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Commercial Vehicle Value of Time and Perceived Benefit of
Congestion Pricing

by

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A dissertation submitted in partial satisfaction of the
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Professor Martin Wachs, Chair
Professor Mark Hansen
Professor Elizabeth Deakin

1999

Commercial Vehicle Value of Time and Perceived Benefit of
Congestion Pricing

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Kazuya Kawamura

Abstract

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Congestion Pricing

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Kazuya Kawamura

Doctor of Philosophy in Civil Engineering

University of California, Berkeley

Professor Martin Wachs, Chair

This study investigated the value of time for commercial vehicles in urban areas and its implications for perceived benefits created by congestion pricing projects. Central questions explored were

- 1). Do values of time differ among commercial vehicle operators? If so, what explains the differences?
- 2) Will congestion pricing make particular segments of the commercial vehicle industry better-off than others due to differences in values of time?

In the first part of the study, stated preference data for measuring commercial vehicle value of time were collected by interviewing 70 truck operators in California. The value of time was estimated based on the point of diversion at which the switch of facility occurred in the stated preference questions, and also using a modified logit model in which the coefficients to be estimated were assumed to be distributed lognormally across the population. The former approach revealed that the value of time can be well replicated

with a lognormal distribution. The latter approach, or the random coefficient logit model, indicated that the mean and standard deviation of the value of time were \$23.4/hr. and \$32/hr., respectively. Comparisons between data sets that were segmented according to business type, shipment size, and the method of driver compensation indicated that for-hire trucks tend to have higher value of time than private ones, and the companies that pay drivers hourly wages have higher values of time than those who pay by commission or fixed salary.

Using the SR91 congestion pricing project in Southern California as a case study, perceived benefits for commercial vehicles were calculated based on the value of time estimated by the logit model. The analyses revealed that trucks with high values of time receive a disproportional amount of benefit, especially if the toll is expensive. The comparison between for-hire and private trucks indicated that the former, due to their considerably higher mean value of time, tend to receive much greater benefit individually and collect slightly more aggregate benefit than the latter despite smaller numbers. However, the share of the benefit received by each sector is relatively unaffected by the level of the toll charged.

Chair

Date

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CHAPTER 1: INTRODUCTION

1.1 Overview

This study merges two topics of current interest in transportation policy: the commercial vehicle industry and congestion pricing. The concept of congestion pricing, a scheme that imposes varying tolls on road users during the congested periods to account for the greater marginal cost of travel at those times, has been studied mostly from theoretical perspective since 1950's. Recent openings of actual freeways with congestion pricing, such as I-15 in San Diego, and SR91 in Orange and Riverside counties, have revived interest in the subject primarily because of the availability of empirical data and because the pricing seems to be influencing traveler's choices. From the perspective of the operators of congestion priced facilities, trucks have the potential to be a major source of revenue for such facilities because past studies have shown that commercial vehicles have higher values of time than passenger vehicles [Waters, 1993], and thus should be able to bear substantially higher tolls compared with private travelers. Also, the trucking industry has significant political influence through its lobbying organizations, and its economic impacts on local, regional and national economies are enormous. As congestion pricing gains acceptance as a feasible transportation demand management tool, the assessment of the impacts on commercial vehicles as well as their perceptions and responses will be necessary.

The total domestic bill for highway freight for 1995 was estimated to be \$350 billion, which is approximately 5 % of the Gross National Product and amounts to more than

\$1,200 per person¹ [Wilson, 1996]. Despite the obvious importance of the commercial vehicle industry to the economy and transportation in this country, transportation researchers and local and regional transportation planning bodies have paid relatively little attention to it in the past mainly due to the lack of data.

Goods movement is in many ways more complex than passenger movement. There are numerous types and sizes of vehicles carrying goods that vary in value, size, shape, and weight. Trip length can vary from 500 feet to 4,000 miles. Some trucks may be empty while others may be carrying urgent shipments. The daunting task of collecting and organizing data to address this multi-dimensional problem has discouraged researchers from addressing policy issues related to the commercial vehicle industry.

The study of commercial vehicle behavior in urban area is particularly scarce, in contrast to the interstate carrier industry which has attracted attention in the past especially before and after deregulation in 1980. While most of the travel miles of interstate trucks occur on rural roads, in terms of contribution to urban congestion local and short range commercial vehicles overwhelm interstate trucking.

For a rational commercial vehicle operator, choice of facility or scheduling under congestion pricing is based on the trade-off between the toll and the travel time savings, and depend solely on the perceived value of time. Our basic hypothesis is that perceived

¹ For inter-city freight, freight bill is calculated from the revenue of motor carriers. For local freight, owning and operating cost of vehicles are used.

value of time for commercial vehicles varies according to measurable attributes of the owners or operators of the vehicle. Thus, congestion pricing affects various types of commercial vehicles differently. The main aim of this study is to conduct a welfare analysis of congestion pricing projects for different groups of commercial vehicles using perceived values of time obtained from surveys. In particular, the study strives to provide quantitative answers to the following questions:

- 1) Do values of time differ among commercial vehicle operators? If so, what explains the differences ?
- 2) Will congestion pricing make particular segments of the commercial vehicle industry better-off (or worse-off) than others due to differences in values of time?

The main thrust of this study is in understanding the existing condition of the commercial vehicle industry through data collection and identifying the way a policy may effect them. The commercial vehicle value of time is measured and a case study is used to demonstrate the effect of congestion pricing. We do not make recommendations for controlling truck traffic using congestion pricing nor propose a toll schedule for trucks that may maximize the benefit for the society. The reason is two-fold. Firstly, there is a need to limit the scope of study in the interest of time and resource. Commercial vehicle industry is understudied, and understanding the operation and use of trucks should be the foremost concern. Secondly, to make a policy recommendation, long-term analysis of impacts must be performed. While such an endeavor may be a valuable extension of this study, in the absence of the data from actual congestion pricing of commercial vehicles and sufficient

time to allow for the development of long-run responses, for example relocation of terminals and schedule changes, long-term analysis will likely to produce highly speculative and not very useful results.

As discussed in the next chapter, there have been few efforts in the past to quantitatively address the impacts of congestion pricing on commercial vehicles. Therefore, the first part of this study focuses on the development of an analysis framework including econometric models for the value of time, and calculation of perceived change in benefit. In the second part of the study, the framework will be applied to an existing congestion priced road to take advantage of the traffic data which became available only during the last few years. The SR 91 Freeway in Orange County, California was chosen as a case study to test the applicability of the framework and to quantify welfare changes in real world situations. To learn whether congestion pricing makes some segments of the commercial vehicle industry better or worse off, we must rely on assumptions and inputs to the analysis. Therefore, careful assumptions were made and a sensitivity analysis was conducted to identify the effects of imposing different toll schedules.

1.2 Organization of the Dissertation

This dissertation is organized in seven chapters. The second chapter provides an overview of the motor carrier industry as well as a review of past studies of commercial vehicle value of time, and congestion pricing with an emphasis on identifying research needs and possible strategies. A discussion of the analysis framework is provided in the third chapter. Data sources, survey methodology and the summary of the survey results are presented in

Chapter 4. Detailed discussion of the econometric model used to estimate value of time parameters and the analysis of the outputs are included in Chapter 5. In Chapter 6, the SR91 congestion pricing project is used as a case study to illustrate the welfare impacts on commercial vehicles. And finally, a summary of the findings and a discussion of potential areas for future study are included.

CHAPTER 2: MOTOR CARRIER INDUSTRY OVERVIEW

Since we are interested in the effect of congestion pricing on different segments of the commercial vehicle industry, in this chapter, an overview of the industry including the common criteria for the segmentation of the carrier types is presented. Grasping the broad picture of the industry and learning about recent developments that are effecting the operation of trucks will help in formulating the hypothesis for the differences in value of time and consequently in assessing the impacts of congestion pricing on different types of motor carriers.

According to data compiled by the Eno Transportation Foundation, trucks account for about 79% of the total domestic freight bill [Wilson, 1996]. In terms of ton-miles, trucks' share is about 27%, which is less than that of rail, which is about 40%. In terms of tonnage, however, trucks account for about 45% and rail about 26%. Since the deregulation of interstate trucking by the passage of the Motor Carrier Act of 1980 and subsequent legislation that prohibit states from regulating rates, routes, and services of intrastate trucking businesses (except for household goods), the share of freight shipment that is regulated has drastically declined. In 1992, only about 25% of highway ton-miles were regulated, compared with about 55% before deregulation. Approximately, 5.2 million heavy vehicles are registered in this country and a little less than 10% of them are registered in California where the survey for this study was conducted [Department of Commerce, 1995]. The Commodity Flow Survey of 1993 estimates that approximately

11% in value and 7% in weight of total domestic commodity movements occur in California where the value of time data were collected [Department of Commerce, 1996].

The motor carrier industry can be segmented in a number of ways. The most common segmentation criteria used in research studies are by business type, shipment size, and trip length. Commercial vehicles that are used to provide services, such as transportation of goods and personnel, for the company that owns them are called "private" fleets. In contrast, trucks that transport goods that belong to clients for a fee are called "for-hire" fleet. Nationally, for-hire fleets account for a small portion of heavy vehicles, but a much greater share of vehicle miles, as shown in Table 1.

Table 1: Share of Vehicles and Vehicle Miles by Business Type

	For-Hire	Private
Vehicles	85%	15%
Vehicle Miles	57%	43%

Source: [Department of Commerce, 1995]

Traditionally, for-hire fleets can be further divided into "common carriers" which provide services to the general public and "contract carriers", which operate under a contract with specific client(s). However, since deregulation, most for-hire companies operate as both contract and common carriers to maximize business opportunities.

Generally motor carriers are divided into three shipment size groups: parcel/package, less-than-truckload (LTL) , and truckload (TL). While a parcel/package normally weighs less than 100 pounds, a LTL shipment can be as much as 10,000 pounds. While the parcel/package and LTL shipments usually go through one or more terminals for

consolidation and distribution, TL shipments seldom do except at intermodal terminals. Although several large companies exist within each group, such as UPS and Federal Express for parcel/package, Consolidated Freight, Viking Freight System, and Yellow Freight System for LTL, and J.B. Hunt and Schneider National for TL, none of them is dominant. For example, the nation's largest carrier by revenue, UPS, accounts for only 4.3% of the total industry revenue [Hall and Chatterjee, 1995]. Since parcel/package and LTL carriers require a network of terminals and a fleet management system, there are only about 500 companies in those segments while there are over 70,000 TL carriers [Fawaz, 1993].

Another criterion often used to classify motor carriers is trip length. There is no standard for the threshold trip lengths, but most common division is local (less than 50 miles from home base), short-haul (between 50 and 100 miles), medium-haul (between 100 and 500 miles), and long-haul (longer than 500 miles). The share of the number of vehicles and vehicle miles for each segment is presented in Table 2.

Table2: Share of Vehicles and Vehicle Miles by Trip Length

	Local	Short-Haul	Medium-Haul	Long-Haul
Vehicles	65%	16%	12%	7%
Vehicle Miles	31%	18%	27%	24%

Source: [Department of Commerce, 1995]

The Motor Carrier Act of 1980 and subsequent legislation have impacted the industry in a number of ways. One study estimates that deregulation has saved about \$20 billion annually in domestic transportation cost [Winston et al., 1990]. In the LTL segment, the

requirement for an expansive network of terminals and excess capacity has created an entry barrier; and the number of LTL companies has not increased. However, increased competition among the existing carriers has led to a drastic decrease in rates. For the TL segment, the number of carriers increased by as much as 24%, mostly due to the entry of small owner-operators. While the number of for-hire carriers increased, the competitive environment created by deregulation led to a rise in the bankruptcy rate from only 0.0024% in 1978 to 1.8% in 1984 [Glisson, 1991]. The deregulated environment also created a need for brokers who can consolidate shipments from different motor carriers to increase the utilization of trucks for the carriers. Brokers also coordinate between shippers and carriers to schedule shipments in a manner analogous to travel agents. The number of licensed brokers has grown from only 80 in 1975 to more than 8,000 in 1993 [ICC, 1993]. In general, deregulation forced the motor carriers to be efficient and cost conscious compared with the regulated era. Furthermore, by eliminating the compartmentalization of the industry that was maintained by the Interstate Commerce Commission under regulation, deregulation made it possible for motor carriers to seek new market, thus increasing the flexibility of the utilization of the travel time savings.

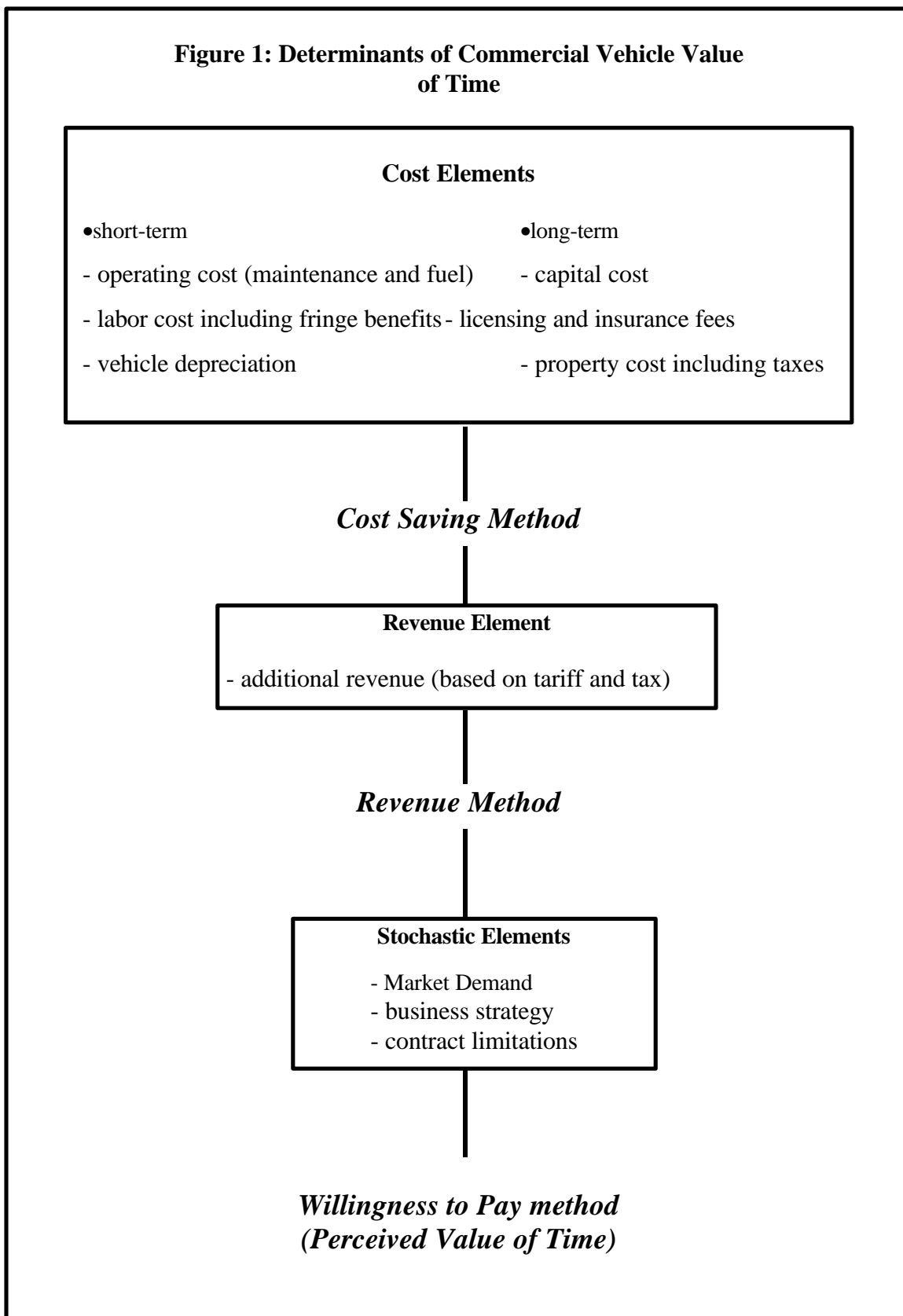
CHAPTER 3: THEORETICAL FRAMEWORK

3.1 Commercial Vehicle Value of Time

In the past, at least four methods have been used in research by which to determine commercial vehicle's value of time. They are: 1) The cost savings method, which is based on the cost savings to operators per unit of time, 2) The revenue (net operating profit) method, which estimates the net increase in profit resulting from the reduction in travel time, 3) The Cost-of-Time Savings method, which "calculates the cost of providing time savings" for a specific project [Adkins, et al, 1967], and 4) The willingness to pay method, which measures the "market" or "perceived" value of time from observed or stated choices under trade-off situations involving time and money. A summary of past studies of commercial vehicle value of time by Waters et al. (1995) reveals considerable range, due partially to the differences in the methodologies of measurement.

Of the four methods, the Cost-of-Time Savings that calculates marginal cost of providing time savings for specific projects is of little value to this study. It may seem that for a sophisticated firm that maintains detailed financial information to support fleet operation decisions, the calculation of a value of time using any of the remaining three methods should be a simple task. However, as discussed in the following section, various constraints and the fact that the relationship between travel time and marginal profit is usually influenced by various exogenous factors, make the calculation of value of time not as straightforward as it may at first seem. The factors that influence value of time and the relationship between them are depicted in Figure 1.

Figure 1: Determinants of Commercial Vehicle Value of Time



The cost saving method calculates the savings or increases in expenditure for the areas depicted as the cost elements in the figure that occur with a change in travel time. The distinction between the short-term and long-term is based on the time required to realize the savings. While short-term factors lead to immediate savings in day-to-day operating costs or increases in revenue, the savings associated with the long-term factors can only be realized through reductions in capital investment costs such as number of trucks and terminals, and consequently require long-term business planning.

Using Interstate Commerce Commission (ICC) freight data, Adkins et al. derived the commercial vehicle value of time for each ICC region based on the cost saving method [Adkins et al., 1967]. For the Pacific region, the value of time for inter-city trucks was estimated to be \$4.95/hr. (\$26.7/hr. in 1998 prices). Adkins et al. found that driver's wages, which account for 74% of total costs, dominated other cost elements. A breakdown of other cost elements is: 16.2% for vehicle depreciation, 3.5% for the interest on capital cost, 5.3% for driver's fringe benefits, and 1% for property tax. Waters et al. compiled a summary of commercial vehicle values of time used by 14 agencies in various countries² for evaluating costs and benefits of highway projects [Waters et al., 1995]. While the methods differ among agencies, the values were determined from cost analyses that typically included labor, vehicle operation, and cargo handling and storage. The values of time ranged from \$14.5/hr. to \$35.6/hr. for the agencies in the U.S. and Canada, while the values found in other countries varied from \$11.4/hr. to \$17.8/hr in 1998 prices.

² The breakdown is six in the U.S., three in Canada, three in Australia, one in New Zealand, and one in Norway/Sweden.

Under the assumption of a profit maximizing firm, the value of time should equal the marginal profit for a unit of time, which gives rise to the revenue method. The revenue method calculates value of time based on the increases or decreases in profit that occur with a change in travel time. Theoretically, the cost saving method becomes the revenue method if the revenue element, which is the additional revenue generated from using the travel time savings to increase business volume, is added. Naturally, for the revenue method, value of time is affected by the level of utilization of the travel time saved.

Haning and McFarland calculated the amount of additional revenue that can be earned by for-hire carriers using travel time savings to increase business volume [Haning and McFarland, 1963]. First, the increase in revenue miles was estimated, and then was converted to revenue per hour assuming an average speed of 38 miles per hour. Since the amount of increase in revenue depends on the efficiency with which the travel time savings can be used to conduct additional business, the revenue method usually calculates minimum and maximum values of time for which low and high levels of utilization of travel time savings are assumed. Haning and McFarland estimated the range of value of time to be between \$17.4/hr. and \$22.6/hr. in 1998 US dollars. Waters et al. also calculated minimum and maximum values of time for for-hire carriers using the revenue method [Waters et al., 1995]. For the minimum case, in which travel time savings do not lead to any increase in the carrier's output or reduction in the operating cost, value of time was assumed to be the driver's valuation of leisure time³. The study estimated it to be 40% of average driver's wages. The average driver's wage was derived from the data collected

in British Columbia, Canada. The maximum case assumed that 100% of travel time savings could be converted to conduct additional business. Thus, value of time was calculated as the market value of one hour of truck's service that was estimated from the data collected in British Columbia⁴. The minimum and maximum values of time were calculated to be between \$6.1 /hr. and \$34.6/hr in 1998 prices, respectively. It should be noted that the studies mentioned above only covered for-hire carriers.

The willingness to pay method measures the exchange rate between time and money a firm is willing to pay. Consequently, if a firm has a perfect knowledge of the relationship between travel time and profit, it is possible to equate the revenue method with the willingness to pay method. However, in real-world situations, the perceived value of time implied by the revealed or stated choice can be considerably different from the theoretical value.

The components included in the stochastic factors are the sources of the discrepancies. Imperfect information can result in the use of time that is not profit maximizing. For large companies or private fleet operators, it is conceivable that a fleet manager may be uninformed about the financial aspects of the business because the bills for the operating costs such as fuel and parts and the payments from the clients go directly to the accounting section of the company. Therefore, drivers or dispatchers may not have the information necessary to evaluate the change in profit that accrue from his/her choices. Also, business strategies such as hiring and purchasing of trucks may not always be profit

³ This assumption is valid only if the travel time saving is used for driver's personal leisure.

maximizing. Instead, those decisions are frequently based on the manager's prediction of future market demand and business trend. Furthermore, contracts with both employees and clients can place constraints on the company's choices. For example, if the truck driver's labor contract requires a minimum of 8 hours of pay for each working day, then several minutes of travel time saving will not make a difference in labor cost unless overtime is involved. Also, the amount of additional revenue generated from conducting more business depends on the level of demand for additional service.

Since actual behavioral changes under a policy or a program can be best predicted using the perceived value of time, the benefit/loss calculations based on the revenue method may not accurately assess the true effects. For example, if the perceived values of time are different from the theoretical values, there can be a situation in which some trucks that should take the congestion priced road based on the revenue method value of time may not do so, since the perceived values of time are lower. For this case, the use of the revenue method overestimates the benefit of congestion pricing. Also, the method by which the value of time is evaluated affects the interpretation of the results. While the revenue method is often applied in determining the long-term impacts, the willingness to pay method is suited for forecasting travel behavior, and evaluating public acceptance and political repercussions.

Several studies based on the willingness to pay method have been conducted in Europe [De Jong and Gommers, 1992] [Widlert and Bradley, 1992] [Wynter, 1995]. Since it is

⁴ The calculation did not include fuel cost.

difficult to observe actual choices made by commercial vehicles under time and money trade-off situations, all three studies used stated preference surveys. The study by De Jong and Gommers is unique in that it compared the value of time based on the revenue method to that obtained from the stated preference survey. The revenue method calculated the value of time to be about 61 guilders/hr. (\$41.7/hr)⁵, while the stated preference data estimated it to be 57 guilders/hr. (\$38.9/hr.) using the logit model. The study by Widlert and Bradley also employed a logit model to estimate the value of time from stated preference data. Their study found the average value to be 30 kronas (\$6.0/hr.), which is considerably lower than the findings from any other studies. Both studies covered motor carriers as well as shippers that may or may not have private fleets. Wynter also employed stated preference survey, but questions were based on actual trips taken by the respondents. The questions were designed to find out the level of congestion or toll level that would have prompted the respondent to switch from toll road to freeway or *vice versa*. The travel time and distance for each trip were estimated from origin and destination data using travel demand forecasting model. Wynter found the mean and standard deviation of the value of time to be 8.65 francs/min. (\$103/hr.) And 5.94 francs/min. (\$70.9/hr.), respectively. Wynter also found that the distribution of value of time can be closely approximated by a lognormal density function. It should be noted that Wynter's study only surveyed for-hire motor carriers, thus covering a relatively homogeneous population compared with this study. While the reason for the extreme variation among the findings from foreign studies is not certain, it suggests limited

⁵ All the figures from foreign studies presented in this chapter are in 1998 US dollars. The average exchange rate for the year each study was conducted was used to convert the original figures to US dollars and the Consumer Price Index was used to adjust to the 1998 prices.

usefulness of those results for the commercial vehicles in the U.S. In addition, none of the studies mentioned in this chapter compared the values of time for different types of motor carriers.

3.2 Congestion Pricing

This section presents the analysis of the short-run impact of congestion pricing on commercial vehicles using an illustrative example. The traditional concept of congestion pricing imposes a substantially higher toll on road users during the congested periods to account for the greater marginal cost of travel at those times. Without congestion pricing, the social costs of traffic congestion always exceed the private costs since the social cost is a combination of private and external costs. The private cost is the perceived cost for the users of the facility and is a reflection of the average cost of a trip. The private costs include vehicle operating cost, maintenance, the opportunity cost of travel time, and tolls. The external costs can be considered to be the social costs that are not perceived by travelers. When a traveler chooses to use a roadway, the decision is based on the private or average cost. He/she is oblivious, for example, to the marginal increase in travel times to other motorists that result from the addition of his/her automobile to the traffic stream. This increase in the travel cost for all travelers can be considered an externality, since it is not reflected in the choice process of the newcomer. Social cost includes other externalities, such as road maintenance, as well as environmental and health costs. The combination of private cost and social cost is the full cost of travel. Congestion pricing imposes a toll that is equivalent to the social cost, thus making the perceived cost equal to the true marginal cost. While congestion pricing can be an effective tool for cost recovery,

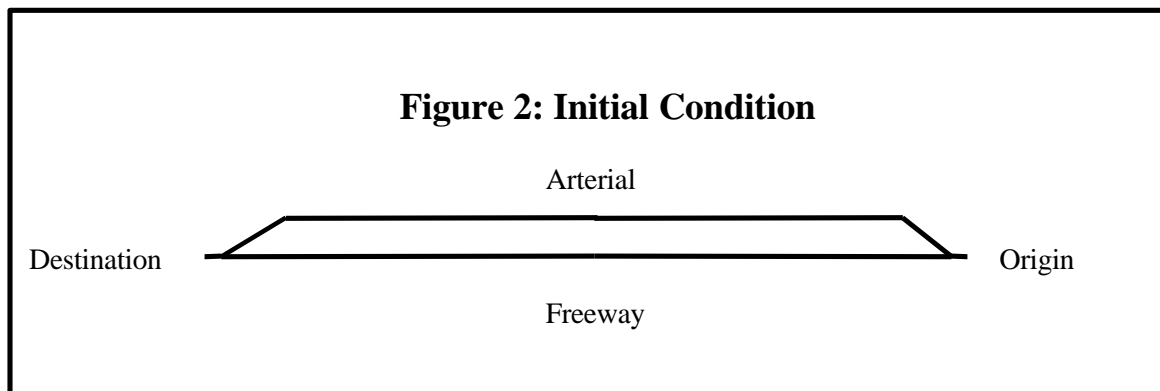
demand management, and pollution control, several studies (such as Daganzo, 1995, and Evans, 1992) have pointed out that the toll inevitably results in a loss of consumer surplus when the revenue from the toll is excluded from the analysis. In the past, elected officials have been reluctant to support congestion pricing. In fact, the proposal for implementing congestion pricing for the San Francisco-Oakland Bay Bridge has not obtained the authorization from the California State Legislature [FHWA, 1996 A].

While the traditional concept of congestion pricing works to correct the distortion in marginal travel cost, new types that are more politically appealing are emerging. Instead of imposing a congestion toll on every lane, these facilities give road users a choice between taking the free lanes that can be congested and the toll lanes that guarantee free-flow speed travel. For I-15 in San Diego, the existing HOV lanes, which had a low utilization rate, were converted into toll lanes. In the case of SR91 in Orange and Riverside Counties, toll lanes were constructed using the median of the existing freeway. The toll lanes are also open for high-occupancy vehicles for free. Conceptually, these facilities create a market with different levels of price and quality, and are quite different in aim from the original form of congestion pricing. Following is the analysis of the impact of implementing a type of congestion pricing used for SR91.

3.3 Benefit from Congestion Pricing for Commercial Vehicles

Suppose that a freeway and an alternative arterial route connect an origin and a destination as depicted in Figure 2. The traffic demand between the origin and destination is determined by socioeconomic factors and can be considered fixed in the short-term.

Assuming rational behavior, the demand for each facility is determined by the equilibrium of the generalized costs of travel which can be divided into the distance-dependent costs and time-dependent costs. The marginal time-dependent cost with respect to time is the



perceived value of time. Each traveler chooses the facility that minimizes the generalized cost of travel. In the following analysis, only inequalities are used to describe the relationship between travel time and traffic volume. As a result, the analyses presented in this section are robust as they will hold for any form of congestion function as long as the travel time increases with traffic volume.

If the travel distance on the arterial is greater than the freeway⁶, which will be the assumption for the remainder of this chapter, then using the arterial must provide time saving to be a feasible alternative. However, for heavy vehicles, any feasible alternative route should not require an excessive detour since the distance-dependent components of the vehicle operating cost are considerable. Using the vehicle operating cost calculation

suggested in a study by Fawaz for a vehicle with a gross weight of 80,000 pounds, the cost for traveling one mile, excluding labor, is broken down using 1987 prices [Fawaz, 1993]:

Fuel cost = \$0.240

Maintenance cost = \$0.277

Depreciation = \$0.275

Fuel cost is only moderately affected by travel speed. For example, using the figures from NCHRP Report 111 for a semi-trailer, fuel consumption while traveling at 20 mph on a freeway is only 0.082 gallons per mile less than running at 54 mph on a four-lane arterial with two stops per mile [Highway Research Board, 1971]. Using the assumptions that 20% of maintenance and 40% of depreciation is time dependent [Waters, et al, 1995], and a diesel fuel price of \$1 per gallon, the total of the distance-dependent costs for traveling on an arterial, excluding labor, becomes \$0.46 per mile in 1993 dollars. Meanwhile assuming \$19 per hour in 1993 dollars for wage and fringe benefits, which is the figure used by Waters et al., the time-dependent (i.e. labor) cost is equal to \$0.32 per minute. Therefore, if the alternative route requires a long detour, it is unlikely that the saving in the labor cost can overcome the increase in distance-dependent costs.

The aggregate travel cost for commercial vehicles traveling between the origin and destination during a time period can be calculated by the following equation:

$$Total\ Travel\ Cost_I = \sum_{i=1}^n (OC_{Ai} + TT_{Ai}VOT_i) + \sum_{i=1}^m (OC_{Fi} + TT_{Fi}VOT_i) \quad [1]$$

⁶ The findings from this section will still hold if the arterial offers shorter travel distance than the freeway.

where, at equilibrium condition

$$OC_{Ai} > OC_{Fi} \quad ; \text{ for all } i$$

$$TT_{Fi} > TT_{Ai}$$

n, m = Number of travelers using the arterial and freeway, respectively

OC = Vehicle operating cost, not including cost of time

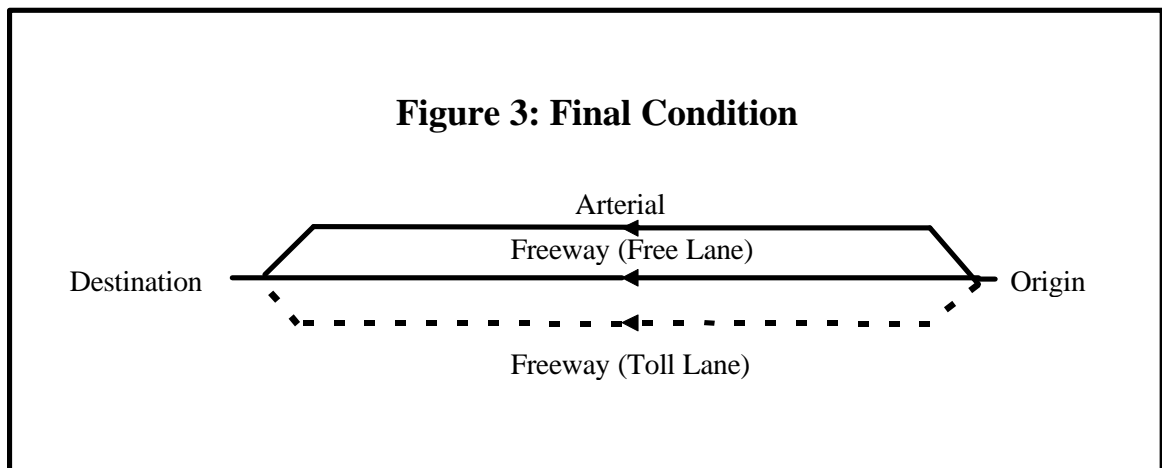
TT = Travel time

VOT = Value of time

A, F = Subscripts for Arterial and Freeway, respectively

I = Subscript for initial condition

When toll lanes are added, as depicted in Figure 3, the traffic is divided among three facilities.



Assuming that the distance-dependent cost, OC , is the same for free and toll lanes of the freeway, the total cost can be written as:

$$\begin{aligned}
 Total\ Travel\ Cost_2 = & \sum_{i=1}^j (OC_{Ai} + TT_{A2}VOT_i) + \sum_{i=1}^k (OC_{Fi} + TT_{F2}VOT_i) \\
 & + \sum_{i=1}^l (OC_{Fi} + TT_{F2}VOT_i + Toll) \quad [2]
 \end{aligned}$$

where,

j, k, l = Number of travelers using the arterial, free lanes, and toll lanes, respectively

A, F, T = Subscription for arterial, free lanes, and toll lane, respectively

2 = Subscript for final condition

The addition of the toll lanes increases the total capacity of the corridor. Thus,

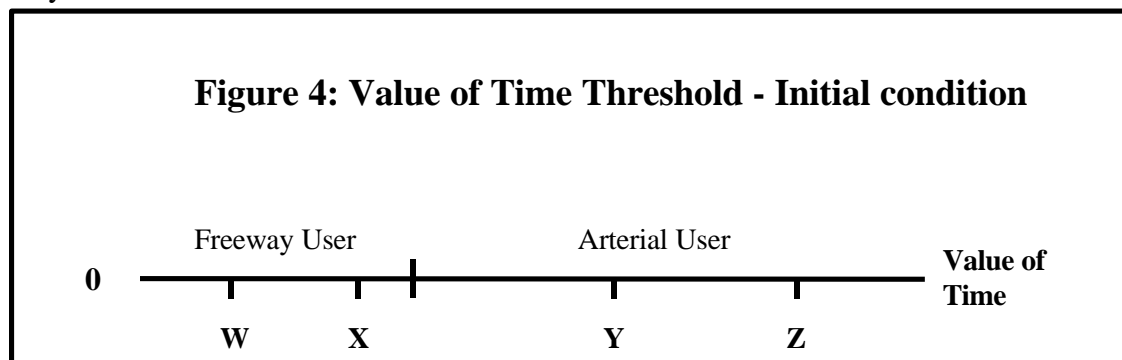
$$TT_{T2} < TT_{F2} < TT_{F1} \quad [3]$$

$$TT_{T2} < TT_{A2} < TT_{A1} \quad [4]$$

$$TT_{T2} < TT_{A2} < TT_{F2} \quad [5]$$

And consequently, the total travel cost decreases. Furthermore, since the travel times on both arterial and free lanes are reduced, every traveler benefits from the addition of the toll lanes. However, as shown in the next section, the magnitude of the benefit can vary depending on the value of time.

In order to compare the changes in benefits of travelers having different values of time, assume that there are four trucks, W, X, Y, and Z, with different values of time but identical distance-dependent costs. Since the vehicle operating cost is greater and travel time is shorter for the arterial, choice between the freeway and arterial is determined by the valuation of the travel time savings offered by the arterial against higher operating cost. As shown in Figure 4, there is a threshold value of time at which the choice of facility switches.



The trucks W and X, whose values of time are lower than the threshold, initially use the arterial while the other two choose freeway. Since each truck chooses the facility that minimizes the generalized cost of travel, following inequalities can be written:

$$OC_F + TT_{F1} VOT_i < OC_A + TT_{A1} VOT_i \quad ; \text{ for } i = W, X \quad [6]$$

$$OC_F + TT_{F1} VOT_i > OC_A + TT_{A1} VOT_i \quad ; \text{ for } i = Y, Z \quad [7]$$

These inequalities can be manipulated to become:

$$VOT_i < \frac{OC_A - OC_F}{TT_{F1} - TT_{A1}} \quad ; \text{ for } i = W, X \quad [8]$$

$$VOT_i > \frac{OC_A - OC_F}{TT_{F1} - TT_{A1}} \quad ; \text{ for } i = Y, Z \quad [9]$$

Therefore, the threshold value of time is $\frac{OC_A - OC_F}{TT_{F1} - TT_{A1}}$ at the initial condition.

As shown in Figure 5, the increase in capacity from the addition of the toll lane reduces travel times on free lane and arterial, and consequently, prompts X and Z to change from free lane to arterial and from arterial to toll lanes, respectively. W and Y remain on their initial choices of facilities.

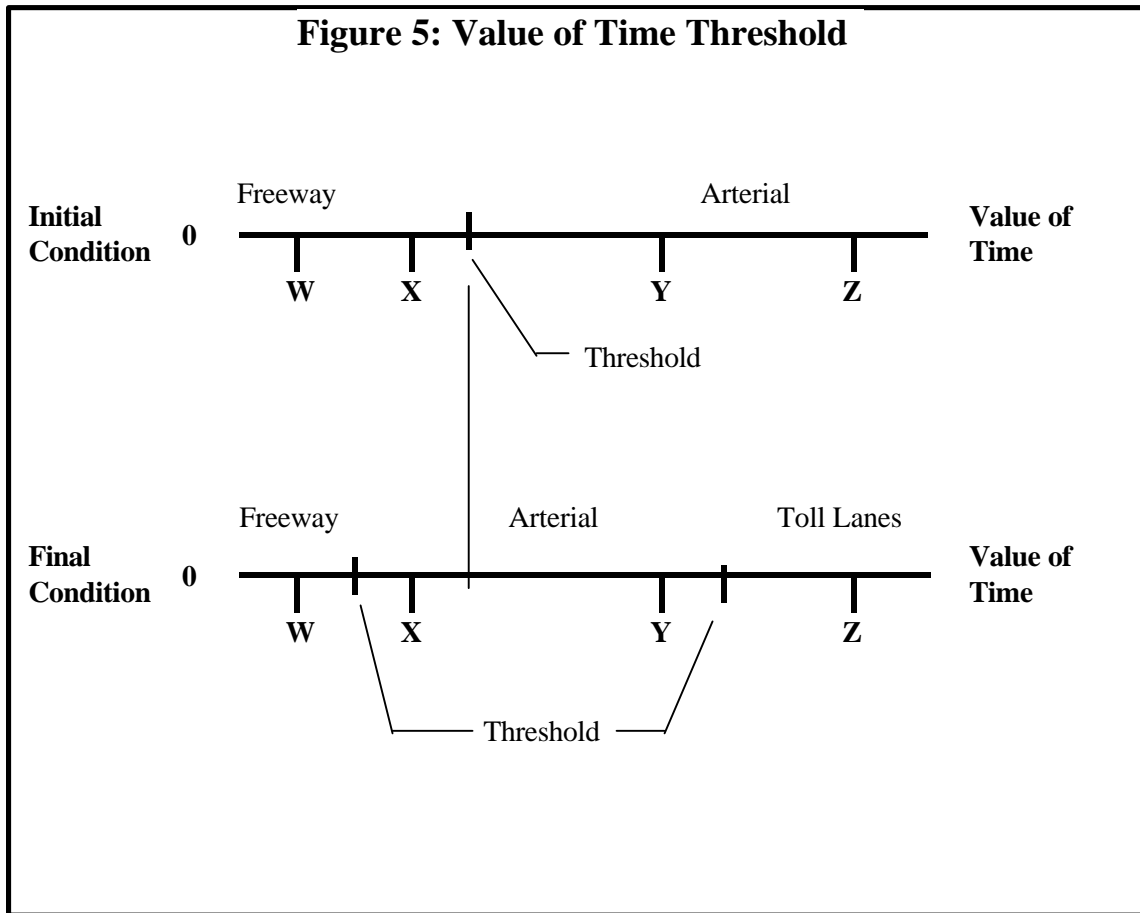
The inequalities are:

$$OC_F + TT_{F2} VOT_i < OC_A + TT_{A2} VOT_i \quad ; \text{ for } i = W \quad [10]$$

$$OC_F + TT_{F2} VOT_i > OC_A + TT_{A2} VOT_i \quad ; \text{ for } i = X \quad [11]$$

$$OC_T + TT_{T2} VOT_i + Toll > OC_A + TT_{A2} VOT_i; \text{ for } i = Y \quad [12]$$

$$OC_T + TT_{T2} VOT_i + Toll < OC_A + TT_{A2} VOT_i; \text{ for } i = Z \quad [13]$$



These inequalities result in:

$$VOT_i < \frac{OC_A - OC_F}{TT_{F2} - TT_{A2}} \quad ; \text{ for } i = W \quad [14]$$

$$VOT_i > \frac{OC_A - OC_F}{TT_{F2} - TT_{A2}} \quad ; \text{ for } i = X \quad [15]$$

$$VOT_i < \frac{Toll - (OC_A - OC_T)}{TT_{A2} - TT_{T2}} \quad ; \text{ for } i = Y \quad [16]$$

$$VOT_i > \frac{Toll - (OC_A - OC_T)}{TT_{A2} - TT_{T2}} \quad ; \text{ for } i = Z \quad [17]$$

Therefore, the value of time thresholds are, from left to right in the Figure 5, $\frac{OC_A - OC_F}{TT_{F2} - TT_{A2}}$

and $\frac{Toll - (OC_A - OC_T)}{TT_{A2} - TT_{T2}}$.

The changes in the travel cost caused by the addition of the toll lanes can be written for each traveler as:

$$\mathbf{DTravel Cost}_W = (TT_{F2} - TT_{F1}) VOT_W \quad [18]$$

$$\mathbf{DTravel Cost}_X = OC_A - OC_F + (TT_{A2} - TT_{F1}) VOT_X \quad [19]$$

$$\mathbf{DTravel Cost}_Y = (TT_{A2} - TT_{A1}) VOT_Y \quad [20]$$

$$\mathbf{DTravel Cost}_Z = Toll + OC_T - OC_A + (TT_{T2} - TT_{A1}) VOT_Z \quad [21]$$

The equations indicate that all four trucks experience a reduction in travel cost from the addition of the toll lanes. However, the magnitudes of the benefit are difficult to compare with these equations since the trucks are using different facilities. Therefore, the differences between the cost savings were calculated. Recalling that the four trucks are identical except for the value of time, the differences in the travel cost savings between the trucks can be found by:

$$\begin{aligned} & \mathbf{DTravel Cost}_X - \mathbf{DTravel Cost}_W \\ &= OC_A - OC_F + (VOT_W - VOT_X)(TT_{F1} - TT_{A2}) - (TT_{F2} - TT_{A2}) VOT_X \quad [22] \end{aligned}$$

$$\begin{aligned} & \mathbf{DTravel Cost}_Y - \mathbf{DTravel Cost}_X \\ &= OC_F - OC_A + (VOT_Y - VOT_X)(TT_{A2} - TT_{A1}) - (TT_{A1} - TT_{F1}) VOT_X \quad [23] \end{aligned}$$

$$\begin{aligned} & \mathbf{DTravel Cost}_Z - \mathbf{DTravel Cost}_Y \\ &= OC_F - OC_A - (VOT_Y - VOT_X)(TT_{A2} - TT_{A1}) + (TT_{T2} - TT_{A2}) VOT_Z + Toll [24] \end{aligned}$$

These equations indicate two important relationships between the magnitude of the benefit received from the addition of the toll lanes and value of time. First, since it can be shown that all three equations produce negative values, the reduction in travel cost gets greater as the value of time increases (see Appendix A for proof). This is easier to understand intuitively. If there is only one facility, then the benefit from travel time reduction is linearly proportional to the value of time. Therefore, a higher value of time results in greater benefit. The advantage of a high value of time even becomes greater for our example. The trucks with high value of time have an option of taking another facility with even shorter travel time in exchange for paying a toll and/or experiencing a higher operating cost. Since the trucks do not change their routes unless the travel cost can be reduced, when they do, those trucks inevitably receive greater benefit than those which do not. Also, the equations indicate that the difference in the benefit between two trucks is a function of the margin of the values of time. Based on these facts, in order to perform benefit comparisons between various types of truck operators, perceived value of time must be obtained for each type. In the next chapter, the methodologies for the surveys that were conducted to collect necessary data to estimate perceived value of time are discussed.

CHAPTER 4: SURVEY

4.1 Objective

Data from various segments of the motor carrier industry are needed to compare values of time and benefits gained from congestion pricing. Since there are no existing commercial vehicle value of time data that are stratified by industry segments, the next best source of data is existing disaggregate data from past surveys which can be used to estimate the value of time. The disaggregate data are necessary because they can be stratified according

to various criteria such as business types and shipment sizes, and value of time can be estimated for each segment. The most straightforward method by which to estimate value of time is to observe the choices made for trade-off situations between time and money. Therefore, a search was conducted for the existing data that were disaggregate and included time-money trade off information. Commercial vehicle surveys such as the 1990 Nationwide Truck Activity and Commodity Survey (NTACS), the 1992 Truck Inventory and Use Survey (TIUS) and the 1993 Commodity Flow Survey (CFS) were reviewed. Surveys conducted by federal agencies, such as these three, are confidential, and disaggregate data are rarely distributed to the public. Also, those surveys do not contain any information that can be used to estimate perceived value of time. Other surveys, conducted mainly at state and regional levels, focus on identifying travel patterns and obtaining data to calibrate demand forecasting models, and do not provide useful data for this study [Lau, 1995]. Therefore, a survey that was specifically designed to provide the data needed to conduct this study, although labor intensive and time consuming, had to be conducted.

The survey had to fulfill the following requirements: 1) value of time can be estimated from the survey data 2) coverage has to be broad so that various segmentation schemes can be used, 3) it must target the decision makers who plan the day-to-day operations of the truck fleet (e.g. the person who decides whether or not to use toll roads) and 4) it must collect pertinent information that may be used to identify factors that effect the value of time, such as fleet characteristics, company size, fleet operation, cargo type and value, and management strategy.

4.2 Sample Source

Contact information for truck operators was obtained from researchers at the University of California, Irvine. In the Spring of 1998, the UC Irvine team conducted a telephone survey of truck operators by drawing randomly from "1) 804 California based for-hire trucking companies with annual revenues over \$1 million, 2) 2129 California based private fleets of at least 10 vehicles and 3) 2325 for-hire large national carriers not based in California with annual revenues of over \$6 million" [Regan and Golob, 1999]. The names and contact information for these companies were purchased from Transportation Technical Services Inc., which collects information for over 46,000 truck operators from a large insurance company. The UC Irvine team's effort resulted in a sample of 1177 responses, which is the equivalent of 35% of the companies contacted. While the UC Irvine survey provided one of the most comprehensive listings of California based truck operators available, it did not collect data that could be used to estimate value of time. The benefit of using the contact information provided by the UC Irvine team is that it already contained the names of the decision maker for truck operations for each company. From the list of 1177 respondents, 238 based in Southern California, which included Los Angeles, Orange, San Bernardino and Riverside Counties, and 120 based in Northern California including Alameda, Contra Costa, Solano and Sacramento Counties were extracted. The two areas were selected because of high geographical concentration of truck operators (the survey was conducted by face-to-face interviews), and potential subjects' familiarity with the concept of congestion pricing (there are several such facilities in Southern California).

4.3 Survey Methodology

To help the formulation of the survey plan and questionnaire, an exploratory survey was conducted in August 1998. The objectives of the exploratory survey was to assess the degree of variability in fleet management among different types of motor carriers and to collect general information about the way the trucks operated. Six companies were chosen at random in the San Francisco Bay Area. They were asked about their daily schedule of truck operations and about their management structure. Also, the draft version of the survey questionnaire was tested to make sure that the subjects were able to understand it clearly. Based on the information gathered from the exploratory survey, the questionnaire for the main survey was finalized.

Stated preference surveys, in which respondents are asked to state their valuation or choice of alternatives for hypothetical situations, were chosen for several reasons. First, since most of the congestion priced roads do not allow heavy vehicles, revealed preference data, recorded choice behavior for actual situations, were impossible to obtain. Also, with a limited amount of resources available, conducting a survey that covers broad types of motor carriers, and at the same time, provides a sufficient sample size for each segment was difficult. In stated preference surveys; however, multiple responses can be obtained from each subject in a short period of time. With appropriate correction for the bias introduced by repeat responses, as discussed in the next chapter, stated preference surveys can provide necessary data efficiently. Furthermore, the stated preference framework allows the questions to be tailored to meet specific need of a study, which enables the value of time to be measured directly from the responses.

Despite the advantages mentioned, stated preference surveys are also prone to the inclusion of various types of bias which can be quite serious. The most obvious problem is that the preferences indicated for hypothetical scenarios can be different from those observed in actual situations. The discrepancies can be caused by the respondent not considering the consequences of the choices as seriously as he/she would in actual situations, or the respondents may see the survey as an opportunity to make a political statement through the preferences indicated. Ranking or rating data obtained from stated preference surveys can be unreliable since the magnitude of the preferences may not be reflected in the responses [Hensher, 1994]. Also, ranking and rating of alternatives seems to be an unusual activity in transportation, and consequently the likelihood of discrepancies between the true and stated preference may increase. These problems, however, can be reduced with careful planning of the survey and applying appropriate modeling techniques.

The comprehensive review of contingent valuation, which is a measurement of the willingness to pay through surveys, conducted by a panel of experts for the National Oceanic and Atmospheric Administration for the assessment of the damage caused by the Exxon Valdez incident recommended personal interview as the most appropriate method over telephone and mail surveys [Portney, 1994]. When the survey is conducted face-to-face the interviewer can directly observe the attention level and the attitude of the subject and proceed accordingly. If the subject seems not to understand the concept of congestion pricing, for example, the interviewer would not proceed with the stated preference questions until the subject gains clear grasp of the scenarios and the consequences of the

trade-offs. Although conducting personal interviews require substantial resources, they were deemed justified in exchange for the improvement in the quality of the data collected.

The surveys for the Southern California and Northern California motor carriers were conducted in November 1998 and January 1999, respectively. The final questionnaire, included in Appendix B, contained 25 questions⁷ regarding the characteristics of the company and fleet management and operations, and 10 stated choice questions in which the subjects were asked to state the choices between the toll lanes and free lanes for varying levels of tolls and travel time differences. The respondents were owners of the company, dispatchers, and transportation managers. The name of the contact for each company was already identified during the UC Irvine survey. While most subjects were familiar with the congestion pricing projects in California, a description of a congestion priced freeway segment where travelers can choose between the free lanes and toll lanes was given.

A direct way to determine value of time is to observe a scenario for which the switching of the mode occurs. For example, if a motor carrier is willing to pay \$10 to save 10 minutes by taking a toll lane but would not pay \$12 for the same time saving, the value of time is estimated to be between \$60 per hour and \$72 per hour. While observing the switching value results in a sample size equal to the number of respondents, using a discrete choice model, as discussed in Chapter 5, utilizes the information from all responses.

Initially, the stated choice scenarios were designed to cover values of time between \$8 and \$150 per hour. However, the first part of the survey (conducted in Southern California) recorded no truck operator with a value of time greater than \$120 per hour while several indicated less than \$8 per hour. Thus, for the Northern California survey the scenarios were modified to cover a range from \$4 to \$120 per hour. Since the scenarios were designed to measure value of time in approximately \$10 per hour increments, a follow-up survey was conducted to obtain more detailed data. For the follow-up survey, five additional stated choice questions, identical in format with those in the main survey, were asked by mail for the Southern California survey and by interview during the Northern California survey. These questions were tailored to each respondent according to the value of time range indicated during the initial survey. The follow-up surveys were designed to narrow down the value of time to within \$2 to \$3.

The amount of time saving in the hypothetical scenarios was limited to 15 minutes or less, reflecting the savings recorded for a segment of existing congestion priced freeways. Furthermore, values such as 11, 9, 21 were avoided for both travel times and tolls. The reason behind this is that those values may be indistinguishable from "major" threshold numbers such as 10 and 20 in terms of decision making, making it hard for the respondents to perceive the difference between one scenario and another. While an attempt was made to create an orthogonal choice set, in which the independent variables (toll and time saving for this case) are uncorrelated, perfect orthogonality could not be attained while following the aforementioned rules. While orthogonal design of the independent variables is used widely in stated preference surveys to avoid

⁷ Questions 10 and 22 were omitted. See Appendix B for the explanation.

multicollinearity, its value has recently been questioned. Fowkes et al. have shown that orthogonal choice sets do not result in minimum variance when a ratio of parameters such as value of time is being measured [Fowkes et al, 1993]. Also, Hensher and Bernard have pointed out that the orthogonality in a choice set does not always result in orthogonal estimation data [Hensher and Bernard, 1990]. Finally, the order of the questions was randomized to avoid the effect of fatigue and help maintain the subject's attention level.

The data collection began by contacting the name of the decision maker for each company listed in the UC Irvine database to set up an appointment for a face-to-face interview. Although a total of 358 company names and contact persons were obtained from the UC Irvine database, only 235 could be contacted. Even though at least three attempts were made to reach each person, some people were often away from the office or on the phone constantly. In the end, a total of 70 companies were interviewed, which is approximately a 20% response rate. Also, 30 out of 43 respondents in the Southern California survey responded to the follow-up survey conducted by mail. In the next section, the characteristics of the responses are discussed.

4.3 Sample Characteristics

Tables 3 through 5 show key sample characteristics. As shown in Table 3, about 60% of the sample were collected in Southern California. The contact list contained a far greater portion of for-hire companies in Southern California, particularly near the Port of Long Beach compared with Northern California. Table 4 indicates that a majority (55%) of the respondents in Southern California specialized in truckload (TL) business, while about

55% of the respondents in Northern California specialized in less-than-truckload (LTL) business. The regional differences in respondents' characteristics may be due to the impact of the ports of Long Beach and Los Angeles. The total tonnage handled by the two ports was approximately 100 million tons in 1997 while the ports of Oakland and Sacramento processed only 12 million tons [Army Corps of Engineers, 1997]. The motor carrier industry in the Southern California is more dominated by the demand created by the ports, which require specific types of services such as drayage connecting port and rail terminals or container transport. Consequently, there is more demand for for-hire motor carriers, and particularly TL carriers in that region. The tables also show that very small percentage of the respondents transport both LTL and TL shipments while the split between TL and LTL carriers is about even.

Table 3: Breakdown of Respondents (Area vs. Business Type)

	Private	For-Hire	Total
So. Cal	14	29	43
No. Cal	25	2	27
Total	39	31	70

Table 4: Breakdown of Respondents (Area vs. Shipment Size)

	TL	LTL	LTL and TL	Total
So. Cal	24	17	2	43
No. Cal	11	15	1	27
Total	35	32	3	70

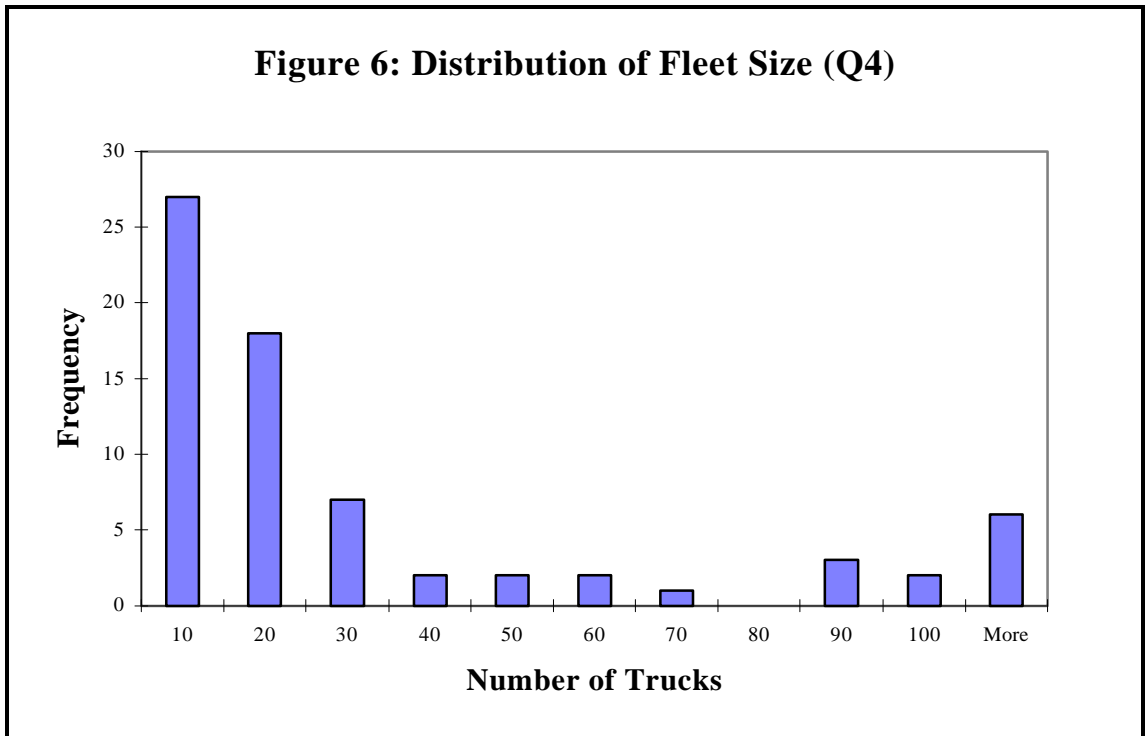
Table 5 shows that the breakdowns by shipment sizes are almost the same for private and for-hire fleets.

Table 5: Breakdown of Respondents (Business Type vs. Shipment Size)

	TL	LTL	LTL and TL	Total
Private	16	15	0	39
For-Hire	19	17	3	31
Total	35	32	3	70

Some of the key findings from the survey are discussed in conjunction with Figures 6 through 10. Also, the findings from other questions are included in Appendix C.

A fleet is defined as a group of trucks that are operated out of the same terminal. Even though some large companies such as Consolidated Freight or Trimac own a large number of trucks throughout the country, trucks are operated and managed at a local fleet level. Therefore, in terms of measuring value of time, the analysis should be conducted at that level. The distribution in Figure 6 shows that most of the respondents operated less than 100 trucks with relatively small fleets of between 0 and 20 trucks being most common. The median is 13.5 trucks. There are only several large fleets with more than 200 trucks.



A trip is defined as all of the activity between a truck leaving and coming back to the base terminal. Figure 7 indicates that nearly half of the respondents dispatch each truck from the terminal only once a day while Figure 8 shows that a considerable portion of the trucks only make one pick-up or delivery per trip. This seemingly contradictory result can be explained by looking at the data in further detail. The comparison of the average number of stops per trip between the fleets that make only one trip a day and those make more than one trip reveals that the former group averages 8.3 stops per trip while the latter makes only 2.7 stops. Therefore, the fleets that make only one trip a day are utilizing the trucks efficiently by linking stops.

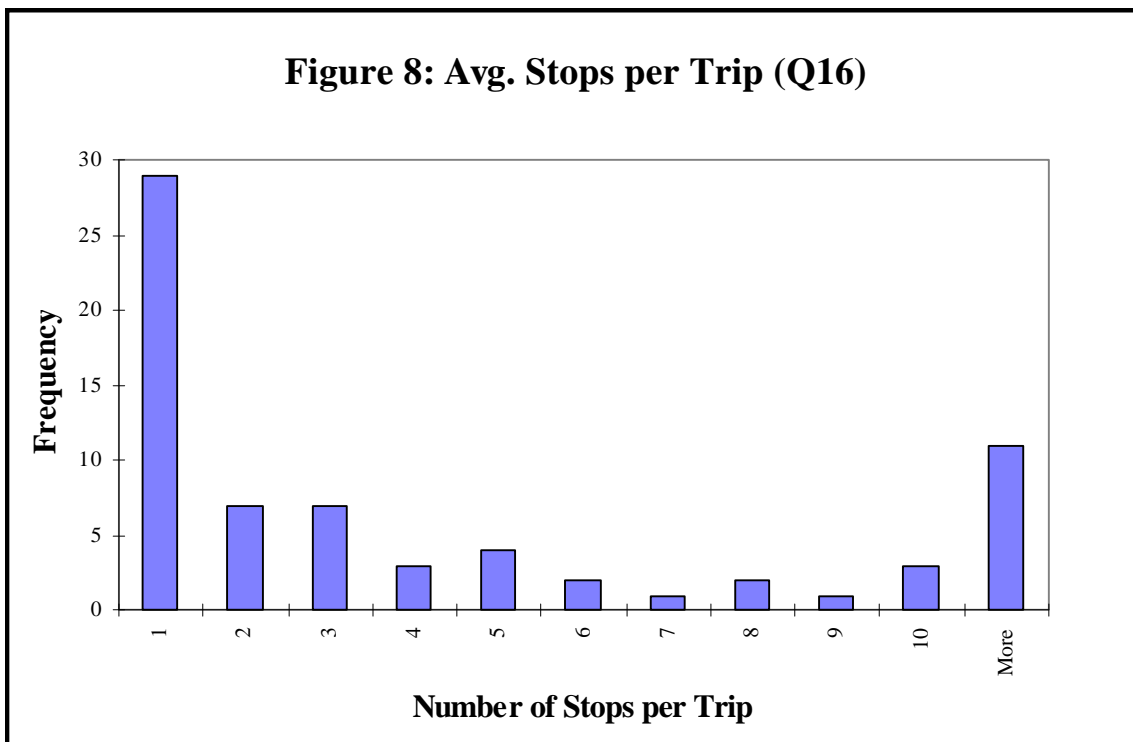
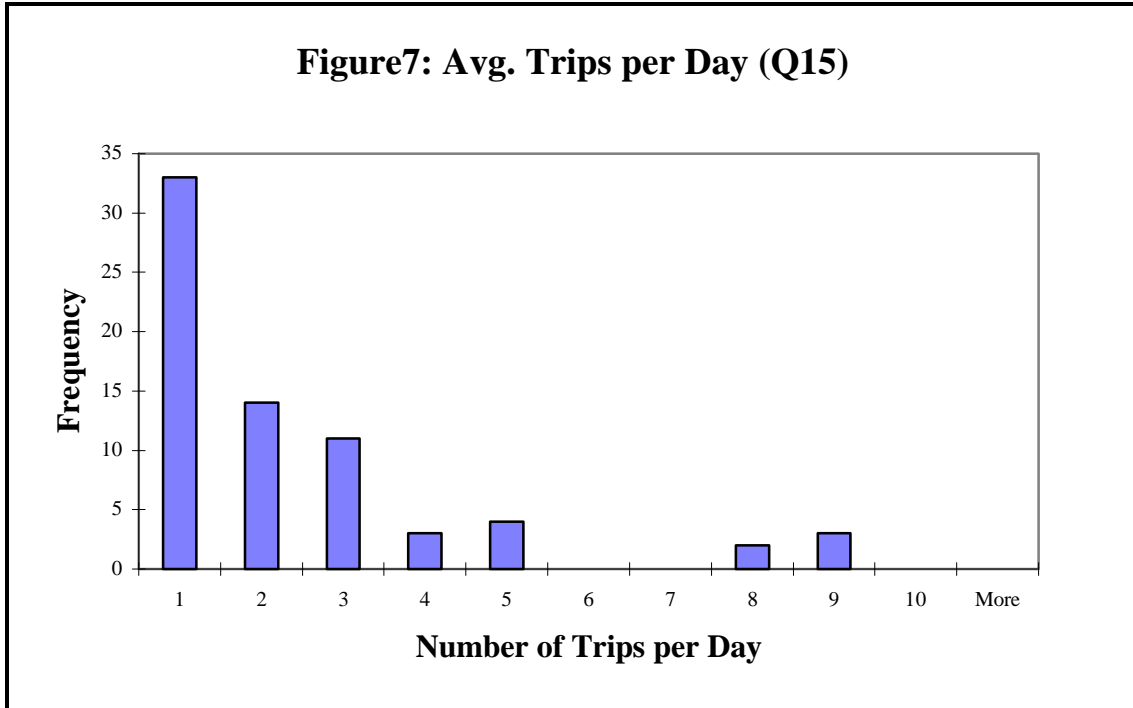
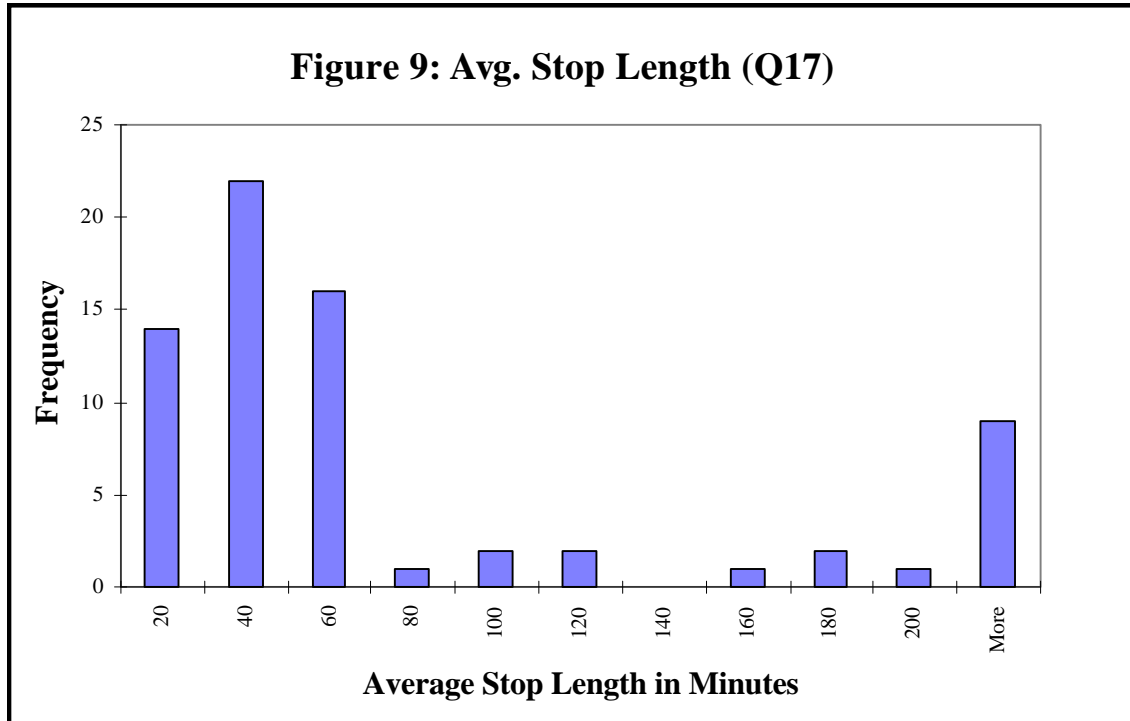


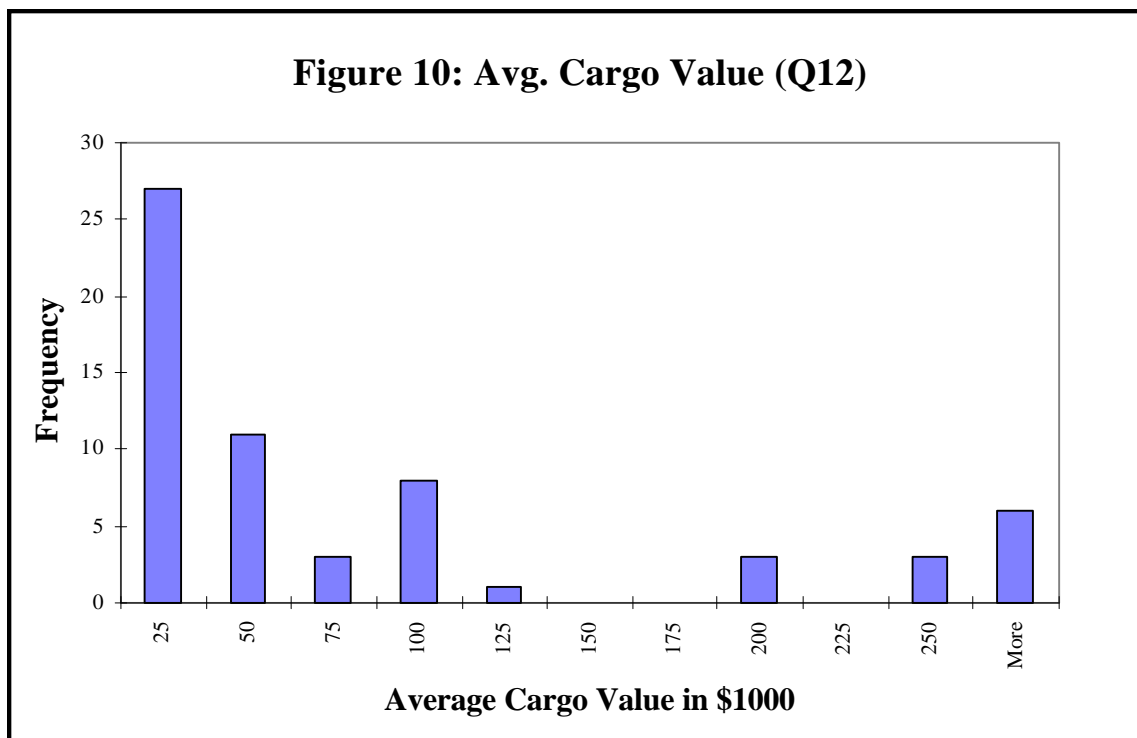
Figure 9 shows that most companies' average stop length does not exceed one hour.

However, some trucks such as those transporting construction machinery or equipment

repair technicians make prolonged stops at construction or repair sites. These type of truck uses are included in the category of more than 200 minutes per stop.



As shown in Figure 10, more than half of the respondents indicated that the average value of cargo transported by their trucks was less than \$50,000. Competition from air transportation may be the reason for this relatively low figure. Trucks generally do not carry expensive cargo compared with air planes. The average revenue per ton-mile for trucks was about 20 cents while air planes recorded about 80 cents [Wilson, 1996]. Several respondents indicated that they avoid transporting expensive cargo to reduce insurance costs.



Since the list of company names and contacts is selected from the respondents to another survey, selection bias is of concern. The comparison of the sample statistics against the data from mandatory-response surveys, such as Truck Inventory and Use Survey (TIUS) and Commodity Flow Survey (CFS), should reveal the degree of bias. Unfortunately, the former is a vehicle based survey, and a comparison can not be made. Similarly, the CFS can not be used since service trucks are not included. The best sources of data for comparison are the 1990 Nationwide Truck Activity and Commodity Survey (NTACS) and the UC Irvine survey even though both are discretionary-response surveys. The NTACS was conducted by the Bureau of Census and covered more than 22,000 trucks nationwide with a response rate of 50%. Since the data are not available at state level, Census Region 9, which includes Pacific Coast states and Hawaii, is used for the

comparison. Following is a comparison of the data that are common among at least two of the three surveys.

- Share of private fleet

Survey (44%), NTACS Region 9 (43%), UC Irvine (43%)

- Number of daily stops (median)

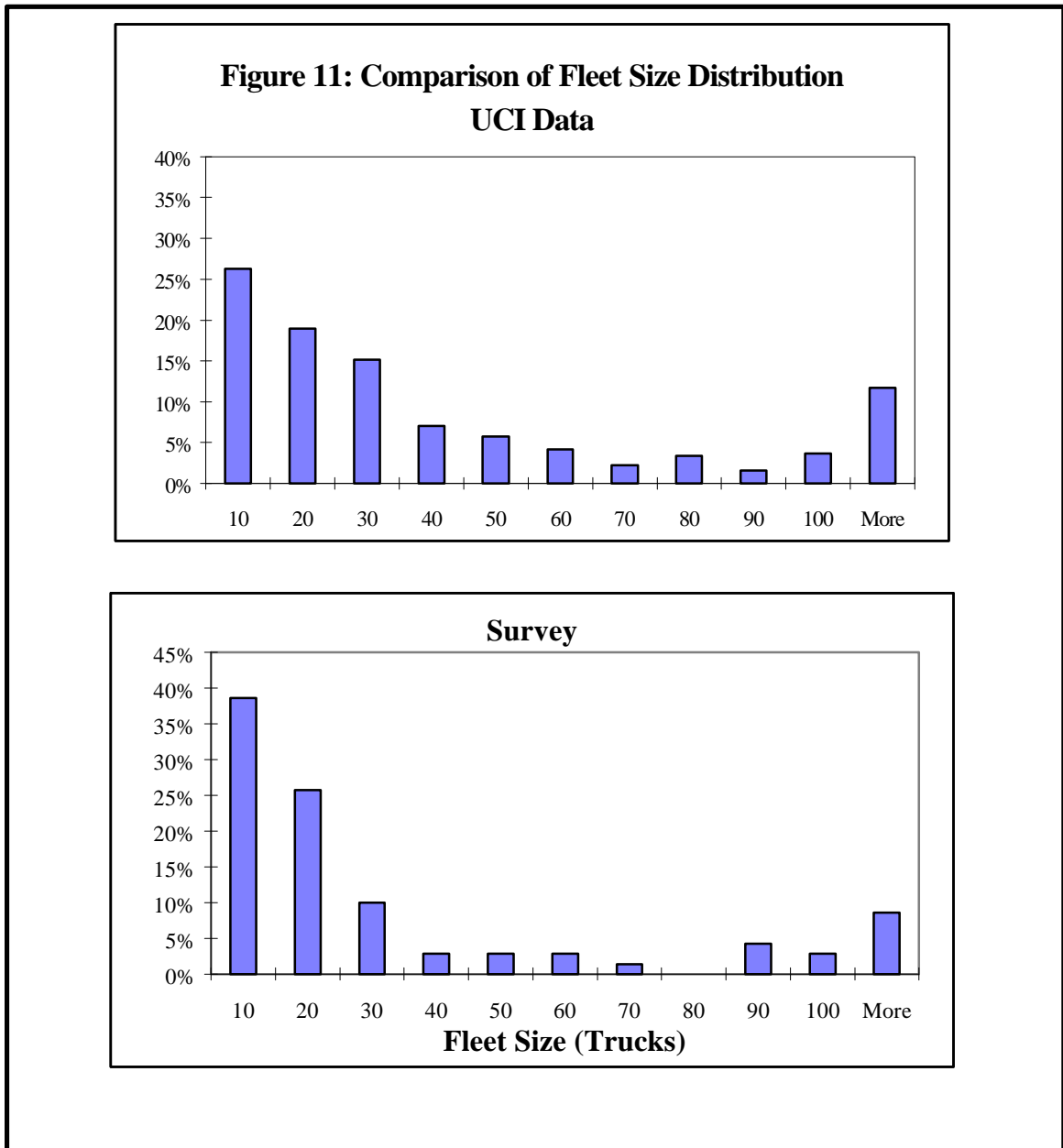
Survey (3), NTACS Region 9 (3)

- Share of Truckload fleet

Survey (54%), UC Irvine (51%)

Based on the assumption that the NTACS and UC Irvine surveys covered the motor carrier industry without much bias, these figures show that the collected sample seems to represent the general universe of the motor carrier industry without a bias with respect to business type or shipment size. Also, as a means of additional comparison, Figure 11 compares the trip length distribution against the UC Irvine survey.

The figures show that while general shapes of the distributions are similar, the survey included a higher percentage of smaller fleets with less than 20 trucks. This result probably stems from collecting data mainly in the metropolitan areas. It is reasonable to speculate that larger fleets tend to locate terminals in rural areas with low land price. The survey was conducted mostly in semi-dense industrial areas where not many large terminals were found.



In stated preference surveys, it is important to assess reasonableness of the responses. If too many responses contradict each other or are unrealistic, there is a strong possibility that the respondents misunderstood the questions or were not answering truthfully. Surprisingly, the responses to the stated preference questions showed a high level of consistency. Many of the respondents converted, some even using a calculator, each hypothetical trade-off scenario into the value of time before making a choice. Some of the

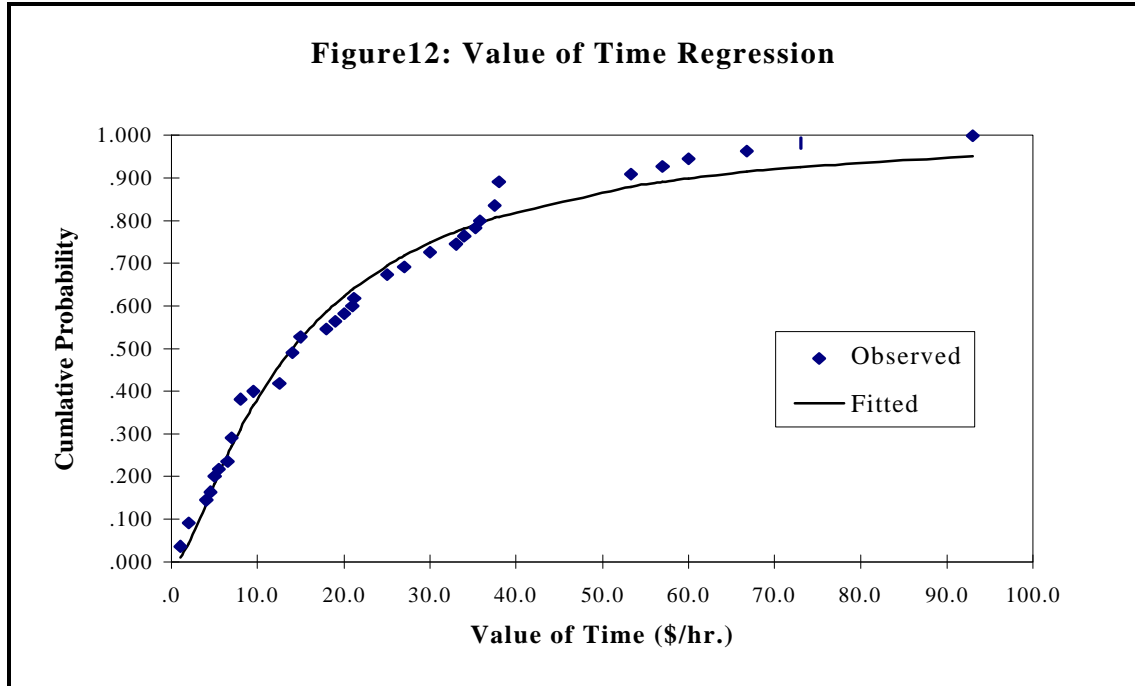
respondents used a specific break-even point for operating cost or the amount of revenue per hour that is necessary to generate profit, and made the choices accordingly. Overall, only three respondents gave contradictory or illogical answers, in which switching of lane choice occurred more than once, to the first 10 questions. However, for the follow-up questions, 26 out of 55 respondents gave illogical answers. This phenomenon seems to be independent of the method of the survey. For the follow-up survey in Southern California, which was conducted by mail, 43% of the respondents gave at least one illogical answer while the Bay Area survey, conducted by face-to-face interviews as a part of the main survey, resulted in 48% illogical respondents. Many of the subjects commented that for the follow-up questions, in which the range for the value of time indicated by the initial survey was further divided into six increments (each increment was typically \$2 to \$3), the scenarios offered approximately the same trade-off values to them. This finding indicates that while the motor carriers' choices are based on a logical break-rule, that rule is flexible and creates a range, rather than a specific number for value of time. The treatment of illogical responses is discussed in the next chapter.

CHAPTER 5: COMMERCIAL VEHICLE VALUE OF TIME

In this chapter, commercial vehicle values of time are estimated from the stated preference data. In addition to the overall value of time, different schemes for segmentation, by business type, shipment size, and the bases for employee compensation, are used to separate the data into two groups, and the value of time is estimated for each group.

5.1 Value of Time Based on Switching Point

As mentioned in the previous chapter, the stated preference questions were designed to narrow down the range of the value of time for each respondent within \$2 to \$3 per hour based on the level of trade-off where the choices switch from free lane to toll lane. A total of 55 data points (of which 28 were collected by follow-up mail survey and the remaining 27 by in-person interview) were fitted with lognormal distribution using the least square method. The fit of the data is depicted in Figure 12. Of the 55 respondents used in the curve fitting, 26 made at least one illogical choice in their responses. Of those, 19 respondents made only one illogical that conflicted with all the others. For these respondents, the value of time was estimated after eliminating the illogical choice from the data. For the remaining seven response sets that contained more than one illogical choice, the interpretation that minimized the number of conflicting choices was applied to identify the value of time.



A random variable X has lognormal distribution if $\ln(X) \sim N(\mathbf{m}, \mathbf{s})$. The mean, M , and variance, S^2 , of a lognormal variable are

$$M = \exp(\mathbf{m} + \mathbf{s}^2/2) \quad [25]$$

$$S^2 = \exp(2\mathbf{m} + \mathbf{s}^2)(\exp(\mathbf{s}^2) - 1) \quad [26]$$

The statistics from the regression are shown in Table 6.

Table 6: Non-Linear Regression Results

Parameter	Estimate	Standard Error
\mathbf{m}	2.640	0.0250
\mathbf{s}	1.139	0.0396

$$R^2 = 0.986$$

$$\text{Mean(VOT)} = 26.80$$

$$\text{Standard Deviation (VOT)} = 43.68$$

The remarkably high R-square indicates a good fit using the lognormal distribution curve. In the past, researchers have asserted that value of time should have a lognormal distribution. This is because the microeconomics theory correlates value of time with income, which is known to have lognormal distribution [Ben-Akiva et al., 1993] [Aitchison and Brown, 1957]. As mentioned in Chapter 3, a stated preference survey of commercial vehicles in France also showed a good fit using the lognormal distribution [Wynter, 1995]. The mean value of time is \$26.8/hr. This value is within the range of values found by the past U.S. studies using the cost or revenue methods. Waters et al. estimated driver's wage including fringe benefit to be between \$17.3 and \$24.5 per hour, and other operating costs, which are both time and distance dependent, at about \$8.2 per hour in 1998 prices [Waters et al., 1995]. The standard deviation is considerably larger than the mean, indicating a wide distribution of values. The finding that the value of time is well replicated by the lognormal distribution is used in correcting the bias introduced by repeated sampling from each respondent as discussed in subsequent sections of this chapter.

The data points for the two highest values of time on the graph correspond to a household goods mover and an air conditioner service company. While the values of time exceeding \$70/hr. seem extreme, brief discussion with each respondent after the interview revealed that their choices were completely logical. The moving company usually dispatches a car carrying up to four employees accompanying a truck. The survey respondent stated that since the moving can not begin until the truck arrives at the job site, when the car arrives before the truck, which happens occasionally because cars can utilize car pool lanes, the

labor cost associated with the waiting time for up to four employees easily exceeds \$80 per hour. For the air conditioner company, the labor cost (including the fringe benefits) is more than \$80 per hour since the truck drivers are also electrical technicians who repair and maintain air conditioning units. Also, other respondents that recorded the values of time exceeding \$60/hr. include a carrier of fish and other perishable commodities and a concrete ready-mix company that faces a severe penalty if the delivery to the construction site is not on time. There are also several data points at very low value of time. The lowest point, \$0.5/hr., belongs to a construction company that sends specialized trucks to construction sites throughout the western United States. Once a truck arrives at a construction site, it does not leave the site for several weeks. For these trucks, several minutes of difference in the travel time to the construction site is not critical since the time window for arrival is usually more than 24 hours and the trip usually take a day or longer. In addition, each truck is on the road only once every few weeks. The second lowest value of time belongs to a for-hire carrier that transports gravel and debris from construction sites. The respondent stated that since they charge clients by the number of hours it takes to haul construction materials, moderate traffic delay can actually increase profit for the company. Also, the pickup and delivery time window is more than 12 hours for this company. A dairy product company that has the third lowest value of time seems to have excess transportation capacity since each truck is on the road only one to two hours a day. If transportation capacity exceeds the demand, travel time savings can not be converted into additional revenue. Also, the time required to fill each truck with dairy product is considerably greater than the delivery time, making travel time savings less significant since shorter travel time means longer wait at the plant. Seven of the ten lowest values of

time belong to private carriers. Also, eight have delivery or pickup time windows longer than four hours. Thus, individual assessment of the characteristics of the business and fleet operation requirements reveals that these decision makers might have been completely logical in responding to the questions.

5.2 Logit Model and Value of Time

Founded on consumer behavior theory, the logit model has been applied in a variety of transportation studies including the measurement of value of time. The following discussion gives a background on use of the logit model to obtain the value of time from discrete choice data.

Assume that the utility function for individual n for choosing alternative i is defined by,

$$U_{in} = \mathbf{a}C_{in} + \mathbf{g}T_{in} + \mathbf{e}_{in} \quad [27]$$

where C_{in} and T_{in} are monetary cost of travel and travel time for alternative i for an individual n , respectively. The variables \mathbf{a} and \mathbf{g} are parameters. The last term, \mathbf{e}_{in} , represents the unobserved portion of the utility and is considered to be a random variable. The sources of this stochastic portion of the utility are; unobserved attributes, taste variations, measurement errors and imperfect information, and proxy variables resulting from the imperfect relationship between the attributes and the alternatives [Ben-Akiva and Lerman, 1985]

Assuming that the random variable, \mathbf{e}_{in} , is identically and independently distributed (IID) with extreme-value (Gumbel) distribution, the probability, P_{in} , of choosing alternative i among j alternatives is calculated by the standard logit formula

$$P_{in} = \frac{\exp(V_{in})}{\sum_{i=1}^j \exp(V_{in})} \quad [28]$$

Where V_{in} is the observable portion of the utility (i.e. $\mathbf{a}C_{in} + \mathbf{g}T_{in}$) [McFadden, 1974].

The estimates of the coefficients, \mathbf{a} and \mathbf{g} are usually obtained by the maximum likelihood method with the log of the product of the individual choice probabilities as the objective function.

Since the marginal utility of cost and time can be found by

$$\frac{\partial V_{in}}{\partial C_{in}} = \mathbf{a} \quad [29]$$

$$\frac{\partial V_{in}}{\partial T_{in}} = \mathbf{g} \quad [30]$$

respectively, the coefficients indicate the marginal effect on utility caused by change in the attributes of alternatives. Finally, the value of time is calculated by taking the ratio between the marginal utility of cost and time, which is equivalent of the quotient of the coefficients

$$\text{Value of Time} = \frac{\mathbf{g}}{\mathbf{a}} \quad [31]$$

While the logit model can be quite useful in the analysis of travel behavior, problems that stem from some of the model's underlying assumptions have been pointed out [Ben-Akiva and Lerman, 1985]. Aggregate estimation of the logit model assumes that the coefficients in the utility function reflect "average" or "representative" behavior, and the model does not capture the variation of the coefficients over individuals. Therefore, the use of the logit model is somewhat contradictory when the objective of the study is to measure the differences in the coefficient values. In the past, this problem has been addressed by: 1)

including socioeconomic variables that may explain the variation of the coefficients in the utility function, 2) relaxing the constant coefficient assumption (e.g. assuming the coefficients to be random variables with known or pre-specified distributions), 3) segmenting the data into groups with relatively homogeneous characteristics and developing separate models for all segments. In the past, the second approach, while theoretically appealing, has not been applied widely due to the computational difficulty in calibrating the model. In this study; however, software developed by Kenneth Train, David Revelt and others at the Department of Economics at the University of California was used to calibrate such a model, often called a random coefficient logit or mixed logit, in conjunction with the segmented data base.

Another problem associated with the logit model is the Independence of Irrelevant Alternatives (IIA) property. The IIA property holds that the ratio of the choice probabilities for two alternatives are unaffected by the presence of other alternatives. This well known property of the logit model is caused by the assumption of independently and identically distributed (IID) error terms, and can result in erroneous results when two or more alternatives share common characteristics, generating correlation in unobserved utility. One such example is a choice situation among three or more alternative routes where a significant portion of two of the routes overlaps, which is a real possibility in this study. However, the random coefficient logit model does not exhibit IIA property as discussed in the next section.

In addition to its intrinsic properties, recent studies have pointed out potential problems caused by the use of stated preference data in the logit model framework. The assumption of IID error terms is violated when multiple observations from a single individual are used to calibrate the model because by definition, the responses are correlated. Again, the random coefficient logit model provides a solution to this problem as discussed in the next section.

5.3 Random Coefficient Logit Model

The problem of bias caused by repeated responses has been discussed rather extensively in recent years, mainly due to the growing popularity of stated preference data. Also, the use of panel surveys, in which the respondents are surveyed several times over a time period, presents a similar type of problem. It has been known that correlation in the error terms results in the underestimation of standard errors for the coefficient estimates [Ortuzar et al., 1997]. Carillo et al. has confirmed the presence of this bias using the Bootstrap and Jackknife resampling techniques [Carillo et al., 1996]. In the logit framework, erroneous standard error estimate poses a serious problem since the values of the coefficients are normalized against the variance of the error term [Bradley and Daly, 1992]. Thus various ad-hoc correction techniques such as multiplying the standard errors by the square root or even the third root of the number of observations have been applied [Bates and Terzis, 1997]. A more sophisticated approach proposed by Abdel-Aty et al. adds a parametric correction factor to the utility function. The correction factor is assumed to be normally distributed with zero mean and the variance of the distribution is estimated as a part of the model calibration process [Abdel-Aty et al., 1994].

A different approach in which the coefficients are assumed to be random variables with some pre-specified distribution has been applied to solve this problem [Revelt and Train, 1997]. In this approach, the coefficient vector for an individual can be written as $\mathbf{b}_n = \mathbf{m}_b + \mathbf{h}_b$, where \mathbf{m}_b is the population mean vector of \mathbf{b}_n , and \mathbf{h}_b is the vector of stochastic deviation from the mean. Thus, the utility function for individual n can be written as $U_n = \mathbf{m}_b X_n + \mathbf{h}_b X_n + \mathbf{e}_n$, where X_n is the vector of attributes. When decomposed like this, the last two terms of the right-hand side can be considered to be the stochastic portion of the utility, which consists of \mathbf{e}_n alone in the standard logit model. Under this new formulation, the stochastic portion of the utility function is no longer independent, and the correlation over alternatives and scenarios can be captured by estimating the distribution of the coefficient. Some of the problems associated with the standard logit framework such as the IIA property and the bias from using repeated observations are not present in the random coefficient logit. However, until recently, computational requirements for calibrating the model, as discussed below, have discouraged practical application of the random coefficient framework⁸.

With the random coefficient logit model the probability for an individual n to choose i among j alternatives is expressed as

$$P_n(i) = \frac{\exp(\mathbf{b}_n X_{in})}{\sum_{i=1}^j \exp(\mathbf{b}_n X_{in})} \quad [32]$$

⁸ In the late 1970's, the Electric Power Research Institute used random coefficient specification with lognormal distribution to analyze the demand for automobiles [Ben-Akiva and Lerman, 1985].

where \mathbf{b}_n is the coefficient vector that is constant for each individual but varies across the population and X_{in} is the vector of an alternative's attributes. Since the coefficients are allowed to vary over the population, each individual has unique utility function. Thus, the probability (conditional on \mathbf{b}_n) for the sequence of the observed choices for individual n is

$$CP_n = \mathbf{P}_t P_{ni(t)}(\mathbf{b}_n) \quad [33]$$

where t denotes each question. The unconditional probability, evaluated over all possible values of \mathbf{b}_n is given by

$$P_n = \int CP_n f(\mathbf{b}_n) d\mathbf{b}_n \quad [34]$$

where $f(\mathbf{b}_n)$ is the distribution of the coefficient to be estimated. Equation 34 can not be solved in closed form and analytical solution is impossible, which has been a major obstacle to applying the random coefficient model in practice. The software developed by Revelt and Train approximate P_n by simulation. Specifically, for given values of parameters that specify the distribution of the coefficients, $f(\mathbf{b}_n)$, many values of \mathbf{b}_n are randomly drawn, and a conditional probability, CP_n , is evaluated for each draw. The unconditional probability, P_n , is approximated by the average of CP_n from many draws. The simulated log-likelihood function is the summation of the log of the unconditional probability over all the respondents. While the simulated log-likelihood is a biased estimator, the amount of bias decreases as the number of draws increases. In the experiment conducted by McFadden and Train, the standard deviation in the parameter estimates caused by using simulated loglikelihood was between 0.4% and 8% of the estimated coefficients with 1000 draws [McFadden and Train, 1995]. The selection of the number of repetitions is a question of balance between computing time and accuracy, and

several test runs were conducted to assess the sensitivity of the coefficient estimates. In this study, 500 draws produced very stable estimates.

5.4 Parameter and Coefficient Estimates

The utility function used in determining the value of time is introduced as equation 27.

Reiterating, the utility for an individual n choosing alternative i is expressed as

$$U_{in} = \mathbf{a}_n C_i + \mathbf{g}_i T_i + \mathbf{e}_{in} \quad [35]$$

Where, for this study

i = alternative; taking the free lane or toll lane

C_i = monetary cost associated with alternative i ; 0 for the free lane and the amount of the toll for toll lane alternatives

T_i = travel time for alternative i

\mathbf{e}_{in} = unobserved stochastic portion of utility

The software developed by Revelt and Train allows the coefficients, \mathbf{a} and \mathbf{g} , to have normal or lognormal distributions that vary over the population but are fixed within the responses obtained from single individuals. In other words, during the calibration of the model, the values of the coefficients are held constant for each individual while they are allowed to vary across the population according to a specified distribution. Since the responses were obtained within a short time period, the assumption of a constant utility function for each respondent is reasonable. For this study, the model is fitted assuming that both coefficients are lognormally distributed for the following reasons. First, it is in accord with the results from previous analyses. As discussed in 5.1, the values of time

inferred directly from the point of mode switch are well replicated by a lognormal distribution. Also, the only other comparable study, by Wynter, produced a similar result. A quotient of two log normal distributions is also lognormally distributed. Therefore, assuming that both \mathbf{a} and \mathbf{g} as such will produce lognormally distributed value of time. Another, more theoretical reason is that a lognormally distributed random variable is always positive (or negative if multiplied by -1). Since both travel time and out-of-pocket cost should have, in theory, a negative effect on the utility of any logical traveler, this property of lognormal distribution is appealing.

In this report, the terms parameter and coefficient are used to distinguish the parameters of distributions from the coefficients in utility functions. Since any lognormal distribution is specified by two parameters, a total of four parameters (two for each coefficient) had to be estimated. First, the parameters were estimated using all data points. Then the data were segmented into two groups according to shipment size (truckload vs. less-than-truckload), business type (private vs. for-hire fleets), and the basis for compensation (hourly vs. other pay scale including fixed salary and commission by mile or load). Therefore, a total of seven models were fitted.

Difference in shipment size can effect the schedule and the number of linked trips, which, in turn, may determine the degree of aversion to delay. It is assumed that the degree of competitiveness in private and for-hire markets is different, causing for-hire fleets to be more sensitive to delay. In terms of impact of delay on labor cost, the companies that pay their drivers based on commission, whether it be by miles driven or the number of loads

transported, or pay fixed salary are not effected. On the other hand, each minute spent in traffic adds to the labor cost for the companies that pay the drivers by the hour, making them more sensitive to travel time. While these three are used as the factors that may explain the variations in values of time, there are numerous other possibilities. For example, one can argue that the size of the fleet, value or type of cargo, or the number of employees can effect value of time in some way. However, due to the limited size of the sample, these other factors, particularly continuous variables, were not used to segment the data.

There were 29 respondents that stated at least one illogical choice, mostly in the follow-up surveys. In contrast to the switching point analysis, there is no need to determine the value of time for each respondent in the logit model. Therefore, illogical answers were used in the model without correction or interpretation⁹. Table 7 shows the parameter estimates and associated asymptotic standard errors for seven random coefficient logit model fitted. The parameter estimates, m and s , are the means and standard deviations of $\ln(a)$ and $\ln(g)$, respectively. All s are significant at 99% the level, indicating that the coefficients actually vary across the population.

Table 7: Parameter Estimates and Asymptotic Standard Errors

Data Group	g (Time Coefficient)				α (Cost Coefficient)			
	m	SE	s	SE	m	SE	s	SE
All	-1.091	0.155	0.869	0.104	0.376	0.134	0.548	0.096
Private	-1.262	0.239	0.745	0.208	0.518	0.247	0.744	0.140
For - Hire	-0.883	0.225	0.689	0.191	0.304*	0.197	0.616	0.165

⁹ The estimates from the data set that do not include the responses from the follow-up survey are included in Appendix D.

TL	-1.117	0.274	0.911	0.191	0.405	0.225	0.684	0.192
LTL	-1.028	0.196	0.663	0.160	0.346	0.198	0.602	0.133
Hourly	-1.001	0.213	0.871	0.130	0.364	0.170	0.504	0.126
Other	-1.357	0.279	0.519	0.196	0.361*	0.226	0.644	0.162

Note: * Significant at 90% level (one-tail). All other coefficients are significant at 95% level

A further assessment of the fit of the random coefficient model based on the likelihood ratio index is provided in Table 8.

Table 8: Comparison of Likelihood Ratio Indexes

Data Group	Sample Size	$L(\text{Logit})$	$L(\text{RCL})$	Logit	RCL
All	985	-521.0	-350.7	0.237	0.486
Private	430	-224.3	-149.9	0.248	0.497
For - Hire	555	-292.3	-195.8	0.240	0.491
TL	495	-255.9	-178.2	0.254	0.481
LTL	445	-237.5	-156.1	0.230	0.494
Hourly	635	-344.2	-226.2	0.218	0.486
Other Pay Base	350	-174.9	-120.6	0.279	0.503

The likelihood ratio index, or r^2 , is an informal goodness-of-fit statistic for a discrete choice model. It is calculated as

$$r^2 = 1 - L(\mathbf{q})/L(0) \quad [36]$$

where, $L(\mathbf{q})$ and $L(0)$, are the values of the likelihood functions evaluated at the estimated coefficients and at zero, respectively. The likelihood ratio index is analogous to the R-square in regression models. The figures show that allowing the coefficients to vary across the population results in substantial improvements, about doubling the likelihood ratio indexes for all seven models. Also all the likelihood ratio indexes are very comparable in magnitude, indicating a small effect of data segmentation on the fit of the models.

The results of the test of parameter vector variations across the data segment, in which the null hypothesis is, $\mathbf{B}_1 = \mathbf{B}_2$, where \mathbf{B}_n is the vector of parameters for segment n , are shown in Table 9. The test statistic based on the likelihood ratio is

$$\chi^2 = -2[L(\mathbf{B}_{All}) - \sum_{n=1}^2 L(\mathbf{B}_n)] \quad [37]$$

and has chi-square distribution with degrees of freedom equal to the difference in the total number of parameters estimated from the segmented models and the pooled data model.

Table 9: Test of Parameter Vector Variations

Comparison	Likelihood Ratio Test Statistic
Private vs. For-Hire	9.74
TL vs. LTL	32.74
Hourly vs. Other	7.74

Note: All statistics are significant at 95% level

The results indicate that the parameters, when tested jointly, do vary across the market segments. However, the test for the variation between individual parameters, shown in Table 10, produced different results. The t-test statistic is,

$$\text{t-statistic} = \frac{B_1 - B_2}{(SE(B_1)^2 + SE(B_2)^2)^{1/2}} \quad [38]$$

where B_n denotes the parameter estimates for segment n .

Table 10: Test of Parameter Variations

Comparison	t-statistic			
	γ		α	
	μ	σ	μ	σ
Private vs. For-Hire	-1.153	0.199	0.678	0.595
TL vs. LTL	-0.264	0.993	0.195	0.352
Hourly vs. Other	1.014	1.499	0.009	-0.683

None of the differences is significant at 90% level. The results from the two tests suggest that when all four parameters are considered jointly, there are variations between the data segments. However, the variation can not be attributed to any of the individual parameters. It should be noted that the mean of the lognormal distribution is a function of both m and s , therefore, it is possible for two distributions with different parameters to have the same mean.

Since the parameters are difficult to interpret in the lognormal distribution, the mean and standard deviation of the coefficients are calculated by equations 25 and 26 and presented in Table 11.

Table 11: Estimated Coefficients¹⁰

Data Group	Sample Size	g (Time Coefficient)		a (Cost Coefficient)	
		Mean	Std. Dev.	Mean	Std. Dev.
All	985	-0.490	0.521	-1.693	1.002
Private	430	-0.374	0.322	-2.214	1.904
For - Hire	555	-0.524	0.408	-1.638	1.112
TL	495	-0.495	0.563	-1.894	1.464
LTL	445	-0.446	0.331	-1.695	1.120
Hourly	635	-0.537	0.573	-1.633	0.878
Other Pay Base	350	-0.295	0.164	-1.765	1.266

For the time coefficients, standard deviations are generally comparable or sometimes greater than the mean, indicating the distributions to be spread out. For the cost coefficient, however, all the standard deviations are well below the means, showing more concentrated distributions. In other words, sensitivity to travel time has greater variation within the population than that for out-of-pocket cost. The mean of the time coefficient is the greatest for the model which included only the companies that pay the drivers by the

¹⁰ The attributes were expressed in negative values. Therefore, the coefficients were multiplied by - 1.

hour. In contrast, the companies that pay fixed salary or by commission have the smallest value. The private fleets have by far the largest cost coefficient while other groupings did not produce markedly different results. Comparison between the segments reveals that business types seem to effect sensitivity to travel time and out-of-pocket costs. As predicted, for-hire carriers seem to be much more sensitive to travel time than private fleets. A similar assessment can be made for the comparison of pay scale. As expected, the hourly pay group is more sensitive to the travel time. For the comparison of shipment size, the differences in the coefficients seem not as great as the other two. However, truckload carriers may be more sensitive to the out-of-pocket costs.

5.5 Value of Time Estimates

As described in equation 31, the value of time is the quotient of the time coefficient divided by the cost coefficient. Since the estimates are defined as random variables in our models, the quotients will also be random variables. The quotient, X_1/X_2 , of two lognormally distributed variables with parameters $(\mathbf{m}_1, \mathbf{s}_1^2)$ and $(\mathbf{m}_2, \mathbf{s}_2^2)$, respectively, is also lognormally distributed with parameters $(\mathbf{m}_1 - \mathbf{m}_2, \mathbf{s}_1^2 - 2\mathbf{s}_1\mathbf{s}_2 + \mathbf{s}_2^2)$. In this study the covariance term, $\mathbf{s}_1\mathbf{s}_2$, was taken to be zero based on the assumption that within each data group, the cost and time coefficients are uncorrelated. While segmenting the data into groups should help reduce the correlation to a some degree, this problem must be addressed in future studies.

Table 12 presents the characteristics of the value of time distributions for each data group. In addition to the mean and standard deviation defined by equations 25 and 26, the mode and median are calculated as

$$Mode = \exp(m - s^2) \quad [39]$$

$$Median = \exp(m) \quad [40]$$

Table 12: Value of Time Distributions

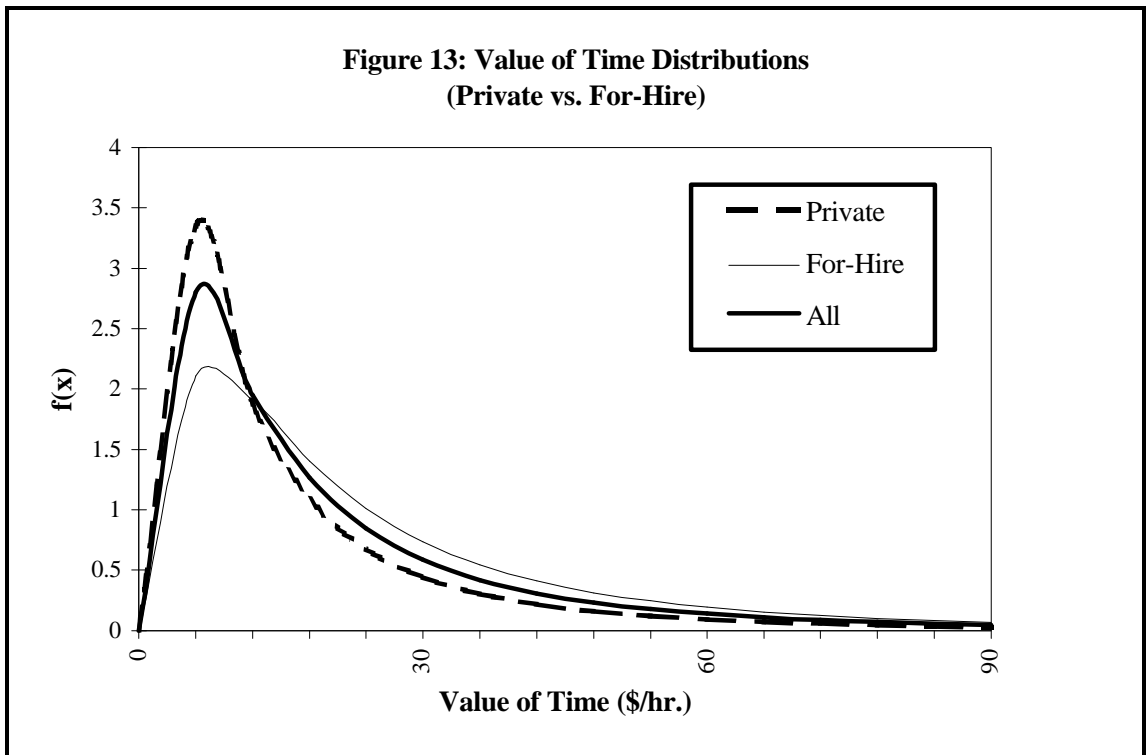
Data Group	Mean	St. Dev.	Mode	Median
All	23.4	32.0	4.8	13.9
Private	17.6	24.8	3.4	10.1
For-Hire	28.0	32.4	7.8	18.3
TL	25.0	40.4	3.6	13.1
LTL	22.6	25.0	6.8	15.2
Hourly Pay	25.4	33.5	5.6	15.3
Other Pay Scale	15.1	14.9	5.5	10.7

Note: Values are in \$/hour.

The overall value of time is \$23.4/hr, which is \$3.4/hr lower than the figure based on the switching points calculated earlier using a different sample (55 respondents). The standard deviation is considerably greater than the mean, indicating a rather flat distribution. Both the mode, which is the peak of the density curve, and the median occur at much lower values of time than the mean, indicating a severe skew to the right. The skew is caused by a small portion of the population with extremely high values of time. The for-hire group has the highest value of time while the "other pay scale" group recorded the lowest mean. Depending on the segmentation, there is as much as \$12.9/hr. difference in the mean values of time, which is substantial considering the relative magnitude with respect to the values of time themselves. Comparisons between the data group indicate that the for-hire trucks tend to have higher values of time than the private fleets. Also, the companies with

hourly pay are likely to have higher values of time than those which pay fixed salary or commission.

Figures 13, 14, and 15 show the comparison of probability density functions for private and for-hire, TL and LTL, and hourly pay and other pay scale data groups, respectively.



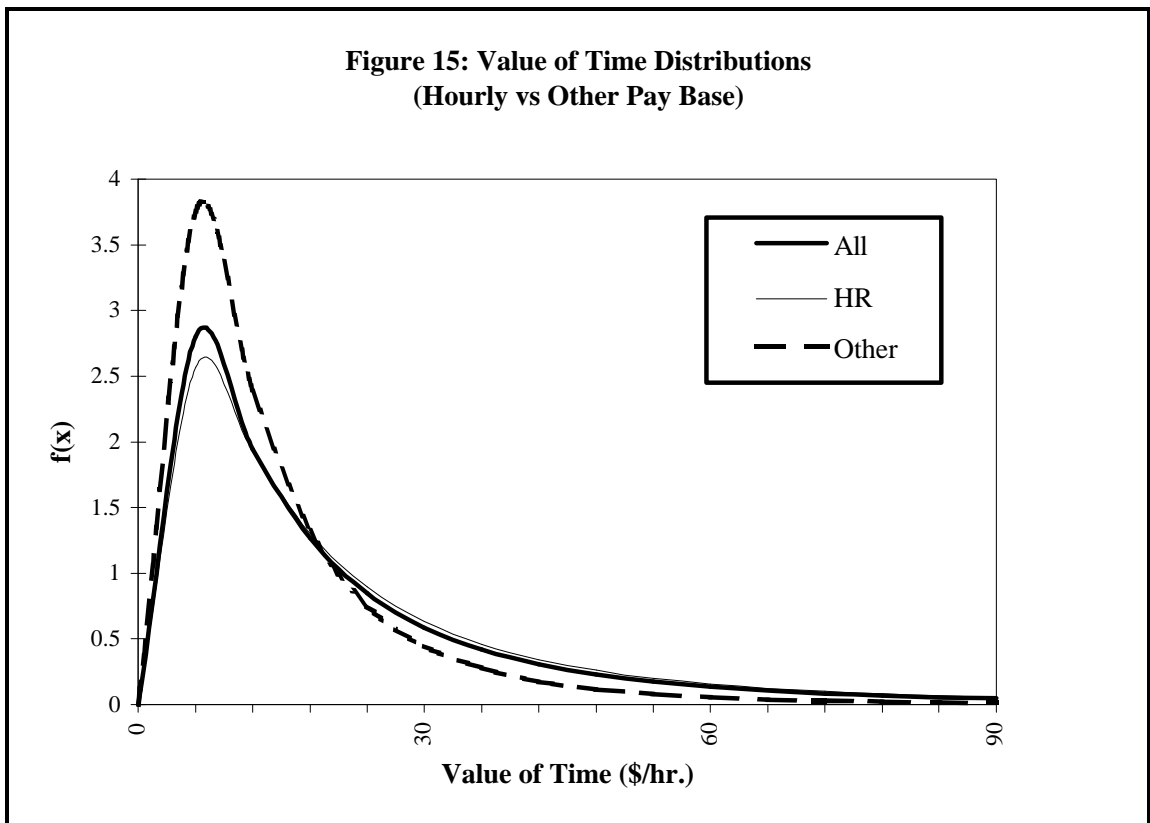
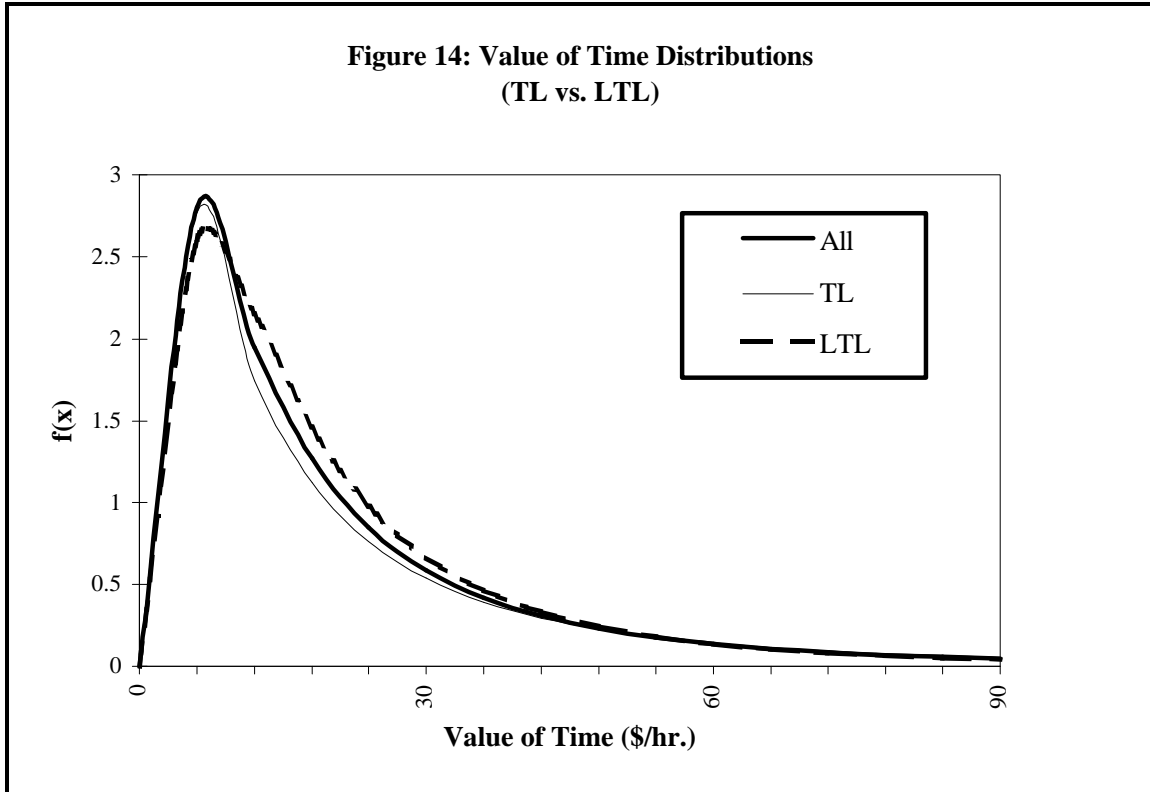


Figure 13 clearly illustrates the difference in the distributions between private and for-hire fleets. The private fleets' distribution peaks at a smaller value of time, and in general has a much steeper slope than the for-hire fleets'. In fact, the distribution for for-hire fleets is distinctively spread out when compared against the curves in other figures. Meanwhile, the distributions for TL and LTL carriers, shown in Figure 14, are very similar to each other and also to the overall curve. Figure 15 illustrates that the "other pay scale" group has a distribution similar to that of private fleets, while the companies with hourly pay are not significantly different from the overall curve.

Since it is quite possible that the method of pay is actually a proxy for the business type, Pearson's Chi-Square test of independence was conducted. The p-value for the null hypothesis (i.e. the probability that the observed data can occur if two are independent) is 0.3, which does not firmly indicate the presence of a dependence. Therefore, if in fact a correlation exists between the method of pay and business type, it is probably not a relationship strong enough to use one as a proxy for the other.

5.6 Summary

In this chapter, the values of time of commercial motor carriers were estimated first based on the level of time-money trade-off where the switch of the mode occurred in the stated preference surveys, and later a more sophisticated approach utilizing the random coefficient logit model was applied to compare the utility coefficients and the values of time across business type, shipment size and pay scale. Following is the summary of the findings.

- The values of time estimated from the switching points can be replicated very closely with a lognormal distribution. The mean and the standard deviation were found to be \$26.8/hr. and \$43.7/hr., respectively.
- The highly significant parameter estimates and the substantial increases in the likelihood ratio indexes obtained from the random coefficient logit models indicate that the marginal utility of out-of-pocket cost and travel time vary across the population.
- For all the segmentation schemes tested, the marginal utility of out-of-pocket cost seems to show a stronger concentration around the mean (i.e. smaller standard deviations) compared with the marginal utility of time.
- For-hire fleets tend to have greater marginal utility of time and smaller marginal utility of out-of-pocket cost compared with private fleets.
- The companies that pay drivers hourly wages seem to be associated with greater marginal utility of time than the carriers that pay fixed salary or commission.
- Truckload carriers were found to have greater marginal utility of out-of-pocket cost compared with less-than-truckload carriers.
- The mean and the standard deviation of the value of time for the entire sample were \$23.4/hr. and \$32/hr, respectively. Both are smaller than the values found in the switching point analysis.
- The distributions of values of time were severely skewed to the right for all types of motor carriers.
- Segmentation by business type and pay scale produced a distinctive distribution for each group, while shipment size did not seem to matter.

- For-hire fleets tend to have higher values of time than private fleets.
- The companies with hourly pay seem to be associated with higher values of time compared with the fixed salary or commission based companies.
- Segmenting the data by shipment size did not seem to result in different values of time.

CHAPTER 6: CASE STUDY

In Chapter 3, it was shown theoretically that in a setting identical to the SR91 corridor where toll lanes are constructed next to free lanes, the amount of benefit received by each vehicle reflected the value of time. In this chapter, the value of time distributions estimated in the previous chapter will be applied to calculate the change in perceived benefit created by the SR91 toll lane project to see whether the finding holds for the aggregated benefit for many trucks. The analysis will be performed not only for the case including all commercial vehicles but also separately for the private and for-hire trucks. The SR91 toll lane project was chosen as the case study because it is located in California, where the survey was conducted, and also because traffic data before and after the implementation of the project were readily available.

6.1 SR91 Toll Lane Project

SR91 is an twelve lane (including four toll lanes) freeway that connects the employment centers of Orange County to the residential developments in the Inland Empire, including the cities of San Bernardino, Riverside, and Corona. The explosive population growth in the Inland Empire during the last two decades, combined with the lack of a local employment base have put a severe strain on the SR91 to accommodate commuting traffic. Due to the mountainous terrain along the Orange and Riverside county line, viable parallel routes have not been constructed despite extreme congestion in the corridor. The average commuting time for the people using the SR91 is about 65 minutes each way, which is almost three times the national average [Sullivan, 1996].

Congestion and the lack of alternative route created an ideal situation for a congestion pricing facility. In 1995, four toll lanes in the median of the existing freeway between the city of Anaheim and the Riverside county line were opened. The toll lanes are approximately nine miles in length and are operated by a consortium of private companies. Users are required to purchase a transponder, or Automatic Vehicle Identification (AVI) device that is used to collect tolls electronically by overhead detectors. The westbound toll schedule for weekdays except Fridays is shown in Table 13. On Fridays, the westbound toll between 3 and 7 p.m. is \$1.10.

Table 13: Weekday Westbound Toll Schedule

	6 PM-4 AM	4-5 AM	5-7 AM	7-8 AM	8-9 AM	9-10 AM	10-11 AM	11AM-6PM
Toll	\$0.60	\$1.60	\$2.85	\$2.95	\$2.85	\$1.60	\$1.10	\$0.85

The toll schedule for the eastbound mirrors the westbound schedule with the highest toll rates charged for the afternoon peak period from 3 p.m. to 7 p.m. Sullivan's study

recorded that the toll lanes carry about 30,000 vehicles per day. The additional capacity provided by the toll lanes resulted in a 20 minute reduction in peak period travel time on the free lanes. Also the toll lanes, which always guarantee free-flow speed (65 mph), provide an additional 12 to 13 minutes of time saving. During the off-peak, travel time saving is minimal.

Currently, heavy vehicles are not allowed on the toll lanes. However, for the purpose of assessing the potential impact of congestion pricing on commercial vehicles, which may become a reality in future at other sites, the following analyses are conducted assuming that the toll lanes are open to heavy vehicles.

6.2 Benefit Calculations

Under the assumption that firms seek to maximize profit, the benefits for commercial vehicles are measured by the reduction in generalized travel cost including the value of time. Also, all the operators of commercial vehicles are assumed to be rational (i.e. they always minimize travel cost). The baseline against which the gain in benefit is measured, is set as the condition before the opening of the toll lanes. At present the travel time on the free lanes is 20 minutes less than the baseline. Taking the toll lanes results in an additional 12 minutes of time savings. For example, for a motor carrier whose perceived value of time is \$20/hr., the perceived benefit from using the toll facility during the peak period at \$3 per trip can be calculated by

$$\text{Perceived Benefit}^{11} = (20 \text{ min.} + 12 \text{ min.}) \times \$20/\text{hr} \times 1 \text{ hr.}/60 \text{ min.} - \$3$$

¹¹ As discussed in Chapter 3, perceived value of time may be different from that based on the revenue (net profit) method due to imperfect information and other stochastic factors. Therefore, perceived benefit can

$$= \$7.67 \text{ per trip}$$

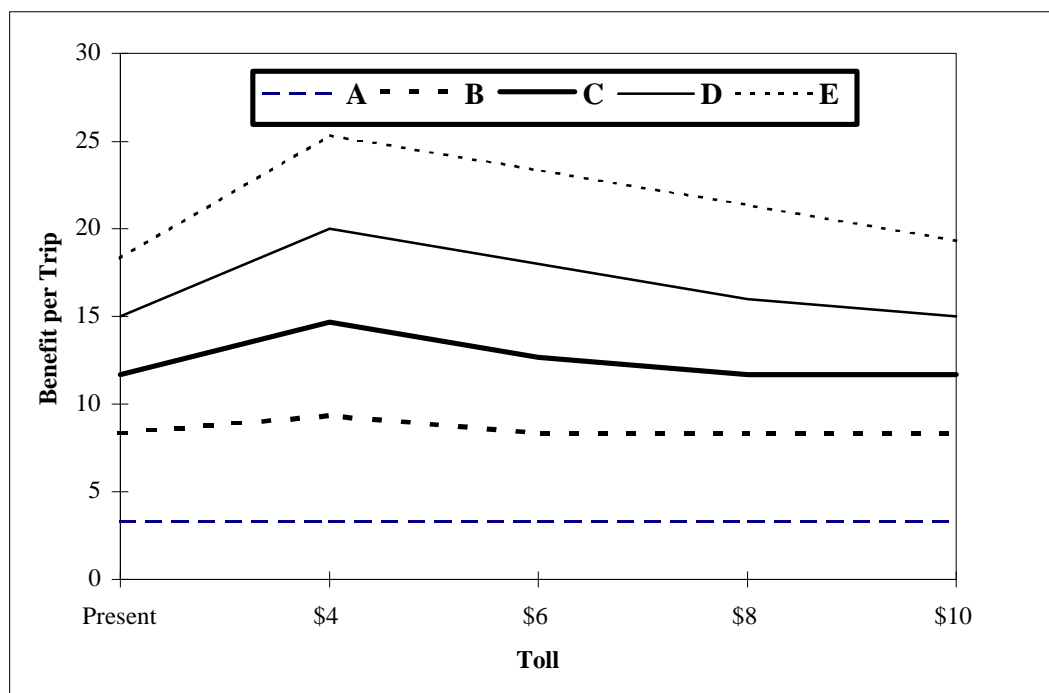
While the benefit from a capacity expansion project which reduces travel time by the same amount for every traveler is proportional to the valuation of travel time saving, the addition of a parallel toll facility creates a slightly different picture. Assuming rational behavior, the choice between the free lanes and toll lanes is determined by the time savings offered by the toll lanes, the amount of the toll, and the value of time for each traveler. For example, if the time saving is 12 minutes as in the SR91 and the toll is \$6 for trucks, only those with the perceived value of time exceeding \$30/hr. will choose the toll lanes. The \$30/hr. will be referred as the "threshold" value of time.

To demonstrate the effect of value of time and toll level, the analysis of the benefits received by five imaginary travelers on the SR91 corridor with different values of time is depicted in Figure 16.

also be different from actual increase in net profit. Furthermore, since the choice of facility is based on the perceived value of time, the choice itself may not be optimal for trucks.

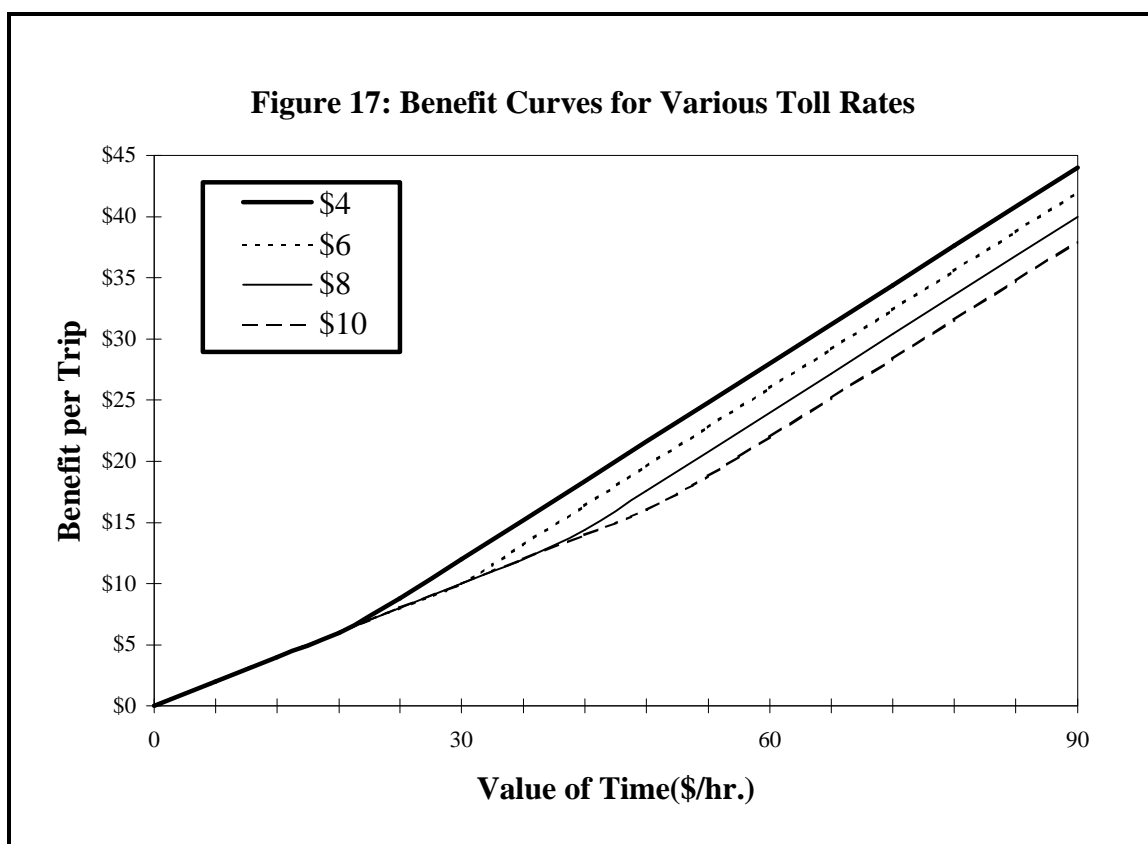
Figure 16: Benefit per Trip

User	VOT	Scenario: Toll Levels				
		Present	\$4	\$6	\$8	\$10
A	\$10	\$3	\$3	\$3	\$3	\$3
B	\$25	\$8	\$9	\$8	\$8	\$8
C	\$35	\$12	\$15	\$13	\$12	\$12
D	\$45	\$15	\$20	\$18	\$16	\$15
E	\$55	\$18	\$25	\$23	\$21	\$19



In the "present" scenario, trucks are not allowed to use the toll lanes and receive benefit only from the reduced travel time on the free lanes. The shaded cells in the table indicate the situations in which the toll lanes would be chosen. The figure underscores two important observations. First, the higher value of time is associated with greater benefits received at every toll level. Second, the increase in the toll levels affect each traveler in a different way. The increase does not affect traveler A, who always uses free lane. The benefit for the traveler E, who always chooses toll lane is reduced with each rise of the toll

by the amount of the increase. Also, for travelers B, C, and D, switching from the toll lanes to the free lanes actually dampens the effect of the toll increase, as illustrated by the slopes of the lines. A different perspective on the relationship among the toll level, value of time, and benefit is depicted in Figure 17.



The figure clearly shows that after the kinks in the lines that occur at the threshold value of time, the benefit curves become steeper due to the 12 minutes of additional time savings, because the slope of the curve reflects the amount of time savings. The difference in the slopes, or more specifically the vertical difference between the lines to the right of the kink and the rightward extension of the lines left of the kink (not shown) is the benefit created by the toll lanes. Also, the figure indicates that increasing the toll moves the kink to the right, making the toll lanes more exclusive, and at the same time, it reduces the

benefit for those who use the toll lanes. These results are applicable only if the number of vehicles analyzed is relatively small compared with the corridor capacity and the entire traffic volume, and consequently the travel times on both toll and free lanes are not effected significantly by the shift between tolled and free lanes.

To compute the aggregate benefit, the individual benefits shown in Figure 17 must be combined with a choice model for the free and toll lanes and the distributions of the value of time presented in Figure 13 in Chapter 5. In addition, the truck volume on the SR91 corridor must be determined. Furthermore, in order to make a comparison between business types, the volume must be obtained for private and for-hire trucks separately.

The average daily truck volume on SR91 can be obtained from the annual report published by the CALTRANS [CALTRANS, 1996]. The two-way volume of vehicles with more than 3 axles measured at the count station within the study segment is 5,900 vehicles per day while the total volume is 236,000. The benefit calculations assumed that the daily traffic volume is split evenly in both directions. Since the CALTRANS' report does not provide hourly volumes, the truck traffic peaking characteristics for urban areas that is recommended in the Federal Highway Administration report is applied to distribute daily volume into hourly volumes [FHWA-B, 1996]. Unfortunately, traffic counts that disaggregate truck volumes by business type or any of the segmentation criteria used in this study do not exist. Therefore, the estimate of the split of the truck traffic between the for-hire and private operations on SR91 was derived from trip frequencies obtained from a travel diary survey conducted as a part of the 1990 Nationwide Truck Activity and

Commodity Survey. The travel diary survey of 1,126 trucks in Census Region 9 (that includes Alaska, California, Hawaii, Oregon and Washington) indicated that 60% of the trips made during the survey by trucks over 26,000 pounds of gross vehicle weight belonged to private operations, and the remainder to the for-hire fleets [Oak Ridge National Laboratory, 1992]. No data are available to assess whether this trip rate can be translated into the split of traffic volume on freeways or the variability of the split among freeways. The trip frequency was used simply because it was deemed to be the most appropriate statistic available upon which to base the estimate.

Since the travel time saving from the toll lanes during off-peak hours is negligible, the benefits are calculated only for the peak periods, from 5 to 9 a.m. and from 3 to 7 p.m.¹² The annual benefits are calculated assuming that there are 52 weeks in a year with 5 working days for each week, since the toll lanes do not provide time saving on weekends.

For the SR91 corridor, the travel time reduction on the free lanes induced by the shift of trucks to the toll lane is negligible due to the low truck volume. Using a well-known travel time formula [Bureau of Public Roads, 1964]

$$T = T_F [1 + 0.15 (V/C)^4]$$

where,

T = Average travel time on a facility

T_F = Travel time under free flow condition

V = Traffic Volume

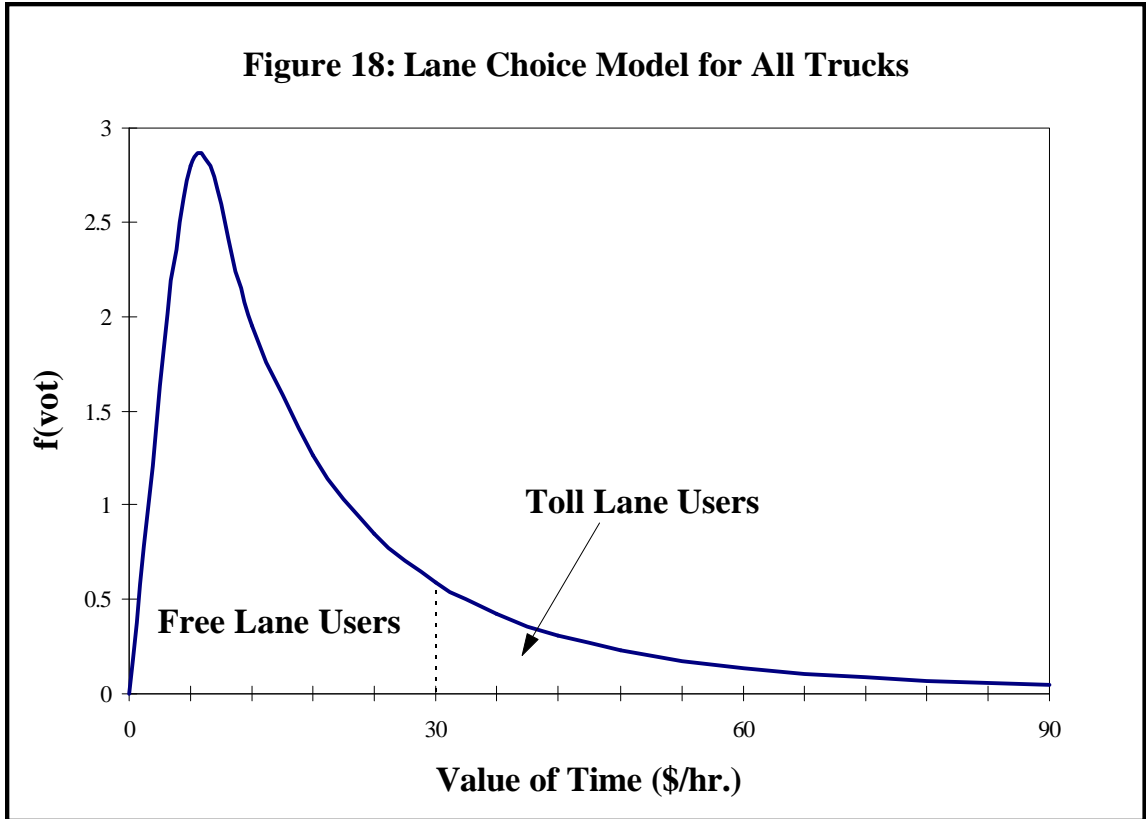
¹² Peak periods are determined based on the traffic volumes found in Sullivan's report. The toll lanes usually provide travel time savings for westbound only in the morning and eastbound only during the afternoon peaks.

C = Capacity of link

the reductions in the free lane travel time are found to be below 30 seconds even if the toll for trucks is set at \$3¹³. Currently, the toll lanes carry only 30,000 vehicles a day in both directions [ARDFA, 1999]. Even during the peak period, traffic volume is well below the capacity. Also, the variable toll rate guarantees that the toll lanes will always travel at free-flow speed. If an increase in demand brings the condition to near or over the capacity, the toll is raised to limit demand.

The lane choice is calculated using a deterministic model in which trucks are assumed to choose the toll lanes if and only if their value of time is above the threshold. This deterministic lane choice model is graphically presented in Figure 18, for a particular toll level. The split between the free and toll lanes is the ratio between the areas right and left of the dashed threshold line. The areas can be found from the lognormal cumulative distribution table. The calculation of the aggregate benefit, however, is more cumbersome since the travel times for the toll lane users and free lane users are different from one another. To compute the aggregate benefit, the expected values of time for toll lane users and free lane users must be calculated separately, then multiplied by the time savings.

¹³ This result holds for other congestion functions such as [Keeler and Small, 1977].



The expected value of time for the free lane users, $E[VOT_F]$, can be found by evaluating

$$E[VOT_F] = \frac{\int_0^K \{VOT \times f(VOT)\} dVOT}{Area_L} \quad [41]$$

where,

K = threshold value of time (e.g. \$30/hr. for the \$6 toll example)

$Area_L$ = Area left of the threshold value of time under the density curve (the area left of the dashed line in the Figure 16)

$f(VOT)$ = density function of value of time

The numerator in the equation 41 can be estimated by simulation. A random number, θ , is generated many times, and for each θ the distribution function of the lognormal distribution with parameters, \mathbf{m} and \mathbf{s} , is evaluated as

$$\frac{K}{s\sqrt{2p}} \exp\left\{-\frac{1}{2s^2} [\ln(Kq) - m]^2\right\}. \quad [42]$$

The average value is the approximation of the numerator of equation 41. For this study, a bootstrapping technique was used in which the random number, θ , was drawn 600 times for each trial. The process was repeated 100 times and the average of the values obtained from the trials was calculated.

Once the expected value of time for the free lane users was determined, the value for the toll lane users, $E[VOT_T]$, were found easily by evaluating the following

$$E[VOT_T] = \frac{\int_K^{\infty} \{VOT \times f(VOT)\} dVOT}{Area_R} \quad [43]$$

Where,

$$\begin{aligned} Area_R &= \text{the area right of the threshold value of time, } K \\ &= I - Area_L \end{aligned}$$

$$\begin{aligned} \int_K^{\infty} \{VOT \times f(VOT)\} dVOT &= \int_0^{\infty} \{VOT \times f(VOT)\} dVOT - \int_0^K \{VOT \times f(VOT)\} dVOT \\ &= E[VOT_{ALL}] - \int_0^K \{VOT \times f(VOT)\} dVOT \end{aligned}$$

The expected value of time for all vehicles, $E[VOT_{ALL}]$, is the mean value of time determined in the previous chapter. Since the threshold value of time, K , is determined by the toll, this process was performed for each toll scenario.

The aggregate benefit equals

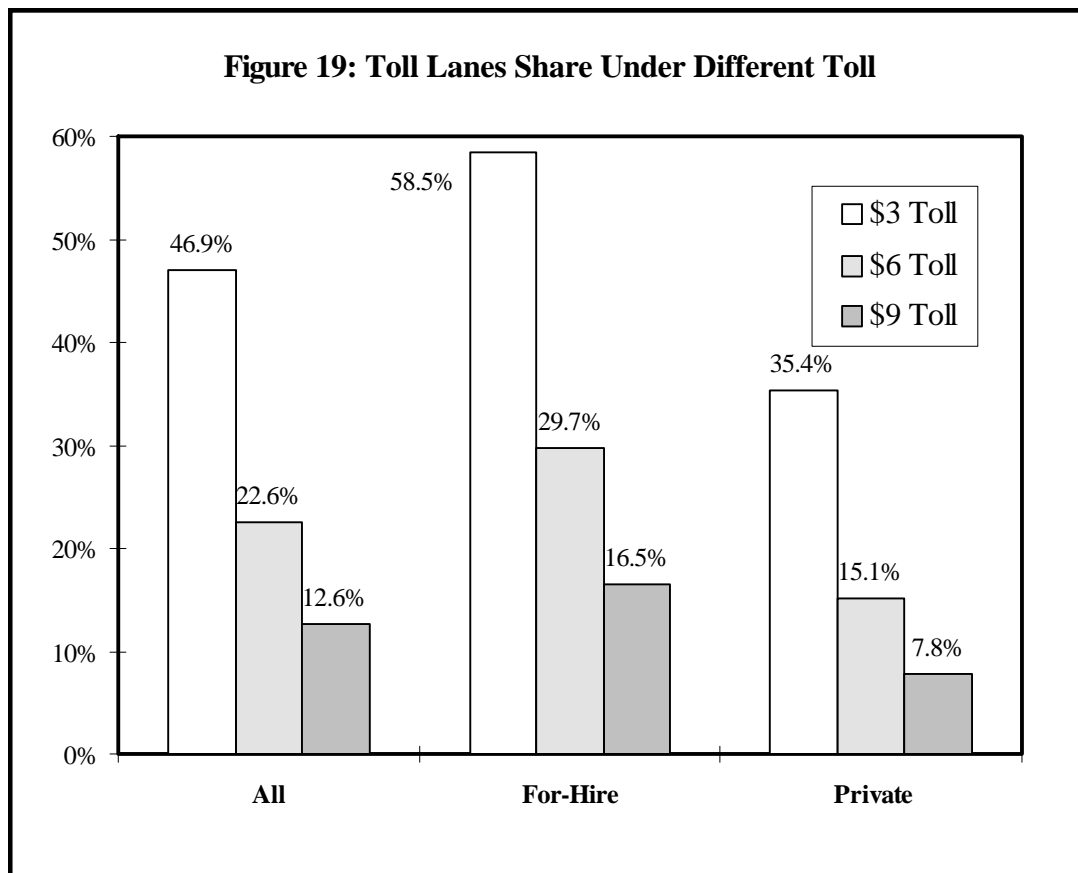
$$\text{Aggregate Benefit} = \text{Free Lane User Benefit} + \text{Toll Lane User Benefit} \quad [43a]$$

$$= 20 \text{min.} \cdot E[VOT_F] \cdot V_F + (32 \text{min.} \cdot E[VOT_T] - \text{Toll}) \cdot V_T \quad [43b]$$

Where V_F and V_T denote the truck traffic volumes using the free lane and toll lane, respectively, that are determined using the lane choice model described earlier.

6.3 Analysis Results

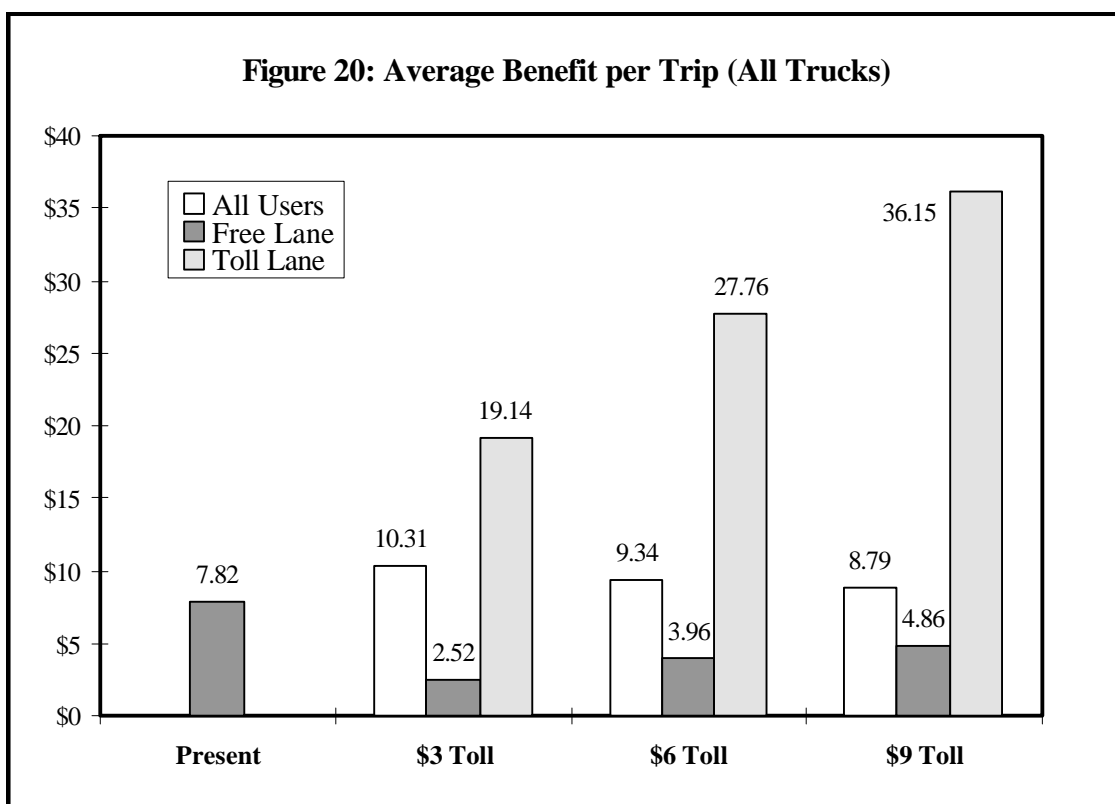
The shares for the toll lanes for all trucks, for-hire, and private trucks for three toll levels, \$3, \$6, and \$9 are shown in Figure 19.



As expected, the toll lane's shares decrease as the toll increases. Also, the distribution of the value of time, which was shown in Figure 13, is reflected in the toll lane share. The mean value of time is highest for for-hire trucks and lowest for private trucks. At all toll

levels, the mode shares are the highest for the for-hire trucks and the lowest for private trucks. Furthermore, the change in the lane share that occurs with the increase in the toll also reflects the shapes of the distributions. For the for-hire trucks, which have a relatively flat distribution compared other two, the decrease in the toll lane share is more gradual than the others. The decrease is the most severe for the private trucks, which have the most pronounced peaking in the distribution.

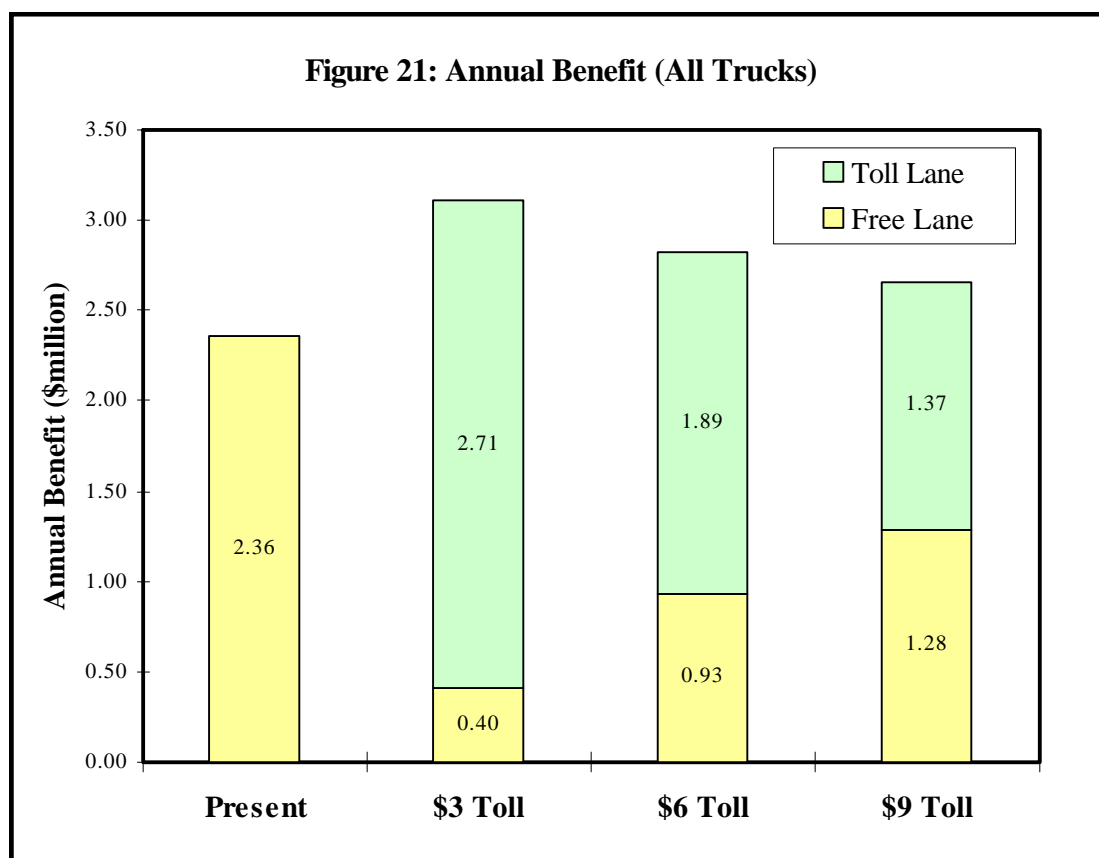
The average perceived benefits received by free lane users, toll lane users and all users combined are shown in Figure 20.



The average benefit for all users is highest for the \$3 toll and decreases as the toll increases. However, the benefit always remains above the present level. The figures also clearly show that users of the toll lanes receive more than five times the average benefit of

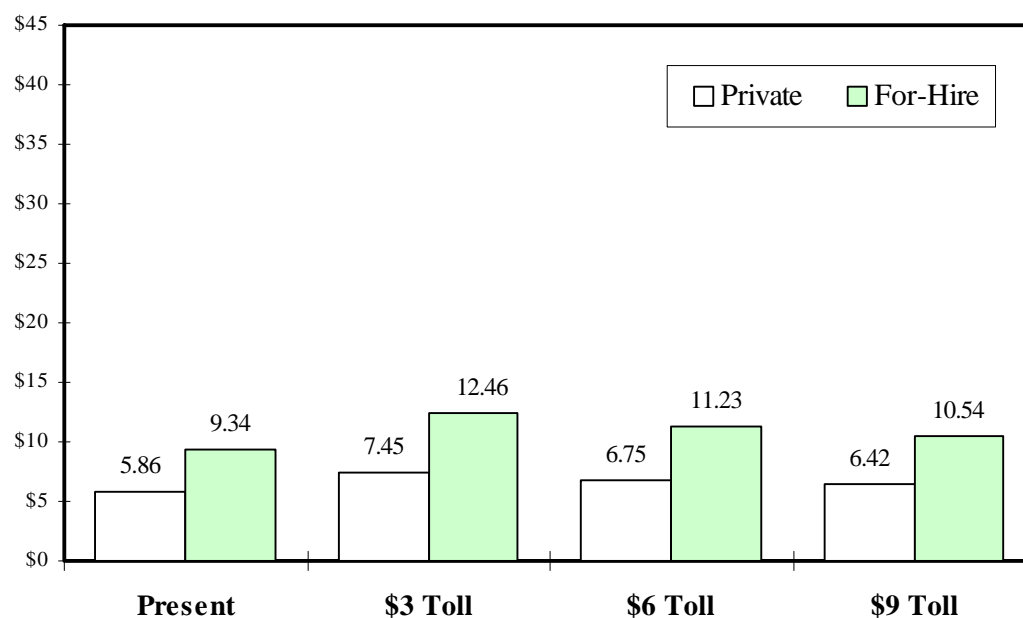
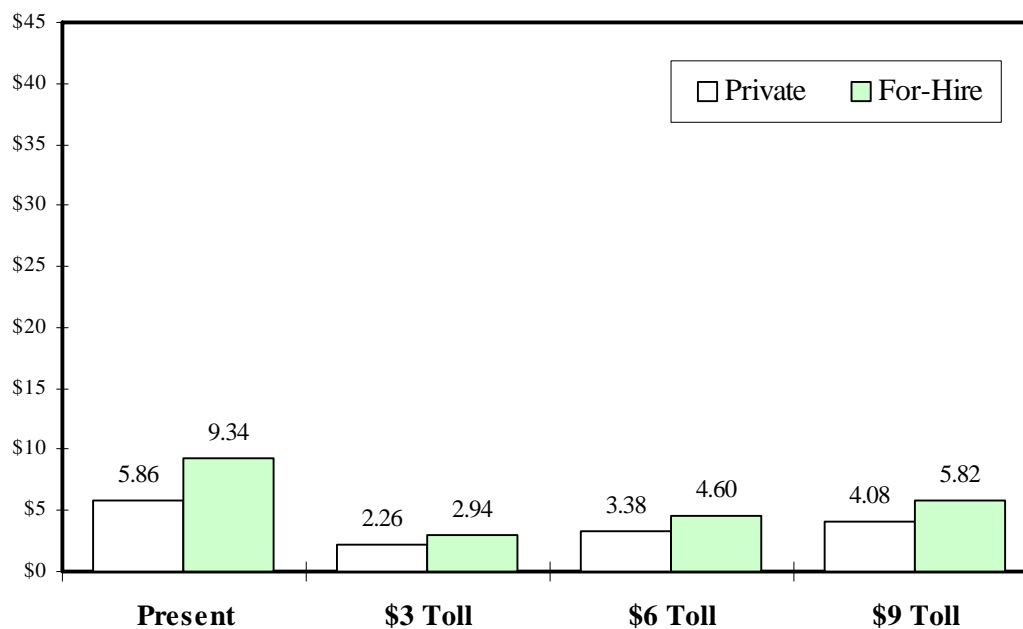
those remaining on the free lanes. As the toll is raised, the average benefit for free lane users increases due to the shifting back of trucks with relatively high values of time to the free lanes. Also, it makes the toll lanes more exclusive for those with very high values of time, increasing their average benefit significantly. Trucks that use the toll lanes under the \$9 toll scenario (i.e. those with the values of time above \$45/hr.) would receive only \$28.22 of benefit per trip on average if they are forced to use the free lanes as in the present condition. This is analogous to a regular capacity expansion project. They receive an extra \$7.93 in benefit per trip from using the toll lanes while the others receive nothing.

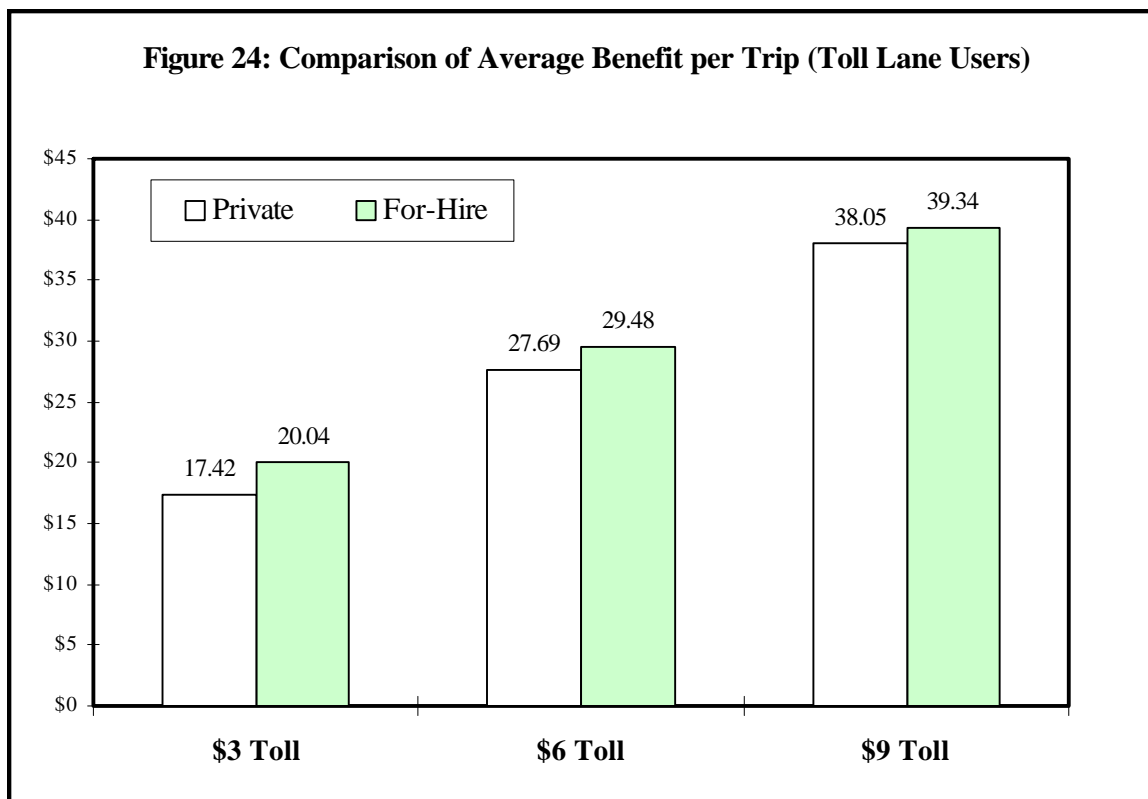
Figure 21 shows that trucks on the SR91 corridor currently receive well over \$2 million of



annual benefit from reductions in travel time on the free lanes induced by the construction of the toll lanes even though they are not allowed on the toll facility. If the trucks were to be allowed on the toll lanes for a \$3 toll, \$750,000 of extra benefit would be added, which is more than a 30% increase. However, as the toll is increased, the additional benefit declines due to the decrease in the number of trucks on the toll lanes and the increase in the out-of-pocket expense. At a \$9 toll, the total benefit is only \$290,000 more than the present condition. Under this scenario, analysis of the share of the benefit received by toll and free lane users reveals that a large amount of benefit goes to those with high values of time. For a \$9 toll, 52% of the total benefit goes to the toll lane users who constitute only 12.6% of the users. Under present conditions, 45% of the benefit goes to the same 12.6 % of trucks. Therefore, even though no one will be made worse off, opening the toll lanes to trucks will widen the gap between the benefits received by the trucks with low and high values of time.

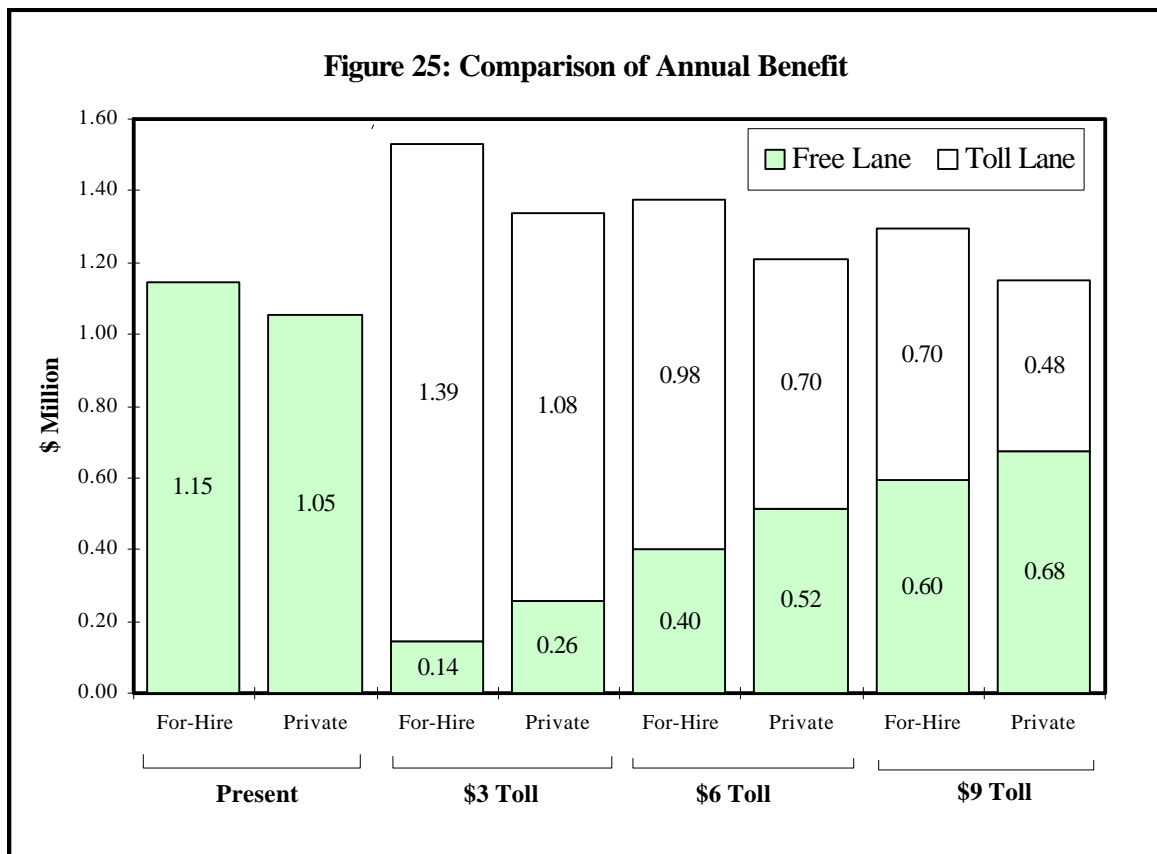
Figures 22 through 26 compare the benefits received by for-hire and private trucks. Comparison of the average benefits per trip, shown in Figures 22 through 24, reveals that for-hire trucks consistently receive more benefits than private carriers regardless of the choice of facility they travel on. However, as shown in Figure 24, the difference in the benefit is the smallest for the users of the toll lanes, especially when the toll is high. This is because the distributions of for-hire and private carriers are similar toward the right tails (i.e. high value of time). Therefore, the differences in the values of time with business type decrease as the toll lanes become more exclusive. Although not as obvious, the same trend exists for the benefit for all users, shown in Figure 22.

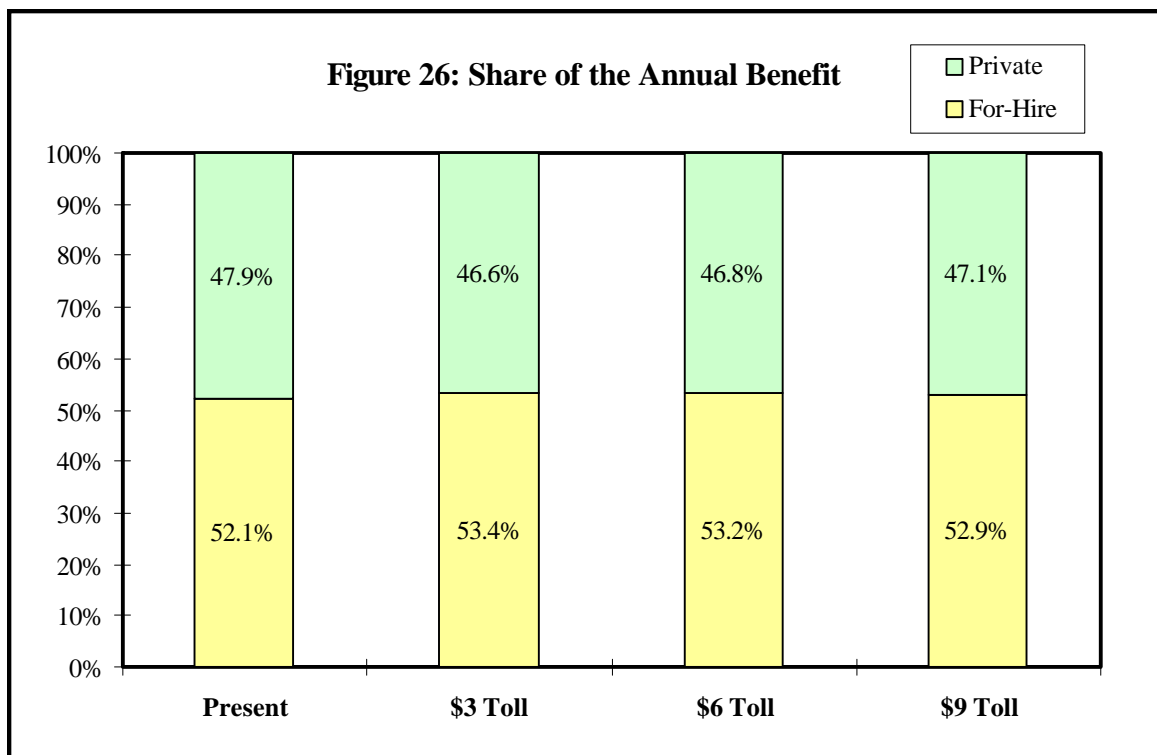
Figure 22: Comparison of Average Benefit per Trip (All Users)**Figure 23: Comparison of Average Benefit per Trip (Free Lane Users)**



Comparison of the annual benefits, shown in Figure 25 and 26, reveals that the for-hire carriers receive more benefit than private fleets despite their smaller numbers (the share of the for-hire trucks is assumed to be 40% of the traffic). As indicated by the considerable jump in benefits between the present condition and the \$3 toll scenario in Figure 25, for-hire trucks would benefit the most from the opening of the toll lanes to heavy vehicles. The jump is about 33% for for-hire trucks while it is only about 28% for private trucks. Also, the figure indicates that the share of the benefit going to the toll lane users is different. At a \$3 toll, less than 10% of the benefit for the for-hire trucks comes from the free lane users who account for over 40% of the traffic. The figure is about 20% for private fleets, due to the high lane share for the free lanes at about 65% of traffic. At a \$9 toll, still more than half of the benefit for for-hire fleets belongs to toll lane users, though

they account for only 16.5% of volume. Interestingly, the shares of annual benefits between the for-hire and private trucks, depicted in Figure 26, is almost unaffected by the toll level. As discussed in the previous section, any increase in the toll only impacts those using the toll lane. Coincidentally, the numbers of trucks using the toll lanes are not very different between private and for-hire fleets, because the higher value of time for the for-hire trucks is off-set by the higher share of the traffic for the private trucks. Since the travel time saving offered by the toll lanes remains constant regardless of the fee charged, the increase in the toll reduces the benefit equally for the trucks that remain on the toll lane (by the amount of increase). Therefore, the value of time distributions do not influence the change in benefit caused by the toll rate increase except for trucks that switch the lanes, which is very few in this case.





6.4 Summary

In this chapter, the effects of the value of time distributions obtained from the survey were analyzed for the SR91 toll lane project under the assumption that the shifting of trucks between the toll lanes and free lanes will not create substantial change in the travel times on either. While the results of the analyses may not be extended to passenger automobiles due to the difference in traffic volume, the findings indicate that the value of time, both as an average as used in most cost-benefit studies and as a probability distribution, has a direct impact on the incidence of the benefits created by congestion priced facilities.

Trucks on SR91 have enjoyed substantial benefit both collectively and individually since the opening of the toll lanes in 1995. Currently they receive over \$2 million of perceived benefits from the travel time reductions on the free lanes induced by the added capacity

the toll lanes created. This amount does not include the benefits from other sources such as reduction in air pollution, and the use of toll revenue. The benefit would rise to over \$3 million if trucks were allowed on the toll lanes for a \$3 fee. As the toll is increased, the collective benefit declines; although trucks that remain on the toll lanes would continue to receive considerable benefit. An analysis showed that over 50% of the benefit goes to trucks within the upper 12.6% of the value of time distribution if the toll is \$9. Therefore, when a toll facility is expensive to use, the benefit from the toll facility tends to go only to a limited portion of the population.

The comparison of the benefits received by for-hire and private trucks showed that the flatter distribution and the high mean value of time for the for-hire trucks would give more benefit to them than to the private trucks. Currently, for-hire trucks as a group receive about 9.5% more benefit than the private trucks despite of the assumption that only 40% of the trucks on the SR91 are for-hire. At the individual level, for-hire trucks receive 60% more benefit than private trucks on average. This result, especially the individual benefit, is transferable to regular capacity expansion projects. The for-hire trucks would also benefit most if the toll lanes were to be opened to heavy vehicles. Interestingly, the business type does not effect the average benefit received by the toll lane users because of the similarity in the shapes for the upper part of the value of time distributions. Also, it was found that the share of the aggregated benefit that belongs to each business type is not effected significantly by the toll charged.

CHAPTER 7: CONCLUSIONS AND FUTURE RESEARCH AGENDA

The objective of this study was to explore the following questions:

- 1). Do values of time differ among commercial vehicle operators? If so, what explains the differences?
- 2) Will congestion pricing make particular segments of the commercial vehicle industry better-off than others due to differences in values of time?

This study provided interesting and reasonably robust answers to these questions under several simplifying assumptions. In this chapter, a brief review of the analysis methods and key findings is presented. Also, a number of unresolved issues associated with each part of the study, as well as the possible approaches to addressing them, are discussed as a future research agenda.

7.1 Measurement of Commercial Vehicle Value of Time

The hypothesis to be investigated was that the characteristics of companies such as fleet size, business type, travel frequency, fleet operation strategies, shipment size, and the method of compensating drivers have an influence on commercial vehicle value of time. The stated preference data for measuring commercial vehicle value of time were collected by interviewing 70 truck operators in Southern California and the San Francisco Bay Area. The response rate was approximately 20%, and selectivity bias was not observed in the comparisons against two other larger survey data sets that cover similar geographical areas.

The value of time was estimated in two ways: first, based on the level of time-money trade-off where the switch of lane occurred in the stated preference questions, and second using a modified logit model in which the coefficients to be estimated were assumed to be distributed lognormally across the population for each data set. The former approach revealed that the value of time can be well replicated with a lognormal distribution, verifying the assumption employed in the logit model. The latter approach, often referred to as the random coefficient logit model, indicated that the mean and standard deviation of the value of time were \$23.4/hr. and \$32/hr., respectively. Comparisons between data sets that were segmented according to business type, shipment size, and the method of driver compensation indicated that shipment size does not effect the value of time. Meanwhile, for-hire trucks tend to have higher value of time than private ones, and the companies that pay drivers hourly wages have higher values of time than those who pay by commission or fixed salary.

Probably, the small sample size is the most significant shortcoming for this part of the study. The sample size placed a limit on the degrees of freedom in the value of time model. The random parameter logit model tends to be unstable for small sample sizes, and often the optimization process does not converge. Possible relationships between value of time and continuous variables such as trip length, fleet size, trip frequency, and value of cargo, were never analyzed. With a larger sample size, data could be segmented into several groups using quartiles, for example, and comparisons could be made. Also, to keep the interviews short, scenarios for the stated preference questions were not designed to investigate the effect of travel characteristics such as travel time and trip length, or even travel time variability/reliability on the value of time. The methods for analyzing these relationships have been studied for passenger travel in recent years, and application to commercial vehicles may be possible. With an expanded sample, these issues can be addressed in a future study.

Another issue is the correlation between the cost and time coefficients. In this study these coefficients were assumed to be uncorrelated because of the lack of an appropriate computer program to measure the covariance. Since the value of time is the ratio of these coefficients, the presence of a correlation will result in a bias. Train and Revelt, who wrote the computer program for the random coefficient logit model, have also developed a technique to estimate the covariance among coefficients. The technique specifies the log of the coefficient vector, $\ln(\mathbf{b})$, to be distributed with mean \mathbf{b} and variance-covariance matrix, Ω that includes the covariance among the coefficients. While a program that applies this

technique of estimation is not yet available, with Train and Revelt's cooperation it may become possible to use the same method for this study in the future.

While this study focused on the measurement of perceived values of time, the analysis of costs of truck operations for different types of companies can shed light on the reasons behind the differences observed. In addition, the comparison of the perceived and theoretical value of time, derived from the logistic cost, can be helpful in assessing the efficiencies of different types of truck operators.

7.2 Perceived Benefit

Using the SR91 congestion pricing project in Orange and Riverside counties as a case study, the benefits for commercial vehicles were calculated based on perceived value of time. The analyses showed that commercial vehicles on SR91 have received over \$2 million of perceived annual benefit since the opening of the toll lanes in 1995 due to the added capacity. If the toll lanes were opened to heavy vehicles, the annual benefit would reach over \$3 million. Further analyses revealed that trucks with high values of time will receive adisproportional amount of benefit, especially if the toll is expensive. The comparison between for-hire and private trucks indicated that the former, due to considerably higher mean value of time, tend to receive much greater benefit individually and collect slightly more aggregate benefit than the latter despite smaller numbers. However, the share of the benefit received by each sector is relatively unaffected by the level of the toll charged.

Several assumptions had to be made because of the lack of data to estimate the truck volume on SR91. To our knowledge, detailed truck traffic data that extend beyond daily volumes, axle counts, and peaking characteristics have never been collected on a continuous basis on a major road in this country. Travel characteristics such as business type, shipment size, and trip length are usually collected from company surveys, and it is difficult to transfer those data to the composition of the traffic on a particular facility. Fortunately, the computer data on truck operations that contains these characteristics is usually maintained by the Department of Motor Vehicles or similar organizations. Also, on a visible part of each truck, a number is painted that links it to the computer data. Therefore, the detailed truck traffic data that are required to conduct policy studies such as this project can be obtained from a traffic survey even though it may be an expensive effort.

The case study can be extended to include situations in which congestion pricing is implemented on an existing facility. While the SR91 project offered a Pareto improvement, in which no one is made worse-off, extending congestion pricing to an existing road or bridge will reduce benefits for some travelers. Since all of the existing congestion pricing projects in this country provide Pareto improvements, a simulated case must be created. The comparison of the results against those for SR91 will provide an insight into the effects of the types of congestion pricing facilities and the distribution of value of time.

Although the small volume of trucks and relatively flat grade of SR91 justified the assumption that the travel times on both free and toll lanes were not effected by the mode

share, this can be relaxed in future studies. If the trucks were allowed to use the toll lanes on SR91, there would be increases in benefits for passenger cars on the free lanes and decrease in benefits for passenger cars on the tolled lanes. Further analysis could be performed to determine the net effects of these changes on the distribution and level of benefits to passenger car travelers.

Finally, the framework presented in this study can be transferred to passenger travel by relaxing some of the simplifying assumptions. First of all, the changes in travel times on tolled and free lanes with respect to different toll levels and values of time distributions must be calculated. This will require an equilibrium traffic assignment. A technique similar to the traffic assignment module used in the UTPS type of models that is modified to incorporate the random coefficient logit model may be developed to perform the task. Also, the measurement of benefit is much more complicated for passenger travel since it involves changes in utility, which are not measurable. However, alternating measurements such as compensating variations and consumer surplus, which can be directly obtained from the random parameter logit model, may be used to measure the change in utility¹⁴.

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