise, emissions, and truck congestion in residential neighborhoods. In the meantime, continued growth and the clustering of warehousing and distribution facilities shapes traffic patterns in particular regions. Finally, congestion limits the time of day when trucks can travel in urban areas, and impacts the reliability of their shipments. Policies that deal with these local issues will affect patterns of goods movement in the future. Specifically, Czerniak et al. points out “any policy or program that reduces congestion across the system could have a positive effect on goods movement and a concomitant benefit to business productivity” (Czerniak et al. 2002, p. 3).

#### **2.1.4 Stakeholders**

We identify several key participants based on the description of the transport system thus far. Each of these stakeholders has varying perceptions of the system, and sometimes opinions vary within stakeholder categories. Enumerating all of the participants in the urban goods movement process provides insight into the types of challenges that may arise between them based on their conflicting interests. Also, considering stakeholders early in a planning process can facilitate policy implementation and increase the chances of compromise and successful planning.

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<sup>3</sup> Each TRB committee produced a Millennium paper commenting on or forecasting critical changes in their related field. The paper referenced here was produced by the Urban Freight Committee, AB107.

The stakeholders involved in urban goods movement include shippers; receivers; forwarders; trucking firms (including service delivery companies); truck drivers; terminal operators and firms in other transport modes; urban residents and passenger travelers; road and traffic authorities; and the government (Ogden 1992, pp. 51-59). Table 1 gives a description of each stakeholder along with their main responsibilities or objectives.

**Table 1 Stakeholders in urban goods movement**

<b>Stakeholder</b>	<b>Description</b>	<b>Responsibility / Objective</b>
Shippers	(Origin) Entity that arranges and pays for freight delivery	Minimize total costs
Receivers	(Destination) Entity that receives the shipment	Level of service based on time and reliability; inventory levels
Forwarders	Broker of transportation services; benefits from economies by combining shipments; may own fleet or contract to trucking firms	Maximize profit (minimize costs and maximize throughputs)
Trucking firms	For-hire delivery services that vary by size, area of operation	Maximize profit or vehicle earnings (over short- and long-run)
Terminal operators	Acts like both a shipper and receiver	Overall efficiency
Urban residents and passenger travelers	Citizens in the urban area	Having access to goods; paying costs of inefficiencies; negative externalities of trucks
Road and traffic authority	Agency that constructs, controls, and maintains roadways	Balance service between trucks and other road users
Government and society at large	Entity that allocates public resources to and within sectors, including transportation	Facilitating economic development; balance stakeholder concerns within sectors

Each stakeholder contributes to freight delivery or planning. For example, shippers that use forwarders or for-hire delivery may not worry about travel routes or delivery scheduling; they will notice changes in the cost or level of service. Chapter 3 expands the discussion of stakeholder interests in conjunction with specific policy alternatives.

## **2.2 Including trucks in urban transportation planning**

Since the public sector is responsible for balancing economic development with the negative externalities caused by freight transport, we review the evolution of the freight planning process.

Subsection 2.2.1 highlights early actions which led to current freight policies. After, we review the state of the practice with respect to freight modeling and impact measurement.

### **2.2.1 Historical background**

Before the 1950's planners did not include freight in transportation planning applications. However, starting in the 1950's, some early mentions of truck trips appeared in the Chicago Area Transportation Study and the Detroit Land Use Study (Chatterjee 1995). Shortly thereafter, in 1960 Benjamin Chinitz produced one of the earliest documented works on freight planning, *Freight and the Metropolis*, which looked at freight movements in New York City. The first recognition of freight as a national issue appeared in the 1962 Federal Aid to Highway Act<sup>4</sup> (Czerniak et al. 2002). One early, yet comprehensive text on urban goods movement is *Economics of Urban Freight Transport* by Pearman and Button (1981). This text covers the costs of urban freight, explains how freight demand depends on consumer demand and includes early applications of demand modeling before reviewing the optimal supply strategies both to the firm and society. Even with these early references available, freight remained largely ignored in planning applications because the complexities of truck movements were not generally well understood and data was expensive to obtain.

Two early conferences by the OECD (1970) and the US Highway Transportation Research Board (1971) were influential in providing a basis for further development in freight planning. These two conferences reviewed current freight information and defined a research agenda for methods of integrate freight into existing transportation planning (Ogden 1992, p. 8). Between 1973 and 1988 an irregular series of five additional conferences were held on urban goods movement. Based on the topics presented at each of the five sessions, Ogden summarizes the critical freight issues during these years. They include rail issues (an earlier topic), freight facility location planning, regulation,<sup>5</sup> integration of freight into modeling practices, and traffic management (an emerging topic). He also notes that environmental and social issues were largely ignored at these meetings. Up until this point, urban freight issues had a small research following, improvements were slow, and few resources available

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<sup>4</sup> The 1962 Federal Highway Act is often cited for requiring cities to plan using the well-known 3C's process (comprehensive, coordinated, and continuing).

<sup>5</sup> It is not surprising that the topic of regulation consistently appeared on the agenda, given the deregulation of the air industry in 1978 (Airline Deregulation Act) and both the rail and trucking industries in 1980 (with the Staggers Act and Motor Carrier Act, respectively).

A shift in the interest of freight issues occurred in the 1990s. In 1993 a national survey noted that neither freight forecasting nor planning was part of large-scale transportation planning applications (Cambridge Systematics et al. 1997). However, the funding for and presence of the survey was a presentiment of future interest. In 1991, the Intermodal Surface Transportation Equity Act (ISTEA) had included urban freight as one of 15 planning factors that required attention at the planning level. Since then, the commitment level toward freight including resources to study and quantify urban goods movements has increased. The inclusion of freight as an emphasis point in the 1998 Transportation Equity Act for the 21<sup>st</sup> Century (TEA-21) reiterated its importance in the planning process. Since then, increasing interest in freight by planners and researchers has led to greater documentation of feasible and desirable policy solutions to the problems created by increasing truck volumes.

### **2.2.2 Predicting freight tips**

Federal grants provided funding for guidebooks on how to quantify, forecast and model freight movements,<sup>6</sup> while a rich dialogue on freight modeling over the past 15 years has led to a steep increase in development. Earlier guidebooks provided information on freight demand factors, how to obtain applicable data, simple modeling techniques to interact with a traditional four-step passenger demand model, and techniques for site planning and forecasting. Several case studies were included for reference. Based on these references, and the compatibility with existing passenger models, freight models developed over these years were largely based on the four-step framework.

Despite these investments, academics have criticized this framework, suggesting that the first two steps (trip attraction/production and trip distribution) do not represent the complexities in a supply chain and that mode split based on a random utility model may not be valid (Garrido 2001, pp. 19-21). For example, in freight distribution, trips may accumulate (such as at manufacturing facilities) and all be dispatched simultaneously causing unexpected vehicle flow frequencies, and urban truck traffic can involve multiple delivery and/or pick-up locations in one trip (Holguin-Veras 2005). The random utility model used in mode choice (step three) may be inconsistent with goods movement decisions that are based almost exclusively on minimizing cost<sup>7</sup>. Additionally, route choice in the network assignment process (step four) may be more complex

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<sup>6</sup> For example, see Cambridge Systematics et al. 1996, 1997, and 2003.

<sup>7</sup> Additionally, note that minimizing total cost to shippers may not be synonymous with minimizing transportation costs.

for freight, as the single decision-maker in the passenger model is replaced by producers, wholesalers/distributors, consumers, and carriers that are all involved in route decisions related to freight shipping (Garrido 2001, pp. 21-22).

Despite the above criticisms, some benefits to maintaining the four-step modeling framework exist. The main motivation for continuing to use and further develop the four-step framework is its compatibility with passenger models. Especially in urban areas, understanding the interactions between truck trips and passenger movements is crucial for evaluating policy scenarios with potential congestion and emission impacts. In the meantime, practitioners have been responsive to some of the critiques. The most sophisticated, recent models now capture some nuances traditionally not included in the four-step framework. For example, the Los Angeles County freight model uses a hybrid approach for trip attraction/production and trip distribution which captures commodity-specific characteristics as well as tour-based trip chaining (Fischer et al. 2005). Based on the recent strides in freight modeling, we expect that the state-of-the-research will continue to evolve rapidly over the next several years. Current progress and development in quantifying goods movements and freight modeling translates into the increased availability of more robust policy tools, facilitating better policy analysis both empirically and conceptually as the field advances. However, we recognize that rapid development indicates that the field has not yet reached maturity. Also, despite continuing efforts to overcome these problems, data limitations do exist and many research questions remain unanswered. For example, the author is unaware of any study estimating how well past model forecasts represent current demand values in absolute terms.

### **2.2.3 Impacts of freight trips**

Since freight projects were introduced as a key planning factor in federal legislation, freight performance measurement or impact analysis has received some attention. However, most interest is at the federal level; therefore, most measures developed thus are national in scope. These initiatives measure federal concerns such as border crossing delays, cargo insurance rates, and origin-destination travel times on key freight corridors or interstates (HBS Inc. 2000).<sup>8</sup> The federal initiatives are indicative of a small body of work which focuses on the aggregate impacts

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<sup>8</sup> The FHWA efforts at performance measurement are outlined through several documents (in addition to the one cited) on the FHWA Freight Management and Operations website at: [http://www.ops.fhwa.dot.gov/freight/freight\\_analysis/perform\\_meas.htm](http://www.ops.fhwa.dot.gov/freight/freight_analysis/perform_meas.htm) [Last accessed 17 April 2005].



to intercity freight movements (often across modes), but which does not directly correspond to our urban application.<sup>9</sup>

We are aware of very few efforts that analyze policy impacts related to urban freight. Kawamura summarizes current MPO efforts of impact measurement as “an ad-hoc adoption of passenger demand forecasting models... [in which] the accuracy and sensitivity attained by such techniques is obviously not adequate for evaluating the costs and benefits of proposed freight projects” (2003c, p.1). After performing a survey of 28 states and 8 MPOs, Douglas reiterates the same idea, saying

The most critical need for further research is to help increase the number and scope of the published sources that quantitatively document the effectiveness of various truck-related roadway improvements or management strategies in improving safety, reducing congestion, and increasing productivity. To conduct an effective evaluation of project costs and benefits the transportation professional needs documented, quantitative evidence of the potential benefits of a strategy (2003, p.31).

The most germane efforts to address these issues have been at the University of Illinois at Chicago, where Kawamura is a leader in this field. We review his work more thoroughly in Chapter 4.

## **2.3 Increasing demand, problems, and solutions**

In the previous section, we reviewed the inclusion of freight in transportation planning applications. Since ISTEA in 1991 and more recently TEA-21 in 1998, freight has been an agenda item in the urban, statewide, and federal planning processes. In addition to the development of freight modeling and impact measurement, identifying freight policies and subsequent implementation methods have also received more attention and continue to be documented. This section first provides some insight into freight demand and then describes the concurrent problems. Finally, we summarize available and recommended freight policies.

### **2.3.1 Understanding demand**

Understanding where traffic congestion comes from precedes analyzing congestion-alleviation measures. Goods movement is a derived demand; the need for travel comes from consumer demand for the final product (and consumers rely on the transport of these goods to access them).

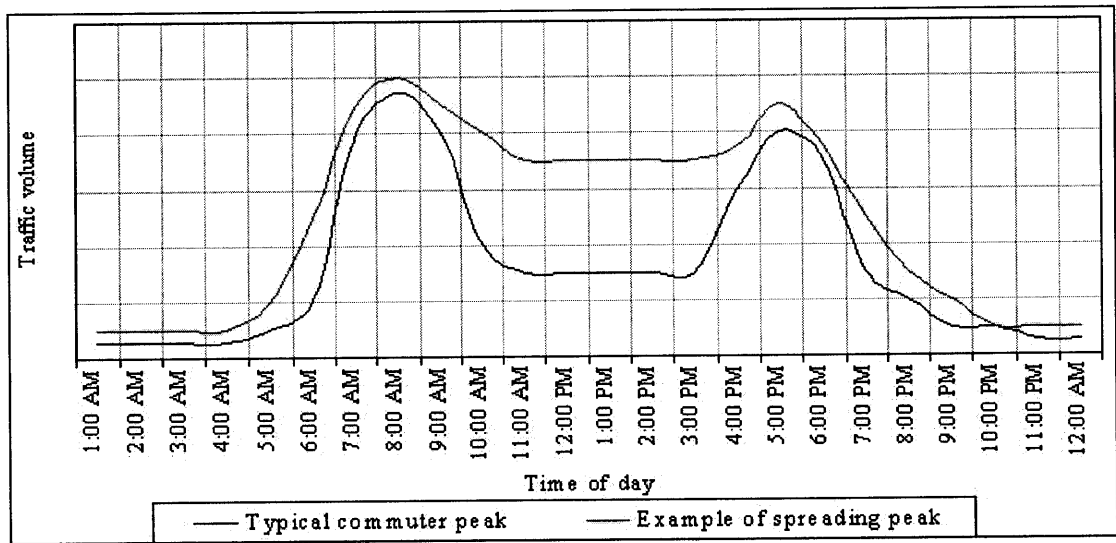
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<sup>9</sup> Intercity-freight impact measurement is summarized and improved by Professor D. Forkenbrock at the University of Iowa, who has contributed several papers on the subject.

This section looks at four basic components of transportation demand and then narrows to a discussion specific to freight demand.

**General**

Quantifying transportation demand is more complex than demand for a widget at the store. First, the amount of capacity needed depends on both temporal and spatial dimensions. Congestion occurs at a unique time and location when volumes approach capacity levels. Since most people start their workday between 8 and 9 AM, many cities experience high travel demand on highways toward employment centers between 7:30 and 8:30 AM. This period, when traffic approaches capacity is called the *peak*. In larger cities, this peak demand may actually occur over several hours, for example from 6 to 9 AM across the region. An example of typical commuter peaks is shown in Figure 1. In the case of large, highly-congested metropolitan areas, the morning and afternoon peak periods are hardly discernible in a graph of traffic volumes by hour of day. An example of this type of spreading peak travel is also shown in Figure 1.



**Figure 1 Examples of diurnal traffic volumes**

Second, transportation demand is a function of the service offered. When congestion is very high, service deteriorates and demand declines. As additional cars entering a highway and the total volume approaches capacity, each trip will take considerably more time; roadway users have different patience levels for withstanding the delay and uncertainty associated with their trip. In this case, users that are more sensitive to the service level will chose alternate routes, departure times, or modes. For example, a truck traveling a long distance on a congested urban highway may decide to take a circular highway to bypass downtown traffic or travel through the city at

night, when fewer cars are on the direct route. Alternately, the shipper may decide that two loads may be combined or that the particular trip is not necessary; the trip may be avoided entirely when the service level becomes so poor.

On the other hand, relatively uncongested roadways often attract people to travel, or *induce* demand. In the same way that people may divert, shift, or avoid trips on a congested highway, excess supply entices passenger and freight drivers to supplement or modify original travel plans.

Third, urban transport comprises an interconnected network. System interdependencies exist throughout the network based on complement/substitute relationships existing between the roads. Correlation of demand between two connected links is positive; whereas, the demand on two parallel roads (which are complements in the system) may be negatively correlated. In either case, correlation exists and traffic volumes on many sets of links in the network impact volumes on others.

Finally, transportation and land use are interrelated. Urban planners note that transportation and land use are related and interact with each other in the long term, even though the impacts are difficult to both predict and quantify. Because transportation affects land use, the usage of a particular roadway in the short- and long-run may vary significantly.

### ***Goods movement***

Here, we review the demand for freight travel which is relatively inelastic and difficult to estimate. Urban freight demand is unique from passenger demand because no mode choices exist. Pearman and Button (1981, p. 36) give three hypotheses about the elasticity of freight travel:

- Elasticity for freight travel demand varies with the elasticity of the demand for the final product;
- The smaller the cost of transportation as a percentage of total costs, the less elastic that demand will be; and
- Travel demand by a certain mode will be more elastic if it is easier to replace.

Freight demand is relatively inelastic. This is reflected in the relatively difficult and long time-frame of proposed methods to eliminate urban freight demand. These are:

- Replace urban freight with passenger movements (for example, increasing passenger travel for purchases versus home deliveries);
- Replace the goods movement with a freight substitute (for example, replacing coal with electricity);

- Alter the structure of urban areas to bring shippers and receivers closer to the primary activity of the city (although the opposite seems to be occurring in many cities with the suburbanization of facilities based on low land values); and
- Reduce the quantity of goods that are produced or consumed in total (unlikely in a growing economy).

Since freight movements are correlated with economic development, deliberately limiting freight travel demand would be counterproductive, with negative social, political and economic consequences (Odgen 1992, pp. 63-64).

Forecasts of increasing freight demand combined with the inelasticity of urban freight travel suggest that truck volumes are increasing. In the meantime, freight traffic must compete with passenger flows for limited roadway space. Related concerns are outlined in the next section.

### **2.3.2 Challenges of increasing truck volumes**

Increasing volumes of truck traffic present several, conflicting challenges to transportation planners. A recent National Cooperative Highway Research Program (NCHRP) synthesis report *Strategies for Managing Increasing Truck Traffic* enumerates these concerns and reports state- and metropolitan-level rankings for the most ‘serious’ and ‘widespread’ problems (Douglas 2003, pp. 5-10).

Ten categories of challenges are given (each containing up to four specific concerns). These categories are as follows:

- Traffic congestion;
- System deficiencies (specifically relating to road design and geometry issues);
- Safety;
- Infrastructure deterioration;
- Multimodal connections (relating to facility availability and connectivity);
- Environmental impacts;
- Quality of life (i.e. residential living and accessibility);
- Economic development; and
- Losses in productivity due to congestion.

Table 2 gives state and MPO survey results ranking the challenges of increasing truck volumes.<sup>10</sup>

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<sup>10</sup> Surveys were sent to all 50 states and to 23 of the largest metropolitan areas in the country. Responses totals were 28 and 8, respectively.

**Table 2 State and MPO highest-ranked challenges of increasing truck traffic**

	Serious	Widespread	Serious and widespread
State	<ul style="list-style-type: none"> <li>• <b>Congested urban highways</b></li> <li>• <b>Congested urban roads</b></li> <li>• Air quality</li> </ul>	<ul style="list-style-type: none"> <li>• Pavement deterioration</li> <li>• Truck parking</li> </ul>	<ul style="list-style-type: none"> <li>• Pavement deterioration</li> <li>• Multi-vehicle crashes</li> </ul>
MPO	<ul style="list-style-type: none"> <li>• <b>Congested urban highways</b></li> </ul>	<ul style="list-style-type: none"> <li>• Air quality</li> <li>• Increasing transportation costs</li> </ul>	<ul style="list-style-type: none"> <li>• <b>Congested urban highways</b></li> </ul>

Source: Douglas 2003, pp. 5-10.

We summarize the survey results for states and MPOs. States listed their challenges in the following order: congested urban highways, inadequate truck parking facilities, congested urban streets, pavement deterioration, congested intercity streets, and noise. Three of the top five concerns are congestion-related. Not surprisingly, congested urban highways and roads were listed as the most ‘serious’ concerns, in addition to emissions and air quality concerns. The most ‘widespread’ challenges reiterated the concerns about pavement deterioration and inadequate truck parking facilities. Safety issues are largely absent from the above table, although states do consider multi-vehicle crashes involving trucks to be a ‘serious and widespread’ concern.

Challenges listed by MPOs reflect their role of balancing local economic development with quality of life concerns for residents at the metropolitan level. MPOs listed their challenges as follows: noise, congested roadways, substandard design geometries, poor air quality, incompatible land uses, and increased transportation costs. Again, the most ‘serious’ concern was congested urban highways and roads; whereas the most ‘widespread’ challenges were poor air quality and increased transportation cost.

### **2.3.3 Policy options**

In response to these diverse challenges, many policies are available to transportation planners. Several of these policies are specific to congestion mitigation, yet many of them deal respond to other challenges such as infrastructure deterioration and safety. As interest in freight planning increases, freight policy applications increase as well. We summarize several sources to create a comprehensive review of freight policies.

An early summary is presented by Ogden (1992, pp. 17-18, 137-292), using seven categories to capture common international freight policies, including

- Traffic management;
- Location and zoning of land use;

- Infrastructure;
- Licensing and regulations;
- Pricing;
- Terminals and modal exchange; and
- Operational strategies.

Then, Visser et al. (1999, pp. 9-10) reduced Odgen's summary to six modified categories<sup>11</sup> and added several policy categories related to new technological policy options. These included

- Traffic information systems;
- Intelligent Transportation Systems (ITS);
- Electronic Toll Collection;
- Logistic information systems;
- Vehicle technology improvements; and
- Voluntary Co-operation programs.

Both of these summaries were international in scope. The more recent study (Douglas 2003, pp. 18-24) which documented the challenges of increasing truck volumes (above) provided additional measures not previously included. These are

- Improved highway design;
- Roadway facilities;
- Enforcement/compliance; and
- Alternative infrastructure investment.

Finally, we note additional policies including using human-powered transport in urban areas (Litman 2004), and improving freight flows by specifically reducing auto, or passenger, congestion levels (Allen et al. 2000, p. 22). All of these measures for balancing freight goals with social goals are summarized in Table 3. We categorize the policies into 10 categories and include author references.

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<sup>11</sup> Visser et al. reduced Odgen's categories by combining 'infrastructure,' 'operational,' and 'traffic management' strategies into 'network' and 'parking and loading' categories.

**Table 3 Summary of freight policy options**

<b>Policy category</b>	<b>Description</b>	<b>References</b>
Operational	Route prohibition and regulation of trucks	Odgen (1992); Visser et al. (1999); Douglas (2003)
	Identifying specific facilities for parking, loading and unloading	Odgen (1992); Visser et al. (1999); Douglas (2003)
Multimodal/Facility	Spatial concentrations of generators / attractions	Odgen (1992); Visser et al. (1999)
	Transfer points at the border of urban areas to limit movements in the urban area	Odgen (1992); Visser et al. (1999)
	Improvements for port/shipping, air, or rail infrastructure	Douglas (2003)
Vehicle-Based	Vehicle regulation based on size or weight	Odgen (1992); Visser et al. (1999); Douglas (2003)
	For better performance or minimizing energy use	Visser et al. (1999)
	Additional inspection or enforcement resources	Douglas (2003)
Pricing	Use of market mechanisms to manage congestion	Odgen (1992); Visser et al. (1999)
Signing	Providing traffic information	Visser et al. (1999); Douglas (2003)
ITS	Including new vehicle control systems	Visser et al. (1999); Douglas (2003)
	Using electronic toll collection systems	Visser et al. (1999)
Private Sector	Between or within companies to improve the distribution of goods	Visser et al. (1999)
	Co-operative pick-up, delivery, terminal use	Visser et al. (1999)
	Using human-powered transport in urban areas	Litman (2004)
Highway Design	Improved geometrics, structures, standards, or pavements	Douglas (2003)
Roadway Supply	Dedicated roads, ramps, or climbing lanes for trucks/commercial vehicles	Douglas (2003)
Passenger/Auto	Car use reduction strategies	Allen et al. (2004)

### 2.3.4 Policy summary

State and MPO surveys indicate that the most prevalent challenge to increasing truck traffic is congested urban highways and roadways. While existing policies summarized above are designed to deal with all of the challenges related to increasing truck traffic, mitigating congestion is the motivation behind many of them. Moreover, many strategies aimed at alleviating congestion will provide additional benefits simultaneously, such as reducing truck-idling time and concomitant emissions. Travel demand that approaches or exceeds roadway capacity can be mitigated by increasing roadway supply or applying demand management measures.

Supply-side policies are those above that focus on adding capacity, such as dedicated truck lanes, roads or ramps. However, physical limits exist in densely built environments. In this scenario, road supply is provided through technology or ITS<sup>12</sup> solutions, such as installing ramp meters and variable message signs, designed to facilitate traffic flows. On the other hand, travel demand management (TDM) methods impose restraints on travel to ameliorate congestion. These TDM measures include road pricing and land use management. Examples of TDM methods specific to freight include time-of-day or road restrictions and parking prohibitions.

Although environmentalists argue that demand-management policies are more sustainable than adding to supply, they are politically difficult to accept. For example, supplying more roadways often equates to more travel, higher emissions and other forms of environmental degradation from induced travel demand. As such, roadways may eventually reach saturated levels even with higher capacity. This congestion is evidence of economic activity, yet must be balanced from a sustainability perspective that includes social goals as well.

Demand management policies are more sustainable for the same reasons that they are politically sensitive: they are based on inducing behavioral changes. For example, route prohibitions keep trucks out of residential areas or off of major roadways during peak hours. Suppose a firm providing goods movement is making travel choices based on cost minimization algorithms; then route prohibitions may create longer travel times and additional costs for goods movements. Requiring firms to adjust their travel routine and find methods to make up for the new higher costs is unlikely to gain popular support.

One demand management measure rarely implemented due to its political infeasibility is congestion pricing. As mentioned in Chapter 1, economists advocate charging people to drive on

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<sup>12</sup> Intelligent Transportation Systems



roadways that once were “free” because they measure the cost of travel imposed on others. Nonetheless, pricing is difficult for citizens and policymakers to accept. Congestion pricing would affect freight movements. On one hand, trucks paying additional costs to travel on the roadway will be reluctant to absorb the new costs and may change their travel patterns. On the other hand, congestion pricing is such a strong demand management policy that by pricing some of the trips off the road, it would greatly reduce the costs of congestion to trucks by providing travel time savings and increased reliability. Chapter 3 further describes this policy option.



## Chapter 3

### Congestion pricing literature and experiences

Assume that you are driving on a highway and there are very few cars on the road. When one extra car enters at the coming access point, you simply move a lane left without changing your speed. Several more cars and trucks enter the roadway; again, none of them changes the pace of travel and everyone continues to drive at the same, uninhibited speed, known as “free-flow speed.” Finally, the roadway is fairly full and one more vehicle enters ahead. They merge into the right lane cleanly, but as they sneak into the next left lane, just in front of you, you tap your breaks. This leads several vehicles behind you to tap each of their breaks. Everyone is now experiencing light congestion as that one additional vehicle has imposed a slight delay onto several other road users. Here, the driver of that vehicle does not perceive him or herself as imposing delays on others; they enter the road and believe that they are merging into the normal pace of travel. What they don’t realize is that they have impacted travel speed for several people just behind them on the roadway. All of the existing drivers are now traveling a fraction slower than before, as witnessed by the series of brake lights. At this point, as additional cars and trucks enter the roadway, total travel time delays for everyone else on the road continue to increase.

Now assume that on the same roadway, during heavy travel times, each road user has to pay a toll to access the highway. Assume that this toll value varies and is always equal to the social costs that were imposed on other users when each additional car or truck joined the traffic stream. Therefore, the largest toll value occurs during the most congested time of day and tapers off before and afterwards. Personally, you take a moment to reconsider your trip, wondering if you should take it a bit later to pay less, use another road or travel mode, or even if you need to travel at all. Although you may decide to keep your travel plans as they were, other cars and trucks may

alter their plans. Because some road users were unwilling to pay the toll, you now travel at free-flow speed for your entire journey segment, enjoying the new travel time savings and increased reliability associated with your trip. However, you are aware that you paid for those benefits.

Like the stakeholders specific to freight discussed in Chapter 2, groups have varying opinions about the new tolls on the highway. The urban economist is relieved that road users are now paying their true costs of travel, or the ‘marginal cost’ of each vehicle adding themselves to the traffic stream. The road agency can use the new revenue to better maintain the roadways and add additional transit service – returning the taxes to travelers in general. Some travelers that can no longer afford the new tolls are irritated though, as are some drivers on the parallel access road who are now experiencing even more congestion from diverted traffic. Existing bus users are pleased because now that more passengers are riding the bus, the transit agency has increased frequency on their route. Likewise, some truck drivers with important deliveries (of high-value products such as electronic widgets) or traveling on tight schedules are pleased with their faster, more reliable trip. However, other owner-operator truckers who are paying the tolls out of their pocket from the small margins for their delivery, are constrained by competition from passing on the costs to customers, and are frustrated that they don’t have any other mode choice options. For example, even though they feel the tax is too much for them, they don’t have the option of taking their shipment of low-tech widgets on the bus or subway.

This narrative begins to illustrate the concepts and complexities associated with congestion pricing covered throughout this chapter. While the overall emphasis of this thesis is on the impact of congestion pricing schemes on urban truck travel, the evolution of related literature and general economic theory are first reviewed. Then, we turn our attention to marginal cost studies and policy implications that are specific to freight. Finally, we present a review of international pricing experiences and their impacts on freight travel. Note that this type of pricing policy has several names associated with it, including road pricing (not necessarily associated with congestion mitigation goals), congestion charging (specific to the London scheme), and value pricing (intended to soften its perception among the public). We will not differentiate amongst these names; we refer to all congestion-alleviation or marginal-cost toll schemes as ‘congestion pricing’ throughout this document.

### **3.1 General literature review**

This literature review focuses on the general progression of congestion pricing literature, applicable both to cars and trucks. In many cases the research was performed with the passenger-transport planner in mind and freight is not mentioned explicitly. Yet these works provide the

foundation of more recent research (covered in the next section) that focuses on urban goods movement. First, we review the highly-influential, initial works and follow with a summary of the economic theory behind congestion pricing. Next, we comment on the political feasibility of pricing and types of pricing schemes.

### 3.1.1 The foundations of congestion pricing

The earliest reference of congestion pricing to roadways was found in Pigou's text *The Economics of Welfare* (1920 pp. 193-4, cited by Mohring 1999, p. 193). He first assumed two roadways ABD and ACD connecting A and D with equal travel times,  $TT_{ABD} = TT_{ACD}$ . Then he asserted that if shifting a few vehicles from one road to the other would greatly reduce travel time on one road while only slightly increasing it on another, then a "rightly chose method of differential taxation" would be justified. In fact, it would be "superior" if the toll value was chosen correctly. Economist Frank Knight challenged this idea by pointing out that Pigou assumed a misallocated public road which caused the externality. Knight argued that roads offered in a competitive market would obviate the need for the tax. Although Knight's assertion of using competitive markets was improbable, Pigou pulled the reference from subsequent editions of his text (1924, cited by Mohring 1999).

The development of the literature stemmed from modifying the assumptions that Pigou made in his initial case. He assumed a uniform lane width, no junctions, technically-identical vehicles, and the omission of pollution and safety considerations. Moreover, complements and substitutes are priced efficiently and correctly (without subsidies) and regulatory policies are flexible in responding to externalities. Based on these assumptions, the 'Pigouvian toll' is the appropriate corrective solution and little room is available for improving or further developing solutions. However, by modifying these assumptions and attempting to model this scenario, a large body of work has developed in the last 85 years.

First though, note that the original works of Wardrop, Walters, and Vickrey initiated the modeling and economic analysis research that underpins work in congestion pricing today. Wardrop (1952) formalized the two alternative travel scenarios given by Pigou by defining two principles of route choice known as 'user optimal' (when travel times on each route are less than any unused route) and 'system optimal' (when total travel time on the network is minimized). These principles led to static, models, which were the first approach to studying traffic congestion and pricing scenarios. Walters (1961) proved that travel time and average cost could be related in a unique function. This equation, known as the *generalized cost* function, provided the foundation for economic analysis by allowing for direct translations between time and cost.

Finally, after developing several applications of marginal-cost pricing theory to urban transportation starting in the 1950's, Vickrey (1969) introduced the second approach to studying congestion pricing with his dynamic "bottleneck" model. Vickrey assumed that all travelers wanted to arrive at work at the same time but were prohibited from doing so by a bottleneck in travel capacity. Additionally, two costs were assigned to each trip: travel time costs and schedule delay costs (the penalty that people assign to arriving early or late). With these assumptions, he demonstrated that in total, travelers will incur identical costs either by paying a variable road toll and not experiencing any delay from queuing or by not paying tolls and waiting in long queues. As such, tolls are justified since they benefit the highway agency and travelers are indifferent. Both dynamic (more-realistic) and static (simplistic) modeling techniques, introduced by Vickrey and Wardrop, respectively, continue to be used in congestion pricing planning applications today.

Transportation planners attempting to entice motorists from traveling during the peak have used the dynamic and static models above to study variations of Pigou's assumptions and the politically-feasible solutions to rectify them. For example, some alternative scenarios (cases where Pigou's initial assumptions do not hold)<sup>13</sup> that have received attention in the literature include:

- Optimal road capacity with suboptimal pricing;
- Uniform, step-wise pricing of a bottleneck situation;
- Congestion alleviation policies focused on land-use strategies; and
- Optimal congestion pricing with an available untolled alternatives (Button and Verhoef 1998, p. 6).

In addition to these technical studies, other research focuses on transitions from theory to applications. Additional studies focus on implementation and political feasibility; these address equity impacts, environmental benefits, technology options for implementation, and revenue-spending alternatives.

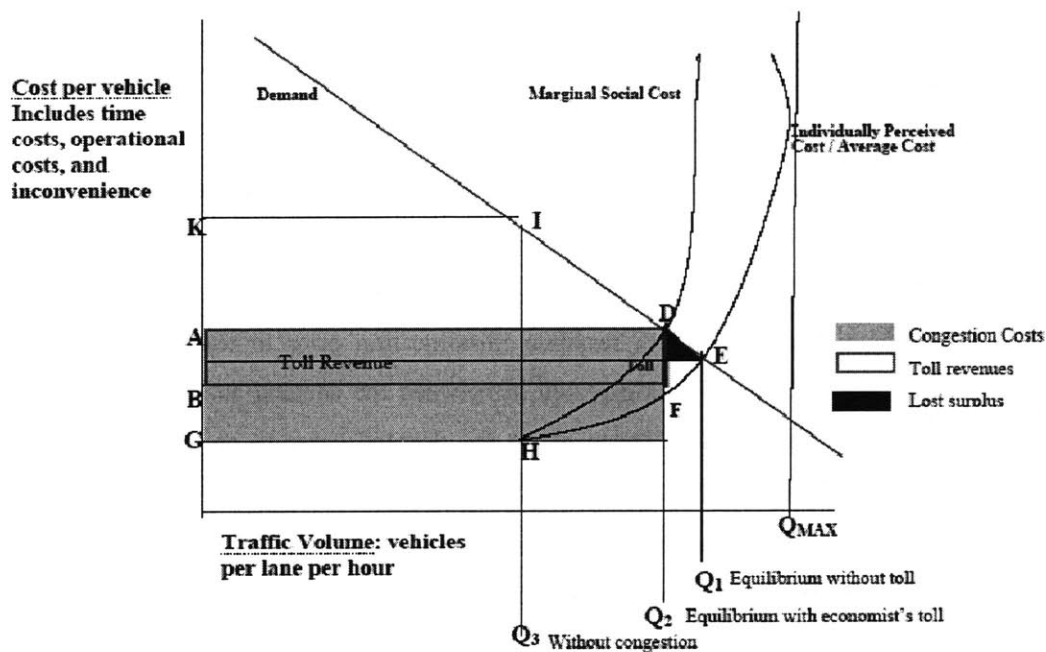
### **3.1.2 Economics of congestion pricing**

Pricing as a tool for resource allocation is not unique to transportation. For example, electricity and water provision similarly have peak periods limited by infrastructure capacity. These industries charge higher prices when demand is the highest (during the peak period) to deter use by some customers that are more price-sensitive. This pricing strategy thereby spreads usage into

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<sup>13</sup> These cases are known as 'second-best' scenarios because their solutions are not Pigouvian, which is considered the 'first-best' solution.

the ‘shoulders’ of the peak, or the time periods immediately preceding or following the peak period. In each case, assuming constant returns to scale exist, or where one additional dollar of infrastructure investment provides exactly one additional unit of output, then marginal-cost pricing is recommended. Marginal cost is traditionally defined as the additional cost of producing one more unit of output. In transportation, the marginal cost is the additional cost to all road users of accommodating one extra vehicle on the roadway. Employing tolls that equal the marginal cost of travel to each road user ensures that the value of additional trips made exceeds its cost on all other users, or society. Failure to consider externalities (such as congestion and pollution) by tolling inevitably leads to excessive use of the infrastructure.<sup>14</sup> This concept, demonstrated by the anecdote at the beginning of the chapter, can be visualized with a supply-demand curve.



Source: Adapted from Salvucci (2004).

### Figure 2 Economics of congestion pricing

Figure 2 is a graphic representation of the static pricing model mentioned above; the demand line is a time-independent function. The average cost curve shows the generalized cost that the driver perceives on the roadway, which is effectively their travel time translated into dollars. The

<sup>14</sup> An analogy can be made with a competitive firm. If such a firm did not charge marginal cost for the units they sold and the costs of producing one additional unit exceeded the price consumers were paying, then there would be an incentive for over consumption and the firm would go out of business.

marginal cost curve is the cost of accommodating one additional driver on the road.<sup>15</sup> Note that marginal costs are higher than average costs, revealed by the curves. These curves increase and have a wider separation moving right along the Y-axis, as the number of vehicles on the road increases. The increased separation between the lines is due to the fact that the marginal cost of each additional road user in congestion (the sum of all the travel time increases to every one else) increases much more quickly than the rate at which travel time increases for that individual user.

The two key points about the graph are:

- Existing traffic demand, E, occurs where the demand curve meets the *average* cost curve, resulting in the current price (paid in travel time and travel costs); and
- Modified travel demand given congestion pricing (and the addition of tolls), D, occurs where the demand curve meets the *marginal* cost curve.

The difference on the cost axis between the average and marginal cost curves at the point  $Q_2$  reflects the toll value, while the difference in the number of users ( $Q_1$  and  $Q_2$ ) shows the decline in traffic volumes resulting from the toll.

Values reflecting costs and benefits to individual users and society can be identified in the graph:

- Existing losses per hour, or the costs imposed on others, associated with excessive infrastructure use (from resource misallocation prior to toll implementation) are represented by the area captured in between the demand and social marginal costs curves when  $Q_1$  is extended *above* the demand curve to *meet* the to the marginal social cost curve (not explicitly shown in Figure 2);
- Revenue generation in the toll scenario is equal to ABFD, or the price of the toll ( $A - B$ ) multiplied by new demand,  $Q_2$ ;
- Lost surplus to former road users who have modified their travel plans is represented by the triangle, DEF.

Note that the curve presented here is a static representation of travel demand. The static model is based on the fundamental diagram of traffic, stating that there is an inverse relationship between speed and density. (See Appendix A for details.) This model is a good representation of

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<sup>15</sup> Note that the average and marginal cost curves only include the cost of travel time; they do not include fuel, maintenance, or other fees associated with driving. Sensitivity analysis with and without these additional costs provide similar toll solutions (Mohring 1999)



the interactions that occur at the link-level, since it is independent of temporal and spatial considerations.

### **3.1.3 Political feasibility**

While congestion pricing is well-understood in the literature and supported by economists, few applications of the policy exist. The impacts on road users sketched in the anecdote at the beginning of the chapter show that not everyone will directly benefit from a congestion pricing scheme. These citizens are likely more vocal opponents than the relative winners in the scheme who are better off with the roadway tolls. However, Gomez-Ibanez (1992, pp. 359-60) suggests three options for improving the feasibility of implementing a congestion pricing toll scheme that focuses on revenue allocation, environmental concerns and policy manipulation.

Perhaps the most important concern for political feasibility is finding an attractive use of the generated revenues. Citizens are generally more favorable towards taxes that are dedicated, meaning they are reserved or set aside for a particular purpose. Policymakers may offset the tolls raised or reverse a decline in the quality of transportation infrastructure. Citizens are more receptive to a new toll or tax when they are certain of where the revenues are allocated and believe that it is a worthy cause. Also, citizens are more open to tolls as a means of financing additional infrastructure than as a way to influence behavior changes.

Second, appealing to the environmental benefits of congestion pricing may provide enough justification to advance the policy where exacerbated local or regional air quality problems exist. Air pollution goals alone may not be a strong enough reason to cause political action, but the dual benefits of minimizing emissions and ameliorating congestion with pricing can gather additional support. Congestion pricing reduces emissions both by minimizing the stop-and-go traffic conditions that lead to idling vehicles, but also by curtailing some travel demand with increased costs. Note that while economists will primarily be focused on using variable pricing so that roadways keep moving at free-flow speeds, environmentalists will likely be more interested in the demand management effects of tolling and prefer tolls throughout the day. Even with these differences, working together to serve two goals will increase the political feasibility of the policy.

Finally, Gomez-Ibanez suggests that small victories in setting up tolling systems and supporting legislation will ease future implementations of congestion pricing and that policymakers should take these measures when appropriate. For example, a federal ban prohibiting tolling on interstates negates congestion pricing as a policy tool on several urban highways; reversing or modifying this ban might open the door to future pricing schemes. Also,

if congestion exists on some roads that already have financing tolls in place, varying these tolls during the congested period might be more politically acceptable since the road was not previously *free*.

### **3.1.4 Types of pricing schemes**

Congestion pricing schemes can be segmented by geographic scope and technology used in implementation. The four variations in geographic scope are area-level, ring road, corridor-based, and point. The area-level schemes (ALS) cover an entire region and entry at any point requires a toll, which allows access to the entire tolled area. Ring road and corridor-based schemes are both highway-based and charge variable tolls depending on the level of congestion on the highway segment. Finally, point-based schemes refer to variable-priced facilities such as bridges or tunnels. Note that these types of schemes may overlap with each other in an urban area.

Toll collection increasingly employs high-technology systems. The earliest congestion pricing implementation (in Singapore) first relied on paper licenses which were colored-coded and large enough for manual viewing when accessing the priced region. Singapore has since updated the tolls to an electronic system where devices inside of a vehicle communicate with gantries overhead. Alternately, in London, video cameras record the license numbers of motorists traveling into the area-based scheme. Finally, a new GPS-based scheme exists in Germany, which charges trucks for the distance traveled on roadways in the country. Table 4 summarizes the few applications of congestion pricing by their geographical scope and the type of technology used in implementation. We elaborate about the impacts on freight in some of these cases later in the chapter.

**Table 4 Congestion pricing schemes by geographic scope and type of technology**

<b>Location</b>	<b>Geographic scope</b>	<b>Technology</b>
Singapore	Area-licensing scheme	Electronic
London	Area-licensing scheme	Camera
New York City	Point	Electronic
Southern California (SR-61 and I-15)	Corridor	Electronic
Austria, Switzerland	Corridor	Electronic
Germany (expected 2006)	Corridor	GPS; camera
Scandinavian cities (Stockholm, Bergen, Oslo, Trondheim)	Ring road	Manual; electronic
Paris (A-1)	Corridor	Manual; electronic

### **3.2 Literature specific to urban freight**

Understanding the impacts of congestion pricing on freight are important for two reasons: (1) if trucks are currently mispriced then inefficiencies likely exist in their travel patterns; and (2) increasing interest in congestion pricing as a mitigation strategy for passenger travel means that understanding the impacts on trucking is both timely and relevant. Given the foundations of congestion pricing above, this section reviews literature related to urban goods movement.

#### **3.2.1 Congestion costs**

In the aforementioned *Economics of Urban Freight Transport*, Pearman and Button (1981, pp. 165-171) include an analysis of congestion pricing impacts in their discussion of the microeconomics of urban goods movements. By initially assuming that no congestion-alleviation benefits are associated with the new toll charges, they show that urban freight delivery will be disadvantaged because travel time benefits are small and inelastic trips absorb the fees.

In a second scenario, they levy a toll on both passengers and freight. Reduced congestion (primarily from a passenger mode shift) shows benefits to urban goods movement. In this case, the authors note three components that contribute to reducing the generalized cost<sup>16</sup> of travel:

- Journey speeds increase;
- Fleet and crew utilizations increase; and
- Wear and tear costs decline.

Even though Pearman and Button do not include reliability improvements in their benefit calculation, congestion-pricing tolls are offset by the lower generalized cost of travel. The sensitivity of delivery costs in prior traffic determines the difference between the toll and generalized cost reduction. Edward and Bayliss (1970, as referenced by Pearman and Button 1980, pp. 167-8) look at the types of costs incurred by trucks, see that most are variable, and infer that the decrease in generalized cost will more than offset the toll value.

A second study, using a simulation model to evaluate an area-based congestion pricing scheme in Coventry, UK, confirms these results (Bone 1975, as referenced by Pearman and Button). With the average VOT for passenger and freight travel at £0.20 and £0.75, respectively, a £0.33 toll resulted in a 30 minute round-trip, travel time savings for trucks. In summary, passenger cars paid £0.16 in disbenefit, while light, medium, and heavy trucks were shown to have benefits of £1.24, £0.06 and £0.37, respectively. Even without the generalized cost savings to trucks, they conclude that the actual toll value is about one percent of total production costs for goods delivered. Therefore, they suggest that trucks could absorb the fee. This perspective above does not account for the low profit margins traditionally associated with the carrier trucking business (by focusing on the shipper perspective instead).

Pearman and Button (1981) also discuss the short- and long-term impacts and some critiques to their pricing analysis. First, they conclude that, in the short-term, urban good movement will be relatively inelastic, such that congestion pricing may have little effect on the number of trips taken because the freight volume may be near an optimal value. (However, they comment that efficiencies can be discovered based on the results above. Some medium-duty trucks should be rerouted as small or large truck shipments because of the higher benefits received by each of these truck types.) In the long-term, land-use patterns will be affected, but it is difficult to ascertain which of two competing factors will dominate. If tolls are higher than transport costs,

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<sup>16</sup> Generalized cost refers to the total cost term that includes both travel time and monetary cost components.

then suburban relocation may occur; whereas, if the decreasing generalized costs offset the tolls, a strong incentive exists to remain in the central-business district.

They also discuss three main critiques to their congestion pricing policy. First, increased costs to freight could escalate the cost of retail goods prices, leading to inflation. Second, any product price increases that do occur because of the congestion pricing scheme will be regressive (meaning that the less you earn, the more you will pay as a percentage of your income) because price increases will affect necessity items. For example, necessity items purchased by low-income people costs a higher portion of their income with the price increases, which is similar to adding or increasing a regressive tax to the goods. The authors assert that both of these claims are unfounded when increased system efficiencies from the pricing implementation are considered. Third, pricing schemes which only account for marginal congestion costs may actually increase externalities in the urban area. Here, Pearman and Button agree that if a pricing scheme spreads truck travel into later hours of the day or through residential communities, then total externality costs in the form of “noise, air pollution, dirt, visual intrusion, vibration, etc” (Pearman and Button 1981, p. 170) may actually increase. A 1996 Transportation Research Board (TRB) report responds to this externality issue and is reviewed below.

In summary, a full congestion pricing scheme would likely have advocates in the freight community, but Pearman and Button recognize that such a policy was politically infeasible in the near future. We revisit these early conclusions on the positive pricing impacts towards urban goods movement. Lastly, in this study, the authors note that their pricing scheme does not account for the cost of providing the infrastructure and roadways (Pearman and Button 1981, p. 170-1). This insight is likely the same foundation that motivated the work by Small et al. (1989) reviewed next.

### **3.2.2 Infrastructure costs**

Small, Winston and Evans (1989) contributed to the relationship between congestion pricing and goods movement by jointly looking at congestion charging and optimal road investment for the first time. In the past, policies related to each topic were considered separately which, they argued, did not make sense because they were interdependent (both aim to minimize a form of road costs). Investment had two components: capacity, to accommodate flow; and durability, to ensure long-term pavement performance. Since each is expensive to provide, they are scarce, and the appropriate response to scarcity is pricing.

Small et al. (1989) showed that with two types of scarcity, two separate pricing schemes should be levied. Capacity scarcity caused congestion, so congestion pricing should be applied;

scarcity in pavement durability caused pavement deterioration, so an equivalent road-use fee based on durability impacts would also be appropriate. This proposal combined the typical engineer/policy-maker focus on mitigating road wear with the economist's interest in congestion pricing. Effectively, they proposed that auto users pay to use scarce capacity since they are primarily responsible for the congestion that ensues, while trucks pay for the rights to use the limited durability available in the roadways. However, they focused their study on the road-wear fees because congestion pricing under capacity constraints is well-documented elsewhere. The entirety of their new dual-pricing policy scheme was well-supported with quantitative methods.

In theory, this research has several implications for the surface freight industry. First, such policies would provide incentive for trucks to minimize their loads per axle (ESAL) while relaxing some of the current weight restrictions, thereby minimizing pavement deterioration. Also, they showed that a small increase in pavement durability would result in sizeable reductions in long-term building and road maintenance costs (and subsequent fees imposed in their road-use fee scheme). The quantitative evidence showing cost savings from pavement deterioration present a compelling argument for adopting this policy framework.

Despite the supporting evidence, and in addition to general opposition to congestion pricing schemes, two additional barriers indicate why policymakers are slow to adopt this framework. The first reason is the change in costs to truck trips. While intercity freight costs would decline, urban trips would pay more, as noted by Small et al.

With the durability improvements that we recommend, the new road user charge for a typical 80,000-pound, fully loaded five-axle tractor-semi trailer combination in intercity use, for example, would be less than two-thirds the average fuel and weight-related taxes and registration fees currently paid; whereas the charge for a more damaging 33,000-pound two-axle van in urban use would triple current taxes and fees (1989, p. 116-7).

Additionally, fee increases noted here would provide a large incentive to minimize ESAL. The authors recognize that this would likely increase the average size of trucks on roads, which would have unfavorable safety and quality of life implications for urban residents. In theory, the framework would increase efficiency though, while reducing costs and increasing the longevity of roadways. Hau (1992) augmented this research by developing the parallel demonstration of economic theory that further substantiates these claims.

### 3.2.3 Social costs

So far, this section summarized two studies of congestion pricing on freight. The first study by Pearman and Button reviewed early pricing analyses which suggested resulting benefits to trucks. The second work by Small et al. redefined the scope of congestion pricing by including infrastructure costs (largely impacting freight) into a modified version of the traditional pricing framework. Now, we discuss a study which suggests that in addition to incorporating infrastructure costs, all marginal social costs should be included in a pricing framework. By including all marginal costs, we respond to a critique validated by Pearman and Button (1981) stating that congestion pricing during the day may lead to noisy trips at night which may irritate residents. By valuing all social costs in a congestion pricing framework, we internalize the monetary value of such externalities; therefore, we ensure that trips on the road exceed the marginal costs of their negative externalities on to other urban residents and motorists. This study provides methods to quantify the marginal social costs and underpins efforts to promote economic efficiency by carriers and shippers, and equitable financing by the government (TRB 1996).

Currently, government costs and fees are allocated over aggregate classes, but the costs imposed vary according to factors such as origin-destination, travel time, day, and season of trip. When the fees paid for a particular trip don't match the marginal social costs, then inefficiencies occur within the system. For example, where fees do not cover costs, subsidies exist; on the other hand, where the fees exceed the costs, inequities discourage valuable trips. In the TRB study, marginal social costs and fees are compared in government cost recovery methods for one urban and three intercity freight cases. The social costs calculated in each case include congestion, accident costs, air pollution, energy consumption, noise, and pavement deterioration.

The urban freight case considers a day-long, grocery-distribution truck trip. In this case, the subsidy per truckload kilometer was the highest of all the cases (at \$0.22 per kilometer) and accounted for over seven percent of the carrier's cost. The high subsidy is due to the large percentage of empty travel time (114 empty km vs. 91 loaded km) and because of the high congestion and noise impacts in urban areas. Sensitivity analysis was performed to account for uncertainties in some data (particularly about human health impacts) and variations of typical congestion and pavement costs as a function of temporal and spatial differences. By looking at the sensitivity of each variable included, subsidy per truckload kilometer in the urban distribution case varied from \$0.17 (with the consideration of more durable pavement) to \$0.32 (under combined rising congestion and mitigation assumptions).

Two important differences exist between this marginal social cost study and cited traditional government cost recovery calculations. First, the government study considers only pavement deterioration costs, which dictate current government fees. This implies that the government does not recognize subsidies occurring in urban truck travel. Second, the pavement deterioration costs between the two studies differed (\$10 per truckload in this report versus \$24 per truckload in the government study). Discrepancies in these figures suggest that the aggregate calculations used in the government method may not be accurate across temporal and spatial distributions or that the government is trying to capture additional costs with their overestimate of pavement deterioration costs.

In summary, results of the urban marginal cost study imply that inefficiencies exist because of the subsidy provided. If this subsidy were eliminated, carriers and shippers would likely make several changes to reduce costs such as: rerouting shipments, using equipment that pollutes less, or changing the location of terminals or hours of departure. Charging fees to cover the social costs (across all sources, including goods movement) ensures that in the case of freight, the value of shipment delivery meets or exceeds the costs, guaranteeing efficient and equitable transport.

### **3.2.4 Distributed value of time**

Finally, the last contribution to the literature on freight and congestion pricing is the recent development of a distributed value of time for trucks. Since trucks carry heterogeneous products, they have a range of VOTs. Previously, average values were used to quantifying the travel time improvements into monetary values; this format is problematic because averages do not accurately reflect the heterogeneity of shipments. Therefore, the development of a VOT distribution is critical to producing accurate results and understanding the response of individual trucks to the scheme.

Kawamura (1999 and 2003) empirically derives a VOT distribution for trucks in Orange County, California. (He gives this distribution in conjunction with a theoretical congestion pricing study which we review in the next section.) He shows that while the mean VOT for trucks is \$23 per hour, the median value is \$4 per hour, lognormally distributed. The average values here are similar to those calculated in other studies; yet Kawamura contributes to the field by defining a distribution for truck VOT captures the large variation in the data. Studies which use an average VOT of \$23 per hour without capturing the distribution of values will overstate the benefits to most trucks because the median value is much lower at \$4 per hour.



### **3.2.5 Summary of freight literature related to congestion pricing**

In summary, we present four studies what combine freight and pricing. First, an early modeling application of congestion pricing is given (showing benefits to trucks) with an evaluation of short- and long-term impacts to pricing. Next, the congestion pricing framework is extended to include road investment costs, and then all social costs. Finally, we present a distribution for the value of time to urban trucks, a critical component to further study. The next section describes the international experiences of urban freight in applications of congestion pricing.

## **3.3 Pricing impacts on freight**

This section examines the impacts of congestion pricing on freight from existing applications. First, the most well-known area-based schemes in Singapore and London are reviewed. Passenger congestion motivates these studies, so the effects to freight have been peripheral in the documentation; yet basic information is available and reviewed. Next, the impacts of point congestion pricing on facilities in New York City and the distance-based toll schemes across some European highways (in Switzerland and Austria) are reviewed. Finally, a theoretical study of freight impacts on the existing corridor-based pricing scheme (which does not currently allow truck travel) in Los Angeles is presented and a summary is made.

### **3.3.1 Singapore**

The island city-state of Singapore first implemented congestion pricing in 1975, responding to increased traffic congestion and rising car ownership levels. A manual system of toll collection and administration was installed around the periphery of the central downtown area, to which entering motorists were charged entry fees during morning peak hours. Since then, several modifications to the area-licensing scheme (ALS) have been made, including fee increases, changes to the types of vehicles exempted from entry fees, peak-hour extensions, and technology improvements to an electronic road pricing (ERP) system (Phang and Toh 2004). The evolution of this novel congestion pricing scheme has been well-documented over the years, however the impacts on truck travel have received significantly less attention.

In Singapore, trucks were exempt from early fees in the congestion pricing scheme. Initially, truck volumes increased before, during, and after the peak period compared to pre-ALS volumes, with a 90 percent increase occurring in the peak period itself. Since there was a total vehicle decline of 47 percent, this increase in truck traffic filled some of the vacated road space (Gomez-Ibanez and Small 1994, pp. 15-19). See Table 5 for a summary of 1975 traffic volumes.

**Table 5 Singapore ALS comparative 1975 total vehicle and truck volumes**

Relation to restricted hours	Vehicle Type	Before ALS (volume)	After ALS (volume)	After ALS (% difference)
Before	All Vehicles	9,800	11,510	+ 17
	Trucks	1,572	3,557	+ 126
During	All Vehicles	55,313	29,532	- 47
	Trucks	1,762	3,346	+ 90
After	All Vehicles	12,775	14,401	+ 10
	Trucks	1,937	4,104	+ 112

Source: Gomez-Ibanez and Small, 1994.

In 1989, among other changes in the pricing policy, trucks were removed from the exempt list and subject to morning and evening peak period fees of S\$3.00 (Singapore dollars). In conjunction with these toll additions, truck volumes declined 53 percent. The 1989 reforms did not receive as much attention as the initial scheme and less corresponding data is available (Gomez-Ibanez and Small 1994, pp. 15-19). In 1994, the ERP scheme was established; peak period truck fees stayed the same, and a S\$2.00 mid-day toll was initiated (Phang and Toh 2004, p. 19). Currently, trucks are segmented into three types (light-goods, heavy-goods, and very heavy-goods vehicles) and are charged between S\$0.50 – S\$3.00 for light trucks to S\$1.00 – S\$6.00 for very heavy trucks during the peak (Land Transport Authority 2005).

One lesson learned from Singapore’s congestion pricing history is that pricing is not a significant barrier to increased business activity within the ALS. The impacts of the scheme are difficult to differentiate from changes in the economy that have occurred since 1975; however a vibrant downtown community still exists. Additionally, there were “few immediate discernable effects,” from pricing and by all accounts employment in the ALS has grown since then (Gomez-Ibanez and Small 1994, pp. 20-21).

### **3.3.2 London**

Despite claims that duplicating the Singapore ALS would be infeasible in alternate political climates, London implemented its own ALS in February 2003 among other transportation improvements. Motorists and trucks paid £5.00 per day to enter the central zone, although this

was a departure from the £15.00 originally set for trucks.<sup>17</sup> In practice, trucks have three options for paying the daily tolls as shown in Table 6. The first two options are primarily intended for autos and are used by owner-operator truck drivers, while the third Automated Scheme allows prepayment for vehicle fleets, although it requires a £10.00 annual fee per vehicle plus charges £5.50 per day to cover administration fees associated with the scheme (TfL 2005a).

**Table 6 London congestion pricing payment alternatives**

Schemes	Description	Minimum number of vehicles in fleet	Annual fee per vehicle (£)	Daily fee per vehicle (£)	Payment timeline
General	For general travel into the zone; requires manual payment	0	0	5	Up to 90 days before until midnight of day used
Notification scheme	Open to all vehicles, but primarily aimed at autos	25	10	5	Monthly prepayment of the anticipated usage is directly debited on a monthly basis
Automated scheme	For light vans, light and heavy goods vehicles; eligibility is required and autos are prohibited	10	10	5.5	Monthly prepayment of the anticipated usage is directly debited on a monthly basis

Source: Transport for London, 2005a.

<sup>17</sup> This higher fee would reflect the increased road space that one truck occupies as compared to a passenger car. A value of £15.00 for trucks and £5.00 for autos assumes that each truck contributes three times as much to congestion as an auto and prices for that differential accordingly. (In this case, each truck equals 3 PCEs, or passenger car equivalents.) Increased congestion contributions are from slower acceleration, deceleration, and reduced turning capabilities.

The London congestion pricing scheme has received a lot of attention, although the pricing component is only one part of the comprehensive Mayor's Transport Strategy. This plan recognizes the role that goods movement plays in the economy, examines recent freight trends and impacts, and outlines a framework for achieving increased efficiency and improved environmental practices. The overall plan intends to remedy network deficiencies, environmental impacts, and congestion for road shipments, while leveraging more sustainable freight transport modes. In the meantime, more than 48 million inter-city and 118 million intra-city goods movement trips originate or terminate in London annually (Greater London Authority 2001, p. 258). These trips, with service trips, account for 14 percent of the total annual vehicle kilometers traveled (VKT) in London, and were expected to increase by at least 10 percent by 2011 without any major policy changes. The Mayor's plan includes several policies and improvements in addition to congestion pricing, such as:

- Partnerships intended to represent several stakeholders and present innovative solutions where applicable to specific problems;
- Attention to urban loading/unloading needs;
- Review of the prior London Lorry Ban that prohibits hours and roadways available to goods movement;
- Expansion parking facilities; and
- Adoption of technologies to facilitate efficiency and environmental goals (Greater London Authority 2001, pp. 255-64).

While some of these strategies are already underway, the congestion pricing scheme has been the primary emphasis thus far (and is the primary financing mechanism for other improvements called for in the Mayor's Strategy Plan). In general, implementing pricing has been successful; traffic volumes fell by 15 percent. Additionally, a 30 percent reduction in congestion translated to overall increases in travel speed and travel time reliability (TfL 2004). These changes were immediate and have been sustained over the two years since implementation. In the meantime, popular support of the scheme was confirmed when residents of London re-elected Mayor Livingston in June 2004, 16 months after the launch of his congestion pricing scheme. In fact, in April 2005, Mayor Livingston announced that fees will increase to £8.00 for autos and £7.00 for trucks in July 2005 (TfL 2005b). A summary of impacts related to freight traffic and business trends are presented below.

Overall reductions in road usage were not matched by the vans and trucks. This is likely due both to the inelastic demand of freight trips, but also because the higher value of freight combined

with faster trips was attractive to some carriers or shippers. Trucks previously accounted for four percent of all VKT in the charging zone. Despite a seven percent reduction in total truck VKT, trucks now account for five percent of all VKT in the zone. Similarly, even with a five percent overall decline, the percentage of VKT attributed to vans increased with congestion pricing from 18 to 19 percent (TfL 2004, p. 29). The reduction in trips likely occurred because of some consolidation (an expected response) and some diversion to the ring road. The ring road experienced a total traffic increase of four percent; however trucks and vans had seven and 12 percent increases, respectively (TfL 2004, p. 31).

After two years, business impacts are neutral. A small percentage of businesses (three to eight) reported policy changes in response to congestion pricing. Of the changes made, altering the timing of deliveries was most common, both to avoid the charge and to take advantage of reduced congestion during the peak. Most businesses (between 62 and 82 percent depending on the sector) reported that the cost of running the site or office either declined or has not changed since the introduction of congestion pricing. Also, at this time it appears that early business declines in the retail sector are more likely related to general economic conditions than to congestion pricing since weekend traffic does not significantly differ from weekday traffic and retail patterns have loosely followed those of the country since February 2003 (TfL 2004, pp. 77-90).

Finally, a cost-benefit analysis of the congestion pricing scheme shows net benefits of roughly £50 million per year. Specifically, the benefits in time savings to commercial vehicles (not including reliability benefits) are about £20 million per year (TfL 2004, p. 91). Further cost-benefit analyses show that net benefits to freight can be segmented into travel times and reliability benefits, minus fuel and congestion pricing charges as shown in Table 7 (GOL 2000, p. 79). Note that fuel costs actually turn into a benefit when owners achieve increased efficiencies from more consistent travel speeds (lowering fuel use) and minimized vehicle wear when congestion decreases. Sensitivity analysis was performed under modified fee structures. Freight impacts were similar when charges ranged from £7.50 to £15.00 per entry; however, assuming a fee structure where autos pay £10.00 and trucks pay £30.00, impacts to trucks ranged from a loss of £35 million to a gain of £5 million per year (GOL 2000, p. 90).

**Table 7 Costs and benefits of the London ALS to commercial vehicle operators**

Costs and benefits to commercial vehicle operators		Estimated value (millions of £ per year)
Benefits	Journey times	60 to 90
	Journey reliability	20 to 30
Costs	– Area-license charge	-70 to -80
	– Fuel and other costs	10 to 15
Total		20 to 55

Source: GOL 2000

Despite the benefits estimated above, the Freight Transport Association (a strong voice in the freight stakeholder community) is opposed to the congestion pricing scheme. On one hand, the FTA welcomed the ten-year transport plan and maintains performance measures to monitor the delivery of the Mayor’s commitments (FTA 2004a). The FTA recognizes that congestion is a growing concern and supports several transport solutions such as investing in rail, maintaining and expanding the strategic road network, using real-time traffic information, and improving (expeditious) incident management (FTA 2004b). Beyond that, they assert that the “FTA has never argued that lorries should not pay their way,” but “what the association is seeking is a basis for taxation which is transparent and fair and enables better decision making and road use” (FTA 2004c). Effectively, the FTA supports a distance-based pricing scheme as opposed to a road-based pricing scheme (FTA 2004c).

There are some inconsistencies in the FTA platform. Conveniently, as Small (1989) noted, charges accounting for congestion and pavement externalities (only) on intercity traffic are generally less than the fees that they otherwise pay, whereas in urban areas, they are much more. While distance-based fees are also an appropriate method of taxation, the two tax systems are not mutually exclusive; both promote economic efficiency and equitable financing. Also, all of the transport improvements supported by the FTA are primarily financed by the revenues from the congestion pricing scheme. While costs and benefits do vary depending on the road user, freight transport receives an overall average benefit, in addition to the subsequent improvements outlined in the Mayor’s Transport Strategy.

To support their argument against congestion pricing, the FTA conducted a survey in February 2004 (one year after the start of the scheme) of 167 small local businesses, multi-national brands, and transportation companies. They presented the following survey results:

- 87 percent: commercial vehicles should be exempt from charging
- 85 percent: number of journeys had not changed after charging
- 69 percent: journeys no quicker in the zone
- 37 percent: passed the cost on to customers

All of these survey results are presented to advocate exemption from the scheme, but some of the results may actually lend support to congestion pricing or are not directly related to the exemption argument. First, in explaining the number of journeys, the FTA summarizes feedback from some operators saying, “Although they initially tried to reduce the number of journeys, this could not be sustained and operational requirements have since resulted in an increase.” Perhaps this is more likely a reflection of the benefits observed from the decreased travel time and reliability experienced by high-value commercial vehicle trips, and not actually a reflection of “this [being] a cost that these companies have no choice but to bear” (FTA 2004d). The other conclusions can similarly be questioned. For example, over one-third of operators said that journeys in the zone were no quicker. While this is inconsistent with the Transport for London (TfL) findings, it does not account for the large increase in reliability that shippers and carriers now experience.

While that FTA and their constituents are opposed to paying the social costs of their trips, they welcome additional benefits provided by the general revenue from the scheme. Staff members internal to TfL are frustrated with the FTA platform, since prior to congestion pricing, the freight community complained about the delays. Now that a direct measure for alleviation has been instituted, they claim it is unfair and would like to be exempt, while taking advantage of the additional road space and revenues from the policy.

The London congestion pricing scheme has been successful, measured by travel improvements and overall benefits to stakeholders. While commercial vehicles are shown to benefit from the scheme because of travel time and reliability improvements, they are opposed to paying additional taxes, claiming that the UK already has higher fees for trucks than anywhere else in Europe. More data about the strength of the London economy, in comparison to other cities, will serve as an indicator of regional economic growth in conjunction with congestion pricing and the recent focus on transport remedies. This type of indicator would serve as a good

proxy for the benefits to both shipper and carrier businesses in the region. In the meantime, many cities are watching London's experience as an example from which to learn.

### **3.3.3 New York City**

The Port Authority of New York/New Jersey (PANYNJ) implemented congestion pricing on all bridges and tunnels in their jurisdiction on March 25, 2001. The scheme focuses on use of the E-ZPass system, and all toll discounts for off-peak or carpooling are tied to using the electronic system. Variable truck tolls are determined by the size and weight parameters. As an example, a six-axle trailer truck pays \$30 during the peak, \$25 off-peak including holidays, and \$17.50 from midnight to 6 am.

Three years after implementation, four passenger travel and two commercial vehicle focus groups were held to determine the qualitative impacts of the pricing scheme. The commercial vehicle groups were for dispatchers of common and private carriers, respectively, since they are perceived as having the most influence on the route of a trip. Each group had a representative mix of cash and E-ZPass users, dispatchers who routed peak and off-peak trips, and small, medium, and large sized firms (BBSA 2004).

Overall, the impacts of the congestion pricing scheme were dismissed by members of both groups who claimed that the discounts were too small. While all respondents had difficulty remembering events from 2001 other than 9/11, none of the respondents felt that they had changed their routing or scheduling practices since the congestion pricing tolls were implemented because of the increased costs. Many dispatchers felt that they would make more money by routing trucks on the fastest routes, even if it involved higher tolls. Also, they were neutral about the tolls since they knew increased costs would ultimately be passed on to the shipper (tolls and fuel surcharges were covered), suggesting that marketing about the variable tolls be directed towards shippers who were in a position to modify their schedule to accommodate off-peak shipments. The dispatchers were not concerned about environmental impacts and didn't think that the tolls were large enough to have an impact on congestion anyway (some suggested that an additional 20 to 30 percent price differential between peak and off-peak would be needed to have some affect). Prior to the focus groups, awareness and acceptance of E-ZPass existed, but there was little awareness of (or concern about) the congestion pricing system. Other suggestions to improve traffic in the region included high speed truck-lanes and suspending construction during peak hours.



### **3.3.4 European toll highways**

Other tolling schemes of interest are those aimed towards trucks on Swiss, Austrian, and German highways. These toll schemes are not variably priced or related to current congestion levels, but they are aimed at ensuring equitable and efficient through-trucking on the national highway systems in their respective countries. The systems in Switzerland and Austria (started in 2001 and 2004, respectively) charge between €0.13 and €0.45 per kilometer based on distance, but not based on roadway type, to minimize the amount of diversion onto local roads. These national systems record entry, exit, and the number of miles traveled electronically, and have been successful at reducing through truck trips. During the late 1990's Switzerland experienced a seven percent increase in through truck traffic; whereas the first year the scheme was in place, that total fell by five percent. Transport companies are making efforts to fill their trucks before sending them over the Alps (Economist 2004).

### **3.3.5 Southern California**

A final case of interest among experiences related to congestion pricing and freight is a theoretical study based in Southern California. Even though trucks are not currently allowed on the SR-61 variable-pricing toll lanes, Kawamura (1999, 2003) estimated the short-term impacts of allowing truck usage. First, Kawamura performed a stated-preference survey of 70 truck operators and operating companies (which represented an overall 20 percent response rate) to measure the level of trade-off between time and travel cost. From this, he developed the value-of-time distribution referenced above. This same distribution was utilized in a choice model that estimated the percentage of truck trips willing to use the priced lanes at a given toll rate. Travel time savings for trucks on the existing facility were estimated at \$2 million based on the newly available capacity that the toll lanes provided, even without access to them. Granting trucks access to the variably-priced toll lanes would increase that benefit to \$3 million, given a disproportional amount of benefit going towards high-value trucks, especially with higher toll rates.

### **3.3.6 Impacts summary**

The above cases provide an overview of experiences that trucks have had in conjunction with congestion pricing schemes, each one differing slightly. Singapore had little specific data, but showed that while exempted from the scheme, trucks filled much of the road space made available from reduced auto travel. London saw benefits to trucks, and the traffic patterns illustrated that even while the number of trucks and vans in the toll zone dropped the percentage

of these vehicles as a fraction of total traffic increased. These empirical results substantiate prior theoretical claims. Despite these benefits, which suggest new efficiencies emerging in freight transport, the Freight Transport Association in London is working as a strong opponent to charging trucks as part of the congestion pricing scheme.

Finally, the variable tolls in New York City, highway tolls in Switzerland and Austria, and theoretical application in Southern California provide more evidence that tolling trucks for externalities leads to equitable and efficient trucking. In New York City, the carriers interviewed said that the tolls do not dissuade them from making trips because the reductions in trip times were more important than the fees. However, the distance-based tolls in Switzerland have led to efficiencies and reductions in long-distance travel, and are being implemented across several European countries. Finally, the theoretical work on the SR-61 in Southern California shows that adding variably-priced highway lanes benefits trucks because of the additional supply and diversion of auto traffic; these benefits would increase if trucks were allowed access onto such lanes.

Given the shortfalls in planning efforts for freight reviewed in Chapter 2 and the recent interest in congestion pricing seen in Chapter 3, we design an outline and provide tools to measure the impacts of congestion pricing on trucks. We present this original material next in Chapter 4.

## Chapter 4

### Congestion pricing impacts on freight

The prior chapters showed that planners increasingly recognize the importance of goods movement in the economy and are devoting more resources to understanding them. In the meantime, congestion pricing continues to gain interest as a policy tool because most major metropolitan areas, plagued by heavy congestion and declining budgets, recognize a need for a policy change. The author is unaware of a comprehensive set of factors and tools for considering urban congestion pricing policies and their affects on freight movements with respect to economic and environmental impacts. This chapter intends to remedy this gap.

In fact, few studies have measured the impacts of transportation policies on freight in general. According to Kawamura and Seetharaman (2005),

It is recognized by the MPOs that freight planning should be incorporated at the comprehensive plan level and that piecemeal planning may not be the way to do this. This is supported by the fact that all the long-range plans reviewed at least refer to goods movement in the objective statements. However, in reality, there is no evidence that recommended performance measures for the freight oriented objectives were used to prioritize projects... Even if adequate performance measures existed, as was the case in the East-West Gateway, they were not applied, probably because of technical reasons such as lack of data and forecasting models. If freight projects are to be given a serious consideration for funding, their benefits must be quantified so that they are comparable against other projects.

Given the recent interest in congestion pricing in several urban areas, its effectiveness for mitigating transport externalities and the importance of freight on economic growth, the timeliness of this analysis is appropriate. As noted in Chapter 1, a sense of momentum related to

congestion pricing exists now that London has demonstrated that the policy can be both feasible and effective in a Western democracy. However, since congestion pricing is politically difficult, providing tools to policymakers for evaluating impacts on specific stakeholder groups can help them identify critical data needs and estimate impacts. In this research, we are interested in determining the ways urban truck traffic may respond to a pricing scheme and the economic and environmental implications of this response.

We provide tools to analyze congestion pricing from the freight perspective to fill a crucial gap in transport planning. Congestion pricing is a unique application for studying impacts because social costs are incorporated into the policy, so theoretically externalities such as emissions, noise or congestion are internalized. Since social costs have been quantified before, we present tools to determine whether shipper and carrier benefits outweigh the new fees. Although empirical evidence indicates that this is true in other applications, we do not attempt to generalize those trends. Instead, we hope to explain which variables determine whether congestion pricing is favorable for trucks and provide tools to policymakers for evaluating freight in conjunction with a congestion pricing scheme in their region.

After we review the scope of freight transport and related stakeholders in 4.1, we analyze the congestion pricing in conjunction with freight. Section 4.2 guides the reader through the freight perspective on implementation decisions, such as choosing a type of scheme and correctly determining the toll level. Section 4.3 enhances existing studies, which quantify the impacts of urban freight, by considering the impacts on freight stakeholders. We elaborate on the ways which transportation policies, such as congestion pricing, may affect freight movements.

## **4.1 Scope of freight transport**

This section first reviews the urban truck trip as part of the freight process. Next, freight stakeholders are categorized into three groups: shipper, carrier, and public-sector (including urban residents, auto drivers, and public agencies).

### **4.1.1 Freight process**

Freight movements are more complex than their passenger counterparts, involving multiple decision makers and several transport movements within a larger supply chain process. Whether shipments are raw materials or final products, inventory levels at the receiving end dictate the frequency and size of orders. For the shipper, the complete logistics process includes more than the cost of goods delivery, but also costs related to warehouse or in-transit inventory, stock-outs due to demand or transport variability, ordering and administration, and insurance on the

shipment. We assume that ordering, administration and insurance costs cannot be avoided (and are outside our scope), but that delivery and inventory costs depend on the level-of-service in the transportation network.

The urban transport component is also only one part of the larger supply chain, which may include several transport segments on many modes, as products are altered from raw materials to consumer goods across several stages in a production process. Logistics or supply chain managers typically aim to minimize total costs, which is not always consistent with minimizing transport costs. Minimizing total cost may involve choosing a more expensive, reliable transport mode that capitalizes on inventory reductions from efficiency gains or service improvements in transport. Urban transportation improvements from public policy changes may have more benefits than just delivery time savings.

#### 4.1.2 Stakeholder grouping

In Chapter 2, we enumerated the participants in the urban goods movement process to provide insight into the types of challenges that arise among them because of conflicting interests. These stakeholders include shippers; receivers; forwarders; trucking firms (including service delivery companies); truck drivers; terminal operators and firms in other transport modes; urban residents and passenger travelers; road and traffic authorities; and government. Refer to Table 1 for a description of individual stakeholders and their objectives. These stakeholders are now re-categorized into three summary groups: shippers, carriers and public sector, shown in Table 8.

**Table 8 Stakeholder groups**

Stakeholder groups	Members	Group description
Shippers	Shippers	Origin and destination entities responsible for coordinating transport in conjunction with total supply-chain process
	Receivers	
	Terminal operators	
Carriers	Forwarders	Agents of transportation services
	Trucking firms	
Public sector	Urban residents and passenger travelers	Entity responsible for allocating public resources, managing roadways, and regulating to ensure that public interests are preserved
	Road and traffic authority	
	Government / society	

Shippers now comprise all origin or destination entities that produce, process, or sell the goods being transported. They aim to minimize total costs which include inventory,

transportation, etc. For example, shippers may choose a more expensive, reliable transport service if it allows them to reduce total costs by holding less inventory. Because of their 'total cost' perspective, they (1) understand the trade-offs between price and service and (2) are sensitive to reliability and its implications on warehousing and stock-out costs.

Therefore, shippers may be willing to pay a higher price for superior service. The classic example of this trade-off is among modes (such as choosing air over truck or truck over rail for improved service); however, in urban areas all deliveries are made by truck and no modal choices exist (although choices between carriers do exist). Congestion pricing gives shippers the option to pay a fee for better service during the peak period. Since few implementations of congestion pricing exist, this option is traditionally not available to shippers, but would provide a practical alternative for them. Shippers would benefit from having the choice of paying more for improved service during peak hours, especially if they ship high-value or time-sensitive goods, in which the benefits seen in inventory reductions may outweigh increased costs of shipping.

Carriers are the firms that provide transport service. Sometimes shippers have privately-owned trucks as well, but these vehicles behave like carriers and have similar profit-maximization goals as an external (or for-hire) service. In addition to large freight forwarding or trucking firms, many owner-operator trucks also exist in the carrier market, making it extremely competitive. Heavy competition means that margins are tight and the prices charged by any single carrier are close to their actual costs. Carriers improve their profits by increasing productivity wherever possible, but typically fear that any new cost will cut into their (already) low margins. Unless new costs are readily absorbed by the shipper, carriers are reluctant to accept them and will often go out of their way to avoid them.

These patterns are visible with the pricing schemes in London and New York based on the way that carriers interact with shippers. In London, carriers are fearful of passing costs on to shippers because they want to maintain a competitive edge; yet at the same time they have trouble absorbing the new costs because their margins are already low. They have reacted negatively to the tolls because, in this case, costs are absorbed internally: only 37 percent passed the costs on to their customers (FTA 2004d). For the remaining 63 percent, the costs may have reduced their profits. Note that improved travel time could allow for additional deliveries each day and this increased productivity may compensate for the increased costs, but most carriers say that the time savings within the zone are too small of a fraction of their total daily travel time to allow for an additional trip, or any large (or offsetting) productivity gain.

On the other hand, in New York, where carrier prices are negotiated independent of tolls (and tolls are charged ex post facto), carriers have a sense of security with their profit levels and are

not too concerned about the facility tolling schemes (BBSA 2004). In fact, in cases where a carrier makes multiple deliveries in one truck, they will charge each shipper the entire toll value, effectively exploiting higher tolls to increase their profits. While they do not feel that the tolls are high enough to induce routing changes, they welcome increasing the tolls enough to divert other trips. The carriers recognize that less congestion associated with higher tolls would make their delivery schedule more reliable.

The final stakeholder group, referred to as the public sector, comprises the citizens, transport agencies, and government (representing the interests of society at large). The public sector balances the goals of each member: aiming to ensure economic development and fiscal accountability in the transport agency, while mitigating impacts on the urban environment and citizens. Additionally, passenger autos—not a primary focus of this research—are included in the public sector group. Until recently, policymakers rarely considered impacts on urban freight because of both data deficiencies and the complexity of the logistics process. In addition to little understanding of the impacts of policy on trucks, the public sector must overcome the fact that truck impacts on urban residents are poorly understood as well. For example, accident, air quality and noise impacts are difficult to quantify, but in principal should add to the toll value charged to trucks in a congestion pricing scheme. Since the level of toll paid by trucks in a pricing scheme will change their responses, and ultimately the impacts felt by the trucking industry, understanding all of these relationships and having the tools to quantify them is important to public sector agencies which write policy. An outline which guides truck-related implementation decisions for congestion pricing and analyzes the impacts, presented in the rest of this chapter, is intended for the planner who seeks to balance the multifaceted goal above by considering the contribution and role of each stakeholder group.

## **4.2 Implementation decisions and predecessors to impact analysis**

Before quantifying and evaluating the impacts of a congestion pricing scheme on urban trucks, several characteristics of the scheme must be defined. We address the following implementation questions:

- What type of congestion-pricing scheme is proposed?
- At what level will the toll be set?
- How does the toll vary?

We anticipate that policy or decision makers are aware of these implementation decisions, but don't necessarily expect that they have considered them in the context of urban truck movements.

Additionally, these decisions affect the impacts of congestion pricing on urban trucking; we discuss each of them below. Perhaps the largest variable affecting the impacts on freight, though, is the magnitude of the following consideration:

- What are the demand predictions for passenger and freight transport in various congestion pricing scenarios?

We discuss each of these topics in the remainder of this section, concluding with general recommendations. The type of scheme chosen affects impacts quantified in the next section.

#### **4.2.1 Types of congestion pricing schemes**

We recognize that several additional categories of general toll roads or schemes exist, but deliberately narrow our focus to three existing types. They are:

- Area-based pricing schemes (London or Singapore);
- Point or facility pricing (New York's variable tolls on bridges and tunnels); and
- Corridor pricing (on highways, such as the Southern Californian SR-61).

Various schemes and the extent their geographic scope will determine toll values, and cumulatively affect the impacts experienced by urban goods movement. Several variables contribute to the type of scheme chosen, which goes beyond the extent of this thesis. See Ensor (2005) for a comprehensive summary of the types of tolling systems, as well as a software tool available to planners and policymakers to screen multiple toll options or evaluate which single option is most appropriate for a specific metropolitan area.<sup>18</sup> Ensor's evaluation tool uses multi-criteria analysis that is goal-based, site-specific, and considers both passenger and freight movements; it is a valuable resource for decision-makers interested in choosing and planning toll schemes in their area. Here we assume that readers are already familiar with a specific type of congestion pricing scheme for their region.

#### **4.2.2 Toll level**

In theory, toll fees in a congestion pricing scheme are set equal to the marginal subsidy to capture external costs. The *marginal subsidy* reflects (1) the change in costs to the public sector with incremental increases in system use (*marginal costs*) minus (2) the incremental fees paid by

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<sup>18</sup> Ensor's multi-criteria analysis tool evaluates how well alternatives meet criteria for road pricing and subsequently provides order-of-magnitude rankings for each alternative, serving as a sketch-planning or screening tool. However, where more detailed estimates or regionally-specific information is available, these values can substitute original criteria to allow for more robust rankings among alternatives.



motorists with increases in system use (*marginal user fees*). As such, the level of marginal subsidy is proportional to the inefficiencies in the system. The marginal social costs included in the subsidy calculation—infrastructure, congestion, accident costs, air pollution, energy consumption, and noise—are compared with marginal user fees as shown in Table 9.

**Table 9 Marginal subsidy computation**

Marginal social costs	
	Infrastructure
	External accident
	Congestion
	Emissions
	Petroleum consumption
+	Noise
-	Marginal user fees
=	<b>Marginal subsidy</b>

TRB (1996) give methods, look-up tables, and equations for calculating each component of the marginal subsidy. In the meantime, we isolate variables needed in the marginal subsidy calculation, shown in Table 10. These variables determine the level of tolling, which in turn is a major component of evaluating the impacts of congestion pricing on urban trucks. The outcome of a congestion pricing policy moves toward equilibrium over time because of the cyclical dependencies in some of these variables; we address this subject in more detail in a later section.

**Table 10 Needed variables for marginal subsidy calculations**

Variable	Infrastructure	Congestion	Accidents	Emissions	Petroleum consumption	Noise	User fees
Truck volume	X	X	X		X	X	
Time of day		X					
Facility type		X					
Trip distance					X	X	X
Vehicle characteristics	X	X		X			
ESALs	x						
PCEs		x					
Age of vehicle				x			
Driving characteristics				X			
Drive cycle				x			
Speed				x			

Here we describe the needed variables for the marginal subsidy calculations in Table 10. Most of the externalities depend on existing truck volume, meaning that the impact of one additional truck is dependent on the current number of trucks on the roadway (assuming a linear or piece-wise linear relationship exists among the variables). Marginal congestion costs are the most complex, as they are dependent on truck volume, time of day, facility type, and truck vehicle characteristics. On the other hand, accident externalities require only one variable for computation (given the corresponding equations and look-up tables found in TRB 1996). Three externalities consider vehicle characteristics, although each one depends on a unique variable: infrastructure depends on the estimated single-axle load (ESAL) factor of trucks; congestion depends on the passenger car equivalent (PCE) value of trucks; and emissions depend on the age of trucks (as a proxy for engine and exhaust output). Emissions externalities also rely on two driving characteristics: (1) drive cycle (including acceleration, deceleration, and start/stop frequency) and (2) speed.

As noted in Chapter 3, this TRB report also performed case study analyses for several freight trips, including an urban delivery truck. Each case compared the marginal subsidy value with the

total price that shippers pay to deliver the specific goods. In the urban delivery truck scenario, as noted in Chapter 3, the marginal subsidy equaled about seven percent of the shipping price. Given an average shipper price of \$2.62 per vehicle-mile for urban delivery,<sup>19</sup> we estimate the average subsidy at about \$0.18 per vehicle-mile. Now, assuming that the average urban truck trip is 46 miles (see Section 2.1.2), we estimate an approximate urban toll at \$8.00. Given equivalent toll values (in pounds sterling) today in London, this figure seems reasonable to us.

### **4.2.3 Toll variation and technology choice**

Variable pricing to spread peak period usage is a concept familiar to many people. Movies, utility companies and airlines all vary their prices to entice people to use their service when excess capacity is available. Charging road users different prices throughout the day to encourage them to use the facility in the off-peak is an effective way to manage demand. Also, since externalities vary throughout the day, tolls would vary as well. In theory, the toll level responds to externalities associated with each trip, which changes with the traffic level throughout the day.

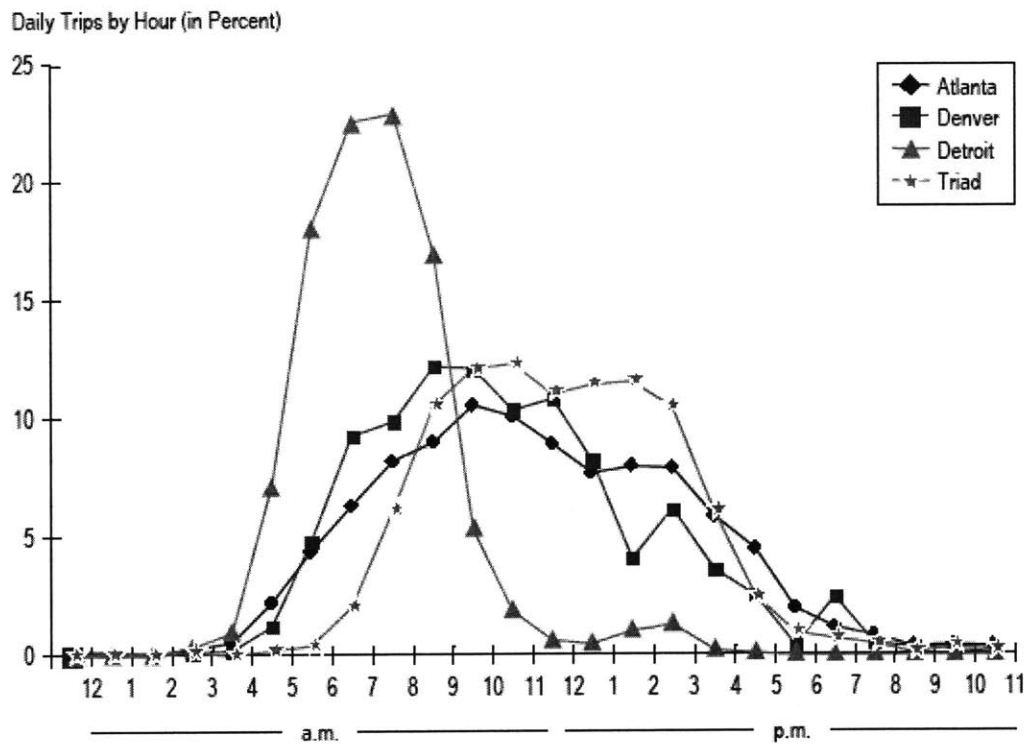
The implementation decision determining the level of toll variation is actually masked behind the type of technology adopted for the scheme. The adoption of electronic pricing systems allows the most flexibility in variable charging. The area-based scheme in Singapore, point-based scheme in New York, and corridor scheme in Southern California all utilize such systems and have variable toll prices throughout the day. The systems in California and Singapore are the most flexible, changing the toll level in half-hour increments during the peak period. New York, on the other hand, has three time periods over which tolls vary. In the case of London, video cameras and manual payment methods substitute for the use of entirely electronic systems; yet they are still able to differentiate between day-time congested periods and off-peak nights and weekends. New York, London, and Singapore, despite periods of toll variation throughout the day, all set prices based on the day of the week (weekday versus weekend); whereas in the California scheme, the prices vary throughout the day, and differ from day to day depending on the levels of traffic. Any toll scheme that varies across at least two time periods attempts to capture externalities in each time period; toll variation (during the day or from one day to the next) is a defining feature of congestion pricing schemes. The technology chosen for a local

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<sup>19</sup> TRB 1996, p. 164. The original 'average shipper price' for urban delivery was \$2.23 per vehicle-mile. We adjusted this value to correct for inflation from 1996 to 2004 using the Consumer Price Index Inflation Calculator at <http://www1.jsc.nasa.gov/bu2/inflateCPI.html> [Accessed last 17 April 2005].

congestion pricing scheme dictates the flexibility and number of toll periods offered in a day or over a week.

Theoretically, efficiencies are promoted by internalizing externalities through variable tolls which reflect the true costs of driving throughout the day and during the week. For example, time of day variation is important because many urban deliveries travel during the mid-day period, as seen in Figure 3. These mid-day truck trips likely impose fewer congestion and delay costs on other motorists as trucks that travel during the peak. Toll variation can differentiate these costs and charge users appropriate fees.



Source: Reprinted from Cambridge Systematics 2003, p. 4-13

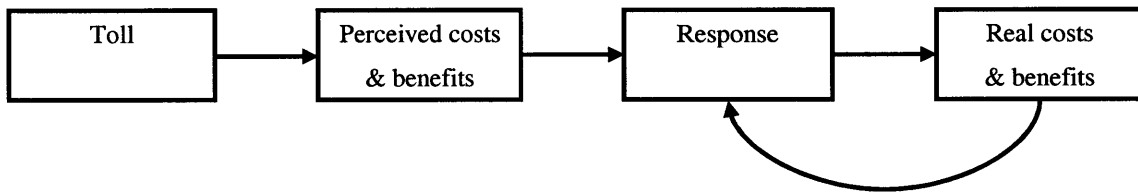
**Figure 3 Percent of daily commercial vehicle trips by hour (no congestion pricing)**

Urban freight would benefit from the flexibility provided by electronic road pricing systems. First, with the reduction in morning congestion, some freight trips with high-value goods or high customer reliability expectations might be inclined to divert to the morning peak period because the benefits of quicker travel times and increased reliability may outweigh the cost of the toll. Second, a system of tolls that charges one price throughout the day is likely to overprice vehicle flows that occur during the midday hours, when traffic flows and concomitant marginal social costs are slightly less than during the peak period. Since the bulk of urban truck travel occurs

during the midday period, any overpricing that does occur would negatively affect urban truck transport.

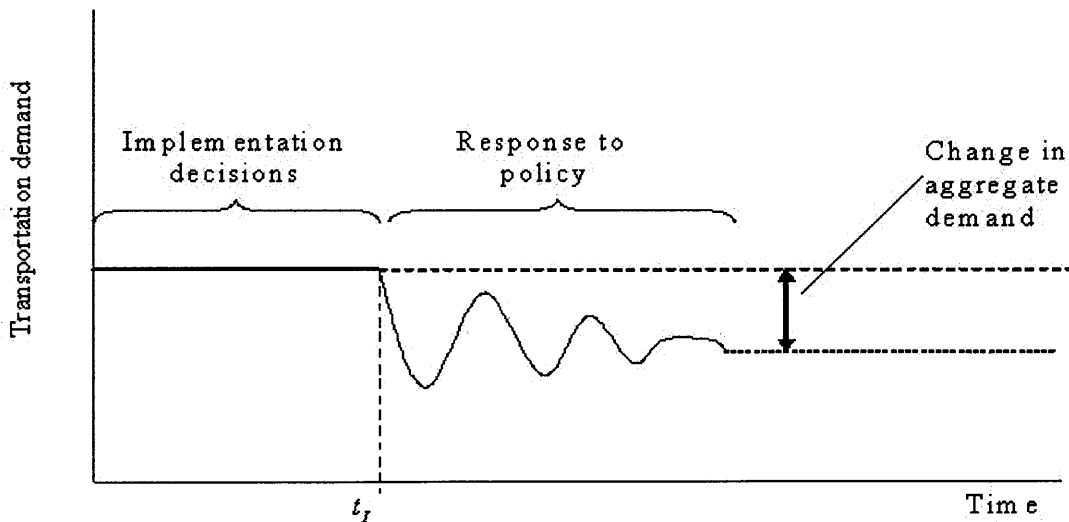
#### 4.2.4 General demand response and equilibrium

Passenger and freight demand response is the final predecessor to analyzing the impacts from congestion pricing on urban trucks. When congestion pricing is implemented (according to implementation decisions described above), a demand response occurs as passenger and freight travel modify existing travel patterns. This process is iterative, as shown in Figure 4.



**Figure 4 Iterative changes in travel demand**

Once the toll is implemented at time  $t_i$ , the perceived costs and benefits of the new policy will dictate travel patterns, leading to a response. However, after actually experiencing the system, users will continue to modify their travel patterns based on the real costs and benefits incurred. Motorists will iterate between the last two stages until a new equilibrium has been reached. This process is illustrated in Figure 5.



**Figure 5 Congestion pricing demand response and new equilibrium**

Responses from the passenger and freight groups will likely be different from one another because of the specific options available to them for diversion and the value that each type of motorist places on improved travel time and reliability. Both autos and trucks can cancel their trip or divert their schedule or route; yet, passenger trips have modal choice options for diversion as well. The extent to which this occurs for unique transport groups is captured in the *price elasticity* of their trip. In each case though, the price elasticity and therefore the magnitude of the responses are dependent on the implementation choices which determine type and scope of the scheme, respective toll levels, and the flexibility in toll variation over the day or week.

Note that we only consider policies that toll both passenger and truck trips jointly (ideally at toll levels which correspond to their respective marginal costs) because charging just one group of motorists would create an imbalance of subsidies. We enumerate possible freight responses in the next section (Section 4.3) where we discuss impacts on urban freight.

#### **4.2.5 Implementation recommendations**

Here, we provide recommendations to policymakers who may be considering pricing and is attentive towards freight stakeholders. First, we discuss revenue allocation noted in Chapter 3. Then, we give recommendations about implementation decisions for the type of scheme, toll values, and level of toll variation which we discussed earlier in this section.

##### ***Revenue allocation***

Revenue allocation affects political feasibility and is a critical component of implementation. Note from Chapter 3 that the difference between the vehicle fees and the expected operating costs of the scheme determine the level of revenues to the operating agency. Also, citizens are more receptive to a new toll or tax when they are certain of where the revenues will be allocated and believe that it is a worthy cause (Gomez-Ibanez 1992, pp. 359-60)

We suggest that while making implementation decisions, policymakers consider dedicating revenues to additional transportation improvements. This applies specifically to freight as well; toll revenues from truck fees should be returned to the freight community. For example, decision makers may spend the revenue improving design geometries, urban loading zones, or major freight or port access areas. This is especially applicable because investment in freight improvements can led to regional economic benefits (Kawamura, 2003b).

### ***Type of scheme***

We now turn to the implementation choices presented in earlier in this section; first, we discuss the type of congestion pricing scheme to be implemented. Above, we direct readers to Ensor's multi-criteria analysis tool for choosing an optimal toll option based on regional characteristics. However, we believe that transportation services are under-priced in general and that schemes which are comprehensive in geographic scope will affect more motorists. Since congestion pricing forces motorists to internalize the costs of their trips, we believe that a more comprehensive scheme theoretically leads to larger-scale, long-run economic and social improvements to an urban area. Throughout the rest of this chapter, we implicitly assume that a comprehensive London-type model or area-based pricing scheme is considered.

### ***Toll level***

We agree with economists and believe that toll value for each trip should be equivalent to its marginal subsidy. The subsidy value from the case study in TRB (1996) was equal to about seven percent of shipping costs per vehicle-mile for urban delivery. This suggests that an average toll value for trucks may be about \$8.00, according to our approximations. More-detailed analysis would be needed to determine actual values in a specific case.

### ***Toll variation (and technology choice)***

Urban freight would benefit from variable electronic pricing because of (1) the ease of use, and (2) alternate systems charging identical prices throughout the day are likely to over-charge mid-day truck trips. We emphasize the benefits of electronic pricing in cities or through areas that have a high percentage of truck flows (above seven to nine percent of total traffic). We urge policymakers to consider the impacts of charging identical fees during the peak and midday periods due to the adverse impacts that trucks may incur; we recommend implementing electronic pricing with flexible toll variation.

## **4.3 Impacts on urban freight**

Given these implementation recommendations, here we illustrate the impacts of congestion pricing on urban freight to identify important costs and benefits which we discuss in this section.

Assume that you are a fleet owner with 25 trucks which deliver office goods to central business district (CBD) locations. You pay your drivers \$16 per hour<sup>20</sup> each, although total labor costs including benefits run closer to \$20 per hour. Of your 25 trucks, you pay an average of 5 hours of overtime each day (at a wage of nearly \$25 per hour, and costing you about \$30 per hour total), more than half of which is a result of congestion-related delivery delays, or unreliability in the transportation system.

Next Monday is going to be the first day of a new congestion pricing scheme, similar to the London-scheme, covering several square miles of the downtown CBD area. The electronic implementation was completed on time and all 25 trucks in your fleet are outfitted with new electronic transponders, which were just installed. Your typical delivery schedule includes three trip chains starting from your distribution facility just outside of the urban area: the first with only one delivery, and the next two with 4 deliveries each. Table 11 shows your delivery schedule including driving and delivery times with and without congestion pricing.

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<sup>20</sup> The Bureau of Labor and Statistics (BLS 2004) reported the “median hourly earnings of heavy truck and tractor-trailer drivers [at] \$15.97 in 2002. The middle 50 percent earned between \$12.51 and \$20.01 an hour.”



**Table 11 Hypothetical delivery schedule with and without congestion pricing**

	Activity	Typical schedule: without congestion pricing		Monday schedule: with congestion pricing	
		Activity time (min)	Total time	New activity time (min)	New total time
1 <sup>st</sup> Trip chain	Drive downtown	45	2 hr	<b>40</b>	<i>1 hr 50 min</i>
	Make delivery	30		30	
	Return to distribution center	45		<b>40</b>	
2 <sup>nd</sup> Trip chain	Drive downtown	45	5 hr	<b>40</b>	<i>4 hr 25 min</i>
	Make 1 <sup>st</sup> delivery	15		15	
	Drive to 2 <sup>nd</sup> customer	10		<b>5</b>	
	Make 2 <sup>nd</sup> delivery	15		15	
	Drive to 3 <sup>rd</sup> customer	10		<b>5</b>	
	Make 3 <sup>rd</sup> delivery	15		15	
	Drive to 4 <sup>th</sup> customer	10		<b>5</b>	
	Make 4 <sup>th</sup> delivery	15		15	
	Return to distribution center	45		<b>40</b>	
3 <sup>rd</sup> Trip chain	Drive downtown	45	8 hr	<b>40</b>	<i>7 hr</i>
	Make 1 <sup>st</sup> delivery	15		15	
	Drive to 2 <sup>nd</sup> customer	10		<b>5</b>	
	Make 2 <sup>nd</sup> delivery	15		15	
	Drive to 3 <sup>rd</sup> customer	10		<b>5</b>	
	Make 3 <sup>rd</sup> delivery	15		15	
	Drive to 4 <sup>th</sup> customer	10		<b>5</b>	
	Make 4 <sup>th</sup> delivery	15		15	
	Return to distribution center	45		<b>40</b>	

On Monday, with the congestion pricing scheme in place, CBD speeds doubled and travel times were cut in half, taking time off of your inbound and return trips, and shortening the travel

time to deliver within the zone. An average day of deliveries was reduced by an hour. Additionally, after several weeks you note that the average daily hours of overtime paid out declined from five to two because of improved reliability.

You compute the benefits and costs to your firm, as follows. From the outset, you save one hour on each delivery day and pay \$20 per hour less in wages across the fleet or \$500 per day. The hours spent in congestion dropped from five to two; overtime wages paid out daily declined from \$150 to \$60 per day, saving you an additional \$90 and bringing your total savings to \$590. Assuming that each trip into the pricing zone costs you \$8, and each of your 25 trucks makes three trips per day downtown, your costs are approximately \$600. Since you have a long-standing relationship and exclusive contract with the office-good company, it has agreed to absorb the cost of the tolls, given that you pass on the cost savings from the reduced travel time. As shown from these basic calculations, each firm basically breaks even.

In the meantime, though, benefits to each firm far exceed those computed above. First, for you, benefits surpass the wage savings computed because you have been able to eliminate three vehicles from your fleet (reducing capital costs, insurance, and maintenance). The rest of your fleet has experienced a slight decline in fuel costs because traffic flows into the city are more stable than before. The office supply company has also experienced additional benefits because their total inventory costs were reduced from (1) the decline in in-transit inventory associated with the 25-hour decrease in travel time, and (2) the reduction in safety-stock associated with the reduced probability of stocking out downtown. The level of safety-stock inventory<sup>21</sup> needed is analogous to the overtime fees which you pay for unpredictable congestion delays; however, this cost may be much higher for shippers than for carriers depending on the value and arrival sensitivity of the goods shipped. Now the office supply company is considering making internal changes as a response to the improved services, such as alternating some of its existing daytime shipments to off peak hours and providing more frequent, smaller shipments to its highest land-value locations to reduce the costs of storing inventory on site.

From this illustration, we see that there are several costs and benefits to both shippers and carriers. As each of these changes take place, they are reflected in the total travel demand on the roadway; however, understanding the components which dictate these changes can produce more reliable demand estimates and help planners evaluate political feasibility.

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<sup>21</sup> We recognize that there are many uncertainties which contribute to the total level of safety-stock inventory, such as the variability in production, travel time, and demand. For more information, see Park (2005). Here, we only account for travel time variability when we refer to safety stock.

The direct costs and benefits, along with possible second and third order impacts (extending from the travel improvements and including responses such as making more frequent, smaller shipments) are outlined in the rest of the section. In the previous sections we reviewed stakeholders and congestion pricing implementation decisions in the context of urban goods movement. Now we evaluate the impacts of a pricing policy on freight transport from the perspectives of each stakeholder. First, in section 4.3.1 we comment on the state of the research in measuring freight impacts. Next, in section 4.3.2, we discuss the ways in which urban goods movements may respond to a congestion pricing policy. Finally, in section 4.3.3, we outline measures to quantify impacts according to the three proposed stakeholder groups—shippers, carriers, and the public sector.

#### **4.3.1 Background on measuring impacts**

As noted in Chapter 2, few efforts to address the impacts of freight exist at the urban level. In this section, we describe the contributions of related studies. Through this review, we distinguish between the state of the research and the contributions of our research which is presented in the following sections.

Kawamura is a leader in measuring the impacts of freight and we review his contributions here. In Chapter 3 we reviewed Kawamura’s study measuring the perceived benefits to trucks from the SR-61 toll lanes in Southern California (1999 and 2003a). In that study, he quantified the benefits of travel time savings on the facility using his empirically-derived value of time distribution for the region. Next, in 2002, Kawamura and Seetharaman proposed five goals that freight analyses should address with corresponding measures to quantify these goals. These are summarized in Table 12. Most recently, Kawamura et al. (2003b) employed this framework of measures to evaluate a corridor improvement project in Chicago.<sup>22</sup>

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<sup>22</sup> Note that emissions, noise, and accident calculations were omitted because of the uncertainties associated with the data.

**Table 12 Goals identified for freight analyses and related performance measures**

Goals that freight analyses should address	Measures to quantify goals	Tools used (where applicable)
Economic efficiency and productivity	Regional economic impact	REMI
Increase safety in the region	Accident reductions	-
Protect the environment	Air pollution Noise	EMFAC/MOBILE
Enhance the efficiency of transportation operation	Travel time savings	-
Minimize transportation system maintenance costs	Pavement damage	NAPCOM

Source: Kawamura and Seetharaman (2003b)

Like Kawamura, we recognize the need for evaluating the effectiveness of transportation projects or policies and their impacts on freight; without such tools, policymakers may continue to overlook the impacts on truck travel. We categorize impacts according to each of the three urban-freight stakeholder groups: shippers, carriers, and the public sector. Where Kawamura focused on the public sector and outlines tools for performing benefit-cost analysis, we focus on explaining the behavior and actions of shippers and carriers. We believe that by explaining the stakeholder responses we (1) provide further understanding to policymakers about the resulting changes in transportation flows; (2) give background necessary for understanding and quantifying additional benefits associated with congestion pricing; (3) strengthen linkages between the public and private sector which can lead to synergies in freight planning. We differentiate our work from previous studies in two ways.

First, we concentrate on evaluating the impacts on freight stakeholders from congestion pricing policies. While we anticipate that the background we provide may be adapted to other policy or project analyses, we present it with a specific focus which responds to the growing interest in urban congestion pricing schemes.

Second, we differentiate from prior studies that focus on measuring the impacts *of* urban freight and present tools to measure the impacts *on* urban freight. We recognize that the impacts *of* urban freight may be the motivators for policy change or project implementation and the continued study of these impacts is critical to the public sector who aims to minimize externalities of increasing truck traffic (and is also an urban freight stakeholder); however, we suggest that the

impacts that these projects or policies have *on* freight is particularly important given the economic value associated with goods movement. We focus on analyzing this one component in greater detail.

We believe that the impacts of transportation policies *on* freight have been overlooked in the past, or quantified with tools more suitable for passenger transport. By measuring impacts according to urban freight stakeholder groups, we provide tools which explain how transportation policies impact multiple decision-makers in the supply-chain or freight process. Future research which utilizes this information in a decision-making framework could greatly improve on the generalized cost<sup>23</sup> calculations generally used since freight is so complex. Next, we identify the ways which urban freight may respond to congestion pricing (or other) policies.

#### **4.3.2 Summary of possible responses to congestion pricing**

As described above, the urban delivery component of goods transport is only one stage of a larger supply chain or logistics process. Within the supply chain, many strategic systems and operational choices influence the final delivery of goods in an urban setting and are listed in Table 13. We choose this set of transport choices because their logistics focus is more appropriate for understanding and evaluating freight choices than adopting a passenger framework which only looks at trip characteristics. Based on assumptions about the choices available in urban goods movement, we can anticipate possible freight responses to new transport policies which will allow us to effectively outline ways to measure the impacts.

Table 13 gives eight available freight choices with corresponding descriptions and a summary of contributing variables. The noted dependent variables will affect the choice decision, but because the table represents a hierarchy, all prior decisions will also play a role in the current choice at hand. For example, supply chain decisions to collaborate with suppliers or other strategic partners will influence where the company will locate distribution facilities or what operational strategies are appropriate.

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<sup>23</sup> Generalized cost, as noted in Chapter 3, is the sum of total travel cost plus travel time, where travel time is translated to a dollar value using a value of time average or distribution. This value does not account for reliability or customer service costs that are imperative to truck trips which must deliver within a specific time window.

**Table 13 Hierarchy of response alternatives to policy change**

Choice	Description	Contributing variables
Collaboration	Cooperation and possibly transfer of responsibility between supply chain components	Product characteristics, Cost structure and relationship between entities, current utilization of assets, competitive pressures
Distributional location	Location from which goods are distributed within the urban region	Customer location, total transport volume
Mode	Method by which goods will arrive in urban region	Level-of-service characteristics such as cost, speed, and reliability
Distribution network	Joint efforts at optimization over the following operational decisions	Resources for optimal scheduling or capacity planning
Fleet and vehicle ownership	Owning, leasing, or outsourcing	Shipment characteristics, the ability to track the shipment
Volume and frequency	A simultaneous decision assuming constant derived demand: many, small vs. few, large shipments	Cost, customer service and level of flexibility needed
Scheduling and timing	When and where to ship	Cost, customer service
Routing	Choice of path based on optimization criteria: shortest path, minimum distance, familiarity	Congestion, network restrictions, availability of traffic information; goals of firm: environmental policy, supplier relations, trip purpose

Source: Information adapted from RAND Europe et al. 2003.

Based on assumptions about the choices available for urban goods movement, we can anticipate possible freight responses to new transport policies (which will allow us to effectively outline metrics to quantify impacts). The first three choices—deciding whether or not to collaborate with other firms, determining a location for distribution facilities, and choosing a mode for long-haul shipments—are long-term, systems decisions. Since we are interested in urban trips, we exclude systems-level choices in our research. Given these system-level choices, firms consider operational decisions. Next, the “distribution network” choice represents a joint

optimization over fleet procurement, delivery frequency and scheduling. However, individual operational choices occur depending on customer needs or network influences. These decisions and the corresponding magnitude of impacts are shown in Table 14.

**Table 14 Characteristics of choices available to freight**

Horizon	Choice	Response time	Consider impacts
Strategic	Collaboration	Long-term	Assume none (long-term)
	Distributional location	Long-term	
	Mode	Long-term	
Operational	Distribution network	Medium-term	3 <sup>rd</sup> order impact
	Fleet and vehicle ownership	Medium-term	
	Volume and frequency	Medium/short-term	2 <sup>nd</sup> order impact
	Scheduling and timing	Short-term	Immediate, or 1 <sup>st</sup> order impact
	Routing	Short-term	

Table 14 also gives insight into the level of impact that each choice can have on urban goods movement. Since carriers deliver goods and respond to customer requirements, they make most routing decisions. Given implementation of a new congestion pricing policy, route choices will influence the travel cost and travel time. Additionally, because of the imperfect allocation of congestion pricing fees to shippers, carriers also have some influence over the scheduling and timing of deliveries.

Shippers may change their travel patterns if they have the opportunity to minimize total logistics costs. However, if carriers never pass on the new monetary cost of travel to shippers (or when carrier rates do not reflect the true cost of travel) then the shipper may have no incentive to modify their behavior. Once fees are passed on though, then shippers determine the value of peak period delivery.

Beyond routing and scheduling changes, second and third order impacts may occur. For example, if the new peak period delivery reduces generalized costs or if inventory costs outweigh an increased generalized cost, then the shipper may decide to change the frequency and volume of shipments, as described in our illustration at the beginning of the section. Since the frequency and size of shipments is only likely to change after time and reliability savings are experienced, this service modification constitutes a second-order impact. A third-order impact would occur if in response to the new shipment sizes, shippers stop maintaining their own fleet and instead begin

to use a less-than-truckload delivery service. We quantify first-order impacts in the next section, yet leave quantification of higher-order impacts to carriers and shippers for future research.

### **4.3.3 Impacts by stakeholder group**

This section considers the possible ways which urban trucks might respond to congestion pricing and then quantifies the costs and benefits of such a policy on urban freight according to stakeholder groups.

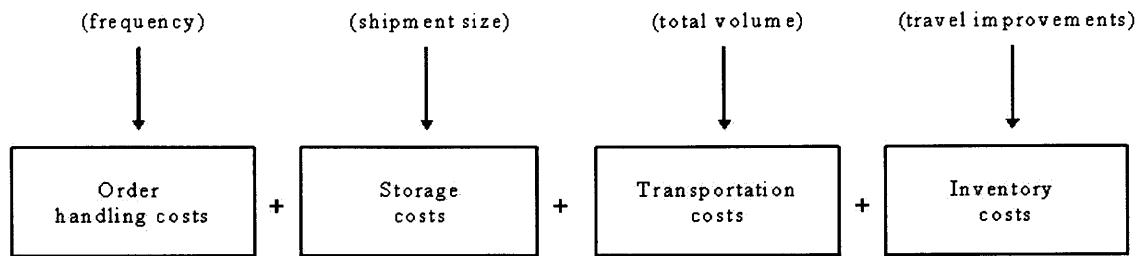
#### ***Shippers***

Shippers have three goals: minimizing total logistics costs, maximizing service to their customers, and maintaining their competitive advantage (Park 1995). Firm competitive advantage is associated with internal long-range decisions, such as collaborating with other firms, determining distribution locations and other strategic decisions that occur within the supply chain, but outside of transportation or logistic decision making. We do not evaluate pricing impacts to shippers in the context of maintaining their competitive advantage. However, we do capture the shippers' costs by quantifying the value of travel time improvements; we capture shippers' service level to their customers by quantifying the benefits of improved reliability, or difference in inventory costs.

We present total logistics costs to shippers below. To determine the impacts to shippers, we quantify costs before and after policy implementation. The impact of congestion pricing to shippers is the difference between the inventory and travel costs (which are the affected components of total logistics cost) before implementation and after the new equilibrium.

Total logistics costs to shippers include order handling, storage, transportation, and inventory costs. These components are shown in Figure 6 with key input variables. For example, the total shipment size will determine the total storage costs at the facility or store. If large shipments are received infrequently, then the space required for storing the product and the risk of product obsolescence increase; however, small (and frequent) shipments will have smaller storage costs. In the case of inventory costs, the travel improvements (including both travel time and reliability) are used to determine in-transit and stock-out inventory costs. Other costs related to the value of time are included in inventory costs.





**Figure 6 Shipper costs: total logistics cost components**

In Table 15 we outline each component of the shipper costs.

**Table 15 Shipper costs per day**

Cost component	Sub-components	Equation	Variables
Order handling		$= C_h * D$	$C_h$ = cost of order handling per delivery
			$D$ = number of deliveries per day
Storage		$= C_s * R_{TL} * D$	$C_s$ = cost of storage per truckload
			$R_{TL}$ = percentage of truckloads per delivery
Transportation		$= C_i * D$	$C_i$ = cost of transportation or equipment and insurance per delivery
Inventory	In-transit	$= C_i * TT * D$	$C_i$ = cost of inventory
			$TT$ = travel time per delivery in minutes
	where	$TT = \frac{TT_c}{(D_c * m_d)}$	$TT_c$ = total travel time per trip chain in minutes
			$D_c$ = number of deliveries per trip chain
			$m_d$ = number of minutes per day
	Time reliability: safety stock	$= C_s * p_s * D$	$C_s$ = cost of stockout
			$p_s$ = Prob (stockout)
Time reliability: early arrivals	$= C_e * p_e * D$	$C_e$ = cost of early arrival	
		$p_e$ = Prob (early arrival)	
Variable travel fees		$= C_f * R_f * D$	$C_f$ = travel fees per delivery
			$R_f$ = percent of travel fees passed on to shipper

Most of the equations and variables above are self-explanatory, but we comment on a few of them here. The cost of transportation,  $C_t$ , is independent of whether the shipper uses private trucks or for-hire carriers. If the carrier uses private shipping, then the cost would include variable and fixed transportation and equipment costs; else, the cost of a for-hire carrier would be a function of the carrier rate, distance traveled, and number of deliveries per day. In each case, transportation costs also include the cost of insurance on each shipment, which is proportional to the value of the shipped goods. Note that the travel time depends on the total travel time of a delivery trip chain and the number of deliveries in that chain. The most straight-forward case would be an out-and-back trip where the chain would include one delivery and all of the travel time would be allocated proportionally. Next, we include two costs for travel time reliability based on whether the variability of shipment arrival times exceed the acceptable delivery times. For a shipper, costs for early delivery are  $(C_e * p_e)$ ; the costs associated with a stock-out or late delivery are  $(C_s * p_s)$ . Lastly, we quantify  $TT_c$  in Table 16 below.

To determine the impacts from a congestion pricing policy on shippers, total logistics costs would be calculated prior to the policy implementation and then after the new demand equilibrium occurred. The first-order impacts are based on changes in the following inventory cost components travel time (in-transit costs), reliability (safety stock and early arrival), and fees (variable travel fees). Each of these variables contributes to inventory cost, so the difference between the before and after costs can be derived using only the final cost component, inventory costs. The impact on shippers (measured in dollars per day) is

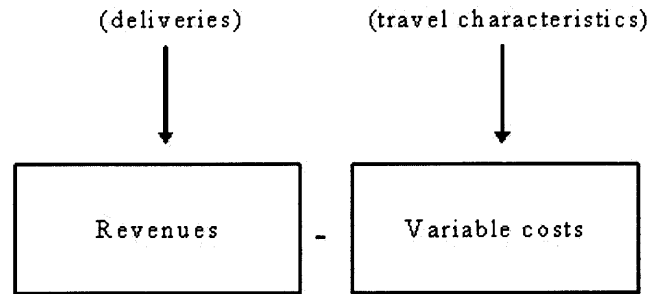
$$\Delta COST^{shipper} = D(C_i * (\Delta TT + C_s * \Delta p_s) + C_e * \Delta p_e + \Delta C_f * R_f)$$

where

$\Delta$  = change in the respective variables (before minus after) from the congestion pricing policy implementation. Note that where costs decline, the shipper benefits, and on the contrary, where costs increase, the shipper experiences a disbenefit of proportional value.

### ***Carriers***

A carrier's main goal is to maximize profits, which is usually achieved through maximizing productivity and providing a level of service that attracts customers. Since they are in a competitive and hence low-margin business, carriers are sensitive to cost increases. We determine here if the benefits of congestion pricing outweigh the new costs. Carrier profits are based on two components, shown in Figure 7.



**Figure 7 Carrier profit components**

We assume that all carrier costs, including those related to administration, equipment, etcetera can be converted to or allocated as variable costs based on the travel characteristics (where capital costs depend on distance and travel costs depend on travel time and reliability) experienced by a carrier. Variable costs have many sub-cost components. These, along with the revenue equations, determine total carrier profits and are given in Table 16.

**Table 16 Carrier profits per day**

Components		Equation	Variables
Revenue		$= R_d * D_c * C$	$R_d$ = carrier rate per delivery
			$D_c$ = number of deliveries per trip chain
			$C$ = no. of trip chains per day
Costs	Capital	$= (C_u + C_{vm}) * d + C_o + C_d + C_g$	$C_u$ = fuel costs per mile
			$C_{vm}$ = vehicle maintenance costs per mile
			$d$ = distance (# miles per day)
			$C_o$ = cost of overhead and annual fees per day
			$C_d$ = cost of equipment depreciation per day
			$C_g$ = cost of loss/damage per day
	Travel	$= \left( C_{fc} * (1 - R_f) + \frac{W}{h_d} * \frac{TT_c}{m_d} \right) * D_c * C$  $+ 1.5 * \frac{W}{h_d} * \frac{(TT_d * p_d)}{m_d}$	$C_{fc}$ = travel fees per trip chain
			$R_f$ = percent of travel fees passed on to shipper
			$TT_c$ = total travel time per trip chain (in minutes)
			$W$ = wage of vehicle operator per hour
$m_d$ = # of minutes per day			
$TT_d$ = avg. number of minutes of nonrecurrent delay per day			
$p_d$ = Prob (delay per trip)			
$h_d$ = number of hours per day			
where	$TT_c = \sum_{i=1}^C \left( rt^i + \sum_{j=1}^{D_c} tt_j^i \right)$	$rt^i$ = travel time of return trip for trip chain i	
		$tt_j^i$ = travel time of delivery j in trip chain i	

Again, we comment on some of the equations and variables. Both revenues and costs are given in dollars per day and variable costs are separated into capital and travel costs. We calculate revenues for each delivery made per day, including those that are part of delivery trip chains. The capital costs account for all fuel and maintenance costs that vary by mile and annual cost, such as overhead and damage, which are converted to daily values. Travel costs include the proportion of travel fees per trip that are not passed on to shippers, but instead are absorbed by the carriers. Ideally, all of the travel fees would be passed on to shippers, so that they could make optimal logistics decisions, but since empirical evidence shows that some carriers absorb these costs, we include  $(1-R_f)$ , which equals one minus the percentage of costs absorbed by the shipper or the percentage of costs absorbed by the carrier. Additionally, travel fees depend on the driver wage rate and total travel time (now a function of congestion pricing), where travel time includes all deliveries in a trip chain and the return trip time. The two components of travel cost account for travel time and network or delivery unreliability, respectively. We assume that the travel time costs are correlated with the number of deliveries per day; whereas reliability costs are given in average minutes of nonrecurrent delay per day. The cost of this unreliability is captured by paying time-and-a-half overtime (a factor of 1.5) to the driver. We do not account for any additional ill-will in customer service that this fosters.

To determine the actual impacts from a congestion pricing policy on carriers, we do an analogous computation to that of shippers. Total profits are calculated prior to the policy implementation and then again after the new demand equilibrium has occurred. The major cost differences will be seen in the travel cost component, assuming that only travel time, reliability (measured in minutes of nonrecurrent delay) and fees differ between the two scenarios. The impact on carriers (measured in dollars per day) is

$$\Delta COST_{travel}^{carrier} = \left( \Delta C_{fc} * (1 - R_f) + \frac{W}{h_d} * \frac{\Delta TT_c}{m_d} \right) * D_c * C + 1.5 * \frac{W}{h_d} * \frac{(\Delta TT_d * \Delta p_d)}{m_d}$$

where, as before,

$\Delta$  = change in the respective variable (before minus after) from the congestion pricing policy implementation.

If the carriers total travel time improvements (over an entire fleet) compensate for more hours than the average vehicle is in use per day, then they will also have capital cost reductions. For each vehicle that the carrier can trim from their fleet, the benefits are equivalent to the capital costs (in miles) divided by the number of miles that a typical vehicle travels per day ( $N$ ), or

$$\Delta COST_{capital}^{carrier} = ((C_u + C_{vm}) * d + C_o + C_d + C_g) / N.$$

Therefore, carrier profits are

$$PROFIT^{carrier} = R_d * D_c * C - \Delta COST_{travel}^{carrier} - \Delta COST_{capital}^{carrier} .$$

Finally, we note that where electronic transponders are used for the fleet management aspects of electronic pricing, carriers may capture additional benefits because improved internal operations that capitalize on the technology may lead to further efficiencies. The impact of additional information based on automatic vehicle location and intelligent transportation systems is not included in this analysis, but could be applicable in further research. The above equation gives the impacts to carriers from congestion pricing given site-specific cost data and travel times for a local implementation plan.

Finally, we distinguish between carriers that must access a tolled facility or region and those that may divert (or if their location is in the tolled region or it is not). In the case where the carrier has the option to enter the tolled facility, we can determine the most profitable option by using the respective travel time and fee values for each choice. We anticipate that given the low profit-margins in the trucking business, trucks that don't need to access tolled areas, but have the option, may not; however, if fees are passed on to shippers, high-value goods movements will be treated with priority. Giving the shipper and carrier the option to choose has value in itself.

### ***Public sector***

The goal of the public sector is to balance increasing economic development with external costs to society, while maintaining fiscal accountability. To balance and analyze these interests, three types of public sector analyses are available: financial analysis, regional income analysis, and social benefit-cost analysis. All of these calculations are outside the scope of our work because of the large influence of passenger flows on the results, yet we review each of them below and comment on each from the freight perspective.

First, we review financial or budgetary analysis. These analyses measure the impacts of projects on an agency budget and are therefore important for “insuring that the project does not create cash flow problems or bankrupt the agency” (Gomez-Ibanez 2000). These analyses do not measure social costs and are parochial, or fiscal. In Section 4.2, we noted that the political feasibility is associated with revenue allocation and suggested that freight-related fees collected from the scheme (computed in this type of analysis) should return to the freight community. Here, we provide tools to compute the congestion pricing revenues related to goods movement.

The congestion pricing revenues related to goods movement are:

$$REVENUE_{cong.pricing}^{public} = \left( \sum_{k=1}^T \sum_{l=1}^{CV} (P_l^k * Q_l) \right) - (C_a * R_{CV})$$

where

$P_l^k$  = the price of the toll in time period k for commercial vehicle type l;

$Q_l$  = the total volume of commercial vehicles of type l;

$C_a$  = administration and operating cost of the congestion pricing scheme; and

$R_{CV}$  = the percentage of commercial to total vehicles using the priced region or facility or

$$R_{CV} = \frac{\sum_{l=1}^{CV} Q_l}{Q_a + \sum_{l=1}^{CV} Q_l} ;$$

and

$Q_a$  = the total volume auto trips.

We assume that the percentage of total agency operating and administration costs applicable to commercial vehicles are proportional to their traffic volume (as a percentage of the total vehicles). An inclusive financial analysis would include incoming cash flows and total implementation expenditures across all transport groups.

Second, we comment on regional income analysis. Planners perform this type of analysis in conjunction with major new investments, as a multiplier to estimate the effects of the external infusion or withdrawal of funds in a region. Since congestion pricing does not require major infrastructure investment compared with road expansion projects, we assume that this type of analysis is outside of the scope of our project.<sup>24</sup>

Third, we discuss social benefit-cost analysis. This type of analysis computes the “net increase in goods or services that a project or policy produces for society as a whole” where *social benefits* are any “new goods, services or amenities created for society” and *social costs* are “goods, services, or amenities that society must forego or give up to produce the project” (Gomez-Ibanez 2000). This type of analysis only considers net increase in benefits and costs and does not include *transfers* in the computation, such as taxes or any other externality which is

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<sup>24</sup> For further reference on regional income analysis related to freight transportation project improvements, see Kawamura and Seetharaman’s (2003b) freight impact analysis for a Chicago roadway expansion where they estimated and included regional income effects in total project benefits.



captured in market prices. Since the benefits and costs used in a social benefit-cost analysis are quantified in dollars, this type of analysis is often confused with the prior types of analysis.

In a social benefit-cost analysis, only benefits created or costs foregone from either of the prior two analyses may be included here. From the perspective of an economist, in this type of analysis, the revenues from congestion pricing tolls would not be included as a net benefit because they are transfers. Benefits included in this type of analysis include externality reductions and travel time savings. However, in the case of congestion pricing, some additional benefits from higher-order impacts may be included (we discuss this in section 5.2). If large technology investments are needed, these would be included as a cost. The complete benefit-cost analysis relies on both passenger and freight flows, so we omit it here. We refer the reader to Kawamura et al. (2002 and 2003b) for more information about calculating freight impacts associated with this type of analysis including travel time savings, accidents, air pollution, noise, pavement damage, and regional income (which is mentioned above).

#### **4.3.4 Summary**

In this chapter, we improve understanding of the impacts of congestion pricing policies on urban freight movements. First, we categorized urban freight stakeholders and reviewed their respective goals. Next, we evaluated congestion pricing implementation decisions and noted the affects of each decision on freight. Finally, we looked at the possible policy responses, and quantified impacts to each stakeholder. Our framework advances the state of the research: few studies are available for quantifying impacts and we are not aware of any that evaluate the impacts on carriers and shippers. Although this framework was designed specifically to address a pricing policy, the idea of looking at the impacts on freight stakeholders can be incorporated into other types of policy evaluations.



# Chapter 5

## Conclusion

Today, many cities experience chronic congestion which is spreading both throughout the day and throughout the metropolitan region. Moreover, urban freight is a large and growing part of the congestion problem. While some transportation capacity expansion is possible on the periphery of regions, the urban core has little remaining space for additional transportation infrastructure. Increasingly, urban areas are turning to demand management strategies to manage this congestion, one of which is congestion pricing.

Congestion pricing was ignored by policymakers in the past who suggested that adding fees to transport would be infeasible in a Western democracy, although today a new interest in the policy has arisen. This is in part from technologies that make it practical and the success of the recent London implementation. Since 2003, policymakers in several large cities have watched the reaction in London. Two years later, the scheme has been a success in many respects: travel times have improved, speeds are up, congestion and delay are down, and weekend business activity (when no pricing restrictions are in place) continues to correspond with weekday activity, suggesting that the scheme has not negatively affected local businesses. Today, several cities are considering congestion pricing schemes, or are being encouraged to do so by citizens who now realize that they too may welcome the flexibility provided from a higher cost, yet better performing transportation network.

On the other hand, traditional transportation planning activities have tended to focus on passengers and ignore urban truck trips in planning applications. Congestion pricing is no exception. The freight process is poorly understood in general and few tools exist to comprehensively determine the response and impacts of transportation improvement projects or

policies on urban freight. While a large body of work related to behavior and decision making supports standardized passenger demand models and impact analysis, policymakers understand far less about the freight process. Nor does widespread data exist to contribute to truck modeling or analysis efforts. Therefore, planners do not evaluate policy responses and impacts on trucks as thoroughly as their passenger counterparts, even for policies of interest such as congestion pricing.

In our conclusion we present our contribution to the field and guide further research efforts. In section 5.1, we comment on four ways in which we have contributed to existing literature related to understanding congestion pricing and the impacts on freight. Then, in Section 5.2, we discuss the next steps related to our research.

## **5.1 Contributions to research**

In this thesis, we outlined factors related to evaluating the impacts of congestion pricing on urban freight. We contribute to existing literature or the planning process in four ways. We

- Summarize the impacts of existing pricing applications on freight;
- Identify policy implementation preferences from the freight perspective;
- Characterize possible freight-sector responses to congestion pricing; and
- Expand understanding of the freight stakeholders by quantifying how transportation improvement policies impact carriers and shippers.

First, we summarized the impacts of existing pricing applications on freight. The author is unaware of another review of the impacts on freight from existing congestion pricing applications.

Second, we identify policy implementation preferences from the freight perspective. Specifically, we address what type of scheme, toll value, and level of toll variation is best-suited for the freight community. Since urban freight has no modal option and depends on a high level of service from the road network, we suggest that the broader the scope of congestion pricing, the more beneficial it is for urban freight movements. We refer readers to TRB (1996) to determine what the theoretical toll should be for trucks, yet using freight characteristics we give an estimate to planners about what that value should be absent better data. Finally, we illustrate the potential negative impacts of not implementing a variable pricing scheme, and suggest that successful congestion pricing have the ability to differentiate toll values according to the costs of trips.

Third, we characterize the possible freight responses to congestion pricing based on carrier and shipper choices. We identify the planning horizon of various choices and discuss which ones

will have first, second, and third order impacts on urban freight movements. For example, we saw in the urban freight illustration in Chapter 4 that if travel time and system reliability increase (first order impact), then larger, more frequent shipments (a second order impact) may reduce inventory costs. Moreover, we identify whether carriers or shippers are responsible for each choice because based on who is absorbing the fees from congestion pricing, the freight response may vary. Shippers have more potential to modify their supply chains based on more efficient transport and we note that mechanisms for passing on fees to shippers is necessary for shippers to realize beneficial higher-order impacts. This outline can provide insight to policymakers who are unfamiliar with the freight process.

Fourth, we expand understanding of the freight stakeholders by quantifying how transportation improvement policies impact carriers and shippers. We believe that efficient freight movements are important to economic growth and believe that there may be additional benefits associated with efficiencies in the supply chain. By outlining the components of shipper costs and carrier profits, we provide the background for (1) quantifying additional benefits associated with congestion pricing and (2) making improved demand estimates from the transportation policy.

In summary, since congestion pricing may be effective for mitigating transport externalities and freight planning is not well-understood, we believe that providing specific tools to policymakers for evaluating the impacts of congestion pricing on freight is both timely and relevant. Other examples of congestion pricing have suggested urban trucks receive benefits from the scheme, but we do not know how these benefits are distributed among the carrier and shipper. We provide background on urban freight and congestion pricing so that both are well-understood. Then, we explain which variables must be considered to make congestion pricing favorable for the private sector and provide tools for policymakers to consider the impacts on freight while evaluating a congestion pricing scheme in their region.

## **5.2 Next steps for research**

Congestion pricing is an effective policy for alleviating traffic problems in urban areas and is under consideration in several cities. Ideally, planners will benefit from the tools provided while quantifying the impacts of a proposed implementation on urban freight. However, first potential benefits from higher-order impacts (referenced in Section 4.3.1) should be quantified for congestion pricing benefit-cost analysis. Additionally, this work can be incorporated into demand estimations or used for calculating the price elasticity of demand. Finally, it may be adopted as

part of a decision making tool for other policy or project analysis, potentially strengthening the linkages between the private and public sector in freight planning.

In subsection 5.2.1 we explain further work related to measuring higher-order impacts. Then, in subsection 5.2.2 we discuss how our work can be extended for estimating demand and price elasticity for urban freight. Finally, in subsection 5.2.3 we explain how our impact evaluation design would be an effective model to extend to additional policy analyses because it links planning with stakeholder goals.

### **5.2.1 Measuring higher-order impacts**

To complete our analysis of congestion pricing, the first extension that we recommend is to measure the higher-order impacts of congestion pricing on freight. We give two reasons for quantifying these impacts. First, although economists reason that benefits derived from all higher-order impacts are “fully captured in the demand curve for transportation and hence are *transfers* rather than new benefits” (Small 1999, p. 164), we argue that in the physical implementation of transportation policy (a) each of the assumptions supporting the economic theory may *not* hold; and (b) understanding which part of the freight or logistics process is most sensitive or susceptible to change based on transport improvement provides unique insight from the public sector into logistics processes. This may allow for improved policy development in the future, or be a device for instituting collaboration between the public- and private-sector decision-makers involved in freight transport planning. Devices which encourage collaboration should be of interest to both the public and private sector because of the synergistic improvements made possible by integrating supply chain management and regional strategic transportation planning (see Sgouridis 2005).

Second, if we assume that economist’s assumptions do hold, freight impacts from congestion pricing provide a unique case where pecuniary externalities (or transfers) associated with the pricing policy may have supplementary benefits to the policy. Economists show that benefits from higher-order impacts are transfers unless some of the new trips associated with the improvement policy have been *diverted* from other markets where they are responsible for negative (as economists call them: ‘technological’) externalities such as contributing to congestion or emissions. In this case, the technological externalities can be quantified and added to the sum of benefits for the policy of interest (Small 1999, p. 144 #16). By evaluating the second and third-order impacts, we could determine what fraction of new trips is associated with these changes compared to the first-order travel time and reliability improvements. To measure these benefits, a researcher would quantify how many new trips are associated with each level of

impacts to determine if the corresponding trips are new to the supply chain or diverted from another location. For example, more frequent deliveries would correspond to new trips; while the relocation of a distribution facility from another city to the metropolitan area with congestion pricing (to take advantage of the efficiency gains) brings new trips to the region which have actually been diverted from another location.

### **5.2.2 Estimating demand**

By explaining the possible responses to freight and outlining components which contribute to shipper and carrier benefits, we provide the background needed for developing a comprehensive demand model. Understanding the supply chain gives insight into how carriers and shippers behave, and by incorporating the cost components outlined in Subsection 4.3.3, future researcher could develop accurate estimations of urban freight demand. Our outline for carrier profits can be adopted for service trips as well, so demand estimations could be made for all urban truck trips. Additionally, by accounting for the complexity of carrier and shipper costs, future researcher could determine the price elasticity of demand. Knowing or having this value would be of great value to policymakers; an accurate price elasticity of demand would facilitate the computations for total freight flows in the region (and hence total benefits) at various toll levels.

### **5.2.3 Policy extension**

Finally, we conclude by suggesting that policymakers integrate the tools developed above—which are based on transport choices and account for each stakeholder in urban goods movement—for varied project or policy analyses in addition to congestion pricing. These contributions may be integrated into (1) a complete congestion pricing benefit-cost analysis which captures higher-order impacts, (2) a demand model which more accurately predicts demand fluctuations by incorporating the logistics process, or (3) a planning or decision making tool which considers freight stakeholder impacts and perceptions for policy or project analysis. In each case, they provide a foundation for strengthening linkages in the public and private sector and facilitate the synergies noted above (in subsection 5.2.1 and Sgouridis 2005). Also, evaluating policies or projects which may impact freight by incorporating transport choices from a supply-chain or logistics focus is more appropriate for understanding and evaluating freight choices than adopting a passenger framework which only looks at trip characteristics.

### **5.3 Final word**

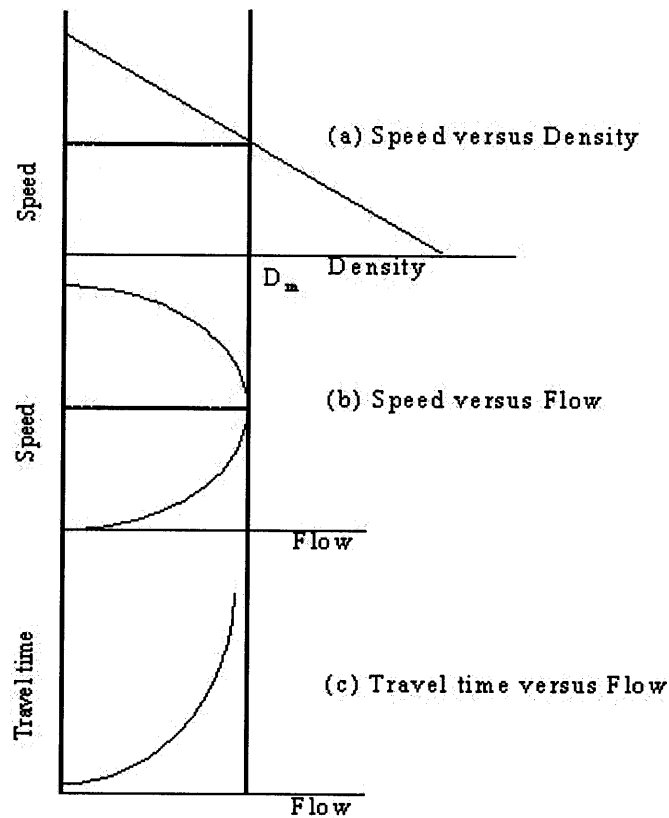
We recognize that freight is correlated with regional economic development and believe that it should continue to be integrated with the passenger-planning process. Also, we recognize that congestion pricing is a compelling policy and believe that the associated benefits could improve transportation efficiency in a region if implemented correctly. Accurate quantification of these benefits may influence political feasibility. While this thesis has moved toward understanding the impacts of congestion pricing policies on urban freight, it is just an early step along the way to implementing sustainable congestion mitigation measures and ensuring continued economic development in urban areas. The author hopes that other researchers and practitioners will pick up the challenge.



# Appendix A

## Derivation of the average cost curve

The supply curve in the congestion pricing diagram is derived from two of the fundamental diagrams of traffic flow theory, which relate flow, density and speed (Garber and Hoel 1999). Using these two figures, shown in Figure A 1 (a) and Figure A 1 (b), we derive the average cost curve in Figure A 1 (c).



**Figure A 1 Graphical derivation of the average cost curve**

The first fundamental diagram of speed versus density shown in (a) shows the inverse relationship that occurs when the volume on a roadway increases, and the corresponding speed decreases. See the point  $D_m$  where the total flow is maximized. This is a critical point in the subsequent figures.

The second fundamental diagram, (b) Speed versus flow, shows speed declining from the top of the parabola as an uncongested roadway becomes increasingly crowded. Note that the top portion of the curve corresponds to uncongested traffic volumes and maximum flow is attained at  $D_m$  (noted above). On the bottom half of the parabola, speed and flows decline until the roadway effectively becomes a parking lot.

Finally, in (c), travel time versus flow is derived from (b). Decreasing speeds and increasing flows translate into an increasing travel time curve. At  $D_m$  (or maximum flow) the roadway is congested and travel times continue to increase while the flow actually begins to decline. Where speed and flow in (b) approach zero, travel times would go to infinity, but we assume that this does not occur and cut off the increasing travel time line.

The cost of travel is the sum of the variable cost of driving (such as fuel and auto maintenance), the monetary cost of any road tolls, and the converted monetary cost of travel time. In the graphical illustration of congestion pricing, Figure 2, we assumed that variable costs were excluded from our example, and travel costs were based only on generalized costs (or the strictly monetary and travel time costs). Therefore, using the final graph (c) above, the supply line, or average cost curve in Figure 2 is derived from the Fundamental Diagram of traffic theory.

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