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Assessing the Value of Delay to Truckers and Carriers

Final Report

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16. Abstract

This project evaluates the value of delay (VOD) to commercial vehicle operators due to highway congestion. The VOD for congestion is a fundamental parameter driving the private sectors' response to public freight projects and policies such as corridor construction and tolling. Factors affecting the commercial VOD include direct operational cost, travel length, travel time variation, inventory holding, and warehouse management. To approach the VOD, two methods are adopted in this project. One is the stated preference (SP) survey. The other is carrier fleet operational simulation. Simulation shows a range of VOD from $94/hr to $121/hr for the case of a central depot and $80/hr to $84/hr for the case of two depots. An SP survey is conducted for truckers and carriers in two scenarios, which results in a VOD range from $25/hr to $65/hr. A comparison between the survey and the simulation results shows that drivers perceive a significantly lower VOD than the simulated VOD in freight operation.

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EXECUTIVE SUMMARY

This project evaluates the Value of Delay (VOD) to commercial vehicle operators due to highway congestion. The VOD for congestion is a fundamental parameter influencing the private sector’s response to public freight projects and policies such as corridor construction and tolling. By understanding the value of delay, freight planners can rank order freight congestion relief projects. However, the value of delay is a difficult parameter to estimate. It draws on both econometric theory and network carrier fleet operational optimization. There are a number of factors in play here. These include factors affecting the commercial VOD such as direct operational cost, travel length, travel time variation, inventory holding, and warehouse management.

Two university transportation centers, UTCM and CFIRE, joined forces to conduct this research. Drs. Adams and Wang, along with other staff and student researchers, began the research in fall 2009. The collaborative approach enables a larger geographic coverage of stakeholders and a better use of complementary research skills.

Two methods are adapted to estimate VOD. One is stated preference (SP) survey. The other is carrier fleet operational simulation. The former addresses the perceived value of time that directly affects travelers’ route choice decisions. The latter deals with the economic impact in the context of commercial fleet network operations in a reasonable competitive market.

The simulation framework uses ArcGIS and C++ to generate a freight network based on the Houston highway system. A set of customers is randomly generated, each having a random demand for service and associated with time windows for delivery and pickup. The heuristic algorithm dispatches vehicles for truckload service on a continuous time horizon. The average VOD is the ratio between additional operational cost and the delay caused by the congestion. This ratio was assessed for two scenarios: single depot and two cooperating depots. Simulations based on different demand size, demand distribution pattern, time window, and location of congestion revealed a range of VOD from \$94/hr to \$121/hr for the case of central depot and \$80/hr to \$84/hr for the case of two depots.

The survey collected the stated preference from truckers and carriers in two scenarios. The first scenario assumes a driver running late by 30 minutes on a congested road, while the second scenario assumes on time delivery or pickup. Several hypothetical tolling alternatives were offered as alternatives to test the driver’s willingness to pay. The data were regressed with the logit model using maximum likelihood estimation. A generic utility function estimates VOD in the range of \$25/hr to \$65/hr.

A comparison between the survey and the simulation results indicates that drivers perceive a significantly lower VOD than they may actually experience. The result also indicates that willingness to pay is much less than what is needed to resolve congestion.

I. INTRODUCTION

Freight transportation plays a vital role in the economy because it connects suppliers, distributors, vendors, and consumers. According to statistics from the Federal Highway Administration (FHWA) in 2009, the United States has 116 million households, 7.7 million business establishments, and 89,500 government units supported by freight transportation. The nation’s efficient and reliable transportation system allows manufacturers to use distant sources of raw materials to produce good for both local and distant customers. It also enables retailers to maintain streamlined and efficient supply chains, resulting in more competitive businesses. Meanwhile, freight transportation is evolving in response to advancements in supply chain strategies. For example, the increase in e-commerce produces demand for a more fragmented, direct delivery freight system. Since the United States has an extensive global commerce, the natural resources and manufactured products from many other countries are also moved through an extended global transportation system. Together with international freight, the United States transportation system moved, on average, 53 million tons of freight each day in 2002, worth $36 billion. This number reached 58.9 million tons per day in 2008 according to the Freight Analysis Framework (FAF)’s estimation. Although the United States economy has been affected by the recent global recession, the long-term prospective economic growth will lead to an additional significant increase of demand for shipping. The FAF forecasted a higher growth rate from 2008 to 2035, compared to the growth rate from 2002 to 2008. The forecasted total volume is 37,211 million tons for the year of 2035 [1].

In addition to the significant increase in volume moved through freight transportation, the value moved is increasing at a much faster speed. Based on the FHWA database, the value of freight moved grew 26.8 percent between 2002 and 2008 while the total tonnage increased only 11.2 percent. This indicated a structural change that goods are delivered more frequently, and in a smaller amount each time. As this pattern keeps continuing, the Office of Freight Management and Operations forecast a growth of value of freight in constant dollars by over 190 percent between 2002 and 2035, which is nearly twice the growth rate forecasted for total tons. The direct result of this growth in value is the increasing supply chain costs associated with inventory management, which drives many industries to develop their own just-in-time system to minimize inventory costs.

Just-in-time is a supply chain management system that requires highly coordinated transportation. Goods transported within this system, are always time sensitive, and always demand more vehicles, because the marketplaces or the manufacturers do not order large quantities of goods. Instead, they order goods or product in small amount, but at high frequency. Due to the smaller stock in storage, delay in just-in-time system would result in much more cost than in the other supply chain systems.

Along with the significant changes in volume and value, the modal split is changing as well. Throughout the United States, there are 985,000 miles of Federal-Aid highways, 141,000 miles of railroads, 11,000 miles of inland waterways, and 1.6 million miles of pipelines. FAF provisional estimates for 2007 also show that the truck transportation increased by more than 10 percent from 2002 to 2007 and carried more total tonnage than all other modes including rail, pipeline, air, and water combined. These numbers suggest that the truck transportation is becoming more and more important compared to the other transportation modes. The most common mode used to move imports and exports between inland locations and international gateways is the mode of trucks. Considering the foreign trade, trucks carry about 58 percent of the value of goods traded with Canada and Mexico, leaving the rail mode as the second.

Truck transportation industry is vital to the economy. In 2002, the value generated by moving goods and people contributes about 5 percent of GDP. Of this 5 percent, three-fifths is generated by for-hire transportation services. A for-hire carrier is a transportation company that provides shipping of belongings to others and is paid for doing so. The remaining two-fifths is generated by in-house transportation, which is usually operated by private carriers. A private carrier is a truck owned by company and used to transport its own freight. Therefore, many drivers work for retailers and other establishments with shipper-owned trucks. Contrary to the role of carriers, the shippers then are the companies consign or receive goods that are transported by the carriers. Based on FAF statistics, there were nearly 3 million professional truck drivers in United States in 2008. All of these drivers, 56 percent drive heavy/tractor trailer trucks, and 31 percent are light/delivery truck drivers. This number will keep increasing in the future since the number of truck drivers is below actual demand.

Regardless of the type of truck services, the freight delay caused by congestion has a direct impact on driving hours, fleet efficiency, and scheduling of warehousing activities all with cost to the national economy. Unfortunately, compared to the rapid growth in demand for truck transportation, the road capacity in the United States is increasing at a much lower rate. This phenomenon challenges every aspect of freight operation and planning, whose objective is to provide effective transportation to operate at minimal cost and respond quickly to demand. The data from FHWA show that between the years from 1980 to 2007, the vehicle miles traveled increased by 98 percent compared with about 5 percent increase in the route miles of public roads. In these same years, the number of commercial trucks climbed 56 percent. In 2007, the light trucks accounted for about 36 percent of highway vehicles miles traveled, and the commercial trucks contributed to an additional 8 percent.

Apart from the imbalance between growth rate of all road capacities and increasing rate of truck demand, the route distribution of trucking operations suggests another impact of increases in truck traffic. Unlike commuter vehicles that usually travel locally, significant amount of freight moves long distances on interstate highway between decentralized warehouses/distribution centers and retailers/customers. For example, long-haul truck traffic carrying commodities between places far apart from each other is concentrated on major routes connecting population centers, ports, border crossings, and other major hubs. Given the forecast that long-haul truck traffic is going to increase dramatically by 2035, long-haul trucking will primarily benefit from increases in interstate highway capacity.

Freight moved on the National Highway System accounted for 26 percent of all trucking in 2007 FAF [1]. There exists a strong preference in route distribution for using certain roadway segments. Together with the volume of passenger vehicles on these roadway segments, road congestion is going to exacerbate with the projected growth of freight traffic. As passenger cars compete for the space on the highway system, growing truck volume incurs congestion where there is not enough capacity for total volume of vehicles. Most of the congestion takes place at the major freight bottlenecks such as airports’ entrances and exits, border crossings, transfer points, or the highway interchanges with a high density of activities. It is often caused by the converging traffic, lane reductions, steep grades, channels, the emerging of rail line, or some intersections in large cities. Other possible causes include the regulation in pick up and deliver time windows and the shortage of facilities such as truck parking area. Since congestion slows down traffic and creates stop-and-go conditions, the truck operation is significantly affected. In 2002, peak-period congestion caused 10,600 miles to operate at speeds slower than the posted speed and another 6,700 miles to operate at stop-and-go conditions. Assuming no changes in network capacity until 2035, FAF forecasts that these numbers will reach nearly 20,000 miles and 45,000 miles, respectively.

On the other hand, according to the *Urban Mobility Report* by the Texas Transportation Institution [2], the congestion is a problem in United States' 439 urban areas, and this problem is getting worse for all the regions. In 2007, considering all the vehicles, congestion cost an extra 4.2 billion hours and 2.8 billion gallons of fuel for urban transportation. The approximate cost for these extra hours and fuels is about $87.2 billion. When compared to 2006, although the gross amount of travel hours decreased by 40 million hours and fuel consumption was decreased by 40 million gallons, the overall cost in 2007 increased by over $100 million due to the significant increase in cost of fuel and truck delay. This overall cost evoked by congestion in 2007 had an increase of more than 50 percent over the last decade.

Many strategies have been implemented to alleviate congestion on most metropolitan freeways during rush hours. One example is the congestion pricing. Congestion pricing is designed to divert some traffic to the alternative routes by charging tolls. Another example is to increase road capacity through capital investment. For most strategies, evaluation of value of travel time is a fundamental issue. Value of time enters these strategies because it is implicit in the modeling of traveler behavior and in gauging logistics impact of congestion. In this way, the public resources can be invested in projects with the greatest impact. Along this direction, a natural effort is to discover the value of delay to the freight community. In this research, we will access the value of delay due to congestion to commercial vehicle operators.

In fact, the US policy makers have shown interest in applying some form of congestion-based pricing for many years [3]. Although some initial attempts failed because of local community opposition. Two landmark legislations made congestion pricing programs vigorous again (Assembly Bill 680 in 1989 and the Intermodal Surface Transportation Efficiency Act in 1991). At least nine congestion pricing programs were implemented during the years from 1995 to 2002. A common feature of all these projects is that the toll varies with time of the day, in an effort to encourage traffic to shift to alternate roads or off-peak periods. However, the toll structures and rules vary widely among these projects. Most congestion pricing projects receive positive evaluations because they fulfill the primary objectives. Some details can be found in the work of Sullivan [4] [5], Supemak *et al*. [6], and Swenson *et al*. [7].

This report presents an assessment of the value of freight delay (VOD) as the fundamental parameter influencing the private sectors' response to public freight projects and policies such as corridor construction and tolling.

II. LITERATURE REVIEW

A. COMMUTER VOT

Value of time (VOT) can be viewed as the opportunity cost of the travel time on a trip. The value of travel time saving (VTTS) then is the maximum amount of money travelers are willing to pay to reduce travel time. If individuals choose their routes based on a combination of time, cost, and other components such as comfort, then the relative weights or values attached to time, compared with the weight associated with the monetary value, can be interpreted as value of time.

There are numerous studies on value of travel time for commuters. Wardman [8] gave a review on how the value of time can be deduced. The idea of attaching a value to time assigned to certain type of activities can be traced back to the work of Becker [9], who proposed that the individual satisfaction did not come from goods consumed directly, but also from the time associated with it. Under this framework, time entered the utility function, where time was converted into monetary cost, by assigning less to recreation time and more to working time. Since then, the concept of value of time emerged. Economists at that time saw the value of time as the opportunity cost of assigning time to activities but work. This opportunity cost was at the wage rate. By appropriately balancing time to different activities, the individual therefore was seen as trying to optimize the outcome of utility function, which is an additive value based on all the activates' time assigned. Deserpa [10] considered minimum time requirement for each activity when assigning times. Then he postulated a utility function considering all goods and all time periods, where work and travel are included. For a long time since Deserpa's work, the researchers believed that the value of travel time saving was somehow equivalent to the marginal wage rate, until Jara-Diaz [11] gave a general proof that there was no reason to expect this. Marginal wage rate is defined as the extra dollar that can be earned if putting another unit time into work activity.

It is also generally considered that the value of travel time savings varies for different individuals. For example, individuals with high income tend to have a high value of time savings. Mackie *et al*. [12] listed, six major influences on an individual's value of travel time savings: the time at which the journey is made, the characteristics of the journey, the journey's purpose, the journey's length, the mode of travel, the amount of time saved. Thus, an appropriate distribution has to be selected carefully when use to forecast an individual's behavior. Recent work on the variation of the value of travel time saving by Hensher and Goodwin [13] and Hensher and Greene [14] suggests that the representation of the distribution by an average is likely to give over optimistic projections of the overall value of time savings. Their evidence shows that most distributions are logically bounded by zero and logically tend to be skewed in the direction away from zero. In other words, the mean of the most distribution is larger than the true value, no matter what distribution is chosen.

Knowledge of commuter's value of time helps develop better tolling program. The standard approach to estimate value of time savings is through examination of urban commuter's tradeoff between travel time and travel cost, which are usually revealed by their choice of transportation mode and route (e.g., toll versus non-toll, auto versus bus). Given the target segmentation, researchers can use a model, such as the logit model, to estimate commuter's willingness to pay to reduce travel time under hypothetical scenarios that describe how the toll structure is constructed and the important characteristics of the road system. Within this approach, stated preference method is the prevailing method to conduct survey or equivalent interviews [15] [16]. Small *et al*. [16] applied this method to study the distribution of commuters' preferences for speedy and reliable highway travel. Their result showed that motorists exhibit high values of travel time and reliability and substantial heterogeneity in those values. In order to improve efficiency and reduce the disparity of welfare impacts, they suggested that road pricing policies be designed to cater to varying preferences.

Another concept worthy of a note is the social value of time saving, which is much more difficult to estimate. Gálvez and Jara-Diaz [17] accessed this social value of time saving using social welfare. Mackie *et al*. [12] pointed out that subject value of time savings should not be used in general for social project appraisal because the proper social price of time is dependent on individual utility of travel time, which is potentially different across individual groups.

B. COMMERCIAL VOT

Value of travel time savings for freight carriers is quite different from value of commuter travel time savings. The benefit from freight travel time savings not only has to do with direct operational cost and personal travel time savings, but also is related to inventory costs due to freight holding and transit time variation. Therefore, the commercial value of time is inherently related to the associated logistics strategy. There are two types of logistics strategies in supply chain management: push vs. pull. Each has different evaluation of value of freight travel time savings. In a push system, also called make-to-stock system, products are produced and stocked, waiting for sale. Since each order placed in a push system is comparably large, a stock out situation due to transportation delay is unlikely. Therefore, the downstream process is not sensitive to upstream material delay. The disadvantage of this kind of system, however, is the expensive inventory cost. The pull system, in contrast, is characterized as a system of downstream work stations pulling stock from upstream stations, only when needed. The freight transportation aims to replenish the stock as it is pulled by downstream stations. One good example is the just-in-time (JIT) system first developed by the automotive industry in Japan. Simply speaking, the objective of the JIT is to reduce in-process inventory and the associated costs. To achieve this purpose, a JIT system is featured by short setup time, perfect quality, price stability, transportation stability, precise timing, etc. Thus, a delay in the transportation process has a significant impact on downstream station, and therefore on the entire supply chain. Since the freight traffic on highway is characterized by commodity, and commodity is often featured by its unique logistics strategy. The logistics strategy therefore determines the value of delay, which is the value of time due to congestion. Nowadays, the highly competitive market has driven manufactures in US to implement this JIT system when it is applicable. This fact motives more and more researchers to investigate the value of travel time savings in the freight network.

A number of studies trying to identify commercial value of time for shippers and carriers have been done in several countries. Most estimated the value using stated preference data. A detailed illustration of stated preference methodology can be seen from the working paper of Fowkes and Shinghal [18]. Since 1992, the Hague Consulting Group [19][20][21] conducted a series of studies measuring the value of freight rates, reliability, damage rate, level of service and delays. At least two studies in Australia were based on the Hague Consulting Group's model. By interviewing the shippers, Wigan *et al*. [22] showed that an estimated value of travel time for freight shippers using road transport is $1.40 (Australian dollars) per hour per pallet for metropolitan multi-drop freight services in Australia. A further study of Wigan *et al*. [23] showed that the value of metropolitan less than full truck load (MLFTL) freight delay per delivery per hour on intra-city routes was $2.2 per pallet, which was clearly significantly higher than other segmentations. They also found that the value of full truck load (FTL) freight delays per pallet per hour on inter-capital routes was $1.50 and on intra-city route it was $0.80. Similar techniques applied in Europe were presented in the work of Widlert and Bradley [24], Westin [25], Fridstroem and Madslein [26], Wynter [27], and Kurri *et al*. [28]. Wynter [27] noted that these values should be seen as underestimates of longer term values, due to structural changes within the industry to take advantage of transport infrastructure and operational improvements. In addition, De Jong [29] estimated that the longer term value of time savings is twice that of the short term.

Generally speaking, there are three major methods that are used in US. These methods included net operating profit methods, cost saving methods, and willingness to pay method. The cost saving methods is based on the cost to operate per unit of time. The net operation profit method estimates the net increase in profit due to the reduction in travel time. The willingness to pay method measures perceived value of time by stakeholders.

Based on Interstate Commerce Commission (ICC) freight data, Adkins *et al*. [30] were able to apply a cost saving method to composite cargo vehicle, a composite intercity bus, and a number of cargo vehicle types. The result is presented by time savings per hour for composite vehicles by each ICC regions. For example, the value of time savings for intercity trucks in the Pacific region was $4.95/hr at their time (1967).

Another earlier study (Haning and McFarland [31]) at the Texas Transportation Institute in 1963 was one of the first estimation through net operating profit approach. In this approach, the travel time saving is assumed to be used for productive purposes. By fixing vehicle and labor costs, vehicles with improved speed will be able to travel farther in the same time, which will simply produce more profit since there is no upper limit for total profit. The value of time saving is then calculated based on the difference between base condition and improved speed condition. The value was found to vary from $17.4/hr to $22.6/hr in 1998 prices. Using a similar method, Water *et al*. [32] obtained a value between $6.1/hr and $34.6/hr in 1998 prices associated with for-hire carriers.

Different from previous studies, Kawamura [33] applied a switch point method in which truck drivers were asked with a choice between an existing free road versus a toll facility for different combinations of travel time and cost, which is actually a willingness to pay study. Using the survey data conducted by researchers at the University of California, Irvine, from the year 1998 to 1999, Kawamura successfully observed the switch points of choosing different road facilities. The average value of time for interviewed truck drivers was found to be $26.8 per hour with a standard deviation of $43.7 per hour. A further segmentation according to business type, shipment size and the method of driver compensation allowed the author to compare between different data groups. This comparison led to the conclusions that for-hire fleets tend to have higher values of time than private fleets and companies paying hourly salary have higher values than the ones paying a fixed wage.

Recommendations for value of time savings for commercial vehicles are available at American Association of State Highway and Transportation Officials (AASHTO) and FHWA [34]. AASHTO [2003 suggests an average of $20.23 per hour while a higher value was suggested by FHWA's Highway Economic Requirements System (HERS) model. The HERS, by considering the value per person, vehicle costs and inventory values, concluded a truck size related value between $28.50 and $41.25 per vehicle per hour, which is seen in Table 1 below.

Table 1. Value of One Hour Travel Time (Updated from 2006 HERS Model).

	Small Auto	Medium Auto	4-Tire Truck	6-Tire Truck	3 to 4-Axle Truck	4-Axle Comb.	5-Axle Comb.
Value per Person	$27.07	$27.07	$27.07	$23.76	$23.76	$23.76	$23.76
Average Occupancy	1.43	1.43	1.43	1.05	1.0	1.12	1.12
Vehicle	$1.46	$1.94	$2.54	$3.55	$9.59	$8.58	$8.25
Inventory	-	-	-	-	-	$0.76	$0.76
Average Value per Vehicle	$40.17	$40.65	$41.25	$28.50	$33.35	$35.95	$35.62

C. TRUCK ROUTE CHOICES

Truck route choice models are generally based on the concept of utility maximization. If time is the only consideration, utility is maximized by taking the quickest path. In practice, utility maximization requires considering number of factors such as income, education, availability of alternative routes, travel time and length of alternative routes, available traffic information, congestion, weather, time of the day, commodity types being transported, and so on. Route choice is also known as a discrete choice problem, which involve choices among a finite set of discrete alternatives. This is contrast with standard consumption models where the quantity of each good consumed is assumed to be a continuous variable. In 1999, Ben-Akiva *et al*. [35] reviewed the standard model of rational behavior. In order to untangle the influences of various psychological elements, they presented a general methodology to model the theoretical framework. This method is based on estimation of an integrated multi-equation model associated with a discrete choice model and the latent variable model system. The complexity of this method indicates the difficulty to forecast the route choices and their distributions. When the problem is reduced to the shortest path problem, it is not easier due to the constraints such as time window and capacity.

There have been numerous practical projects concerning the route choices. Stephanedes and Kwon [36] found that the commuter drivers in Minneapolis-St. Paul metropolitan area freeway system usually consider three alternative routes at most. Enlightened by this finding, Knorring *et al*. [37] assumed that truck drivers rarely consider more than two alternative routes. By using a remote sensing data set of more than 249,465 trucks and 60,000,000 locations records over a 13-day period, they confirmed this assumption by revealed preference analysis. The study showed that truck drivers only considered one alternative route compared with multiple routes for commuters, unless they were caught in an extreme weather condition. One possible explanation behind this is that truckers are more limited on the available paths but not the time of day. They have some flexibility in choosing service hours as long as they are within the regulations of number of service hours. For example, commuter drivers must arrive at their working places during the peak hours. Since the trips have a strict arrival time, they have to consider more alternative routes to ensure on-time arrival. In contrast, the truck drivers, especially long-haul drivers often have a few days time window to pick up and deliver, giving them more flexibility to avoid peak hours instead of through an alternative route. In addition to this, they also observed that if the perceived speed on the through route dropped to 50 mph, about 50 percent truck drivers would shifted to bypass where the perceived speed is 65 mph, resulting in a time saving.

D. ADVANTAGE OF THIS RESEARCH

From the literature above, it can be seen that although the value of time for commuters is well studied, the research on commercial value of time for carriers and shippers is still in process. Our research aims at developing new methodology to access value of time for commercial vehicles due to the congestion, defined as value of delay. This is achieved by using a simulation technique that combines the concept of value of time and the dispatching algorithm in the optimization field. Different than the previous net operation profit method, our simulation envisions a fleet of vehicles operating within an urban area providing truck road service to customers. A set of parameters such as demand location, congestion location, time window, demand size, demand distribution pattern, etc. are all considered due to their significant effects on resulting value of delay. The details are introduced in the methodology section. Within the knowledge of the authors, this method is a state-of-art technique due to its originality and complexity. In addition to the simulation, an improved state preference survey with logit model is implemented as well, to provide a baseline number that can be used to compare with the simulation technique.

III. METHODOLOGY AND RESULT

A. SURVEY METHOD

1. Survey Design

The survey produced data for evaluating perceived value of time due to traffic delay from the perspective of truckers and fleet dispatchers. The survey implements the Stated Preference (SP) method for data collection, which provides a wide array of possible alternatives. Monetary costs and congestion delay are associated with each alternative. Assuming the value of delay for commercial vehicles depends upon the available flexible time for the drivers. Two hypothetical scenarios were developed for travel conditions on a congested non-toll road. In the first scenario, the stakeholders are assumed to be running 30 minutes late by taking the congested non-toll road, while in the second scenario assumes on time delivery or pickup. Both scenarios are followed by options to gain 15, 30, or 45 minutes time saving, respectively, by paying different toll amounts. The tolls were calculated based on value of time saving of $30/hr, $40/hr … $120/hr. A write-in option was provided if the participant wanted to indicate a higher or lower rate than the provided alternatives. Appendix A shows the survey form for truckers.

The survey records the participant’s characteristics that are useful for grouping data for differentiation and analysis. One character here is the type of carrier or type of cargo because commodity type determines logistics strategies, which often specifies delivery time window. Another characteristic is truck size because toll systems charge by the number of axles. The question about ‘who pays the toll and how the drivers are paid’ recognizes that drivers paid by mile are more willing to avoid congestion than those paid by fixed salary. The trip length and flexibility of delivery hours on an average trip are also influential characteristics.

In addition to the face-to-face survey mentioned above, surveys were mailed to freight and transportation companies in an effort to enhance coverage. These later surveys are slightly different than the surveys used to interview drivers because the participants are fleet managers and dispatchers rather than individual drivers. Appendix B shows the survey for freight and transportation companies.

2. Multinomial Logit Model

A multinomial logit model was used to analyze the survey data. The logit model employed in econometric analysis stems from three distinct and separate research fields: applied mathematics, experimental statistics, and economic theory. Early in 1845, the logistic function was developed as a growth curve. In the 1930s, the bivariate probability model was identified from biological statistics [38][39]. After that, around 1950, the theory of discrete choice or random utility became prevailing in economic theory. For example, a bivariate model was used by Farrell [40] to relate the ownership of motor cars of different vintage to household income; a lognormal demand curve was applied by Adam [41] to fit interview data of the willingness to buy indivisible items, such as cigarette lighters, at various prices. However, the full development of the generalized logit model dates from its use in traffic analysis in the 1970s. Theil [42] was the first to generalize the logit model to more than two states, which led to the multinomial logit model. Enlightened by this development, the multinomial logit model was applied to empirical studies such as traffic modal split and many other theoretical problems [43][44][45][46].

Generally speaking, multinomial logit models are used to model relationships between a polytomous response variable and a set of regressor variables. Consider an individual n choosing among alternatives i in a choice set. Suppose the response Y has a set of values y_i corresponding to alternatives i, where $y_1<y_2<\ldots<y_{|I|}$. A continuous utility U is assumed to be determined by the response variables in the linear form.

$$U = -\beta x + \varepsilon$$

β is a m-dimension vector of regression coefficients and ε a random variable with a distribution function F. The relationship between Y and U is then:

$$Y = y_i \Leftrightarrow \alpha_{i-1} < U < \alpha_i,\ i = 1,\ldots,|I|$$

$$\Pr\{Y \le y_i \mid x\} = F(\alpha_i + \beta x)$$

where $-\infty = \alpha_0 < \alpha_1 < \ldots < \alpha_{|I|} = \infty$.

In the generalized logit model, the individual characteristics are treated as constant explanatory variables over the alternatives. Let X_n represent the characteristics of individual n, and $\beta_1, \beta_2, \ldots, \beta_{|I|}$ *are* $|I|$ vectors of unknown regression parameters; they are different from each other. The probability of an individual n choosing alternative i is defined as P_{ni}, where:

$$\begin{aligned} P_{ni} &= \exp(\beta_i X_n) / \sum_{l=1}^{|I|} \exp(\beta_l X_n) \\ &= 1 / \sum_{l=1}^{|I|} \exp[(\beta_l - \beta_i) X_n] \end{aligned}$$

Since the only constraint is $\sum_{i=1}^{|I|} P_{ni} = 1$, the m sets of parameters are not unique. In order to obtain a unique solution, the last or the first set of coefficients is usually set to null. For example, if $\beta_{|I|}$ is set to be zero, the coefficients β_i represent the effects of the X variables on the probability of choosing the i^{th} alternative over the last alternative. The model will result in an m-1 set of regression coefficients, which creates a difficulty for this commercial value of time research. The reason is that only one utility function with one set of coefficients is desirable here, due to the fact that a generic VOD is needed. Although there is a way to address this problem by weighting all the coefficients in different alternatives [47], the better way here is to use conditional logit model.

The conditional logit model assumes that variables have a constant impact across alternatives, while the individual characteristics are treated as constant explanatory variables over the alternatives. This is different from generalized logit model. Let Z_{ni} be the explanatory variables decided by both alternative *i* and individual *n*. Let θ be the global regression coefficients. Then the probability that the individual *n* chooses alternative *i* is:

$$\begin{aligned} P_{ni} &= \exp(\theta Z_{ni}) / \sum_{l=1}^{|I|} \exp(\theta Z_{nl}) \\ &= 1 / \sum_{l=1}^{|I|} \exp[\theta(Z_{ni} - Z_{nl})] \end{aligned}$$

For the purpose of obtaining coefficients, the preferred method of estimation is maximum likelihood. The higher likelihood indicates that model has a better fit to the data. In this case, the log likelihood is:

$$\log L(\theta) = \sum_{i=1}^{|I|} \log P_{ni}$$

In this research, an imbedded PHREG procedure in SAS/STAT software was used to fit conditional logit models after preliminary data processing. Details of this preliminary processing can be found at the SAS website under the support category [48].

Two different utility functions are tested to model VOD in this research. The first one is a traditional utility function that can be found in several works [24]. For an individual *n* choosing alternative *i*, the utility function is defined as:

$$U_{ni} = \theta Z_{ni} = aC_n + bT_i + \varepsilon_i \qquad \text{(Eq3.1)}$$

where
i = alternatives.
n = individual index.
C_n = payment specified by individual *n*.
T_i = travel time saved, measured by 15 min, 30 min and 45 min.
a, b are coefficients of regressors.

ε_i is unobserved stochastic portion of utility. For $\forall i$, ε_i is independent and identically distributed. The logistics distribution of ε_i yields the logit model, which is used in this study. The perceived value of delay is defined as the cost or payment attached to the time saving, which can be derived from the resulting coefficients of regressors. The coefficient of payment is utility/dollar, and coefficient of time is utility/minute.

$$\begin{aligned} \mathit{Value\ of\ delay} &= \mathit{Coefficient\ of\ time} \ / \ \mathit{Coefficient\ of\ payment} \\ &= b / a \end{aligned}$$

The second utility traces back to the work done by Mot *et al*. [49]. In order to model the behavior of choosing among the use of cash and different checks, they showed a utility function having the payment in logarithm as a regressor together with other non-logarithm regressors. The use of the logarithm is a purely empirical choice: it substantially improves the fit as measured by the loglikelihood. Enlightened by their work, the second utility function proposed for this research is:

$$U_{ni} = \theta Z_{ni} = a \log C_n + bT_i + \varepsilon \qquad \text{(Eq3.2)}$$

Due to the logsize payment, the perceived value of delay changes to:

$$\begin{aligned} \mathit{Value\ of\ delay} &= \mathit{Coefficient\ of\ time} \ / \ (\mathit{Coefficient\ of\ logsize\ payment} \ / \ \mathit{Payment}) \\ &= b / (a / C_n) \end{aligned}$$

This research investigated the two alternative utility functions for estimating VOD. Both utilities were tested and measured by loglikelihood using actual data from the Houston area. Table 2 shows that for both scenarios, the utility function in Eq3.2 provides a model with a slightly higher fit, compared to the utility in Eq3.1. However, Eq3.2 does not provide the generic value for value of delay that we are interested in, it only provides a dependent value that is related to actual payment. For this reason, Eq3.1 was used to conduct further analysis, which is shown in a later section.

Table 2. Model Fit.

		b	a	Log L
Scenario 1 (30 minutes late)	Eq 3.1	0.0311	0.0287	−95.59
	Eq3.2 (logsize)	0.0248	−0.9335	−86.90
Scenario 2 (on-time)	Eq3.1	0.0233	0.0565	−91.14
	Eq3.2 (logsize)	0.0993	−1.1618	−80.63

Note: higher LogL indicates better fit. Thus, −86.90 indicates a better fit than −95.59.

More regressors are also considered when formulating the utility. However, the test on both utilities below shows that all the additional regressors have coefficients either equals to zero or very close to zero. Therefore, the loglikelihood remains almost the same as when only two regressors (payment and timesaving) are considered.

$$U_{ni} = \theta Z_{ni} = aC_n + bT_i + \sum_{k=1}^{3} d_k R_{kn} + \sum_{k=1}^{3} e_k F_{kn} + \varepsilon$$

$$U_{ni} = \theta Z_{ni} = aLogC_n + bT_i + \sum_{k=1}^{3} d_k R_{kn} + \sum_{k=1}^{3} e_k F_{kn} + \varepsilon$$

where
$R_{1n} = 1$ if local, 0 otherwise.
$R_{2n} = 1$ if regional, 0 otherwise.
$R_{3n} = 1$ if long haul, 0 otherwise.
$F_{1n} = 1$ if flexibility of delivery hours is less than 3 hrs, 0 otherwise.
$F_{2n} = 1$ if flexibility of delivery hours is from 3 hrs to 5 hrs, 0 otherwise.
$F_{3n} = 1$ if flexibility of delivery hours is from 5 hrs to 12 hrs, 0 otherwise.
$F_{1n} = 1$ if flexibility of delivery hours is more than 12 hrs (such as 1 day), 0 otherwise.
ε = unobserved stochastic portion of utility.
a, b, d_k and e_k are coefficients of regressors, $k = 1, 2, 3$.

Local, regional, and long haul are options provided in the survey, under trip length category. These values indicate how long the typical trip is. Similarly, the options about flexibility of delivery hours are provided to recognize the maximum slack time in the driving schedule.

3. Maximum Likelihood Estimate (MLE)

The likelihood function $L(\theta)$ has the form of:

$$L(\theta) = \prod_{i=1}^{|I|} P_{ni}$$

The MLE maximizes the logarithmic likelihood:

$$\max \log L(\theta) = \max \sum_{i=1}^{|I|} \log P_{ni}$$

This is usually done by equating the derivatives of $\log L(\theta)$ to zero [50].

$$(\partial \log L(\theta) / \partial \theta)^T = q$$

where q is a score vector with element:

$$\partial \log L(\theta) / \partial \theta_j = q_j$$

Let the desired estimates be $\hat{\theta}$, then $q(\hat{\theta}) = 0$. Note that the observation order is not relevant here because the observations are independent. To approximate $\hat{\theta}$, $q(\theta)$ is expanded around some given θ^0 in the neighborhood of $\hat{\theta}$. Let Q denotes the Hessian matrix of $\log L(\theta)$ (the matrix of its second derivatives), the expansion is as following:

$$q(\hat{\theta}) \approx q(\theta^0) + Q(\theta^0)(\hat{\theta} - \theta^0)$$

Then $\hat{\theta}$ is determined by:

$$\hat{\theta} \approx \theta^0 - Q(\theta^0)^{-1} q(\theta^0)$$

Since the above expression only provides a closer approximation than θ^0, an iterative scheme is required. Using Newton's method, where the iteration is processed by:

$$\theta_{t+1} = \theta_t - Q(\theta_t)^{-1} q(\theta_t)$$

The Newton's method is an extremely powerful method. The convergence is usually quadratic, and the error is nearly squared at each step. However, Newton's method may fail to converge if the initial point is too far from the true zero, which makes this method a local technique. Also, it does not work when the derivative is zero. Even for the cases where the derivatives are close to zero, this method may overshoot the desired root due to the fact that the tangent line is nearly horizontal. In general, the most serious problem for this method is the potential failure of convergence.

Scoring method works better for the logit model. Let *E* be the expectation operator, meaning *EQ* takes the mathematical expectation of each element of *Q*. Define *H* as the information matrix where:

$$H = -EQ$$

The iterative scheme is then obtained as following:

$$\theta_{t+1} = \theta_t - H(\theta_t)^{-1} q(\theta_t)$$

All iterative schemes must have a starting point θ_0 and a convergence criterion to terminate the process. Selecting a starting point discreetly may contribute to speedy convergence. Convergence criterion, on the other hand, could be chosen from a lot of options. The most common options are:

(1) Terminate when $\log L(\theta)$ stops increasing.
(2) Terminate when the score vector, if there is one, becomes zero.
(3) Terminate when successive parameters that we are trying to estimate are identical.

4. Survey Result

At the beginning, there were 47 drivers interviewed face to face at the truck stop along the major highways around Houston, San Marcos, Dallas, and Fort Worth in Texas. Later on, another 64 were interviewed near Belvadere Oasis, Cottage Grove, Janesville, Mauston, and Racine in Wisconsin. Most drivers completed both scenarios in the second section of the survey. Table 4 summarizes the survey results from Texas, while the numbers in Wisconsin are summarized in Table 4.

Table 3. Summary on Survey in Texas.

Question	Category	Drivers	Question	Category	Drivers
Type of Carrier	Owner Operator	15	Typical route	Regional	14
	For-hire	18		Long haul	28
	Private-Carrier	11		Local/delivery	4
Typical cargo	Bulk	10	Who decides route?	Me (the driver)	20
	Average Value	27		Dispatcher/manager	24
	High Value	8		Shipper	1
	Other	0		Other	0
Truck Size	2 axle	14	How are you paid?	By Mile	30
	3 axle	5		By Load	6
	4 axle	19		Percentage of Revenue	7
	Other	5		Other	2
Trip Length	11+ Hours	29	Who pays the toll?	I do	21
	5 to 11 Hours	12		For-hire carrier	16
	2 to 5 Hours	0		Shipper	3
	Less than 2 Hours	1		Other	3
Delivery window	1 day	16	Route changes	Never	4
	Less than 12 hours	9		Occasionally	15
	less than 5 hours	4		Often	17
	less than 3 hours	15		Always	11

Table 4. Summary on Survey in Wisconsin.

Question	Category	Drivers	Question	Category	Drivers
Type of Carrier	Owner Operator	17	Typical route	Regional	24
	For-hire	14		Long haul	33
	Private-Carrier	35		Local/delivery	16
Typical cargo	Bulk	17	Who decides route?	Me (the driver)	24
	Average Value	38		Dispatcher/manager	36
	High Value	26		Shipper	2
	Other	0		Other	4
Truck Size	3 axle	5	How are you paid?	By Mile	36
	5 axle	51		By Load	9
	6 axle	6		Percentage of Revenue	16
	Other	6		Other	8
Trip Length	11+ Hours	34	Who pays the toll?	I do	23
	5 to 11 Hours	31		For-hire carrier	36
	2 to 5 Hours	4		Shipper	3
	Less than 2 Hours	0		Other	6
Delivery window	1 day	14	Route changes	Never	6
	Less than 12 hours	11		Occasionally	38
	less than 5 hours	14		Often	13
	less than 3 hours	30		Always	9

In addition to face to face interview, 180 surveys were mailed out to transportation companies in the major cities in Texas. Unfortunately, only 5 of them returned the completed survey after we made phone calls to them.

Since the drivers interviewed may choose one to three options corresponding with 15, 30, 45 minutes time, one to three records were created from each survey. No matter if they selected original payments in the form or specified numbers based on their own judgments, we simply put those numbers under the corresponding piece of records, without any changes or filter, in order to reflect the true value of delay perceived by drivers. The following Table 5 shows the analysis for the entire dataset. Recall that the analysis applies the utility function presented in Eq3.1, for the purpose of having an overall VOD instead of individual payment based VOD.

Table 5. Analysis for Entire Dataset.

	Utility function 1	b	a	VOD $/min	VOD $/hr
Texas	Scenario_1	0.0332	0.03916	0.8488	50.9295
	Scenario_2	0.0233	0.0547	0.4262	25.5700
Wisconsin	Scenario_1	0.0497	0.0439	1.1322	67.9343
	Scenario_2	0.0869	0.0924	0.9403	56.4156
Overall	Scenario_1	0.0414	0.04402	0.9414	56.4834
	Scenario_2	0.0457	0.0825	0.5541	33.2477

b is the coefficient of Travel Time Saving. *a* is the coefficient of payment and log size payment. The VOD is first measured by minute, which is then translated into hours by multiplying 60. From these tables, the overall VOD estimated by the utility 1 is $56.48/hr for the first scenario, compared with $33.25/hr for the second scenario. These numbers confirm the fact that the VOD is higher in the first scenario due to the assumption that the drivers were running late, which causes a bit more urgency to arrive on time. Additionally, in both scenarios, VOD in Wisconsin is higher than that in Texas. This geographical difference is created by the characteristics variation between drivers in Texas and Wisconsin.

In order to investigate the VOD for different truckers' characteristics, this search also used data grouping method to create different logit model. Records for both scenarios were grouped based on several criterions. However, only data from scenario 1 are analyzed because of the tendency of not paying anything in scenario 2. The results for grouping based on how to be paid are shown in Table 6.

According to this result, another observation is made that drivers paid by miles perceived a significantly higher VOD ($73.40) than drivers paid by other methods, such as hourly salary or percentage of the load revenue ($39.50). This is very intuitive because driver paid by mile is losing money during the congestion, in terms of the potential distance that can be traveled otherwise. Particularly, Wisconsin's driver perceived an even higher VOD ($100.51) than the overall VOD ($73.40) when they are paid by mile.

Table 6. Salary Method.

	Utility function 1	b	a	VOD $/min	VOD $/hr
Texas	Paid by mile	0.0199	0.0185	1.0769	64.6129
	Paid by other methods	0.0527	0.0572	0.9220	55.3192
Wisconsin	Paid by mile	0.0487	0.0291	1.6752	100.5093
	Paid by other methods	0.0412	0.1015	0.4055	24.3275
Overall	Paid by mile	0.0335	0.0274	1.2234	73.4040
	Paid by other methods	0.0494	0.0750	0.6583	39.4960

Table 7 below shows the categorization according to type of carrier. The table does not show the difference geographically for the lack of sufficient data It is found that private carriers perceived the highest VOD ($87.82/hr) among the three types of carriers, leaving the for-hire drivers the lowest VOD ($26.26/hr). The reason behind is that a private carrier is a company that transports only their own goods. Usually the carrier's primary business is not in transportation. The drivers appear to know better time sensitive deliveries in the context of their business logistics operations.

Table 7. Type of Carrier.

Utility function 1	b	a	VOD $/min	VOD $/hr
Owner-operator	0.0392	0.0439	0.8930	53.5792
For-hire	0.0396	0.0904	0.4377	26.2632
Private Carrier	0.0469	0.0321	1.4637	87.8190

The survey found drivers are willing to pay more for time saving if the cost does not come from their own pocket. This is a general tendency in both Texas and Wisconsin. In Table 8, the check item 'Other pays toll' means the carrier or shipper pays the toll.

Table 8. Who Pays the Toll.

	Utility function 1	b	a	VOD $/min	VOD $/hr
Texas	Driver pays toll	0.0458	0.0603	0.7604	45.6247
	Other pays toll	0.0259	0.0207	1.2476	74.8552
Wisconsin	Driver pays toll	0.1208	0.1794	0.6732	40.3890
	Other pays toll	0.0466	0.0415	1.1229	67.3735
Overall	Driver pays toll	0.0557	0.0761	0.7327	43.9590
	Other pays toll	0.0399	0.0376	1.0626	63.7540

Table 9. Trip Length.

	Utility function 1	b	a	VOD $/min	VOD $/hr
Texas	Regional	0.0381	0.0627	0.6066	36.3978
	Long haul	0.0234	0.0110	2.1270	127.6225
	Local/Delivery	0.0320	0.0383	0.8355	50.1306
Wisconsin	Regional	0.0410	0.0800	0.5114	30.6822
	Long haul	0.0345	0.0247	1.3971	83.8250
	Local/Delivery	0.0519	0.1070	0.4852	29.1137
Overall	Regional	0.0410	0.0765	0.5363	32.1762
	Long haul	0.0302	0.0212	1.4286	85.7183
	Local/Delivery	0.0410	0.0590	0.6952	41.7100

In the end, grouping based on different route type is presented in Table 9. The result strongly suggests that long-haul driver perceived twice overall VOD ($85.72/hr) as Local/Delivery driver perceived ($41.71). This finding is consistent with the report of Wigan *et al*. [23], where the value of delay on inter-capital routes was about twice as that on intra-city route. One of the possible explanations for this finding is that the long-haul drivers have more time to consider the question before put down a realistic number during the survey, while the local drivers are always in a hurry when they are doing the survey. Another possible explanation is that short distance shipments are usually the most constrained in terms of options for configuring the route. If they are not allowed to change route or not willing to change route, there is little value associated with their time.

B. SIMULATION METHOD

Although perceived VOD might be easy to obtain from interviews with drivers, it might not represent the true VOD to carrier operations. The perceived VOD, the willingness to pay to avoid delay due to highway congestion, includes values of inconvenience, safety, and other psychological factors due to prior expectation and inertia habit. In particular, drivers would tend to decide the value based on cost implication to their own income instead of on the effect to the entire carrier operation or supply chain management. Since our primary objective is to address the true VOD values, simulation can be used to include consideration for many realistic factors affecting carrier fleet operation.

In simulation, a fleet of vehicles operates within an urban area (Houston) providing truck load services to customers. Each customer's demand has an origin, destination, and associated time window constraint. Trips are conducted on a network subject to congestion. A fleet dispatcher continuously makes assignment to drivers as demand unfolds with the time of day. The objective is to satisfy all the demand while minimizing total operation cost. The Savings Method [51] was programmed as the heuristic to solve the problem quickly while maintaining a comfortable level of optimality.

GIS data were collected directly through ArcGIS, as the network input to the algorithm. The entire simulation process envisions a commercial fleet operating in a congested urban setting serving customers at a fixed number of possible locations. A limited number of depots were considered. Scheduling is repeatedly done according to demand updates and realization of the random factors such as demand sizes, customer locations, and time windows. Vehicle diversion is allowed if the vehicle is not dedicated. Soft time windows are considered since the vehicles can wait at the pickup or deliver location if they arrive early. The outputs of the simulation are the total miles traveled by all the vehicles that are used in order to satisfy all the demands under the congested and non-congested scenarios. If the vehicle runs into congestion, the time delayed is translated to the operational cost. Using a standard mile based operating cost, which is based on the driver wages, fuel price, and other cost such as maintenance, the cost of congestion, and the value of delay for carriers can be calculated. The details about this simulation are introduced in following sections.

1. GIS Settings

In order to make a realistic operational environment for carriers, this research used national highway ArcGIS dataset from National Transportation Atlas Database 2009 at the Bureau of Transportation Statistics for the freight highways around Houston. Twenty locations (shown as squares) are eligible for pickup and deliver. These locations are likely ones for businesses in

Houston. Two separate depot locations and one central depot (shown as circles) are considered in two scenarios, respectively. Figure 1 shows this network.

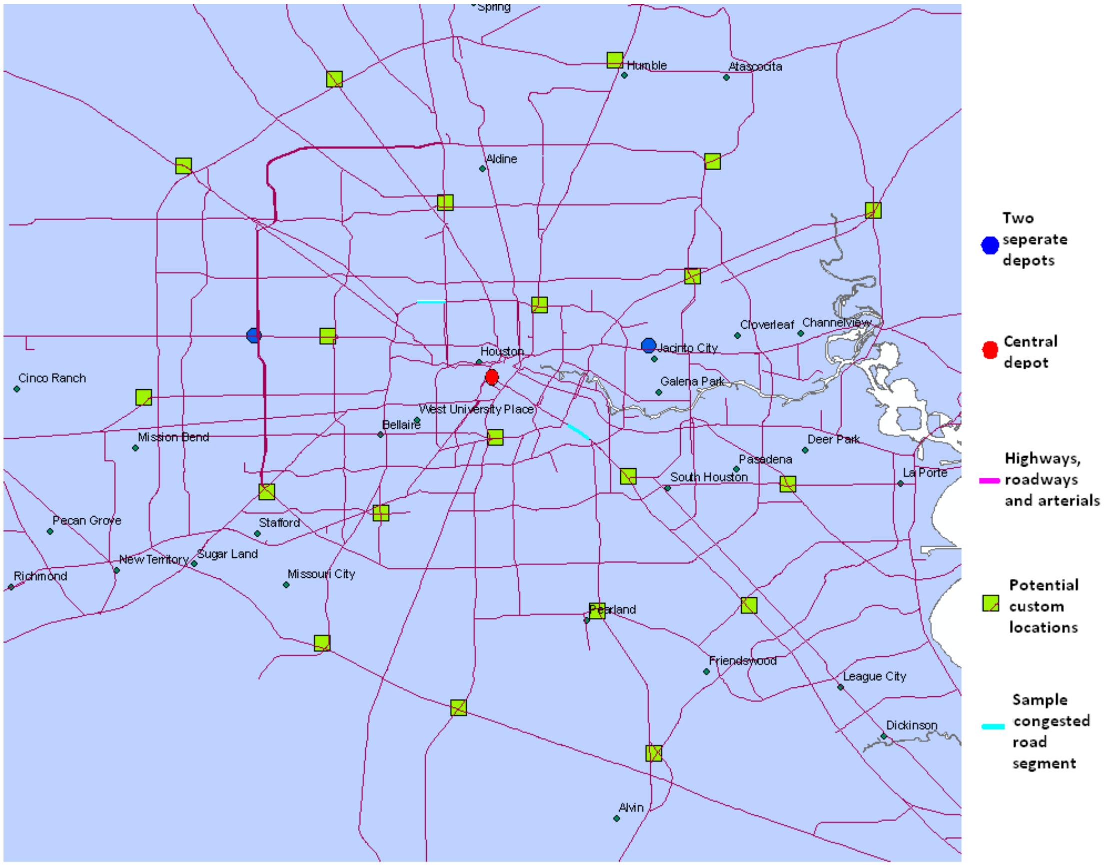

Figure 1. Network Setting.

The shortest paths between each pair of locations are calculated via ArcGIS. Therefore, the cost matrix and time matrix between any two locations and also between the depots and locations are tabulated as input to the simulation. In addition, the vehicle speed is assumed to be 65 mph uniformly except on congested roads. Several congested highway segments are designed and tested sequentially in the simulation to compare with the scenario without congestion in order to examine the effect of congestion, or VOD. Non-congested situation data are obtained here by using original travel time and distance matrix outputted by ArcGIS. On the other hand, congested situation is modeled by adding a delay time at the segments. We decide to choose roads with the highest daily traffic volume subjectively. The traffic information for these roads is readily available by using Google® maps traffic function. Once the congestion is introduced to the scenarios, the shortest paths between locations and depots are accordingly calculated. This leads to different congested cost and time matrixes in comparison with non-congested ones. Various congested situations are created, each corresponding to a different cost matrix and time matrix.

2. Heuristic Algorithm

The algorithm used in this study for the Vehicle Routing and Scheduling Problems with Time Window Constraints is an extension of the saving heuristics proposed in Solomon's work [51], although the initial saving heuristics can be traced back to the work of Clarke and Wright [52]. Some modifications are made for the purpose of serving our particular case. We recognize that there are many other heuristics such as insertion method, sweep method, and tabu search method, as well as optimal method like cutting plane method and column generation. However, we chose the simplest method due to fact that our simulation aims at quick solution and the easy update when new demand emerges.

The scheduling begins with n distinct routes in which each demand is served by a dedicated dummy vehicle. In the case of two or more depots, every depot is checked to ensure that each demand is served by the vehicle coming from the nearest depot. In each step, the tour building heuristic measures the cost saving for joining two constructed tours and joins the two tours with the most saving. Let *0* represent the depot selected and *i, j* represent customer locations, the cost saving from joining two tours, $0 \to i \to 0$ and $0 \to j \to 0$ is then defined as following:

$$Sav_{ij} = d_{i0} + d_{0j} - d_{ij}$$

where d_{ij} is the travel cost from node i to j.

This method will assume that initially each vehicle leaves the nearest depot at the earliest possible time, e_0 (6AM, for example). After a complete schedule for all vehicles has been created, the program adjusts the departure time for each vehicle to eliminate any unnecessary subsequent waiting time at customer locations.

Assume one partially constructed feasible route *u* is $0 \to i \to j \to 0$, and another route *v* is $0 \to k \to l \to 0$. The following step checks the feasibility of joining route *v* after route *u*. Let time window associated with location $p = i, j, k, l$ is $[a_p, b_p]$. Similarly, the arrival time at location $p \in \{i, j, k, l\}$ is t_p and the waiting time at location $p \in \{i, j, k, l\}$ is w_p, which is greater or equal to zero and. If initially each vehicle leaves the nearest depot at the earliest possible time, we have $a_i = t_i$, where t_i is the arrival time at the first location. Denote t_{pq} is the travel time from *p* to *q*, where $p, q \in \{i, j, k, l\}$. The arrival time at *j* is then $t_j = t_i + w_i + t_{ij}$. Also, we know $t_j \in [a_j, b_j]$ since *u* is partially constructed feasible route. However, when route *v* is added to the end of route *u*, the arrival times at *k* and *l* are subject to change if $t_k' = t_j + w_j + t_{jk} > t_k$, where t_k' is the arrival time at location k after joining two routes, and t_k is original arrival time in route *v*. The feasibility check is then trying to find out a set of w_p that ensure $t_k' \in [a_k, b_k]$ and $t_l' \in [a_l, b_l]$. If such a set of w_p exists, the joining is feasible, otherwise it is infeasible. Note, if $t_k' = t_j + w_j + t_{jk} <= t_k$, the joining is always feasible since we can prolong w_j so that $t_k' = t_k$. For longer routes, this feasibility check method still holds.

In each iteration, a feasibility check is conducted between any pair of constructed feasible routes. However, only the two routes with the most saving are eligible to merge. The algorithm terminates when the best saving value in current stage equals to zero or some negative value. The general procedure of this heuristics is presented below. Algorithm pseudo code is attached in the Appendix C.

> ***Step 0.*** Initialization.
> ***Step 1.*** Construct initial feasible routes by generating a set of distinct routes, each for a customer served by a dedicated dummy vehicle.
> ***Step 2.*** Check the feasibility (time window, etc.) of joining every pair of existing routes. For the feasible route joining, check the according savings. Find the best saving among all feasible joining.
> ***Step 3.*** If the best saving is positive, join the two according routes. Then go back to Step 2. Otherwise, terminate.

3. Simulation Framework

In simulation, we assume the carrier or fleet dispatcher operates on a rolling time horizon during the time of day, repeatedly making assignment and re-assignment when new demands emerge and when other conditions have changed. However, if the vehicles are already on their way to pickup load or deliver load, they have to finish that particular demand before they can change their route. Each demand has two locations: the first is the pickup location, and the second is deliver location. Each location is associated with a soft time window, which indicates the permission to arrival early then wait but not late.

Although continuous time simulation is ideal, we chose to divide the daily operation into several periods. Each period lasts two hours. All demands emerged during the current period are considered and scheduled at the beginning of the next period. Figure 2 illustrates this process.

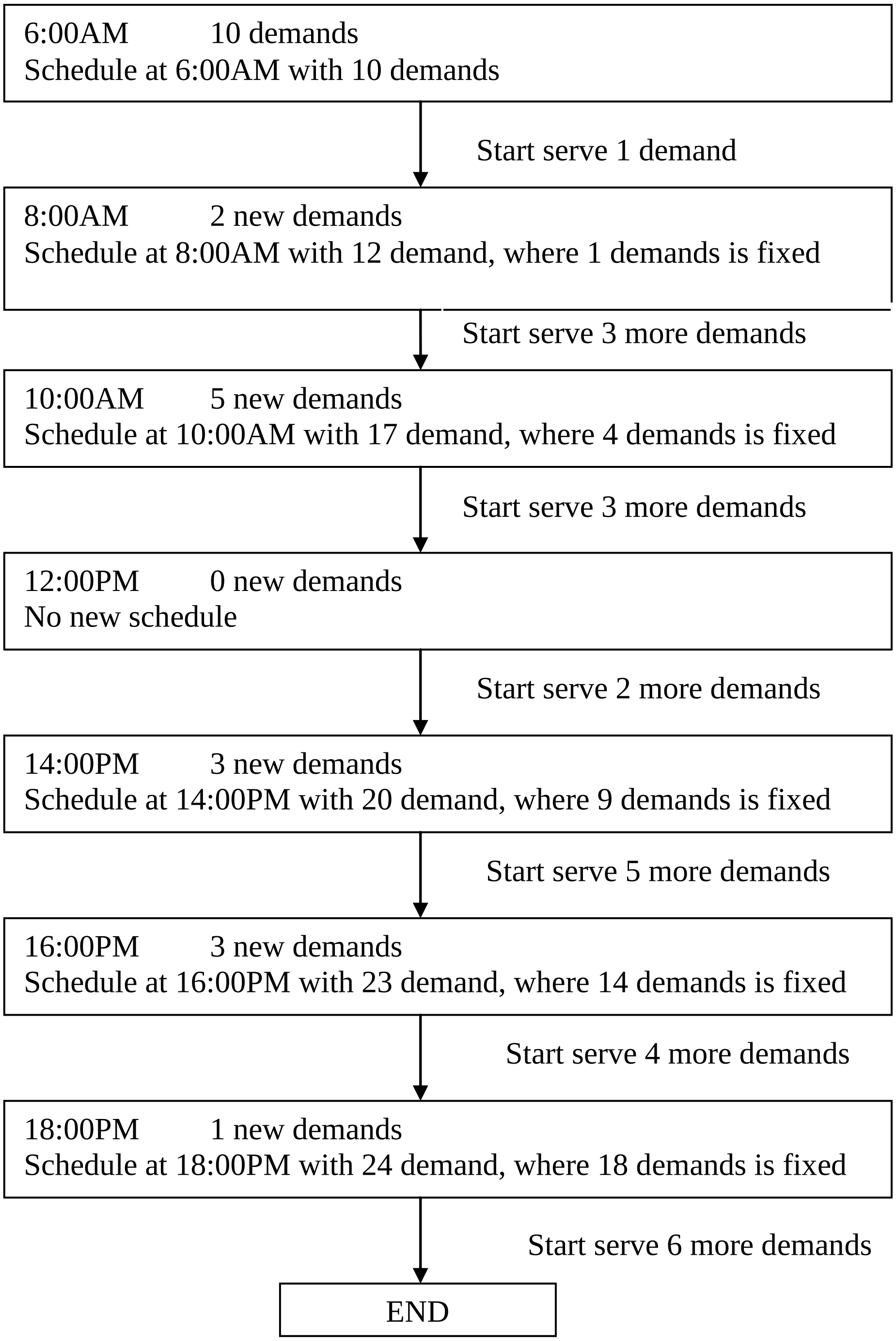

Figure 2. Sample of Daily Simulation.

4. Commercial VOD Calculation Based on Simulation

According to Manders' report [53], driver wages make up 29.3 percent of operating costs. This is very similar to the proportion of operating costs that are represented by fuel price, which is 29.8 percent. Based on the fuel and wage costs above, both of these indicate an operating cost slightly above $2.00/mile. The overall operating cost in our measurement is therefore measured by the total vehicle mileage along with this $2.00/mile unit cost.

In order to assess VOD, we start with a network without congestion first. Assume *n* vehicles need to drive through a particular road segment *m* times to finish their job. If congestion (for example, *t* minutes delay) occurs at that segment, these vehicles would reschedule their route. The result could be either taking alternative routes or experiencing the congestion. No matter what decision is made, additional cost is incurred in the form of a longer travel distance because of congestion. The additional distances are also created from the scheduling side because the demands have to be completed in time no matter how far the vehicle travels. Therefore, VOD is measured by:

$$\begin{aligned}\text{VOD} &= \frac{\text{Additional cost caused by potential delays}}{\text{Potential delays}}\\ &= \frac{\text{Cost when congested - Cost without congestion}}{\text{Vehicle times pass that segment} \times \text{Delays/Vehicle time}}\\ &= \frac{\Delta C}{mt}\end{aligned}$$

Different parameters such as number of the depot, location of congestion area, location of depot, demand size, time window size, and demand distribution pattern are simulated for the purpose of testing the different VOD value.

5. Simulation Result

In order to be representative and avoid bias, we chose several congested roadway locations to calculate the VOD. One location is a 1.22-mile segment on Gulf Freeway along I45. Another one sequentially in the simulation is located at North Loop along I610; segment length is 1.45 mile. We also vary the delay from one minute to 30 minutes for both locations. The result shows that under one minute delay, the drivers are better to stick on the original routes, in another word, experiencing the minor congestion. This is because any alternative road would require a detour longer than one-minute-travel. For the case of having congestion longer than three minutes, the trucks move more efficiently by taking an alternative route to avoid congestion. This is due to the highly developed freight network in Houston, where the alternative route takes no more than five minutes longer than the original route. For the cases with delay between one and three minutes, the resulting change in assignments in the simulation for each instance varies. Some drivers are assigned to alternative routes while others still stick to the congested road.

The test instances are designed as follow: two minutes delay on the chosen highway segment, time windows from 1 hour to 5 hours, demand sizes from 25 to 100, two possible congested locations include Gulf Freeway and North Loop. Again, the calculation of VOD is as discussed in previous section. The tables below summarize the average commercial value of delay for each combination. In Tables 10, 11, 12, each instance has 20 percent demands already known at the beginning of the daily operation, while 80 percent demands emerge as the day unfolds and require constantly scheduling update. On the contrarily, the instances in Table 13 have 80 percent demands known before the daily operation begins, which leaves a small portion (20 percent) to be updated during the operation. The measurement unit in these tables is $/hr. The number on the left side of each cell is the average commercial VOD of 1000 random instances. The number on the right side is the standard deviation. Each instance is a full day operation with randomly generated demands.

Table 10. One Central Depot Case 1.

Congestion on Gulf Freeway	Demand size 25	Demand size 50	Demand size 100
Window size 1 hrs	99.16/22.78	100.03/21.35	100.24/14.15
Window size 1.5 hrs	98.82/25.12	99.83/22.84	100.16/15.63
Window size 2 hrs	98.56/27.16	99.81/27.74	99.38/16.91
Window size 2.5 hrs	98.67/25.09	99.82/28.29	99.62/19.20
Window size 5 hrs	98.25/34.51	98.41/39.50	99.45/31.17
Note*Each number is the average of 1000 cases.			

Table 11. One Central Depot Case 2.

Congestion on North Loop	Demand size 25	Demand size 50	Demand size 100
Window size 1 hrs	102.61/48.92	117.26/44.57	120.89/22.63
Window size 1.5 hrs	101.36/51.92	117.30/27.20	119.79/22.15
Window size 2 hrs	101.40/52.19	117.06/28.02	118.82/23.77
Window size 2.5 hrs	101.97/52.18	117.25/34.55	120.48/27.37
Window size 5 hrs	99.71/58.84	116.55/32.08	118.24/38.68
Note*Each number is the average of 1000 cases.			

Table 12. Two Depots.

Congestion on Gulf Freeway	Demand size 25	Demand size 50	Demand size 100
Window size 1 hrs	81.98/37.13	81.55/23.62	83.81/31.44
Window size 1.5 hrs	81.38/34.40	81.61/23.35	83.34/28.57
Window size 2 hrs	81.08/32.41	81.45/25.51	82.45/29.62
Window size 2.5 hrs	80.05/26.98	80.40/23.39	82.30/30.95
Window size 5 hrs	79.81/24.86	80.13/24.55	81.18/34.13
Note*Each number is the average of 1000 cases.			

Table 13. 80%/20% Demands Split with One Central Depot.

Congestion on Gulf Freeway	Demand size 25	Demand size 50	Demand size 100
Window size 1 hrs	97.73/24.96	97.92/24.48	98.39/22.79
Window size 1.5 hrs	97.10/25.02	97.82/25.49	97.94/21.47
Window size 2 hrs	96.30/25.12	97.79/26.10	98.05/23.15
Window size 2.5 hrs	95.20/25.65	97.06/28.84	97.21/25.59
Window size 5 hrs	93.99/29.20	96.69/33.13	97.33/35.86
Note*Each number is the average of 1000 cases.			

The results are summarized according to demand size and time window size. The first two tables are for the case of one depot with two congested locations tested separately. The resulting VOD ranges from $99.16/hr to $120.89/hr. The third table is for two depots, which shows a VOD from $79.81/hr to $83.81/hr. The last table is tested for the 80 percent demands known before the operation, compared with previous three tables where only 20 percent demands are known at the beginning of the day. The VOD ranges from $93.99/hr to $98.39/hr in last table.

From three tables above, there are three tendencies observed.

- The VOD significantly increases with the demand size in Table 11. This tendency is indicative of the reality. For a larger freight operation with more demands, the possibility of encountering the congestion is higher than a smaller operation. In other words, the impact of congestion is profound for a larger operation. More likely there is less idling time. Thus, the congestion is a direct waste to productivity time. In the other tables, this tendency still exists but not significant.
- For the cases with 80 percent demands known at the beginning of the day, the standard deviation increases with the time window.
- Regarding depot size, VOD in two depots case is at least 25 percent smaller than the VOD in one depot case, regardless of congested location. This illustrates that multiple depots are capable of alleviating the impact from congestion. Assuming an infinite fleet capacity at each depot, the depots can help each other to avoid the congested road or minimize the negative impact.

C. COMPARISON

The simulation is capable of incorporating a decision making process of carriers, who usually must serve their demands in a most efficient manner. Therefore, the result from the simulation reflects the impact to carrier’s fleet. On the contrary, most drivers interviewed during the survey do not have the big picture of freight operation. Some of them are self-employed drivers who only accept one load at a time without guarantee of next load. The VOD to these drivers are therefore significantly lower than from simulation. According to the survey, we also found that a few for-hire truckers travel on the same route every time no matter how congested that route is. This is because their loads and routes are usually decided by the operation managers. Overall, the difference in VOD between truckers and carriers is surprisingly significant: from $80/hr–$120/hr vs. $26/hr–$68/hr, which outweighs the difference between drivers.

IV. CONCLUSION

In this research, the value of time for commercial vehicles is estimated in two methods. The first method applies a logit model to a stated preference survey. The survey was designed and conducted by the research group around several major cities (Austin, Houston, San Marcos, Dallas, and Fort Worth) within Texas and Wisconsin (Belvadere Oasis, Cottage Grove, Janesville, Mauston, and Racine). A total number of more than 400 records were collected. Analysis shows a VOD from $25.57/hr to $67.93/hr without further grouping. The following summarizes major findings from the first method.

1. The drivers are willing to pay more if they are running late.
2. The drivers paid by miles perceive a slightly higher VOD than the others.
3. Private carriers perceive a higher VOD when compared with owner-operators and for-hire drivers.
4. The drivers who pay the tolls by themselves are less willing to use toll road.

The second method proposes a simulation framework to assess the cost of congestion to carriers in an operational environment. A Heuristic algorithm is programmed for fleet dispatching to serve demands in a geographic area as the day unfolds. The value of delay for freight operation is then obtained. Different scenarios based on demand size, depot size, demand distribution pattern, time window, and location of congestion within the freight network are considered. The resulting VOD ranges from $93.99/hr to $120.89/hr for one central depot and $79.81/hr to $83.81/hr for two depots. Three major findings by this second method are summarized below:

1. The VOD increases with the growth of demand size, especially in the second case of central depot.
2. For the cases with 80 percent demands known at the beginning of the day, the standard deviation increases with the time window.
3. The VOD in two depots case is smaller than the VOD in one depot case, irrespective of congestion location.

In addition to the two VOD methods above, a comparison between the survey result and the simulation result was represented at the end of this research. This comparison showed that the driver perceived commercial VOD (varies from $26/hr–$68/hr) is significantly lower than the simulation of real world freight operation (from $80/hr–$120/hr).

A list of future work that can help improve this research is shown below:

1. Develop an optimal algorithm to solve the multiple vehicle routing problems with time window, within a reasonable computer running time.
2. Consider more realistic characteristics in the simulation framework, such as the uncertainty of travel time on every link, different business type for freight operation companies.
3. So far, only several congestion segments are examined independently within the network to calculated VOD. To test more congestion segments with the combinations (meaning several of them occurred at the same time) will provide more solid results.
4. Examine the impact of network configuration and simulation setup on the findings. For

example, what if simulated on the Dallas network. We are also interested in the representative of this simulation, such as the possibility to obtain value of delays for long-haul carriers by re-scaling the distance of network.

5. Collect more survey data for logit model to improve the quality of the result.

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APPENDIX A. TRUCK DRIVER VALUE OF TIME SURVEY

Measurement	Options (Choose at least one option from each row)			
Type of carrier	Owner-operator	For-hire	Private Carrier	
Typical route	Regional	Long Haul	Local/Delivery	
Typical cargo[1]	Bulk	Average value	High value	Other:
Truck Size	2 axle	3 axle	4 axle	Other:
Trip Length	11+ hours	5 to 11 hours	2 to 5 hours	Less than 2 hours
Who decides Route	Me (the driver)	Dispatcher or the fleet manager	Shipper	Other:
How are you paid	By mile	By load	% of revenue	Other:
Who pays the toll	I do	For-hire carrier	Shippers	Other:
How often do you change route to avoid congestion	Never	Occasionally	Often	Always
Flexibility of delivery hours on an average trip	1 day	Less than 12-hours	Less than 5 hours	Less than 3 hours

You are running **30 minutes late**. Please select the maximum you are willing to pay for each scenario:

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

You are running **on time**. Please select the maximum you are willing to pay for each scenario:

Arrival Time: 15 minutes early				**Arrival Time: 30 minutes early**				**Arrival Time: 45 minutes early**			
$30	$20	$13	Other___	$50	$35	$20	Other___	$68	$45	$23	Other___

Background (optional) Affiliation:________ Phone #: __________
ethnicity_______ age_______ family size_____ annual income_________

---

[1] **Bulk commodity**: agricultural product, fertilizer, coal and other mineral, oil product, sand, gravel, log and rough wood, waste and scrap; **Average value**: wood product, paper print, paper board, textile product, base metal, chemical product, machinery, vehicles, office equipment, and mixed freight; **high value**: electronic equipment, precision instrument, perishable product such as seafood, fashion item.

APPENDIX B. DISPATCHER AND FLEET MANAGER VALUE OF TIME SURVEY

Measurement	Options (circle at least one option from each row)			
Type of carrier	Owner-operator	For-hire	Private Carrier	
Route pattern	Regional	Long Haul	Local/Delivery	
Typical cargo[2]	Bulk	Average value	High value	Other:
Fleet Size	0–10	10–20	20–40	40+
Trip Length	11+ hours	5 to 11 hours	2 to 5 hours	Less than 2 hours
Who decides Route?	Shipper	Dispatcher or fleet manager	Driver	Other:
Drivers are paid by	Salary	Percentage of revenue	By the load	Other:
Tolls are paid by	Shipper	For-hire carrier	Driver	Other:
Change route to avoid congestion	Never/Rarely	Sometimes	Often/Always	N/A
Delivery Time window	1 day	Less than 12-hours	Less than 5 hours	Less than 3 hours

Suppose you decide the driver's route. Given the total trip length you selected above, please select a <u>maximum</u> amount of money you are willing to pay for a given amount of time saving.

You are running **<u>30 minutes late</u>**.

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

You are running **<u>on time</u>**.

Arrival Time: 15 minutes early				**Arrival Time: 30 minutes early**				**Arrival Time: 45 minutes early**			
$30	$20	$13	Other___	$50	$35	$20	Other___	$68	$45	$23	Other___

---

[2] **Bulk commodity**: agricultural product, fertilizer, coal and other mineral, oil product, sand, gravel, log and rough wood, waste and scrap; **Average value**: wood product, paper print, paper board, textile product, base metal, chemical product, machinery, vehicles, office equipment, and mixed freight; **high value**: electronic equipment, precision instrument, perishable product such as seafood, fashion item.

APPENDIX C. ALGORITHM PSEUDO CODE

```
(1) Initialization {
        Set K=0
    Set Tempsaving = 0
    Read input data  (cost and time matrix)
        }
(2) Construct initial routes{
        Generate n distinct routes, each for a customer served by a dedicated vehicle
     }
(3) Join routes{
            For i = 0, i <m, i++ {
            For j = 0, j<m, j++{
                Check the feasibility of time windows for connecting j behind i {
                    If infeasible, continue
                    Else if feasible, calculate DSaving
              }
                Check obtained distance saving for connecting j behind I {
                    if DSaving < Tempsaving, continue
                Else Tempsaving = Dsaving, besti = i, bestj = j
              }
        Connect route besti and bestj if only Tempsaving > 0, then goto Step (3)
            2.2.3 Stop when Tempsaving <=0

(4)Termination{
        Tempsaving <= 0
        }
```

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