Establishing Values of Time for Freight Trucks in Order to Better Understand the Impact of Toll Policies

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Abstract: There have been some notable efforts to simulate the movement of trucks across the US highway system, and it is well understood that truck drivers are sensitive to both time and cost when choosing routes. Many freight models in the past have considered only travel time as the path building criterion. However, a key variable in understanding a driver's choice when in the presence of tolls is the value of time. Research has suggested that the value of time varies considerably by the parameters of the haul, principally the type of truck and the commodity carried. Thus, there are many values of time that need to be considered. Behavioral methods of ascertaining passenger values of time are limited in the variety of values of time that can be conveniently obtained, while there are a large number of commodities and truck types that can carry them. Fundamentally, truck drivers attempt to minimize costs, although they may do so imperfectly. This paper uses a policy-sensitive truck cost model to obtain values of time and tests those values of time on a full-scale simulation.

A highly-detailed cost model of trucking was previously developed by Hussein (2010) *(1)* for the purposes of policy analysis. This cost model original followed industry practice by basing most cost components on the length of haul, which would imply that truckers would mostly minimize distance when choosing routes. However, many cost components are more logically related to the time duration of the haul. Thus, to obtain values of time, it was necessary to modify the cost model so that haul duration is properly included. This leads to two possible hypotheses, time and distance-based costs and distance-based costs, each resulting in different values of time.

The values of time were tested by comparing them to published data and by simulating truck traffic in a 10-state region that included numerous toll facilities. Comparisons of the simulation results to actual traffic data from ATR stations from the State of Ohio and from counts provided by the Ohio Turnpike Authority suggest that the values of time more closely follow the time and distance-based cost hypothesis. It was found that a truck cost model, properly configured, is suitable for ascertaining truck values of time for individual commodities carried by specific truck types.

Key words: Logistics- Shipping by truck- Microsimulation-Cost model-Traffic Assignment

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INTRODUCTION

Federal, state, and local policy makers have enacted or are considering many new public policies regarding the freight industry. In terms of revenue generating policies fuel taxes are imposed by the federal government and states to build, operate, and maintain the highway system for both freight and passenger vehicles. In addition, other user charges, such as tolls may be adopted by states and other authorities to finance highways. Other policies indirectly affect the costs to carriers.

Private carriers are the providers of freight services, and they must earn a profit. Carriers usually follow a schedule and often need to deliver goods to the receivers by a specific time. Meanwhile, carriers try to minimize shipping costs by carefully selecting routes, departure times and equipment.

Values of time (VOT) are particularly important because they arise in the evaluation of many different policies. As an example, VOT is usually used as one component of the measurement of total economic benefits from alternative highway improvement projects. Also, some studies adopt a value of time to estimate the effects on vehicles of proposed tolls, new highway connections, highway widening, or lane use policies affecting peak period capacity.

Truckers face different input prices, product characteristics, truck configurations, geographical characteristics, firm size, and driving practices, so it is difficult to estimate shipping costs without knowing all details. A modified version of Hussein's *(1)* truck cost model can be used to calculate the cost of shipping by trucks.

A transportation forecasting model usually includes a traffic assignment. A traffic assignment step customarily processes each mode separately using a network for that mode with attributes important to that mode in order to find the optimum path between all geographic zones. NCHRP Report 606 *(2)* classified freight assignment steps into three types: rules-based assignment, freight truck only network assignment, and multiclass network assignment.

Rule-based assignment is unable to change the paths in response to changes in performance on system or the introduction of new facilities so it typically applies to rail networks. Freight truck only mode and multiclass assignments typically apply only to trucks on highways. Freight truck only assignments assign the freight truck trip table to the highway network using an all-or-nothing assignment process. The shortcoming of this type of assignment is a failure to address the possibility of congestion because it does not have the ability to represent a large number of passenger vehicles sharing the road. However, multiclass network assignment can usually assign truck trips together with passenger vehicles while considering equilibrium principles. Multiclass assignment may also assign truck trips separately by truck size. Dynamic traffic assignments build paths for the trucks that can vary depending on network operating conditions and on congestion as they change throughout the day. It is worth mentioning hours-of-service (HOS) rules, which limit commercial vehicle drivers to 11 hours of driving before 8 hours off duty.

FREIGHT MODELING

Four-step models have offered a familiar platform and opportunities to share existing networks and algorithms for developing a macroscopic approach to simulating freight movements. A truck-based model and a commodity-based model are two major types of freight models. Truck-based models measure the freight transportation in the form of truck movements without consideration of the amount of commodity production and consumption. These models obviously eliminate the mode choice steps since by definition they include only the truck freight mode. Commodity-based models closely resemble the four-step travel demand model for passengers including generation of shipments, distribution of shipments, mode split allocation of shipments, and the network assignment of the resulting vehicles.

Traffic assignment is the last step of a four-step model, which assigns the modal freight trips to the paths identified from the modal network and forecasts freight volumes on individual links of this modal network. The model looks for optimum paths between all geographic zones, and this path is based on impedance factors such as travel time, travel distance, and cost.

The Mississippi Valley Freight Coalition (MVFC) Microsimulation Model

The traffic assignment step for this paper is a part of the MVFC microsimulation model *(3)*, so there is a need to briefly describe the MVFC model. The MVFC microsimulation involves several stochastic processes, during which many random shipments for a given commodity are generated and then randomly assigned to random vehicles which are finally loaded on a road network.

For the road network, the model has adopted the ORNL network containing all major highways in the U.S. and these highways are represented as 112,000 links. Within the region, individual trips begin and end at actual establishments and were loaded at the intersection nearest each establishment. Traffic analysis zones, which were defined to be consistent with FAF, were used within the region only for the purpose of tabulating statistics and rough-checking establishment locations. The MVFC model loaded trips from external (outside the region) super-establishments at intersections nearest the mathematical centroid of FAF zones; such intersections were usually interchanges on interstate highways. To obtain truck volumes on each road, the traffic assignment algorithm inputted a very large set of individual trip records, each trip being identified by its origin location (longitude and latitude), destination location, start time, and truck type. Traffic assignments are potentially both multiclass (many vehicle classes) and dynamic; each trip record has its own path. The MVFC freight model has the capability of at least partially addressing many of the public policies related to freight movements that are listed in NCFRP 6 *(4)*.

Traffic assignments of this research were multiclass and dynamic covering a time period of 84 hours with a single time slice being 1 hour in duration. 84 hours were necessary for all trucks in a day to cover the distance between the farthest points in the continental US and the MVFC region (e.g., San Diego to Youngstown OH). In addition, hours of service rules introduced clock delays on trucks, which had to be allowed for in the total duration, although the HOS rules did not impose any addition impedance that would have affected routing.

LITERATURE REVIEW

A literature search of observed or estimated truck values of time had been conducted by Outwater and Kitchen (PSRC, 2008) *(5)* and Outwater et al (PSRC, 2009) *(6)* to get reasonable values of time for trucks. The two PSRC working groups have agreed that a reasonable value of time for trucks in the Puget Sound region was $40 per hour for light trucks, $45 per hour for medium trucks, and $50 per hour for heavy trucks, which are consistent with the results from Outwater and Kitchen *(5)*. Killough *(7)* focused on value analysis of truck toll lanes in congested conditions. He found that shippers and carriers value of travel time range from $25 to $200 per hour depending on the cargo *(8)*. He gave the value of time for heavy-duty trucks, without identifying different types of commodities. Concas and Kolpakov *(9)* also conducted a study with the objective to compile and synthesize current and past research on the value of time (VOT) and the value of reliability of time (VOR). The study does not show any research about value of time specific for different commodities and truck classes. For the value analysis of truck toll lanes in congested conditions, Kawamura *(10)* used empirically derived value of time distributions to calculate the perceived benefits from the time savings associated with the use of toll lanes by trucks. The mean values of time for toll lane users and non-users were estimated using Monte Carlo simulations. This study differentiates value of time between for-hire ($28/h) and in-house ($17.6/h) trucks. The value of time in Kawamura's study does not consider different types of commodities and different FHWA truck classes. Fowkes et al *(11)* gave values of time per vehicle disaggregated by commodity type. These values have been converted to 1995 monetary values. Fowkes *(12)* conducted a useful review of studies to analyze value of time.

Smalkowski conducted interviews in Minnesota in *(13)* using an adaptive stated preference survey to derive a truck value of time of $49 per hour. Kawamura *(14)* estimated a value of time for trucks at $28 per hour from stated preference data collected in California in 2000. In 2005, FHWA reported that the delay cost for trucks in bottlenecks was $32 per hour. Shippers and carriers assign a value to increases in travel time of $25 to $200 per hour, depending on the commodity carried *(15)*. The value of reliability for trucks is another 50 to 250% higher *(16)*. Wigan et al. *(16)* estimated $1.30 per pallet/hour for urban full truck loads (FTL) and $1.40 per pallet/hour for metropolitan multi-drop deliveries based on contextual stated preference (CSP) surveys of Australian shippers. Holguin-Veras *(16)* estimated the necessary conditions for off-hour deliveries to determine the effectiveness of urban freight road pricing in competitive markets. He found that receivers are likely to experience incremental costs in the range of $14 to $49 per hour of off-hour operation.

The American Transportation Research Institute (ATRI) survey *(17)* found total per-mile marginal costs are $1.73 and the total per-hour marginal costs are $83.68. A cost benefit study was conducted by Smalkoski and Levinson *(13)* to examine the spring load restriction policy of Minnesota. To evaluate savings or losses of travel time that result from investments in transportation facilities or regulatory actions, Kruesi *(18)* established consistent procedures to be followed by agencies within the Department of Transportation.

Travel time accounts for one of the largest costs of transportation, and travel time savings are often the primary justification for transportation infrastructure improvements. Victoria Transport Policy Institute *(19)* examined them both and has developed estimates of travel time values for different user types and travel conditions, as well as various studies. TransFund New Zealand used the travel time values of Victoria Transport Policy Institute *(19)* and considered “work travel” involves travel while paid, “Non-work” travel is all personal travel including commuting, and “Congested Premium” is an additional cost for travel in congested conditions. Wigan, Rockliffe, Thoresen and Tsolakis *(20)* applied contextual stated preference (CSP) methods and the associated multinomial logit models to estimate the value of some factors from an Australian survey of freight shippers using road freight transport in 1998. In order to estimate freight-specific values of time for road and rail transport in Finland, two separate studies using the same methodology were carried out by Kurri, Sirkiä, and Mikola *(21)*. The relative importance of the factors (i.e., values of transport time and delays) was derived from logit models *(21)*. The authors concluded that the average value of time for road transport for the selected commodity groups is about €1.5 per metric ton per hour, and the value of average delay is about €47 per metric ton per hour. For rail transport and different commodity groups, the average value of transport time is about €0.10 per metric ton per hour, and the value of average delay is about €0.5 per metric ton per hour. Ismail, Sayed, Lim *(22)* measured value of time specific to border delays using a stated preference survey and a weighted average freight VOT of between C$100 and C$125 per hour was estimated. A general VOT literature review was performed in this same study and gave an average value of time of 2008 C$47 per hour, which is consistent with US studies.

A truck cost model and spreadsheet costing model were developed by Berwick and Dooley *(23)* for motor vehicle owners and operators to estimate truck costs for different truck configurations, trailer types, and trip movements. Based on the work of Berwick and Dooley *(23)*, Berwick and Farooq *(24)* developed a new software model which does not require any specific software applications except for Microsoft Windows. Many truck configurations, freight options and performance measures are included in this model. Ergun et al. *(25)* focused on the development of optimization technology for reducing truckload transportation cost. They also designed and implemented a highly effective heuristic to incorporate fast routines for checking time feasibility for a tour in the presence of dispatch time windows and for minimizing the duration of a tour by appropriately selecting a starting location and departure time. Hussein *(1)* built a cost model for shipping various commodities and commodity groups by truck between a given origin and destination inside the United States. Total shipping cost is comprised of the individual costs for fuel, labor, depreciation, maintenance, loading and unloading, insurance, overhead, and extra expenses. Hussein's model is used in this work to estimate truck value of time after modifying some parameters to achieve the required goal.

Traffic assignment is generally guided by the use of impedance factors, which in some cases are based on changing speed or travel time, whereas in others a more "generalized cost" approach embodying costs and potentially other factors is used *(26)*.The New York Metropolitan Transportation Commission (NYMTC) adopted multimodal/multiclass equilibrium assignment in their truck model. The Freight Analysis Framework (FAF) version 3 *(27)* is a FHWA funded managed data and analysis program that provides estimates of the total volumes of freight moved into, out of and within the U.S. and the FAF3 database is constructed by Oak Ridge National Laboratory (ORNL). The FAF3 used a stochastic user equilibrium (SUE) traffic assignment with user defined volume delay function (VDF). In addition, passenger vehicles are preloaded on the road. Travelers may change the travel pattern by taking alternate routes as the network (or a specific link of a network) gets congested *(28)*. FAF3 used travel time as the only path building criterion.

METHODOLOGY

Truck Cost Analysis

The literature search failed to find any studies that gave truck values of time based on different commodities and different truck classes, together. Truck costs, in this paper, are computed by using the modified truck cost model, originally developed by Hussein, and then values of time by commodity and by truck class are estimated based on these calculated truck costs.

Description and Example of Truck Cost Model

Hussein's *(1)* cost model is in the form of a spreadsheet, and there are two types of inputs: parameters and constants. Parameters define the service to be provided, such as the commodity (group) that is shipped, how much is shipped, where it is to be shipped, and any additional requests, while constants define the industry environment for providing transportation services including the price of fuel, equipment costs, insurance costs, the current state of technology, and various regulations such as the maximum allowed driving time in a 24-hour period. The total cost per truck for the shipment is the summation of the component costs, which are fuel, labor, depreciation, maintenance, loading and unloading, insurance, indirect, and extras. Detailed information and formulas about the cost model can be found elsewhere *(1)*.

This cost model can help to estimate the total cost for shipping the given commodity from any origin to any destination. The MVFC freight model has only trucks in FHWA Class 2 (single unit: 3-axle, 10 tires for truck) and Class 5 (truck/tractor trailers: 5-axle, 10 tires for tractor and 8 tires for trailer).

Parameters that vary by truck class include the weight of an empty truck and average payload; both of these parameters can be ascertained from tables of FAF2 Technical Documentation provided by FHWA. The empty weights are 24877 lb for Class 2 and 29680 lb for Class 5.

The MVFC freight model considered five indicator commodities: corn, soybean, dairy, plastics and motor vehicle parts. Default values in the original truck cost model are used for most constants (shown in Table 1), but some other values changed, such as truck registration fees (Creglic) based on declared gross weight. It should be noted that Table 1 just shows the constants for motor vehicle parts as an example. In addition, the revised truck cost model does not consider loading and unloading costs and rest periods.

TABLE 1 Constants of Two Hypotheses for Motor Vehicle Parts

Constant	Class 2		Class 5	
	Hypothesis One (Distance-Based)	**Hypothesis Two (Time/Distance-Based)**	**Hypothesis One (Distance-Based)**	**Hypothesis Two (Time/Distance-Based)**
CmaxWt	29700	29700	50320	50320
CmaxVol			3,264	3,264
Cfuel$	2.1	2.1	2.1	2.1
CoptSpd	55	55	55	55
CmaxEff	7.5	7.5	7.5	7.5
CminEff	6	6	6	6
CspdLim	55	55	55	55
Chours	11	11	11	11
Cref	0	0	0	0
Cidle	1	1	1	1
Cwage	0.4		0.4	
Cwage(h)		18		18
Cannual(h)		8760		8760
ChthIns	6000	6000	6000	6000
Cannual	120000	120000	120000	120000
Cnew	125000	125000	155000	155000
Clife	5	5	5	5
Csalv	25000	25000	35000	35000
CmaintGM	0.164	0.164	0.177	0.177
CmaintT	0.00604	0.00604	0.00739	0.00739
Cunload	40	40	40	40
CtrkIns	5000	5000	6000	6000
CcrgIns	0	0	0	0
CothIns	5000	5000	5000	5000
COH	0.17		0.17	
COH(h)		2.32		2.32
Chaz	0	0	0	0
CregLic	636.75	636.75	965.75	965.75
Cpension	6500	6500	6500	6500
CSocialMed	7650	7650	7650	7650

In the original cost model, all the costs vary by distance. However, some of them are clearly sensitive to the time or both time and distance. For example, some truck drivers are paid by the mile but most of them get paid by the hour. Thus, two hypotheses for building the new truck cost model should be taken into account for the sake of comparison. One is *distance-based* and all the features of the original cost model are kept, which is defined as Hypothesis One. Another is *time and distance-based*, which is defined as Hypothesis Two.

Traffic assignment is generally guided by the use of impedance factors, which in many cases are based on travel time. Impedance can also be taken from a "generalized cost" that embodies a variety of factors. Computing a generalized cost is more complicated but it is also more realistic. Usually, the route of the least cost is chosen by drivers, which is determined by actual travel time, distance, user costs (especially highway tolls) and intangible factors. Formally, the equation for the costs on a given route is:

$$Cost = f\,(real\ time,\ distance,\ toll) = \beta^*(real\ time) + \gamma^*distance + toll \quad (1)$$

Where,

β: Constant (dollar per hour), also defined as Value of Time

γ: Constant (dollar per mile), also defined as Per-mile Cost

The value of tolls on non-toll roads and bridges will, of course, always be zero.

The truck cost model can calculate costs for any route for any time of day. One possibility is to hold distance constant (perhaps 200 miles) and change the speed to get different travel times. Another possibility is to hold time constant (perhaps 2 hours) and change speed and distance, simultaneously. For example Table 2 shows costs of motor vehicle parts when the time is constant and the speed and distance are varied. Once many such data points are created by the cost model, values of time and values of distance may be easily obtained by fitting regression lines.

TABLE 2 Truck Costs by Different Distances with Constant Time (2 hours) – Hypothesis Two, Time and Distance-Based

Commodity	Speed (mile/h)	Distance (mile)	Time (h)	Class 2 Cost ($)	Class 5 Cost ($)
	20	40	2.00	83.27	94.95
	30	60	2.00	121.27	136.88
Motor	40	80	2.00	156.15	173.53
Vehicle	50	100	2.00	191.11	208.30
Parts	60	120	2.00	228.63	243.08
	64.33	128.66	2.00	246.70	259.76
	70	140	2.00	273.04	285.35

Value of Time and Per-mile Cost

This section discusses the development of values of time and values of distance for Hypothesis One and Hypothesis Two.

Linear regressions on synthesized data were performed to ascertain the relationship of cost and time and of cost and distance for five commodities and two truck classes. The slopes of the regression lines give the value of time (β) and per-mile cost (γ). Coefficients of determination were all 0.95 or greater, indicating that the cost data were almost linear in both time and distance. All the values of β and γ by commodity by truck class for both Hypothesis One and Two are shown in Table 3.

The analysis also reveals that the constants (β and γ) obtained from the linear regressions are plausible. Table 3 shows that dairy has the highest truck value of time (β) regardless of the truck class, and plastics has the lowest truck value of time for Class 2 but motor vehicle parts have the lowest value of time for Class 5. These results are reasonable given the characteristics of the vehicle classes and the commodities. However, truck values of time for the five commodities and two truck classes seem very low for Hypothesis One compared to the values obtained from the literature review.

TABLE 3 Values of β and γ for Five Commodities and Two Truck Classes– Hypothesis One (Distance-Based Costs)

	Commodity	Class 2		Class 5	
		β ($/h)	γ ($/mile)	β ($/h)	γ ($/mile)
Hypothesis One	Corn	6.8	1.86	14.16	1.95
	Soybean	5.9	1.86	12.04	1.95
	Dairy	10.28	1.94	22.77	1.95
	Plastics	3.39	1.86	11.01	1.95
	Motor Vehicle Parts	4.79	1.86	10.56	1.96
Hypothesis Two	Corn	29.5	1.06	36.89	1.15
	Soybean	28.6	1.06	34.77	1.15
	Dairy	46.14	1.06	52.22	1.15
	Plastics	26.06	1.06	33.74	1.15
	Motor Vehicle Parts	27.48	1.06	33.29	1.15

Toll Analysis

The collected tolls for all toll facilities in the MVFC region are converted to “extra travel time” by using values of time (β), and distance weights (γ/β) are estimated for converting units of distance to units of time. Furthermore, intersection delays are handled by adding extra time to each direction of each surface street.

The ten states in the Mississippi Valley region are Illinois, Indiana, Iowa, Kansas, Kentucky, Michigan, Minnesota, Missouri, Ohio and Wisconsin. Figure 1 shows the locations of all toll roads and toll bridges in these ten states.

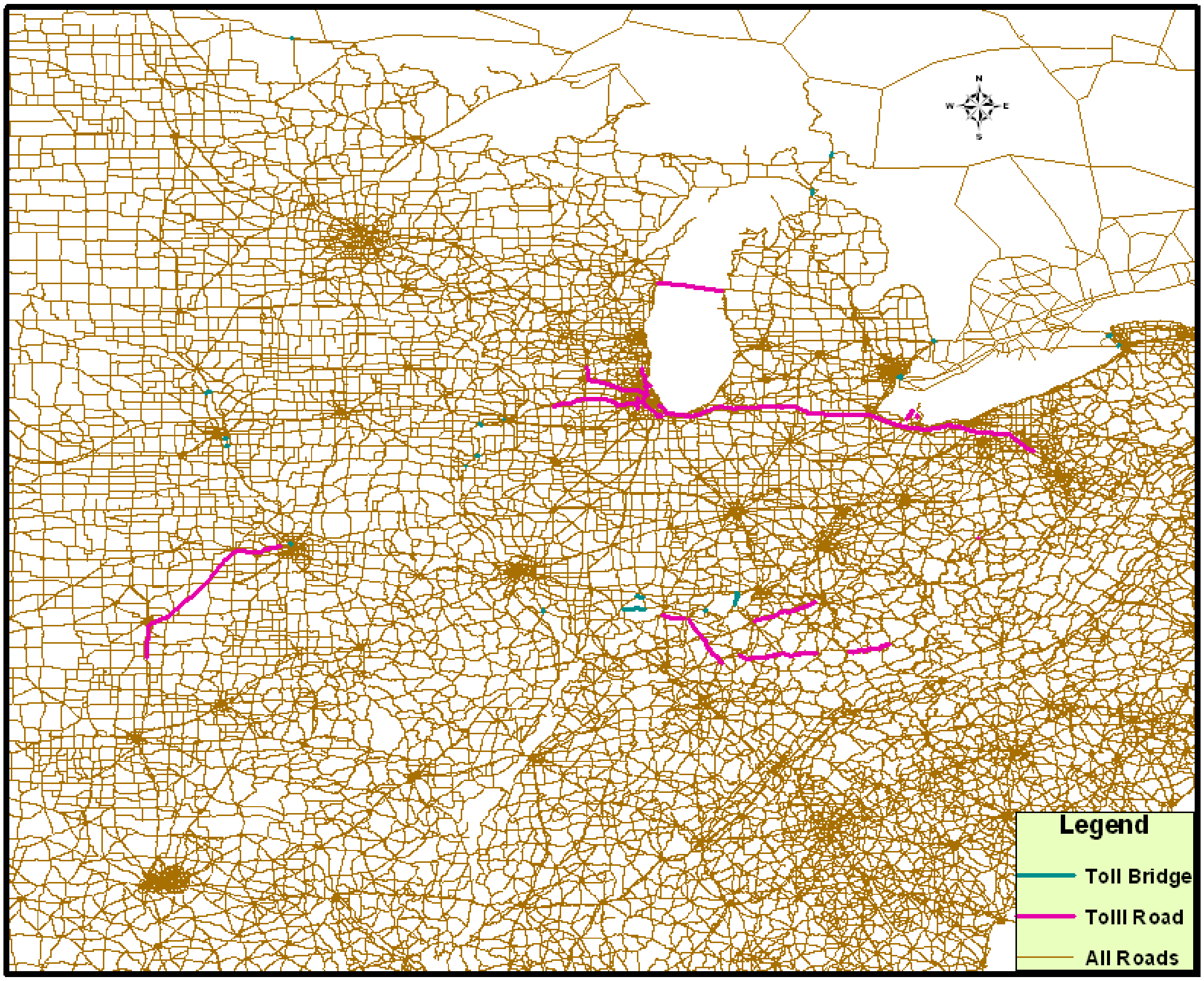


FIGURE 1 Toll Roads, Bridges and Ferry for Ten States in the Mississippi Valley Region

Tolls charged on toll roads and toll bridges in ten states are collected by their financial or operating authorities. Authorities could set tolls pricing in two different ways. The most common way is fixed pricing, where the toll rate remains unchanged throughout the day. The other is time-dependent pricing in which the toll rates change for different time periods according to a pre-determined tolling schedule. In both cases different toll rates can be assigned to different types of vehicles or different user groups. No authority is using dynamic pricing within the study area. Tolls are collected by cash or by an electronic toll collection (ETC) system. This paper uses the average of toll rates across all payment methods. The average toll rates for the two truck classes are shown in Table 5. Toll per mile is calculated by dividing toll rates by facility length (also shown in Table 5).

Table 4 indicates that truck volumes on facilities, such as the Chicago Skyway, with close alternatives and high tolls, are susceptible to being improperly forecasted.

The MVFC freight model only retains all the details for the ten MVFC states and 100 miles extension of these states, while it reduces the network outside the defined area to interstate highway, only. The reduced network has approximately 44,000 links with many attributes retained from the original ORNL network.

TABLE 4 Toll and Toll per Mile for Two Truck Classes

State	Toll Road/Bridge	Toll		Toll Per Mile	
		Class 2	Class 5	Class 2	Class 5
IL	Ronald Reagan	$13.55	$23.65	$0.14	$0.25
	Veterans Memorial	$8.00	$14.00	$0.27	$0.47
	Janne Addams	$10.53	$18.38	$0.14	$0.24
	Tri-State	$9.78	$17.08	$0.13	$0.22
	Chicago Skyway	$6.50	$10.80	$0.85	$1.41
	Fort Madison Bridge	$4.00	$8.00	$6.67	$13.33
	Wabash Memorial Bridge	$0.95	$1.45	$1.06	$1.61
	New Harmony Bridge	$1.50	$3.00	$3.00	$6.00
IN	Indiana East-West	$12.91	$35.17	$0.08	$0.22
KS	Kansas Turnpike	$13.88	$29.13	$0.06	$0.13
OH	Ohio Turnpike	$26.00	$36.00	$0.11	$0.16
MI	Ambassador Bridge	$10.50	$17.50	$6.00	$10.00
	Mackinac Bridge	$13.50	$22.50	$3.07	$5.11
	International Bridge	$12.00	$20.00	$6.15	$10.26
	Blue Water Bridge	$9.75	$16.25	$6.50	$10.83
	Detroit-Windsor	$4.10	$5.19	$4.23	$5.35
IA	Bellevue Bridge	$5.00	$3.00	$27.78	$16.67
	Burt County Bridge	$5.00	$2.50	$7.14	$3.57
	Plattsmouth Bridge	$2.75	$2.25	$10.58	$8.65

Actual Truck Traffic Data Collection and Calibration

The Ohio Department of Transportation provided truck traffic counts collected by several methods including traffic data collected from ATR stations and weigh stations, coverage counts and manual counts. However, based on the pros and cons of traffic data collecting methods, the ATR station data are exclusively used for the analysis since they are the more accurate and reliable. The traffic counts from ATR stations in Ohio are grouped into cars and trucks but only two classes of trucks are taken into account in the traffic assignment step. It is impossible to find the reliable traffic data for precisely these two truck classes. However, these two classes are the major types of trucks traveling in Ohio, so it can be reasonably assumed that the two truck classes are roughly in proportion to total trucks. I-80 has no ATR stations along the vast majority of its length, where it is also called the Ohio Turnpike. Fortunately, the Turnpike Authority, the operator of Ohio Turnpike, does its own counts. However, the Turnpike Authority truck groupings do not match up to any other classifications systems such as the one from FHWA. Turnpike Authority classifies the vehicles by weight not by numbers of axles.

CASE STUDY AND HYPOTHESIS TESTING

The next step was to run the MVFC simulation model with different traffic assignment assumptions about impedance. Three runs are made:

- Run_{simple} (R_{simple}): Impedance is simple travel time.
- $Run_{DistCost}$ ($R_{DistCost}$): Impedance is calculated as a function of distance, time and tolls according to the parameters of Hypothesis One (distance-based);
- $Run_{TimeCost}$ ($R_{TimeCost}$): Impedance is calculated as a function of distance, time and tolls according to the parameters of Hypothesis Two (time and distance-based).

R_{simple} can be used to establish the baseline for the purpose of identifying traffic diversion occurring in the other two runs. R_{simple} is essentially similar to what the FAF assignment did, because FAF assignment also considered only travel time as the path building criterion. Three industrial commodities (dairy, plastics and motor vehicle parts) were assigned in these three runs. However, only the parameters for motor vehicle parts were taken for $R_{DistCost}$ and $R_{TimeCost}$.

Figure 2 (a, b , and c) shows the daily truck volumes for three industrial commodities (dairy, plastics and motor vehicle parts) in Ohio area from all three runs.

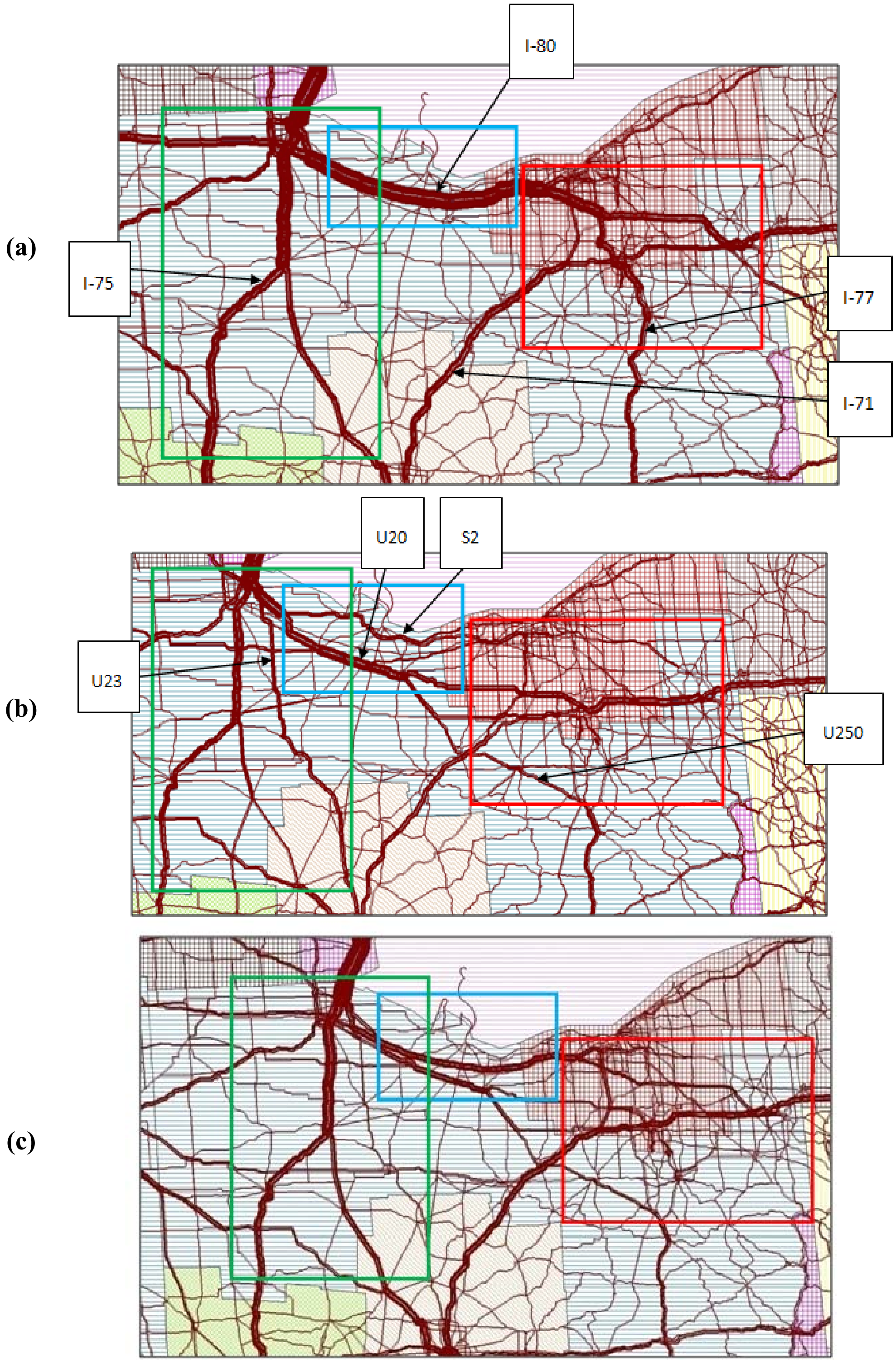


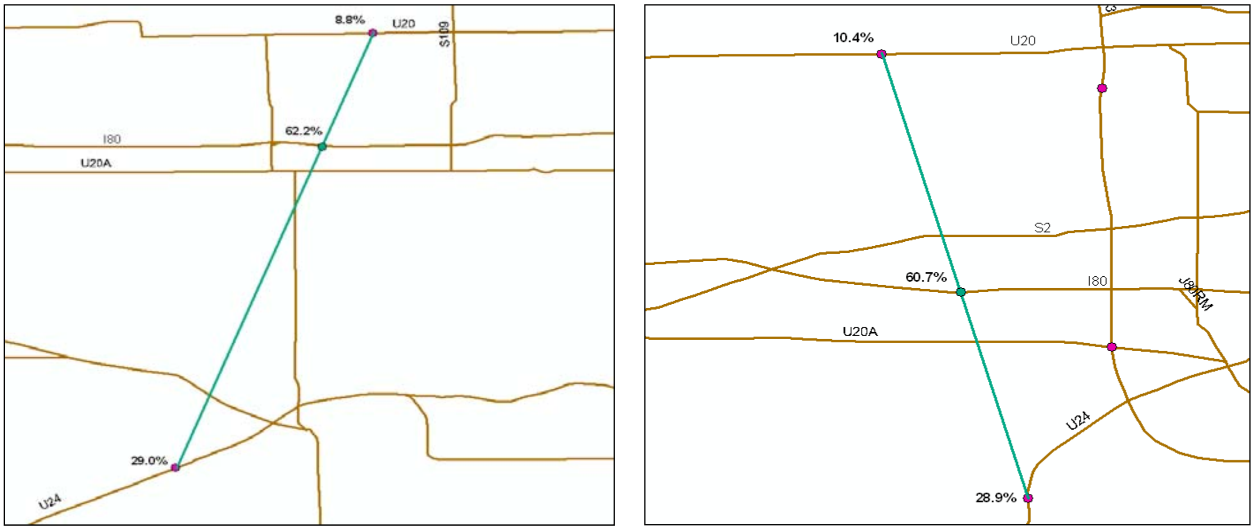
FIGURE 2 (a) Daily Truck Volumes (Class 2 and Class 5) for Industrial Commodities in Ohio Area, R_{simple} (b) Daily Truck Volumes (Class 2 and Class 5) for Industrial Commodities in Ohio Area, $R_{DistCost}$ (c) Daily Truck Volumes (Class 2 and Class 5) for Industrial Commodities in Ohio Area, $R_{TimeCost}$.

From the figure above, it is evident that those three traffic assignments are vastly different from each other. For the traffic assignments located in the blue rectangle box area, the results of R_{simple} in Figure 2a reveal that most of trucks travel on the Route I-80. The results of $R_{DistCost}$ in Figure 2b indicate that the majority of truck traffic has been diverted to the Routes U20 and S2 which are parallel to I-80, and very little truck traffic occurs on the Route I-80 itself. For $R_{TimeCost}$, almost half of trucks have been diverted from the Route I-80 to the Route U20 as seen in Figure 2c.

For the traffic assignments located in the green rectangle box area, the results of $R_{DistCost}$ suggest that a portion of truck traffic has moved to the Route U23 from Route I-75 compared to either R_{simple} or $R_{TimeCost}$. $R_{TimeCost}$ has a little lighter truck traffic than R_{simple} for the green rectangle box area.

For the traffic assignments located in the red rectangle box area, R_{simple} has a large amount of daily truck volume on the I-77 segment between the interchange of Route I-80 and Route I-77 and the interchange of Route I-77 and Route U250, as compared to $R_{DistCost}$ and $R_{TimeCost}$. In addition, a portion of truck traffic has moved to Route U250 from the Route I-77 in $R_{DistCost}$ and $R_{TimeCost}$.

The ATR stations are scattered on some major highways and arterial roads except I-80. Depending on the data availability and the traffic diversion conditions , twenty cutlines were drawn through the ATR stations or I-80 toll road segments within the study area. Each cutline includes three stations where the truck traffic volume passes through in the two directions. Most of the cutlines are within or near Toledo, Cleveland, Akron, Youngtown, Dayton, Columbus, and Cincinnati. The cutlines are numbered 1 through 20 from west to east and from north to south. Because the toll pricing appears to have caused much of traffic diversion, most cutlines are drawn across the toll road I-80. The cutlines allow comparison of truck traffic volume results from the three runs and actual truck traffic volume. Cutlines 1 and 2 are illustrated in Figure 3a and 3b. Comparisons of percentage distribution on cutlines No. 1, 10, and 20 are shown on Table 5. The R_{simple}, $R_{DistCost}$, and $R_{TimeCost}$ Dev columns represent the absolute deviation of the volume percentage distribution between the runs and the actual traffic from the ATR station. S-TDev is the summation of the absolute deviation for the three runs for each station. It can be concluded that the percentage of actual truck traffic volume at each cutline is close to any percentage of R_{simple} and $R_{TimeCost}$ or somewhere between R_{simple} and $R_{TimeCost}$. Some cases show the percentages of actual truck traffic are similar to the percentages of $R_{TimeCost}$, such as cutline No. 10, which indicates that the tolls on the Route I-80 have affected the total impedances greatly in reality and have caused traffic diversion. Table 6 shows the N-TAD for each run, which is the summation of the absolute deviation over the twenty cutlines. The N-TAD indicates that R_{simple} and $R_{TimeCost}$ are relatively close to the actual values. Many other cases show that the percentage of actual truck traffic is similar to the percentage of R_{simple}. An example is cutline No. 6, in which there is no toll on any road intersected by this cutline. This case suggests that in reality truck drivers choose routes mainly based on the real travel time without giving much consideration to the distance. Another example is cutline No. 1, which illustrates that truck drivers still opt to travel on a toll road with less travel time and a shorter distance even though they must pay a toll.



(a) (b)

FIGURE 3 Percentage Distribution on Cutline No. 1 (a) and Cutline No. 2 (b)

TABLE 5 Comparison of Percentage Distribution on Cutlines No. 1, 6, 10 and 20

Cutline, Station	Model Output						Actual Data (ATR Station)	S-TDev
	R_{simple} %	R_{simple} Dev	$R_{DistCost}$ %	$R_{DistCost}$ Dev	$R_{TimeCost}$ %	$R_{TimeCost}$ Dev		
1.1	0.5	8.3	8.2	0.6	3.6	5.2	8.8	14.1
1.2	62.8	0.6	1.4	60.8	41.6	20.6	62.2	82
1.3	36.8	7.8	90.4	61.4	54.8	25.8	29.0	95
6.1	26.1	7.2	11.3	22	16.9	16.4	33.3	95
6.2	44.2	2.9	13.4	27.9	2.2	39.1	41.3	429
6.3	29.6	4.2	75.3	49.9	80.9	55.5	25.4	862
10.1	18.3	8.6	47.9	21.0	25.2	1.7	26.9	31.3
10.2	17.7	16.5	43.5	9.3	33.6	0.6	34.2	26.4
10.3	64.0	25.0	8.7	30.3	41.2	2.2	39.0	57.5
20.1	52.5	1.8	19.6	31.1	28.3	22.4	50.7	55.3
20.2	30.4	8.9	19.2	20.1	22.9	16.4	39.3	45.4
20.3	17.1	7.0	61.2	51.1	48.7	38.6	10.1	96.7

TABLE 6 Total Absolute Deviation (N-TAD) for R_{simple}, $R_{DistCost}$, and $R_{TimeCost}$ Across 20 Cutlines

R_{simple} N-TAD	$R_{DistCost}$ N-TAD	$R_{TimeCost}$ N-TAD
544	1831.4	729.6

Although the traffic assignment outputs showed big differences in some locations of Ohio, it is difficult to tell which traffic assignment fits the field data best based on the visual observation of the figures or the values of traffic volume. In order to further validate the assignment step, it is necessary to evaluate the impacts of impedance factors on traffic diversion by analyzing the percentage distribution of truck traffic volume on each cutline from one run to the other, and compare the volume percentage distributions of three runs to the actual traffic volume percentage distribution. The percentage distribution is obtained by dividing the truck traffic counts of each ATR station on a single cutline by the summation of all volumes for the cutline. The comparison of the actual-field data and simulation runs shows that the percentage of actual truck traffic volume at each cutline is close to any percentage of R_{simple} and $R_{TimeCost}$ or somewhere between these two. Overall, the results of R_{simple} and $R_{TimeCost}$ are very reasonable, which also indicates that the values of constants (β and γ) in $R_{TimeCost}$ are reliable for a microsimulation model.

CONCLUSIONS

This paper uses a policy-sensitive truck cost model to obtain values of time and tests those values of time on a full-scale simulation. It was found that the highly-detailed cost model of trucking previously developed for the purposes of policy analysis is suitable for ascertaining truck values of time for individual commodities carried by specific truck types. The values of time have been tested by using two different hypotheses, time and distance-based costs and distance-based costs. Comparisons of the simulation results to actual traffic data suggest that values of time more closely follow the time and distance-based cost hypothesis.

The comparison revealed that in response to tolls, truck drivers change their routes when the impedance of the original route exceeds the alternative route's impedance. With a lower value of travel time, truckers may consider alternative routes, whereas when the value of time increases truckers prefer the shortest path to save time. The simulation results showed that the MVFC microsimulation model can simulate the truck traffic conditions affected by the toll pricing policy by using a linear function of time, distance, and tolls, so long as there are good estimates for values of time.

Given the fairly large influences of commodity and truck type on value of time and considering the sensitivity of drivers to tolls, there is a need to separately consider many truck classes when preforming traffic assignments that involve trucks.

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REFERENCES

1. Hussein M., Petering M., Horowitz A., 2010. A Policy-Oriented Cost Model for Shipping Commodities by Truck", National Center for Freight & Infrastructure Research & Education, Center for Urban Transportation Studies, University of Wisconsin-Milwaukee.
2. Transportation Research Board, 2008. Forecasting Statewide Freight Toolkit, NCHRP Report 606.
3. Horowitz, A., 2010. Microsimulation of Commodity Flow in the Mississippi Valley Region, National Center for Freight & Infrastructure Research &Education, Center for Urban Transportation Studies, University of Wisconsin-Milwaukee.
4. TRB's National Cooperative Freight Research Program (NCFRP) Report 6, 2011. Impacts of Public Policy on the Freight Transportation System
5. Outwater, M., Kitchen, M., 2008. Value of Time for Travel Forecasting and Benefits Analysis.
6. Outwater, M., Kitchen, M., Ardussi, S., Bassok, A., Rossi, S., 2009. Travel Model Improvements for the Congestion Management Process and Long Range Transportation Plan Update.
7. Killough, K., 2008. Value Analysis of Truck Toll Lanes in Southern California, Transportation Research Board 87th Annual Meeting, pp.11.
8. Federal Highway Administration. Highway Control Systems Handbook. http://ops.fhwa.dot.gov/publications/fhwahop06006/
9. Concas, S., Kolpakov, A., 2009. Florida Department of Transportation, Synthesis of Research on Value of Time and Value of Reliability.

10. Kawamura, K., 2003. Perceived Benefits of Congestion Pricing for Trucks, Transportation Research Record, Issue 1833, pp. 59-65.
11. Fowkes, A.S, Nash, C.A, Tweddle, G., 1989. Valuing the Attributes of Freight Transport Quality: Results of the Stated Preference Survey, University of Leeds, Institute for Transport Studies, Leeds.
12. Fowkes, T., 2001. Values of Time for Road Commercial Vehicles.
13. Smalkoski, B., Levinson, D., 2005. Value of Time for Commercial Vehicle Operators in Minnesota, Journal of the Transportation Research Forum 44:1 pp. 89-102.
14. Kawamura, K. Perceived Value of Time for Truck Operators, Transportation Research Record 1725, Transportation Research Board, Washington, D.C., 2000.
15. Federal Highway Administration publications.
16. Puget Sound Regional Council publications 2008 & 2009.
17. ATRI, 2010. An Analysis of the Operational Costs of Trucking, Transportation Research Board 89th Annual Meeting, pp.17.
18. Kruesi, F., 1997. The Value of Saving Travel Time: Departmental Guidance for Conducting Economic Evaluations.
19. Victoria Transport Policy Institute, 2010. Transportation Cost and Benefit Analysis II – Travel Time Costs.
20. Wigan, M., Rockliffe, N., Thoresen, T., Tsolakis, D., 2000. Valuing Long-Haul and Metropolitan Freight Travel Time and Reliability.
21. Kurri, J., Sirkiä, A., Mikola, J., 2007. Value of Time in Freight Transport in Finland, Transportation Research Record, Vol. 1725 / 2000, pp. 26-30.
22. Ismail, K., Sayed, T., Lim, C., 2009. A Study of the Commercial Vehicle Value of Time for Operation at Border Crossings.
23. Berwick, M., Dooley, F., 1997. Truck Costs for Owner/Operators, Research report, North Dakota State University, Fargo.
24. Berwick, M., Farooq, M., 2003. Truck Costing Model for Transportation Managers. Research report, North Dakota State University, Fargo.
25. Ergun, O., Kuyzu, G., Savelsbergh, M., 2007. Reducing Truckload Transportation Costs through Collaboration, Transportation Science, Vol.41, pp. 206-221.
26. Transportation Research Board, 2008. Forecasting Metropolitan Commercial and Freight Travel, NCHRP Synthesis 384.
27. Oak Ridge National Laboratory, 2010. Network Assignment of Highway Truck Traffic in FAF3.
28. Alam, M., 2010. Network Assignment of Highway Truck Traffic in FAF3, Oak Ridge National Laboratory.