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On the cover: Intermodal freight is one of the most important markets for U.S. freight railroads. Between 1980 and 2009 intermodal containers and trailers increased from 3.1 million to 9.9 million, a 219% increase. In "Heuristic Path-Enumeration Approach for Container Trip Generation and Assignment," EunSu Lee and co-authors identify railroad container routes and present them visually in a GIS map, making it possible to determine traffic densities on major shipping routes of imported container traffic.

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A Message from the JTRF Co-General Editors

This fall issue of JTRF contains the seven papers listed below:

- Heuristic path-enumeration approach for container trip generation and assignment
- Development of best practices for right-of-way valuations and negotiations in transportation projects
- Spatial differences in price elasticity of demand for ethanol
- Passenger car equivalents of light duty trucks and the costs of mixed traffic
- Pre-determining performance-based measures for managed lanes
- Incorporating energy-based metrics in the analysis of intermodal transport systems in North America
- A strategic variance analysis of the profitability of U.S. network air carriers

In the first paper, Eunsu Lee, Peter Odour, Kambiz Farahmand, and Denver Tolliver address a large-scale container assignment optimization problem. They review previous studies, noting that those studies do not provide detailed descriptions of output visualization necessary for informing the public. The authors address this problem in their work and focus on routes from coastal ports to inland locations. Using constrained linear programs in which the objective is to minimize total logistics costs, they identify feasible routes and present them visually in a GIS (Geographic Information System) map. They conclude that visualization makes it possible to ascertain traffic densities along major shipping routes of imported container traffic.

Carlos Caldas, Zhanmin Zhang, Kara Kockleman, Khali Persad, Ragheb Halabi, and Elizabeth Kincaid write on the "Development of Best Practices for Right-of-Way Valuations and Negotiations in Transportation Projects" with the purpose of improving overall project delivery and efficiency. The authors used surveys and personnel interviews of the Texas Department of Transportation to learn about practices and problems they have encountered in right-of-way acquisition and negotiation. The survey and interviews allowed Caldas et al. to synthesize the best practices and identify problems that may hinder negotiation and land acquisition processes. These practices include regular training of personnel, evaluation of right-of-way personnel, fee and review appraisers. Additionally, the authors identified early contacts with property owners, streamlining the valuation process, simplifying property value determination, and establishing frequent communications with property owners as among the best practices.

Hayk Khachatryan, Jin Yan, and Ken Cassavant study differences in the price elasticity of ethanol fuel demand using data from Minnesota and spatial regression. Their approach allows them to obtain geographically varying price elasticities of demand for ethanol, and it departs from current studies in which elasticities of demand do not vary by location. They include demand variables such as income, the number of ethanol stations in close proximity, vehicle stock, distances to major highways and blending terminals, prices, and sales volume from 1997 to 2009. The authors estimated two models, one in which spatial differences were ignored and the other in which these differences were considered. By comparing their results they found that in the first model a 10% increase in ethanol price decreases the quantity of ethanol demanded by 32%, thus showing elastic demand, whereas in the second model a similar increase in ethanol price results in 43% reduction in quantity demanded. Their results also showed spatial varying price elasticity of ethanol demand from -5.0 to -2.2 in the Twin Cities area and -0.5 to -2.7 in rural areas.

Sarah Cosgrove studies drivers to estimate vehicle gaps (following distances) by vehicle type and calculates passenger car equivalents for light duty trucks (LTDs). The specific objectives of the paper are to determine whether or not drivers behave differently when following LTDs than when following cars, and to develop regression equations to appropriately adjust LDTs for their inclusion in the Highway Capacity Manual. In collecting the data, Cosgrove used specially equipped vehicles driven by recruited drivers and restricted the driving to daylight when windshield wipers were not in use and to heavy traffic conditions. Further, Cosgrove used still videos from on-board equipment to categorize light duty trucks. The regression results showed that "car drivers follow pickups more closely than they follow cars," and leave longer distances between their cars and sport utility vehicles, minivans, and heavy trucks. Cosgrove also found that male drivers follow LDTs more closely than female drivers, and that socioeconomic variables such as education and income affect following distances. The additional following distances regarding SUVs and trucks increase the passenger car equivalents of these vehicles and should be factored into the Highway Capacity Manual. Without accounting for these distances, the paper argues that the traditional Highway Capacity Manual overstates capacity by 2.5% and results in external cost of $2.05 billion.

Mark Burris, Chao Huang, Tina Geiselbrecht, Ginger Goodwin, and Matthew MacGregor study managed lanes. Their state-of-the-art review of existing research showed very little done on using performance measures to set tolls on highways. Consequently, they studied tolled and managed lane facilities to identify the methods they use to set tolls and manage their lanes. The authors collected their data through interviews of key personnel in agencies having operational managed lanes across the United States. Additional information was also collected from 20 randomly selected projects that were high occupancy toll (HOT) lanes, express lanes, toll lanes, or high occupancy vehicle (HOV) lanes. From the interviews and the surveys the authors found that most agencies have written goals and objectives but no agency has policies regarding the number of passengers required to be in a car to use a HOT lane. Agencies operating express lanes have preferences for buses, carpools, motorcycles, and low emission vehicles; very limited use of traffic volume as a trigger for price/toll change; and all the surveyed projects recognized varying their tolls for single occupancy vehicles to maintain free-flow traffic conditions. They also found that dynamically priced HOT lanes monitored traffic volumes and changed their tolls frequently to reflect congestion levels.

The paper by John Zumerchik, Jack Flanigan, and Jean-Paul Rodrigue examines incorporating energy-based metrics in the analysis of freight transportation in North America. The paper argues that current methodologies in energy-based sustainability do not account for the complexities of intermodal transits in North America. With this in mind, the authors evaluate current intermodal measures for freight efficiency and then propose alternate metrics for measuring energy-based terminal efficiency. They divide intermodal freight energy usage into the energy used for line haul, modal transfers (lifting, positioning, stacking, temperature control, drayage), and storage. The metrics they suggest are container capacity per acre (CCPA), container handling efficiency factor (CHEF) or transfers per acre, and they argue that these measures can "capture efficiency gains from new operations, designs and technology, including information technology designed to limit rehandling lifts." Zumerchik et al. also discuss the public costs of measuring infrastructure efficiency that stall efforts to divert freight to rail from highways. They conclude that energy-based efficiency analysis is important in ensuring adequate returns on investments and in meeting the goal of diverting highway traffic to rail.

The final paper in this issue is by Paul Caster and Carl Scheraga on the profitability of U.S. air carriers. These authors use the Horngren et al. (2006) method of strategic variance analysis to decompose airline revenue into growth (i.e., changes in passenger miles), price recovery (i.e., changes in sales prices and unit input cost), productivity changes (i.e., changes in input-output relationships), and changes in capacity utilization (i.e., variation in the cost of unused capacity over time). The decomposition allows the authors to identify the strategic positions of airlines and compare them. Caster and Scheraga performed their analysis for all network airlines (Alaska, American, Continental, Delta, Northwest, United, and US Airways) for the periods 2004-2006 and

2007-2009, arguing that three-year windows are necessary for the impacts of strategic choices to be realized. Their results show that all airlines reduced their costs from 2004-2006 and 2007-2009, and that US Airways, United, and Northwest were successful in differentiating their services by raising fares to cover increased costs. Using Delta as an example, the authors showed that it fell short in terms of growth management from 2007-2009, experienced an increase in net income due to growth from endogenous strategies, while for all network carriers revenue passenger miles decreased by 7.64%.

Michael W. Babcock	Kofi Obeng
Co-General Editor	Co-General Editor

Heuristic Path-Enumeration Approach for Container Trip Generation and Assignment

by EunSu Lee, Peter Oduor, Kambiz Farahmand, and Denver Tolliver

A commonly ignored key ingredient in large-scale container network assignment is an impedance-driven geovisualization of optimal routes. In this study, we propose linear optimization models for both trip generation and trip assignment using dynamic programming on a GIS platform, which includes maps and data that are used to develop and generate trips. The proposed models are applied to intermodal railroad routes mostly in the United States. Dendritic optimal networks are figures visually depicting all optimal branches for the network.

INTRODUCTION

Growth of container markets and contracts between ocean and rail carriers has contributed to difficulty in tracking containers from one geographic region to another. Shipping containers have achieved economies of scale, a fact driven primarily by long-haul domestic demand, needing efficient freight operations (Muller 1999). Containerized cargoes have been transported through railway and highway networks connected to seaports in the United States. The average growth rate of the number of containers in North America was 9.44% from 1999 to 2006. The number of imported containers decreased slightly by 0.5% in 2007, but decreased by 8.2% and 14.5% in 2008 and 2009, respectively (U.S. Maritime Administration 2010; U.S. Maritime Administration 2011). The majority of imported containers to the United States came from China from 1997 to 2009, representing approximately 48% of the all imported 20-foot equivalent units (TEUs) (AAPA 2011). Fifty-six percent of import container traffic came through the Pacific areas (20 ports); the Atlantic areas (21 ports) accounted for 39.8% of TEUs and the Gulf areas (11 ports) accounted for 4% of TEUs. According to the intermodal industry statistics of the Intermodal Association of North America, 86.3% of total container traffic was moved by rail in 2009 (IANA 2011). Class I railroads[1] transported 8.2 million of 10 million containers transported in 2009 (IANA 2011, AAR 2010). The 2007 Commodity Flow Survey (CFS) found that the average distance for mixed freight[2] is 160 miles by truck and 1,182 miles by rail (U.S. Census Bureau 2010).

Several studies have been conducted to highlight the importance of container route optimization (Miller and Storm 1996, Luo 2002, Luo and Grigalunous 2003, Leachman et al. 2005, Leachman 2008, Leachman 2010, Levin et al. 2009a, Fan et al. 2009). Luo and Grigalunous (2003) analyzed import and export container markets by optimizing the routes and simulating hypothetical ports as alternative entry locales through Canada to mainland U.S. markets. They also applied a shortest path algorithm to minimize transportation cost, based on an assumption of shipper's behavior, for allocating network volume. They also simulated a hypothetical port in Canada to compete with U.S. ports along the Atlantic Coast of the two countries. In addition, the authors studied the Panama Canal's impact on route choice behavior.

Leachman et al. (2005) and Leachman (2008, 2010) studied the import container markets in the United States by optimizing the routes through assigning an origin trade partner and destination in U.S. inland markets. In these studies, markets were grouped into 21 regions based on regional distribution centers. Levin et al. (2009a) estimated the origin and destination (O-D) for U.S. imports of maritime containerization from the Port Import Export Reporting Services (PIERS) database and the 2003 STB Public Waybill sample database. The growth rate variation of railway shipping from ports to 48 inland markets was based on Bureau of Economic Analysis zones (BEAs) in their study. The estimation focused on the Trans-Pacific mainlane (between Asia and the United States) incorporating maritime, rail, and truck networks. Levin et al. also estimated container flows between origin and destination for U.S. exports of waterborne containerized freight in a series. Levin et al., Fan et al., and Fan used the 2006 STB Public Waybill sample to estimate the volume of containers for imports from the west coast of the United States and Canada. They optimized efficient routes from Asia to U.S. markets through the ports in the Pacific region via railways.

A rapid increase in the number of containers during the last several decades has created capacity, safety, and environmental issues in the port areas. The import containers to the United States are transported through U.S. entry ports, in addition to Canadian and Mexican entry ports. Hughes (2006) proposed and emphasized the importance of visualization to define spatial and temporal attributes of freight movements. The visualization of the trip assignment would be beneficial for analyzing the temporal trends and geographical patterns of imported freight flow. The analysis can be merged into different commodities for the railroad industry and multimodal choice patterns for the large-scale international trade patterns. In this study, we are proposing a way to visualize the container flow to aid in understanding container flows.

Mapping and visualizing feasible routes and estimating number of containers from foreign origins to U.S. inland markets through the North American ports and terminals would provide a better understanding of the freight flow pattern and a systematic view of imported container flow. Several studies provide estimated container flow for international trade (Levin et al. 2009a, Levin et al. 2009b, Leachman 2010, Fan et al. 2010). These studies present discrete flow based on O-D pairs instead of providing detailed segments for possible flow directions. However, the previous studies in the literature do not describe visualization of the output in detail for public communication. This study provides extensive and detailed procedures not found in the previous studies in the literature. Thus, this study focuses on traffic routes from coastal ports to inland markets based on Bureau of Economic Analysis (BEA) zones through established railway networks to generate and distribute trips. The routes can then be assigned an estimated volume on network links based on the number of estimated TEUs, which is called the process of trip assignment. Ultimately, utilizing the developed linear programs for choosing feasible routes, the optimal routes are geovisually displayed in a GIS map. Port authorities, intermodal terminals, and railroads could use the information in this paper as an input to infrastructure investment decisions.

MODEL DEVELOPMENT

Assumptions

International Standard Organization (ISO) containers are 20-foot, 40-foot and 45-foot boxes that represent approximately 52.3% of the total container movements, including inland traffic (IANA 2011). The most common box lengths are 20-foot and 40-foot for international trade (Leachman 2008). All other lengths are 24-foot, 35-foot, 48-foot, and 53-foot containers handled through Pacific maritime ports. In 2007, Pacific Maritime Association (PMA) reported that for 20-foot containers, the shipping volume was 22.1%; for 40-foot containers the volume was 71.3%; all other lengths were 6.6% in the Pacific region (PMA 2009). Thus, throughput in this study is measured in TEUs for maritime and railway shipping. TEU is used for international trade and domestic distribution for container transit from ports (origin), via railways, and eventually to markets (destination). The ports in the study area were aggregated into BEA zones for analysis (Table 1). To represent a BEA zone, major cities were selected as destinations, and a major seaport in the BEA as the origin in the conceptual model. The number of containers originated from the arrival seaports was aggregated into a BEA level since the STB public waybill data are sampled based on BEA zones using 1997 BEA codes. Several intermodal marine ports in a BEA region are aggregated in a BEA code (U.S. Bureau of Transportation Statistics 2010). One or more Class I railroad companies provide intermodal services to the intermodal marine ports (Table 1).

Table 1: Intermodal Service Ports in the Bureau of Economic Zones via Class I Railroad Facilities

Regions	Coastal Bureau of Economic Zone (BEA)	BEA Code	Marine Ports	Class I Railroad for Intermodal Facility						
				BNSF	UP	CSX	NS	KCS	CN	CP
Pacific	Seattle-Tacoma-Bremerton (WA)	170	Seattle	V	V					
			Tacoma	V	V					
			Vancouver	V	V					
	Portland-Salem (OR)	167	Portland	V	V					
	San Francisco-Oakland-San Jose (CA)	163	Oakland	V	V					
			San Francisco	V	V					
	Los Angeles-Riverside-Orange County (CA-AZ)	160	Los Angeles	V	V					
			Long Beach	V	V					
			Hueneme							
	San Diego (CA)	161	San Diego							
Atlantic	Boston-Worcester-Lawrence-Lowell-Brockton (MA-NH-RI-VT)	3	Boston			V				
	New York –No. New Jersey – Long Island (NY- NJ- CT-PA-MA-VT)	10	New York / New Jersey			V	V			
	Philadelphia-Wilmington-Atlanta City (PA-ND-DE-MD)	12	Philadelphia			V	V			
			Wilmington			V	V			
	Washington-Baltimore (DC-MD-VA-WV-PA)	13	Baltimore			V	V			
	Richmond-Petersburg (VA)	15	Richmond							
	Wilmington (NC-SC)	25	Wilmington							
	Norfolk-Virginia Beach-Newport News (VA-NC)	20	Hampton Roads			V	V			
	Charleston-North Charleston (SC)	26	Charleston			V	V			
	Savannah (GA-SC)	28	Savannah			V	V			
	Jacksonville (FL-GA)	29	Jacksonville			V	V			
			Fernandina							
	Miami-Fort Lauderdale (FL)	31	Everglades			V				
			Miami			V	V			
			Palm Beach			V				
Gulf	New Orleans (LA-MS)	83	New Orleans	V	V	V	V		V	
	Houston-Galveston-Brazoria (TX)	131	Houston	V	V					
			Freeport	V	V					
	Tampa-St. Petersburg-Clearwater (FL)	34	Tampa			V				
	Tallahassee(FL-GA)	35	Panama City							
	Mobile (AL)	80	Mobile	V	V				V	
	Biloxi-Gulfport-Pascagoula (MS)	82	Gulfport						V	

Note: BEA represents Bureau of Economic Analysis (BEA) zone developed in 1997. The Class I railroad does not always connect to the ports directly, but in the BEAs instead.

Sources: National Transportation Atlas Databases 2010, U.S. Department of Transportation; Class I railroad company intermodal service maps; Fan (2010).

Input Data and Data Sources

The number of containers in a TEU was acquired from the Maritime Administration Database (MARAD). The MARAD Trade Statistics summarizes the PIERS data, and therefore does not include specific overseas routes, the overseas ports of origin, and the through ports in North America (see also U.S. Maritime Administration 2010). The American Association of Port Authorities and MARAD use the PIERS database for statistics since MARAD provides aggregate traffic information from PIERS. Rail traffic information was derived from the pubic waybill sample used by the Surface Transportation Board (STB) Waybill, and Railroad Fact Sheet published by the American Association of Railroads (2008). The ports throughput was aggregated into a 1997 BEA zone, which the STB waybill uses for determining railroad statistics. Only ports with import data were selected as origin BEA zones. Railway networks were derived from the Oak Ridge National Laboratory (ORNL) database (Center for Transportation Analysis 2009), an online geodatabase for North American railway network information (Peterson 2000). In addition to the base network, this study utilized the impedance developed by ORNL in order to present modal route selection based on the 2003 Commodity Flow Survey, even if route choice is affected by congestion, travel time, market power, and price at origin and destination. The impedance is the generalized cost of different enroute activities (Southworth and Peterson 2000, Thill and Lim 2010). The normalized impedance represents the normalized shipping distance between multiple modes for each commodity. This study reclassifies the impedance into two groups: 1) Transportation impedance that is related to the traversable line-haul links, and 2) Inventory impedance that is terminal access links and logical terminal links (Thill and Lim 2010). This paper also regrouped them into relative and absolute impedance. The relative impedance will increase travel resistance on the links analogous to generating obstacles to slow traffic down; however, the links are still traversable, while the absolute impedance assigns a very large penalty in order to block the roads.

MODEL APPROACH

We can assign a total logistics cost that consists of haulage cost (*CH*), inventory cost (*CI*), and terminal cost (*FT*) for a fixed-charge location problem as follows

$$(1)\quad Min \sum_{i}^{I}\sum_{j}^{J}\sum_{k}^{K}\sum_{m}^{M}\sum_{t}^{T} Q_{ijkmt}(CH_{ijkmt} + CI_{ijkmt} + HS_{kt}CHS^{v}_{kt}) + \sum_{k}^{K} CHS^{f}_{kt}HS_{kt}$$

By redefining, CH_{ijkmt}, as haulage cost from origin *i* to destination *j* through terminal *k* for a container by mode *m* during period *t* which can be equated as the multiplication of the total travel time between origin and destination and the time cost for each mode from the relation; $CH_{ijkmt} = T_{ijkmt} \times CC_{ijkmt} \times W_{ijkmt}$, where CC_{ijkmt} is transportation cost per container/mile, W_{ijkmt} is the percent of traffic from origin *i* to destination *j* by mode *m* through intermodal terminal *k* during period *t*. T_{ijkmt} is a distance variable between locations using mode *m* during period *t*. CHS^{v}_{kt} is a variable cost per unit required to handle movement of a product at terminal *k* during period *t*, while CHS^{f}_{kt} is a fixed cost for keeping terminal *k* operable during period *t*.

Decision variables, for example Q_{ijkmt}, incorporate the number of containers moving from origin *i* to destination *j* by mode *m* in period *t* and an operable terminal, which will serve the demand as represented by binary values:

$$(2)\quad HS_{kt} \begin{Bmatrix} 1 \text{ if a terminal } k \text{ serves the BEA zone during a period } t \\ 0 \text{ otherwise} \end{Bmatrix}.$$

A balancing constraint can be issued for the quantity of supply and demand. The number of outbound containers from all origins ($\sum_{i}^{I} Q_{ijt}$) may not always be equilibrated with the number of inbound containers at all destinations ($\sum_{i}^{I} Q_{jit}$) due to work-in-process in the delivery system, that is, $\sum_{i}^{I} Q_{ijt} \neq \sum_{j}^{J} Q_{ijt}$. Nevertheless, the total number of outbound containers from origin i to a destination j during a period t should be the same as the supply, as $\sum_{i}^{I} Q_{ijt} = \sum_{i}^{I} S_{it}$, where Sit indicates the number of outbound containers from port suppliers. On the other hand, the total number of inbound containers to destination j should equal the demand quantity, that is, $\sum_{j}^{J} Q_{ijt} = D_{jt}$, where D_{jt} represents demand at destination j during period t. For mode combination, the number of through terminals cannot exceed the total demand between origin i and destination j, $\sum_{i}^{I} Q_{ijm\bullet} \geq \sum_{k}^{K} Q_{ijm\bullet}$, $\sum_{i}^{I} Q_{ijmt} \geq \sum_{k}^{K} Q_{ijkmt}$ but the total demand is not sufficient for the condition due to the time lag. In the case of interrupted routes (a_{ijkmt} = 0) such as rail segment abandonment and bridge collapse, the value should be zero for the specific segment from origin i to destination j, while incurring large costs, that is Q_{ijkmt} = 0 when a_{ijkmt} = 0. The relation, a_{ijkmt} = 0, indicates blocked routes of a segment from origin i to destination j through terminal k by a transportation mode m during period t. The number of containers from origin i to destination j cannot be assigned a negative number, as $Q_{ijkmt} \geq 0$.

Equation (1) can be decomposed into smaller shortest path problems: the first term in Equation (3) is set for direct shipping bypassing any hub location, while the second term in Equation (3) is necessary to minimize the total cost.

$$(3)\quad Min \quad \sum_{(i,j)\in P} \sum_{m=\{highway\}} Q_{ij} w_{ijm} \left(CH_{ijm} + CI_{ijm}\right) + \sum_{(i,k)\in P} \sum_{(k,j)\in P} \sum_{k\in N_i} \sum_{m=\{rail\}} Q_{ijk} w_{ijkm} HS_k \left(CH_{ijkm} + CI_{ijkm} + CHS_k^v\right)$$

$$(4)\quad s.t. \quad \sum_{(i,j)\in P} w_{ijm} + \sum_{(i,k)\in P} \sum_{(j,j)\in P} w_{ijkm} = 1 \quad \forall i \in I, \forall j \in J$$

$$(5)\qquad HS_k = \{0,1\}$$

$$(6)\qquad \sum_{k\in N_i} HS_k = \begin{cases} 1 & \text{if } w_{ij} < 1 \\ 0 & \text{otherwise} \end{cases}$$

$$(7)\qquad HS_k - \sum_{k\in N_i} w_{ijk} \geq 0$$

$$(8)\qquad \sum_{k} Q_{ijk} w_{ijk} \leq MQ_k$$

where:

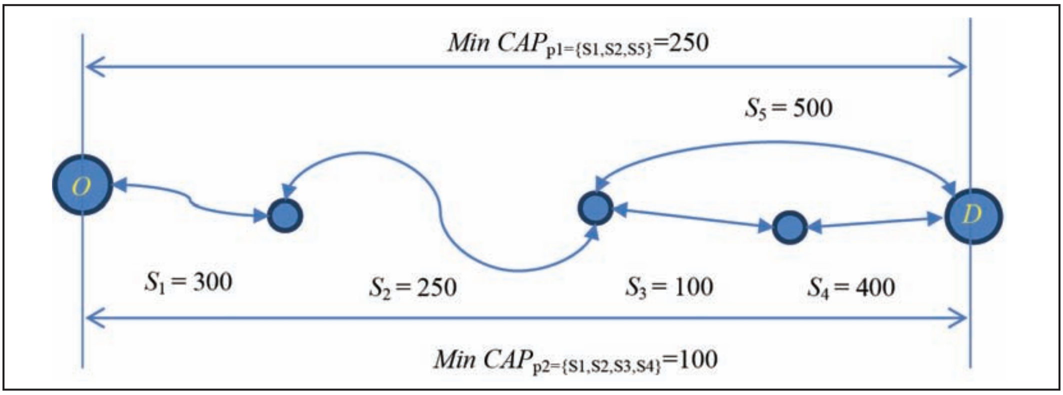
Q_{ij}	= number of containers from origin i to destination j
CH_{ijm}	= transportation impedance from origin i to destination j by mode m
CI_{ijm}	= inventory impedance from i to destination j by mode m
w_{ijm}	= trip assignment ratio to the path between origin i and destination j by mode m
Q_{ijk}	= number of containers from origin i to destination j through intermediary facility k
CH_{ijkm}	= transportation impedance from origin i to destination j through intermediary facility k by mode m
CI_{ijkm}	= inventory impedance from origin i to destination j through an intermediary facility k by mode m
HS_k	= binary variable; if select intermediary facility k, HS_k=1; otherwise, HS_k=0
CHS^v_k	= relative impedance caused by selecting intermediary facility k
w_{ijkm}	= trip assignment ratio to the path between origin i and destination j through intermediary facility k by mode m
M	= arbitrarily large number

The rewritten equation is a capacity-confined *path-based* model. The capacity of the path is determined by $\min\{CAP_{s\in P}\}$, when $CAP_{s\in P}$ is a capacity of a segment s for the selected path P. In other words, the minimum capacity of the selected path P is determined by the minimum capacity among the segments (S_1, S_2, S_3, and S_4) of the selected, alternative path (P) (see Figure 1). In Figure 1, the volume discount factor is not considered.

Q_{ij} in Equation (1) is replaced by $Q_{ij}w_{ijm}$ and Q_{ijk} by $Q_{ijk}w_{ijkm}$ in Equation (3). The total ratio of the trip assignment of an O-D pair transported by truck and rail cannot exceed one, which is 100% in Equation (4). The combined subroutes, from origin i to terminal k and the terminal k to destination j, would create a feasible path. When a trip demand, Q_{ijkm}, exceeds the capacity of a selected path, the trip information is dissected into two parts by a portion (w_{ijkm}) of the initial trip information. For example, when a trip to be assigned onto the selected path is 50 trips and the capacity of the selected path is 30 trips, only 30 trips (w_{ijkt} = 60%) would be feasible through the path and the other 20 trips will be assigned onto the next alternative route. In Figure 1, two feasible paths between origin (O) and destination (D) are found: P_1={S1,S2,S5} and P_2={S1,S2,S3,S4}. Suppose 200 containers need to be delivered between an O-D pair and the shortest path is the path P_2, a carrier would select P_2 and then assign the minimum capacity of the path calculated by $min\{Cap_{p2}\}=100$. The rest of the demand (100 containers) will be assigned to the next shortest path P_1. The $min\{Cap_{p1}\}=250$, which is the larger than the remaining demand. Therefore, the 100 containers would be assigned to the P_2. It is based on the greedy algorithm, by which the best route is selected *a priori*.

The assigned trips to the intermodal terminals are subject to the following constraints: the sum of O-D trips by intermodal transportation ($\sum_{k\in N_i} w_{ijk}$) cannot exceed the value of HS_k (Equation 7), where w_{ij} of the shipments are by truck, and $HS_k - \sum_{k\in N_i} w_{ijk}$ is a combination of multiple routes of intermodal transportation. The total trips of an O-D pair moving through an intermodal terminal cannot exceed the assigned trips on the terminal (Equation 8). Decision makers also must consider the fixed costs and variable costs for intermodal shipping. For example, while delivering products by roadways, truck drivers are charged tolls, which are not proportional to travel distance in the United States, unlike in other countries. Unexpected events during shipping are other possible sources of variable costs, such as road closures and detours caused by weather and natural disruptions. The events and activities occur on transportation networks with road links (segments) and intermodal terminals at origin and destination (nodes).

Figure 1: Capacity of a Path Based on Minimum Capacity of the Segments



The intermodal terminals are presented as points in GIS without connectivity to links, so dummy links can be created for the terminals with a set threshold distance needed to connect them to the nearest road links. Southworth and Peterson (2000) and Lee and Farahmand (2009) introduced an impedance intermodal network model with absolute and relative penalties, which can be expressed as the length of a road, or any disutility value depending on the decision maker's criteria.

The terminal nodes are converted into terminal links, which include the link impedance such as dummy miles (R_N), and a user-defined penalty in miles (X_N) for transferring commodities [see second term in Equation (9)]. Each network segment includes distance-based penalties: resistance (R_S), such as mode and road classification, and absolute penalty (X_S), such as bridge and tunnel clearance or road construction during a certain period. These nodes (N) and links (S) are a subset of an alternative path (P) from

(9) $$Min \sum_{S \in P}(R_S + X_S) + \sum_{N \in P}(R_N + X_N).$$

This study examines an intermodal route, so the different transportation modes from coastal port *i* to terminal *k* by rail and from terminal *k* to inland market *j* by truck are subdivided into separate network definitions. The two different networks are linked at intermodal terminals for connectivity:

(10) $$Min \sum_{S \in P_{HWY}}(R_S + X_S) + \sum_{S \in P_{RAIL}}(R_S + X_S) + \sum_{N \in P}(R_N + X_N).$$

The blocked route *s* would be assigned by the user-defined high penalty value (called reactance in this study) onto a segment (X_S) and a terminal (X_N). For the detailed information for the definition and setting of reactance, see Lee and Farahmand (2009). The terminal nodes are reshaped by dummy links, so we can rewrite Equation (11) as

(11) $$Min \sum_{S \in P_N \Leftrightarrow OD}(R_S + X_S) Q_{OD} w_{P_N},$$

when each route has a percent (w_{P_N}) of the assigned trip (Q_{OD}) to an O-D pair.

The quantity of a shipment on the alternative path is allocated by the portion of O-D trip data, which is the minimum capacity of the selected segments of the path. Equations (7) and (8) are included to measure the total system cost. However, the process will be preceded for finding individual trip's best route in the order of trip assignments for the O-D matrix. In this approach, each trip is selected based on the best alternative route using First-In-First-Out (FIFO) trip information from the O-D table in a given row. Instead of using optimization, this study uses a heuristic approach to generate the feasible routes between O-D. The route exchange method is combined with the FIFO greedy algorithm by enumerating all possible routes in the boundary of s (this process is called path enumeration). In other words, this study enumerates all feasible routes based on the heuristic approach, which is an experience-based geo-technique. Therefore, the holistic, systemic optimum would be the sum of all pairs of paths as

$$(12)\quad \sum_{\{OD\}} \min\left(\sum_{S \in P_N \Leftrightarrow OD} \left(R_S + X_S\right) Q_{OD} w_{P_N} \right)$$

RESULTS AND IMPLICATION

The U.S. container markets are located along the Mississippi River as well as in coastal metropolitan cities, such as New York, Miami, Los Angeles, and Houston (Figure 2). The STB public waybill sample indicates that 70% of the containers went through the Pacific BEA regions, while 21% of the containers were originated from the Atlantic BEA regions. Along the Gulf and Atlantic areas, truck routes are used more frequently than rail networks, while rail is used for container shipping more often than truck routes at the Seattle and Tacoma BEA zone in Washington. Based on the rail market share for the imported containers from the foreign origins, the markets are located along the east and west coasts of the United States and the Mississippi River Valley. The largest markets are Chicago, Memphis, and Dallas. Intermodal terminals (including COFC-TOFC [3] terminals) are also located around the markets. In addition to the Mississippi River Valley markets, Los Angeles is a large market for imported containers by rail shipping.

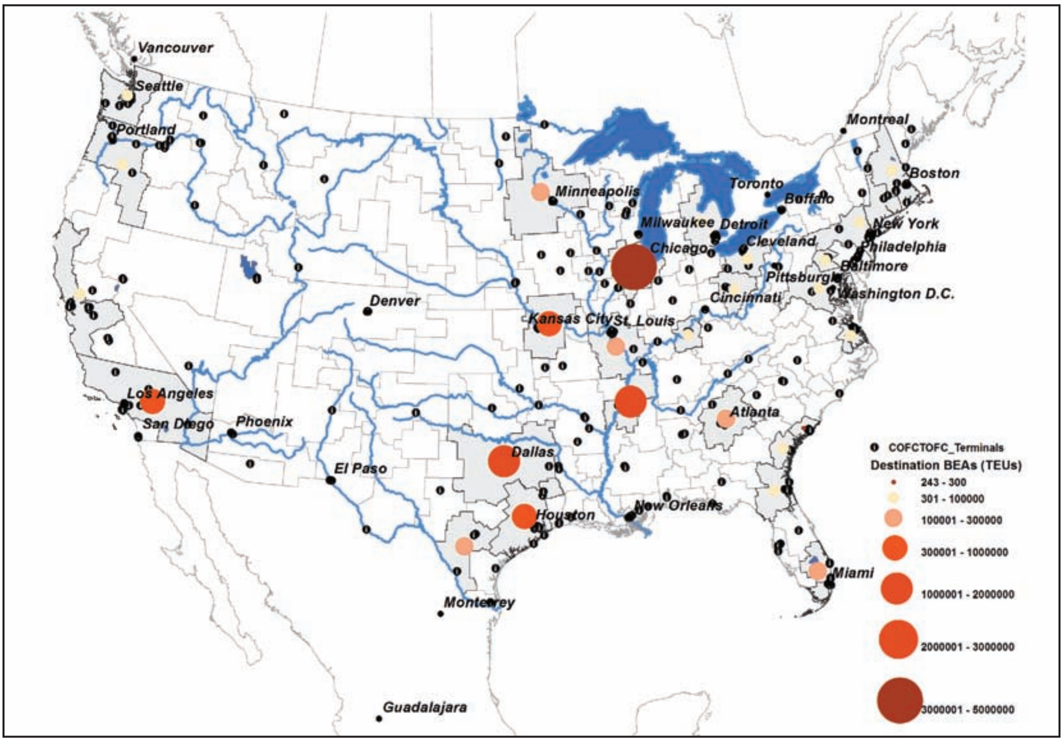
In line with the imported container markets and terminal locations, most of the rail containers originated from the west coast (Figure 3). The rail shipping lanes were estimated by the impedance network with the shortest path algorithm in GIS. The estimated lanes are grouped by selected regions, for example, Atlantic, Pacific, and Gulf of Mexico regions.

Figure 4 shows rail shipping lanes and the density on the segments of the lanes from the East Coast. The containers are loaded on rails from cities such as Boston, New York, Baltimore, Washington D.C., Norfolk, and Jacksonville. Most of the containers are shipped to the Mississippi River Valley and the west coast. In Figure 4, the rail shipping lanes are mixed along the East Coast. Some containers are destined for Vancouver and Quebec, Canada. Landbridge lanes are from the East Coast to Vancouver, Canada, and from Seattle and San Francisco-Oakland in the United States to the East Coast. We speculate that the containers originating from Europe and South America are destined for the East Coast.

Figure 5 shows a high density of the imported containers flowing from the West Coast. A very large number of containers are shipped from the Los Angeles and Long Beach BEA region to Chicago through Kansas City and to Memphis through Dallas. The Seattle-Tacoma BEA region is the next largest West Coast source for the imported containers transported by rail to U.S. inland markets. The containers flow to Chicago through Minneapolis. Some imported containers are shown moving from Portland and Sacramento and headed to Chicago, Minneapolis, and Kansas City. Small landbridge container volumes flow from Pacific ports to the East Coast, including East Coast cities like Boston, New York, Jacksonville, and Miami.

Figure 6 presents the rail shipping density for imported containers through the Gulf of Mexico. In the STB public waybill, one BEA zone, Houston, Texas, shows rail shipping from the Gulf of Mexico. Most of the rail traffic is headed to Los Angeles and northward to Portland and Seattle. The rest of the containers are shipped to New York, Washington D.C., Chicago, Memphis, and St. Louis.

Figure 2: Container Market Density by the STB Waybill Public Sample and Geographical Locations of Intermodal Terminal in 2007



CONCLUSION

One of the major objectives of the study was to geovisualize container flow based on developed linear programs. We implemented the GIS model integrating an impedance approach and investigated the flow of the imported containers in the United States. Using GIS to create visualization, U.S. import container traffic was determined. For the visualization, the STB waybill sample was used as trip information for railroad shipping from the portal BEA regions to inland container markets. Visualization of the freight information could be used for portal areas along the coastal cities to estimate segment density and evaluate container flow. Using geovisualization, it becomes possible to ascertain density and major shipping routes of the imported container traffic, with impedance, for each major direction from the Atlantic Ocean, Pacific Ocean, and Gulf of Mexico to inland markets.

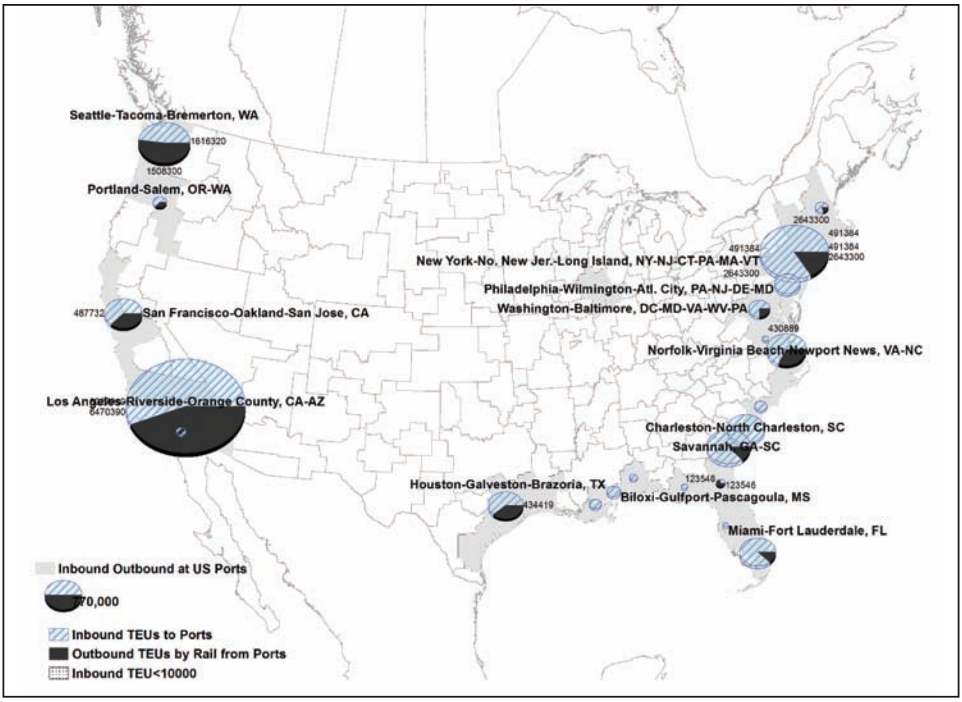
Endnotes

1. Class I railroads are Burlington Northern and Santa Fe Railway (BNSF), Union Pacific Railroad (UP), Norfolk Southern (NS), CSX Transportation (CSX), Kansas City Southern Railway (KCS), Canadian National Railway (CN), Canadian Pacific (CP), Ferrocarril Mexicano (Ferromex), and Kansas City Southern de Mexico (KCSM) as of 2010.

2. Standard Classification of Transported Goods (SCTG) Code is 43 for the mixed freight.

3. Container-on-Flat-Car (COFC) and Trailer-on-Flat-Car (TOFC)

Figure 3: Comparison Import Containers Inbound TEUs to Ports by Ocean Shipping to Outbound TEUs from Ports by Rail in 2007



Note: The same space of inbound TEUs to Ports (dashed) and the outbound TEUs by rail from Ports (in dark) means that all TEUs inbounded to a port are transported by rail from the port to inland markets.

Figure 4: Container Flow from the Atlantic Ports

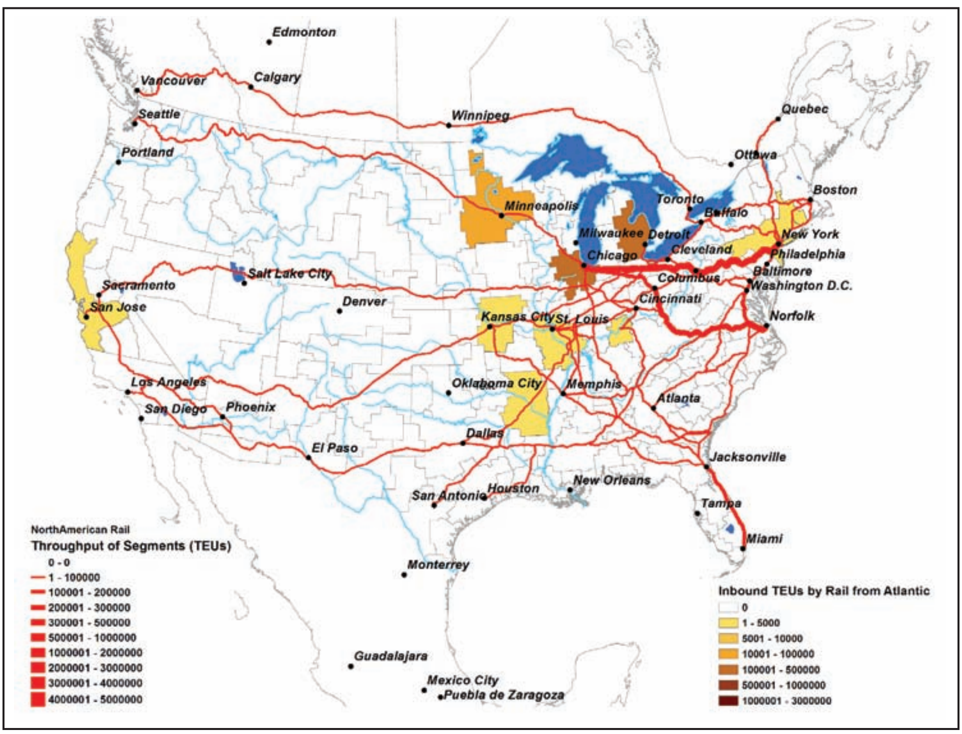


Figure 5: Container Flow from the Pacific Ports

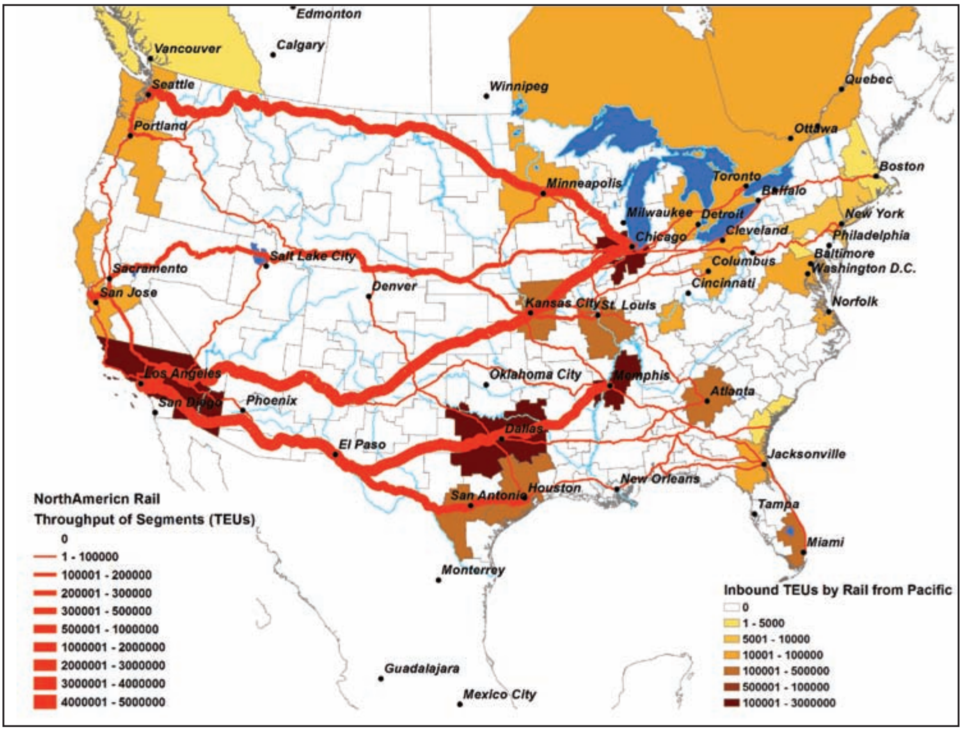
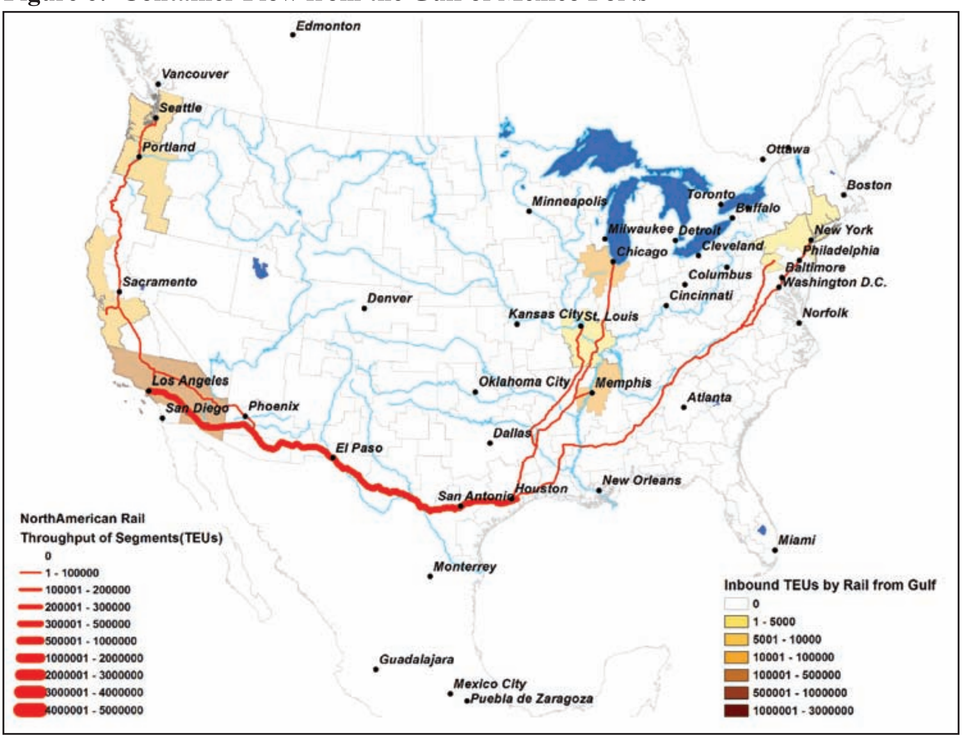


Figure 6: Container Flow from the Gulf of Mexico Ports



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Development of Best Practices for Right-of-Way Valuations and Negotiations in Transportation Projects

by Carlos H. Caldas, Zhanmin Zhang, Kara M. Kockelman, Khali R. Persad, Ragheb Al Halabi, and Elizabeth Kincaid

The valuations of properties and the negotiations with property owners are two major tasks in the right-of-way acquisition process for transportation projects. If improved, those tasks can increase the overall project delivery efficiency. The Texas Department of Transportation (TxDOT) funded a research project that aimed to recommend some best practices for successful valuations and negotiations in Texas. The authors reviewed the different strategies and procedures followed in TxDOT by conducting interviews and surveys with right-of-way personnel. Guidelines supported by recommended practices were identified for both valuation and negotiation and then reviewed and validated by experts. Lastly, implementation guides were developed.

INTRODUCTION

Right-of-Way (R/W) acquisition is an essential part of the complex process of developing a highway project. Because the acquisition process occurs immediately prior to the construction of the highway infrastructure, the pressure is always high to acquire property quickly so that the project can begin. In fiscal year 1999, the Federal Highway Administration (FHWA 2003) reported that the federal government spent nearly $1 billion for R/W acquisition.

R/W acquisition comprises different elements. Among the most vital ones are property valuation and negotiation with property owners. These usually lie on a project's critical path and have an important impact on project schedule and cost. They also affect relationships with property owners because they can engender public trust in transportation planning and in the R/W acquisition process.

A variety of added factors can impede the valuation and negotiation processes as discussed by the following two technical reports. First, Hakimi and Kockelman (2005) argue that time, cost, and public satisfaction are essential performance parameters of successful R/W acquisition for state departments of transportation. They emphasize that inefficient negotiation processes typically frustrate the public and contribute to an increase in project cost and duration. Second, Chang (2005) lists several types of delays in R/W acquisition. These are delays due to pricing, compensation, and impact disputes; title curative (updating title issues and the actual use of the property) and ownership delays; parcel characteristics/improvement delays; environmental issues; legal activity and litigation delays; as well as design change and revision delays. On the other hand, some practices help eliminate such complexity. According to a Federal Highway Administration (FHWA 2006) study, the timing of the involvement of property owners in the design process and the frequency of agency contact with them can have a major impact on successful acquisition. Establishing this connection could result in more timely purchases and the reduction of damages to the affected properties. Similarly, having in-depth interviews with the property owners affords a better understanding of how owners use the property, and helps agents form a comprehensive estimate of just compensation, both of which facilitate negotiations with property owners (FHWA 2002). Further research, however, is needed to identify the best practices for better valuation and negotiation results and synthesize them into useful guidelines.

In an effort to help the Texas Department of Transportation (TxDOT)) reduce the time and cost for land acquisition and build good rapport with the public, the research project described in this manuscript was launched to survey and to synthesize best practices in R/W valuations and negotiations in Texas. The objectives of this research were to identify problems and issues, legal constraints, and other factors related to R/W valuations and negotiations in TxDOT's operations, and to synthesize best practices and create guidelines for these processes to improve their effectiveness. These objectives were achieved by conducting interviews and surveys with R/W personnel from TxDOT to identify and evaluate valuation and negotiation methods and practices, reviewing literature and laws, and forming recommendations based on the above. In order to avoid both the shortsightedness that would result from too narrow a scope, and the decreased applicability that comes from too broad an approach, the scope of this research was limited to practices related only to the valuation and negotiation phases of the acquisition process. The process preceding negotiations (i.e., appraisal review) and the subsequent processes (i.e., condemnation or relocation) are not included in the study. The scope of this research was focused on the state of Texas and the results are more applicable to Texas. However, the procedure followed could be used by other DOTs to obtain R/W acquisition best practices for other states.

OVERVIEW OF RIGHT-OF-WAY ACQUISITION PROCESS

According to the *Real Estate Acquisition Guide for Local Public Agencies* (TxDOT 2004), the R/W acquisition process comprises five phases: planning, appraisal and appraisal review, negotiation, property management, and relocation. Planning is the first phase and mainly involves environmental assessments, location and design studies, and public involvement activities. During the planning phase the laws require environmental assessments that mainly measure the social, economic, and environmental impacts of a project's R/W acquisition and any relocation it might require (FHWA 2001). Public involvement is also critical during the planning phase. The purpose of initiating public involvement is to notify a community of the agency's intentions and to communicate the necessity of a project and the possible social and environmental impacts. This can be done through meetings, newspaper, television advertisements, and letters (TxDOT 2004).

Appraisal is the second phase and is the process of having a parcel appraised and having the appraisal reviewed to establish the amount of just compensation. Prior to parcel appraisal, there should be a pre-appraisal contact with the property owner. This contact should be in the form of a direct meeting with the property owner. In this meeting, the owner is given information regarding the overall R/W acquisition process, the general type of facility to be constructed, and the appraisal procedure that will ensue. A commitment must not be made on value nor should any offers be made before approved values are received. Once the pre-appraisal contact has been made, an appraiser is assigned the task of determining the market value for each parcel. It is the district's responsibility to determine that the appraiser assigned to a parcel is qualified to appraise that particular type of property. After that, the fair market value and just compensation are determined. The fair market value is an appraisal based on an estimate of what a buyer would pay a seller for any piece of property. The amount of just compensation will not be less than the approved appraisal. The approved appraisal takes into account the value of allowable damages and enhancements to any remaining property. Lastly, the agency reviews the appraisal in preparation for establishing an approved value for the property. A review appraiser will examine the report for completeness, consistency in land values, variances in component values, appraisals of any remainders, compensability, and leased properties. Upon completion of the review, the review appraiser will recommend that the appraised value be approved. The approved value will be used as the basis of the state's offer to acquire a property (TxDOT 2004).

In the negotiation phase, agencies make offers to property owners for acquisition of real property and improvements. They also make payments for properties and give notice to property owners to vacate. When all reasonable efforts to negotiate the written offer of just compensation have failed, an administrative settlement can be pursued (FHWA 2006). If an agreement cannot be reached, condemnation proceedings typically follow.

In the property management phase, the clearing of the R/W takes place. This phase can also be time consuming and full of unexpected, sometimes extensive, schedule delays. However, agents who are good property managers can partly recover the large investments made during acquisitions by maximizing the revenue from the sale of excess property purchased during the R/W acquisition process.

Finally, in the relocation phase, residences, businesses, farms, and non-profit organizations are displaced due to federal or state programs designed to benefit the public. However, the law specifies that the displaced persons should not undergo disadvantage as a result of projects done for the good of the public. According to the *Real Estate Acquisition Guide for Local Public Agencies* (FHWA 2006), the relocation process is divided into four parts. Relocation planning comes first and requires the analysis of the location, size, and schedule of the displaced residents. Secondly, the Uniform Act requires supplying the affected residents with general information on their eligibility for relocation, and on the 90-day minimum notice provision that guarantees that they do not have to vacate their property without a 90-day written notice. Next, an advisory service is provided to ensure that relocated owners are fully informed and that they have access to counseling and advice. Finally, payments must be made to affected residents.

REVIEW OF PERTINENT LAWS AND STATUTES

To gain a better understanding and assessment of R/W negotiation practices, the authors conducted a review of the pertinent laws and statutes that affect the valuation and negotiation processes. Federal and state laws were both found to greatly affect those processes.

The principal laws for R/W acquisition on federal projects are Public Law 91-646 and *The Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970*, as amended, also called The Uniform Act. The Uniform Act protects property owners whose property and/or improvements are acquired or who are displaced from R/W acquisition by federal or federally assisted state projects (FHWA 2006). Three sections (or titles) comprise the Act. Title Three, the "Uniform Real Property Acquisition Policy," governs acquiring real property for federal and federally assisted projects (42 USC). The provisions of Title Three encourage agencies to acquire real property through negotiation, and to minimize the possibility of litigation (FHWA 2006). The bulk of this section of the paper addresses this part of the Uniform Act.

For valuation in particular, there are federal and state laws that influence these practices:

- State laws allow the acquisition of private property for public projects, given that the owner is entitled to just compensation (TxDOT 2006). Though the agency must offer the amount that the property owner is entitled to, state law prohibits paying more than the agency is required to pay.
- The *Real Estate Acquisition Guide for Local Public Agencies* (LPAs) suggests that a detailed appraisal should reflect standards that are nationally recognized (FHWA 2006) such as the *Uniform Appraisal Standards for Federal Land Acquisition* (The Appraisal Institute 2000) and the *Uniform Standard Practices for Appraisal Professionals* (The Appraisal Foundation 2006). Complying with federal regulations, the state requires that the appraisal report include certain items, such as a statement of purpose for the appraisal, a description of the physical characteristics of the property, and a description of comparable sales. A parcel can be waived from the requirement for an appraisal if the parcel is donated, or if the proposed acquisition is uncomplicated and low-valued as stated in the Uniform Act.
- The Uniform Act requires that the appraiser give the property owner the opportunity to accompany him or her during any investigation of the property made in preparation of the appraisal. This requirement allows property owners to advise the appraiser or indicate

features of the property that might affect the valuation of the property, or that might not be obvious to the appraiser.

- The state laws also require that the invitation be made in writing, with sufficient lead time for the owner to arrange to be present or to request an alternative time.

Similarly, the R/W negotiation process is restricted by federal and state laws and regulations:

- The Uniform Act states that when the agency moves to obtain necessary R/W properties it should attempt, "to the greatest extent practicable," to do so by negotiation rather than through its condemnation authority (42 USC). A qualified member of the agency's staff should be assigned to conduct the negotiations. However, fee negotiators may be hired when the agency's negotiation staff is insufficient.
- The Uniform Act requires the presentation of a written offer to the property owner explaining the amount of just compensation (including damages) and the basis for that amount (49 CFR Part 24). Delivery of this offer constitutes initiation of negotiations and is the principal date for determination of relocation assistance entitlements (FHWA 2006).
- The acquiring agency must make "all reasonable efforts" to contact each real property owner in order to give an explanation of the negotiation process and the responsibilities of both the acquiring agency and the property owner. The *Real Estate Acquisition Guide for Local Public Agencies* (FHWA 2006) encourages the agency to contact the owners, explaining that the contact can promote good rapport with the property owner.
- The Uniform Act also prohibits agencies from using coercive actions to make an agreement. It forbids advancing the time of condemnation, or deferring negotiations or condemnation.
- The *Real Estate Acquisition Guide for Local Public Agencies* (FHWA 2006) recommends that the negotiator should not imply that the negotiation is a "take it or leave it" proposition, nor should condemnation be used as a threat. In case the landowners refuse the initial offer, an administrative settlement is set in motion as the last effort made before the agency involves its condemnation authority (FHWA 2006). To initiate the administrative settlement process, the property owner's written counteroffer is required and must include his or her signed proposal for full settlement setting forth a specific value with information to support the proposal. The R/W acquisition team would decide either to accept or decline this amount that is typically more than the initial offer of just compensation (due to the consideration of the even larger cost of litigation and project delays).
- If partial property acquisitions leave the property owner with a remainder that has no value to the property owner due to a partial taking, the Uniform Act obliges the agency to make an offer to acquire the remainder along with the portion of the property necessary for the project (FHWA 2006).

IDENTIFICATION OF BEST PRACTICES

In order to identify the best practices in R/W valuations and negotiations in the state of Texas, data were compiled from two different sources: interviews with R/W office personnel in TxDOT, and a survey about the practices and problems encountered by the R/W personnel in TxDOT in the valuation and negotiation processes. Results from the analysis of each data source are discussed in the following.

Analysis of Right-of-Way Personnel Interviews

In an effort to get an insight of the current problems, issues, and any inconveniences associated with the R/W valuation and negotiation processes in Texas, interviews were conducted with the R/W agents in the TxDOT at the Bryan and San Antonio district offices. The issues that agents believed were important to the R/W valuation and negotiation processes were divided mainly into three categories: staff constraints, time constraints, and counteroffers from property owners.

The R/W personnel described that staff constraints are one of the major issues that impede the efficiency and effectiveness of the R/W valuation and negotiation processes. The ratio of projects to personnel is too large which necessitates that each staff member works with various projects at the same time; thus dedicating insufficient time to each project. In spite of the fact that the more often contacts are made with property owners the better, the work load does not allow the staff to meet with property owners more than one or two times.

Time constraints were also identified as an important issue. Property owners, given their least experience in dealing with land acquisition and land value, usually want to take their time to think about the presented offer from the DOT. However, TxDOT allows them only a short time, usually thirty (30) days, to accept or present a counteroffer; otherwise the agency will proceed with condemnation. Moreover, district offices usually aim to make pre-appraisal contacts and work with the owners to establish good relations. This step is usually hindered because of the short time allocated to the negotiation process.

With respect to issues related to the counteroffers from property owners, the interviews revealed TxDOT is usually reluctant to approve counteroffers in which values exceed the approved appraisal amount of just compensation by a constant value, irrespective of the size, location, and usage of the land. This is due to the fact that the agency tends to consider the appraisal value as the best estimate, regardless of other factors that might have been ignored during the valuation process. In some cases, the counteroffer is only a few percentage units of difference from the initial offer, but still exceeds the constant approved amount, and is usually rejected. Furthermore, the 30-day time requirement for counteroffers is not enough for owners to present an acceptable counteroffer in writing, since many have never written a counteroffer before. Though this period is extendable, the extension request requires paper work and approval from the division office.

The agents also made some recommendations during the interviews that would help improve the R/W valuation and negotiation process. The agents thought that negotiators should be encouraged to personally assist property owners to write counteroffers. Assistance can also be presented in the form of a simple document or guidebook explaining how to write a counteroffer. Moreover, the agents pointed out that the time, cost, and effort of acquiring a title of an inexpensive property is unnecessarily too great and inefficient; thus the R/W title waiver should be allowed for small properties in order to save time and cost.

Analysis of Right-of-Way Personnel Survey

This survey permitted deeper insight into the problems/issues that are currently experienced by R/W personnel in relation to valuation and negotiations and shed light on their favorite practices. A total of 35 surveys were received from 18 of the 25 district offices in Texas (representing 72% of the state of Texas). The 18 TxDOT districts from which surveys were returned are: Abilene, Amarillo, Atlanta, Brownwood, Bryan, Corpus Christi, Dallas, El Paso, Fort Worth, Houston, Lubbock, Lufkin, Odessa, Paris, San Angelo, San Antonio, Wichita Falls, and Yoakum. The participants' identities were kept strictly confidential but they, on average, have over 15 years of experience in R/W acquisition (the shortest term was two years and the longest was 33 years) ranging from occupations such as R/W agents, appraisers, administrators, appraisal reviewers, and directors. Furthermore, the respondents have, on average, been involved in 600 parcel acquisitions during their TxDOT tenure, with the least number of acquisitions at 15 and the most at over 2,000. The survey included 12 questions. Multiple choices were provided with the majority of the questions, and respondents were asked to rank them according to their rate of occurrence or importance.

In the first question of the valuation section, participants were asked how often they experienced certain problems during the valuation process. Since the results were close, the ranking for this question was made based on the addition of the percentages of "often" and "sometimes." The two problems most frequently reported as "often" or "sometimes" were the property owner's distrust of the agency and/or disagreement with the appraised value (94.1%) and R/W plan and changes and revisions affecting the nature and extent of acquisition on many parcels (94.2%). Another problem experienced by more than 50% of the respondents was delays in the delivery of appraisal reports. Table 1 summarizes the results of this question.[1]

Table 1: Summary of Responses to Question 1

1. Please indicate the approximate frequency in which you have experienced the following problems during the valuation process.				
	Often	**Sometimes**	**Rarely**	**Never**
1-i. Property owner distrust of agency and/or disagreement with appraised values	38.2%	55.9%	2.9%	2.9%
1-a. Right-of-way plan changes and revisions affect nature and extent of acquisition on many parcels	32.4%	61.8%	5.9%	0.0%
1-e. Delays in the delivery of appraisal reports	29.4%	55.9%	14.7%	0.0%
1-b. Insufficient right-of-way staff to obtain appropriate appraisals in a timely manner	17.6%	23.5%	44.1%	14.7%
1-c. Lack of qualified fee appraisers	14.7%	29.4%	41.2%	14.7%
1-f. Inconsistencies among appraisal reports (e.g., significantly different values for the same parcel)	8.8%	35.3%	55.9%	0.0%
1-d. Poor quality of appraisals produced by fee appraisers	5.9%	38.2%	55.9%	0.0%
1-g. Appraisers do not have time to meet with property owners personally	2.9%	14.7%	55.9%	26.5%
1-h. Disagreement over prioritization criteria used by outsourced appraisers to select which parcels will be appraised first	2.9%	14.7%	50.0%	32.4%

Participants were also asked to rank the importance of given actions during the valuation process. According to the respondents, the most important issue was the way R/W plan changes and revisions affect the nature and extent of the acquisition of parcels (70.6%). The second most important issue was the poor quality of appraisals produced by fee appraisers (67.6%), and the third was delays in the delivery of appraisal reports (52.9%). Although the most frequent problem identified in question 1 (Property owner distrust of agency and/or disagreement with appraised values) was ranked low for question 2, question 1's second and third most important issues (Right-of-way plan changes and revisions affect nature and extent of acquisition on many parcels, and delays in the delivery of appraisal reports) were also found to be among the top three most frequent problems associated with question 2. Table 2 summarizes the results.

Table 2: Summary of Responses to Question 2

2. In your experience, what is the importance of the following actions during the valuation process?

	Highly Important	Important	Less Important	Not Important
2-a. Right-of-way plan changes and revisions affect nature and extent of acquisition on many parcels	70.6%	23.5%	5.9%	0.0%
2-d. Poor quality of appraisals produced by fee appraisers	67.6%	26.5%	5.9%	0.0%
2-e. Delays in the delivery of appraisal reports	52.9%	41.2%	5.9%	0.0%
2-g. Appraisers do not have time to meet with property owners personally	50.0%	41.2%	8.8%	0.0%
2-c. Lack of qualified fee appraisers	47.1%	50.0%	2.9%	0.0%
2-f. Inconsistencies among appraisal reports (e.g. significantly different values for the same parcel)	44.1%	35.3%	20.6%	0.0%
2-h. Disagreement over prioritization criteria used by outsourced appraisers to select which parcels will be appraised first	32.4%	41.2%	26.5%	0.0%
2-b. Insufficient right-of-way staff to obtain appropriate appraisals in a timely manner	29.4%	50.0%	17.6%	2.9%
2-i. Property owner distrust of agency and/or disagreement with appraised values	23.5%	41.2%	29.4%	5.9%

The respondents then were given the opportunity to write in any problems or issues not addressed by the questionnaire. Among the answers were the shortage of qualified review appraisers and property owners not cooperating with the appraiser by not providing the needed information.

Table 3 summarizes the results of the fourth question, which asked respondents to indicate the frequency with which given practices are used during the valuation process. The practice most frequently used is the invitation of the property owner to accompany the appraiser during the appraiser's inspection of the property (100%). The second and third most frequently used practices based on the addition of the rankings "often" and "sometimes" are to encourage fee appraisers to meet property owners in person (100%) and to assign projects according to appraiser's experience (100%). Since all three practices received 100% ratings when combining the two classifications, the rankings were based on the higher value for the "often" category.

Table 3: Summary of Responses to Question 4

4. Please indicate how often the following practices are used during the valuation process.				
	Often	**Sometimes**	**Rarely**	**Never**
4-i. Give the property owner an opportunity to accompany the appraiser during the appraiser's inspection of the property	100.0%	0.0%	0.0%	0.0%
4-h. Share copies voluntarily and routinely of complete appraisal reports with property owners	94.1%	0.0%	0.0%	5.9%
4-d. Encourage fee appraisers to meet property owners in person	88.2%	11.8%	0.0%	0.0%
4-j. Assign projects according to appraiser's experience	82.4%	17.6%	0.0%	0.0%
4-c. Encourage R/W staff to meet property owners in person	82.4%	14.7%	2.9%	0.0%
4-e. Provide the outsourced appraisers with pre-appraisal information obtained by district personnel	78.8%	12.1%	3.0%	6.1%
4-b. Evaluate outsourced appraisers annually on their performance	67.7%	12.9%	16.1%	3.2%
4-m. Reduce the time-lapse between appraisal valuation date and the initiation of negotiation	62.5%	31.3%	6.3%	0.0%
4-g Share and discuss the project's preliminary R/W map with all property owners	55.9%	20.6%	17.6%	5.9%
4-k. Prioritize parcels according to complexity/appraisal difficulty and contract appraisals for those that are most complex first	50.0%	35.3%	11.8%	2.9%
4-l. Utilize most appropriate technology (e.g., mobile device, GIS) to expedite appraisal production	31.0%	34.5%	27.6%	6.9%
4-f. Use the same agent (e.g., consultant) for the valuation and negotiation process	12.9%	9.7%	12.9%	64.5%
4-a. Offer training courses for staff, fee appraisers, and appraisal reviewers	8.8%	50.0%	38.2%	2.9%

The following question asked participants whether they recommended certain practices. The most highly recommended practice is to encourage fee appraisers to meet property owners in person (94.1%). It is apparent that this practice is believed to be very helpful during the valuation process. The second most highly recommended practice is to give the property owner an opportunity to accompany the appraiser during the inspection of the property (91.2%). The third most highly recommended practice is to assign projects according to the appraiser's experience (88.2%). Table 4 presents the results. In the next question, which allowed respondents to address any further comments or issues on the topic, respondents recommended that complex parcels or parcels with greater difficulty be assigned to appraisers with greater experience to avoid delays resulting from mistakes and confusion.

Table 4: Summary of Responses to Question 5

5. Please indicate if you recommend the following practices based on their effectiveness to improve the valuation process.				
	Highly Recommend	**Recommend**	**Not Recommend**	**Oppose**
5-d. Encourage fee appraisers to meet property owners in person	94.1%	5.9%	0.0%	0.0%
5-i. Give the property owner an opportunity to accompany the appraiser during the appraiser's inspection of the property	91.2%	8.8%	0.0%	0.0%
5-j. Assign projects according to appraiser's experience	88.2%	11.8%	0.0%	0.0%
5-c. Encourage R/W staff to meet property owners in person	76.5%	23.5%	0.0%	0.0%
5-e. Provide the outsourced appraisers with pre-appraisal information obtained by district personnel	75.8%	21.2%	3.0%	0.0%
5-h. Share copies voluntarily and routinely of complete appraisal reports with property owners	73.5%	14.7%	8.8%	2.9%
5-m. Reduce the time-lapse between appraisal valuation date and the initiation of negotiation	70.6%	29.4%	0.0%	0.0%
5-b. Evaluate outsourced appraisers annually on their performance	70.6%	26.5%	0.0%	2.9%
5-k. Prioritize parcels according to complexity/appraisal difficulty and contract appraisals for those that are most complex first	67.6%	29.4%	2.9%	0.0%
5-a. Develop training courses for staff, fee appraisers, and appraisal reviewers	64.7%	35.3%	0.0%	0.0%
5-l. Utilize most appropriate technology (e.g., mobile device, GIS) to expedite appraisal production	51.6%	45.2%	3.2%	0.0%
5-g. Share and discuss the project's preliminary R/W map with all property owners	47.1%	32.4%	20.6%	0.0%
5-f. Use the same agent (e.g., consultant) for the valuation and negotiation process	12.5%	9.4%	25.0%	53.1%

The negotiation section of the survey began with a question addressing problems experienced during the negotiation process. Again the percentages for responses of "often" and "sometimes" were added to identify the top problems. The result indicates that the majority of the district office personnel regularly experience the following three top issues: distrust from the public (94%); complaints of low payment (93.9%); and complaints of insufficient time for counteroffers (72.7%). Table 5 presents the seventh question's results.

Table 5: Summary of Responses to Question 7

7. Please indicate the approximate frequency in which you have experienced the following problems during the negotiation process.				
	Often	**Sometimes**	**Rarely**	**Never**
7-a. Property owners complaining of low payment	51.5%	42.4%	6.1%	0.0%
7-h. TxDOT time limitation (i.e., 30 days) for property owners being insufficient in order to present a counteroffer	42.4%	30.3%	15.2%	12.1%
7-i. All administrative settlements over $50K being reviewed by the Division office, even when the counteroffer differs by only a few percentage points	28.1%	34.4%	21.9%	15.6%
7-b. Property owners distrust of agency and/or appraisal methods	27.3%	66.7%	6.1%	0.0%
7-c. Property owners complaining of a slow negotiation process	9.1%	57.6%	30.3%	3.0%
7-d. Property owners complaining of R/W brochures being too technical and hard to understand	3.0%	9.1%	54.5%	33.3%
7-e. Negotiator not contacting the property owners in person	0.0%	18.2%	36.4%	45.5%
7-g. Negotiator not keeping owners updated of the status of the process	0.0%	12.1%	60.6%	27.3%
7-f. Negotiator not being courteous or professional	0.0%	3.0%	57.6%	39.4%

Next, the participants were asked to judge the importance of certain problems or issues that occur during the negotiation process. The results, presented in Table 6, show that most R/W agents consider the following issues as important or highly important: agent not being courteous (100%), not keeping property owners informed (96.7%), no personal contact with property owners (90.4%), and distrust from the public (83.9%).

The ninth question gave respondents the opportunity to write in any problems or issues not addressed by the above two questions. Responses included: "getting title commitments in a timely manner;" "when a negotiator can be too aggressive at the first meeting, the agent should attempt to uncover the owner's concerns and then attempt to ease or solve these concerns to advance the acquisition;" "it is very difficult to explain the need for the property to the owner without a set of construction plans."

The tenth question asked participants to report the frequency with which given practices are used during the negotiation process. In the course of conducting the survey, these practices were selected as candidates for the best practices for successful negotiations. However, only three practices (out of 12) were used "sometimes" or "often" by over two-thirds of the district offices staff. These practices were: personal contact with property owners (100%); an "open-house" event explaining the project (80.6%); and assistance in writing counteroffers (68.8%). The results are summarized in Table 7.

Table 6: Summary of Responses to Question 8

8. In your experience, what is the importance of the following problems during the negotiation process?	Highly Important	Important	Less Important	Not Important
8-f. Negotiator not being courteous or professional	83.9%	16.1%	0.0%	0.0%
8-g. Negotiator not keeping owners updated of the status of the process	67.7%	29.0%	3.2%	0.0%
8-e. Negotiator not contacting the property owners in person	58.1%	32.3%	9.7%	0.0%
8-h. TxDOT time limitation (i.e., 30 days) for property owners being insufficient in order to present a counteroffer	45.2%	19.4%	32.3%	3.2%
8-i. All administrative settlements over $50K being reviewed by the Division office, even when the counteroffer differs by only a few percentage points	35.5%	12.9%	48.4%	3.2%
8-b. Property owners distrust of agency and/or appraisal methods	32.3%	51.6%	16.1%	0.0%
8-a. Property owners complaining of low payment	22.6%	38.7%	38.7%	0.0%
8-c. Property owners complaining of a slow negotiation process	22.6%	35.5%	38.7%	3.2%
8-d. Property owners complaining of R/W brochures being too technical and hard to understand	9.7%	12.9%	58.1%	19.4%

Table 8 summarizes the results of question 11 where the respondents were asked to indicate whether they recommended certain practices. Only six practices (out of 13) were characterized by more than two-thirds of the district office personnel as effective in the improvement of the negotiation process (by combining "highly recommend" and "recommend"). Those are: personal contact of negotiators with property owners (100%); higher limit of approval without TxDOT review (90.9%); an "open-house" event explaining the project (80.6%); streamlined payment process (75.8%); creating guidebook to help property owners prepare counteroffer (75.8%); and encouraging agents to assist property owners preparing counteroffers (69.7%).

Table 7: Summary of Responses to Question 10

10. Please indicate how often the following practices are used during the negotiation process.				
	Often	**Sometimes**	**Rarely**	**Never**
10-d. Require negotiators to present and discuss the offer in person	87.9%	12.1%	0.0%	0.0%
10-f. Conduct an “open-house” event explaining the right-of-way acquisition process for a specific project to the public	64.5%	16.1%	6.5%	12.9%
10-c. Require negotiators to meet owners prior to the beginning of the negotiation process, in order to discuss the project, the R/W acquisition process, and justification of valuation results	33.3%	18.2%	15.2%	33.3%
10-j. Encourage negotiators to assist property owners on preparing and negotiating a counteroffer	25.0%	43.8%	21.9%	9.4%
10-i. Allow more than 30 days for owners to present a counteroffer	21.2%	42.4%	36.4%	0.0%
10-h. Create a guidebook to assist property owners on writing an appropriate counteroffer	6.1%	12.1%	3.0%	78.8%
10-b. Use incentive programs for early completion of the negotiation process (e.g., incentive payments for early completion and penalty for late completion)	3.1%	0.0%	6.3%	90.6%
10-g. Use a streamlined process to provide immediate payment to property owner for low value property rights	3.0%	9.1%	6.1%	81.8%
10-l. Employ land exchange, which is exchanging previously purchased property outside the acquisition area for the needed parcel	0.0%	18.2%	45.5%	36.4%
10-k. Employ land consolidation (which is when remainder parcels are purchased on either side of a new highway leaving the owner with a consolidated property)	0.0%	6.5%	16.1%	77.4%
10-e. Use a closing manual which lists pertinent contacts, phone numbers, and directions to and inside the courthouse	0.0%	0.0%	22.6%	77.4%
10-a. Allow the same person to perform the valuation and negotiation for any given parcel	0.0%	0.0%	3.0%	97.0%

Table 8: Summary of Responses to Question 11

11. Please indicate if you recommend the following practices based on their effectiveness to improve the negotiation process.	**Highly Recommend**	**Recommend**	**Not Recommend**	**Oppose**
11-d. Require negotiators to present and discuss the offer in person	78.8%	21.2%	0.0%	0.0%
11-f. Conduct an "open-house" event explaining the right-of-way acquisition process for a specific project to the public	41.9%	38.7%	16.1%	3.2%
11-i. Increase the limit on the value of the property that is not subject to review by the Division office	39.4%	51.5%	9.1%	0.0%
11-g. Use a streamlined process to provide immediate payment to property owner for low value property rights	36.4%	39.4%	21.2%	3.0%
11-j. Allow more than 30 days for owners to present a counteroffer	33.3%	27.3%	27.3%	12.1%
11-c. Require negotiators to meet owners prior to the beginning of the negotiation process, in order to discuss the project, the R/W acquisition process, and justification of valuation results	29.0%	32.3%	29.0%	9.7%
11-k. Encourage negotiators to assist property owners on preparing and negotiating a counteroffer	27.3%	42.4%	21.2%	9.1%
11-h. Create a guidebook to assist property owners on writing an appropriate counteroffer	18.2%	57.6%	18.2%	6.1%
11-b. Use incentive programs for early completion of the negotiation process (e.g., incentive payments for early completion and penalty for late completion)	9.4%	46.9%	31.3%	12.5%
11-m. Employ land exchange, which is exchanging previously purchased property outside the acquisition area for the needed parcel	9.1%	36.4%	30.3%	24.2%
11-l. Employ land consolidation (which is when remainder parcels are purchased on either side of a new highway leaving the owner with a consolidated property)	6.5%	25.8%	38.7%	29.0%
11-e. Use a closing manual which lists pertinent contacts, phone numbers, and directions to and inside the courthouse in order to reduce staff time at courthouse	3.3%	50.0%	40.0%	6.7%
11-a. Allow the same person to perform the valuation and negotiation for any given parcel	0.0%	6.1%	36.4%	57.6%

The last question of the survey provided the respondents with room to describe any other negotiation practices that they consider helpful and effective. Some examples of these comments are: "If possible, use more than one title company on a project to expedite title services. On projects located far from the home district office, we had a laptop computer with small printer to instantly prepare conveyance documents for owners' signatures—saved time and travel;" "The counteroffer has been very helpful; it provides the owner/TxDOT the ability to settle acquisitions and avoid condemnation, reducing the cost of acquisition and cost of the project;" and "The administrative settlement process has been helpful. It is best to settle a dispute over a small amount than go to condemnation."

SYNTHESIS OF BEST PRACTICES FOR RIGHT-OF-WAY VALUATIONS

To synthesize the best practices of valuations based on the analysis done and the collected surveys, the research team formulated five guidelines that include best practices for negotiation.

The first guideline requires the regular training, monitoring, and evaluating of the expertise of R/W staff, fee appraisers (appraisers assigned from outside TxDOT), and review appraisers (appraisers who double-check appraisals). Several practices can help establish this guideline. First, R/W staff, fee appraisers, and review appraisers should be offered opportunities to attend training courses to ensure their up-to-date understanding of laws and procedures relating to R/W valuations (FHWA 2002; AASHTO 2003; NCHRP 2000). This practice improves the quality and timeliness of appraisals. It is also recommended that the R/W staff, fee appraisers, and review appraisers take refresher courses periodically, or develop an ongoing, in-house employee development program. Moreover, it is essential to monitor the time required to deliver appraisal reports in order to expedite the R/W acquisition process (AASHTO 2003). This can be done by establishing monitoring procedures, especially when using fee appraisers and reviewers. Because appraisers can have different levels of difficulties, it is important to assign projects according to the appraiser's experience. Complex and "problematic" cases should be assigned to experienced appraisers, thus reducing the error rate of the agency's reports. It is also important to periodically evaluate the appraisers' performance to ensure highly skilled and professional development of appraisers. Outsourced consultants should strive to do quality work and to engender property owner satisfaction in order to ensure TxDOT's goals related to public satisfaction and good rapport with property owners.

The second guideline is to involve and contact the property owner personally, early in the acquisition process. This can be done by encouraging R/W staff and fee appraisers to meet property owners in person. This increases the likelihood of better valuations and successful negotiations and establishes good relationships with the property owners. Inviting the property owner (or the owner's designated representative) to accompany the appraiser during the inspection of the property is of paramount importance in implementing this guideline (AKDOT 2001; TxDOT 2006; TxDOT 2000; ILDOT 2004). Also, the offer to purchase the property should be explained to the property owner by including the appraisal basis for the offer and the agency's real property acquisition policies and procedures (TxDOT 2005). However, R/W staff and fee appraisers should not attempt to answer any questions outside their area of expertise to prevent misunderstandings and the communication of incorrect information to the property owners.

The third guideline emphasizes streamlining the valuation process to maximize production time, cost, and efficiency benefits. Several practices can help implement this guideline. First, it is beneficial to prioritize parcels according to complexity/appraisal difficulty, and to conduct appraisals for those that are most complex first. According to one of the interviewees, prioritization was an issue, particularly when outsourced consultants are used. Moreover, the appraisers would be able to save time if they are provided with pre-appraisal information. This practice relieves the appraisers of the need to search for relevant information already accessible through the district office. In addition, obtaining and storing electronic copies of appraisal reports would provide records for future reference that would emphasize the efficiency of the process. Appropriate technology such as cell phones, pagers, and digital cameras would improve the speed and accuracy of data collection by enhancing communication between staff in the field and the central office. It is important to note that outsourced appraisers may sometimes prioritize properties to be acquired according to ease of doing instead of difficulty, especially when the same fee applies to all types of parcels. If these more complex properties are valued at the end of the time schedule window, the process can consume valuable schedule floats (ability to delay certain tasks without affecting the completion date of the project) or cause project delays.

The fourth guideline is to simplify value determinations, reporting protocols, and review procedures and streamline appraisal review procedures (FHWA 2002; AASHTO 2003). For low-value and uncomplicated appraisals, a short form review should be developed, and the reviewer should be involved in the project scope meetings and in the pre-acquisition meetings (FHWA 2005; TxDOT 2006). The FHWA Appraisal Guide encourages agencies to allow the use of the Value Finding Appraisal Format when appropriate (FHWA 2005). It is important to emphasize compromising on issues related to just compensation. Such techniques are recognized for effectively resolving acquisitions in a timely and cost effective manner (FHWA 2002). This practice is recommended by the International Right of Way and Utilities European Scan Team (FHWA 2002).

The last guideline in the valuation of best practices is to inform property owners of what will take place at each step of the entire acquisition process. This can be done by furnishing the property owner with information on the overall anticipated timing of the acquisition process, the general type of facility to be constructed, and the appraisal procedures that will follow (AASHTO 2003; TxDOT 2000). Moreover, it is important to share and discuss the preliminary R/W map for the project with all property owners (TxDOT 2000). Also, informing the property owners of the method for selecting qualified appraisers and estimating values would increase their trust in the coming appraisal (TxDOT 2000). If the property owner knows the process and feels themselves to be a part of it, he or she will be more willing to give helpful information to the appraiser. This cooperation will result in better appraisal reports.

SYNTHESIS OF BEST PRACTICES FOR RIGHT-OF-WAY NEGOTIATIONS

Based on all information obtained from the literature review and data analysis, the research team formulated best practices grouped in five guidelines which are described below.

The first guideline is to frequently and regularly contact property owners in person to promote confidence in the agency and to reduce delays and negotiation costs. Encouraging the agency to perform in-depth interviews with property owners and discussing several project issues (e.g., property usage by the owner and how the project will influence his/her property) can help implement this guideline (FHWA 2006; AASHTO 2003). Furthermore, conducting an open-house event at public meetings and hearings is also beneficial. The potential sellers may have a better understanding of the project by attending an agency sponsored event explaining to the public the project's R/W acquisition process. At this event, agency personnel should make clear which properties the agency would like to acquire, and the potential impact of the project after the acquisition takes place. Also, a R/W agent should be present at the event to answer questions. This type of good communication with property owners is known to be effective in cultivating public trust.

The second guideline emphasizes conducting simplified and efficient negotiation processes, including the title acquisition process, in order to minimize negotiation schedule delays. This can be made possible by requiring negotiators to meet owners prior to the initiation of the negotiation process in order to discuss the project, the R/W acquisition process, and to justify the valuation results. These early meetings reduce the questions, calls, and visits later in the process (AASHTO 2003). Moreover, using a streamlined process to provide immediate payment to property owners for low-valued property rights is essential in improving the efficiency of the negotiation. To save time, a sketch map, if the final map is pending, can be used to accompany the offer on administrative settlements of just compensation. Proper management of the R/W negotiation process can be implemented by keeping track of its key milestones, leading to better efficiency.

The third guideline encourages negotiators to execute negotiations in a manner that builds good rapport with property owners and that increases owners' confidence in the agency. Practices for this guideline include requiring negotiators to present and discuss the offer in person to acquire benefits such as obtaining more information from the owner about the property, explaining the payment to the property owner during negotiation, and establishing a good relationship with the owners. Furthermore, emphasizing the importance of getting to know the property owner at the beginning of the negotiation process would allow room to share common interests and hobbies that makes discussing matters easier. It is a beneficial practice to furnish each property owner with a "folder" that includes comprehensive information on the project, including the written offer of just compensation, a copy of the final appraisal report, plans/maps of the area to be acquired, legal descriptions, and other pertinent information.

The fourth guideline encourages minimizing the possibility of proceeding to condemnation to the greatest extent possible. An important practice is to give the property owner's file to a condemnation specialist or a legal expert before entering the condemnation proceedings in order to assess risks and to determine whether to enter into litigation. It is also essential to encourage negotiators to assist property owners in preparing and negotiating a counteroffer, with no assistance in reaching a specific amount. The owners usually have difficulty preparing a proper counteroffer because it involves gathering all relevant information and presenting it professionally. Some owners complain that the 30-day period allowed to them to present a counteroffer is too short. In many cases, these owners feel so frustrated that they opt instead to bring the case to litigation. If the negotiator can assist the property owners in preparing a suitable counteroffer, the acquisition may not lead to time-consuming condemnation proceedings.

The last guideline is to emphasize the significance of providing property owners not only with legally required information but also with any pertinent information that may enhance public trust. This can be done by ensuring that all information required by law is provided to the property owner when delivering the written offer to initiate the negotiation process. Moreover, the agency should provide notice to property owners of its intention of acquiring the property in discussion, the function of the acquisition, the need for the property to be acquired, the possible impact of the improvement on the property, the capability of the agency to accomplish the project, the right to donate the property to the agency, and the owner's legal protections. However, it is important to make sure that the materials provided to property owners are not too technical and difficult to understand.

CONCLUSIONS

Considerably increasing requirements for upgraded and new infrastructure projects have caused the need for the rapid acquisition of necessary R/W, while simultaneously maintaining good relations with property owners. Valuation and negotiation play critical roles in the R/W acquisition process. This research synthesizes in guideline form the best practices for successful valuations and negotiations in Texas.

To this end, the research team conducted a review of pertinent literature and laws, analyzed relevant databases, and interviewed and surveyed TxDOT R/W personnel. These methods allowed the realities and problems experienced by property owners and agents in TxDOT to be articulated. The best practices and guidelines presented in this paper were drawn from the results of these research methods and are offered to help R/W agents reduce the time and cost of the R/W acquisition process, and to promote public satisfaction with TxDOT's valuation and negotiation processes.

The practices and guidelines include regularly training, monitoring, and evaluating the expertise of R/W staff, fee appraisers, and review appraisers. It also emphasizes involving and contacting the property owners personally early in the acquisition process and on streamlining the valuation process to maximize production time, cost, and efficiency benefits. Simplifying value determinations, reporting protocols, and review procedures is another important factor in addition to informing property owners of what will take place at each step of the entire acquisition process. Other practices include promoting frequent communications with property owners for better coordination and to minimize time, using a simplified and efficient negotiation process in order to reduce time/cost and enhance quality of the negotiation process, and encouraging the agent to perform negotiations in a manner that inspires owner confidence. Lastly, minimizing the possibility of proceeding to condemnation and emphasizing the significance of providing property owners with all the information required by law are also considered best practices.

RECOMMENDATIONS

This research focused on determining the best practices of R/W valuations and negotiations in Texas. It is encouraged that a similar process be followed in different states to obtain related best practices. Moreover, further research can be conducted by building on the above results. The scope of best practices can be extended to processes preceding and following valuation and negotiation, such as project planning, appraisal review, and relocation. In view of the fact that the R/W acquisition process immediately precedes the construction and utilization of the transportation infrastructure, it causes increased pressure for the agencies to acquire land and deliver projects as soon as possible for construction to start. While the different DOTs have been doing an admirable job with the acquisition process, there are several areas in which practices could be enhanced, and therefore the research team encourages the implementation of the practices recommended in this paper.

Endnotes

1. Per a referee's comment, a ranking system based on an index was constructed. In this index, since there were four different responses ("never," "rarely," "sometimes," and "often"), the coefficients of 1-4 were multiplied to the different categories in terms of importance and then a summation of all values for each sub-question was done. As an example, question 1-i had the following response rates: 38.2% (often), 55.9% (sometimes), 2.9% rarely, and 2.9% (never). Applying the index to these numbers, question 1-i received a rating of 3.29 because of the following calculation: 4(0.382) + 3(0.559) + 2(0.029) + 1 (0.029). This calculation was done for each sub-question for all tables in the paper and the top responses were the same as those obtained by adding the percentages for "often" and "sometimes." Since it is easier to understand the latter, the index was not used.

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Spatial Differences in Price Elasticity of Demand for Ethanol

by Hayk Khachatryan, Jia Yan, and Ken Casavant

Increased public environmental awareness, concern for national energy security, and high transportation fuel prices have all served to heighten interest in alternative fuels. A fundamental issue influencing economic viability of the ethanol industry is understanding consumers' demand responsiveness to both gasoline and ethanol price changes. In this paper we present an alternative approach to studying this problem by estimating geographically varying price elasticity of demand for E85 ethanol fuel across the study area. This is a departure from previous studies of ethanol demand, in which price elasticity of demand is spatially identical. Considering spatial heterogeneity in household composition and demand preferences, using stationary estimates to explain price-demand relationships over a large geographic area may lead to biased results and inference. Resulting price elasticity estimates for ethanol demand revealed significant geographic variation (ranging from 0.5 to 5.0), suggesting that use of spatially disaggregated data provides more detailed empirical results and, therefore, a more thorough understanding by policymakers.

INTRODUCTION AND BACKGROUND

Alternative fuel policies are designed to increase U.S. energy independence and to reduce harmful environmental emissions from transportation fuels. According to Renewable Fuel Standards (RFS), biofuels production and use in the U.S. will reach 36 billion gallons by 2022 (Sissine 2007). To meet the RFS target, the U.S. Department of Energy (DOE) promotes use of higher blends of ethanol (e.g., E85—85% ethanol and 15% gasoline) by targeting specific regions and cities to establish high concentrations of flexible fuel vehicles (FFVs). The DOE also explores the possibility of using low level blends of ethanol (e.g., E15—15% ethanol, 85% gasoline and E20—20% ethanol, 80% gasoline) in conventional vehicles. Under requirements of the Government Performance Results Act, the Office of Energy Efficiency and Renewable Energy (EERE) estimates benefits of biofuel promotion programs. Based on these estimates, EERE evaluates the cost effectiveness of its programs and uses the findings in allocating program budgets (Bernstein and Griffin 2006). One of the key parameters used in estimating the benefits of those programs is the extent to which biofuel demand is sensitive to price changes (i.e., price elasticity of demand). Therefore, understanding consumers' demand responsiveness to ethanol and gasoline price changes at a county level is critical to implementing state level renewable fuel policies in a more cost effective manner.

The main purpose of this paper is to investigate consumers' demand responsiveness to fuel price changes across geographical space. In particular, spatial variations for own price and cross price elasticity (gasoline price elasticity) of demand for E85 ethanol fuel in Minnesota were estimated. The model includes explanatory variables, such as disposable income, the number of fueling stations within close proximity, vehicle stock, and distances from ethanol fueling stations to major highways, and blending terminals used to explain variations in E85 ethanol monthly sales (dependent variable). In previous studies of ethanol demand, price elasticity of demand for fuels was assumed to be constant across the study area (Anderson 2010; Hughes et al. 2008; Schmalensee and Stoker 1999; Yatchew and No 2001). In this paper, we start by estimating own price and cross price elasticity of ethanol demand using monthly price observations ($/gallon) and sales volumes (in gallons) of individual E85 service stations in Minnesota. The base model was extended and improved by an alternative specification that accounts for spatial heterogeneity in data structure and provides a set of estimates that were visualized on a map. Henceforth, the terms "ethanol" and

"E85" are used interchangeably. Also, nearly all gasoline sold in Minnesota is required to contain 10% ethanol (E10). Thus, gasoline in this paper refers to E10 fuel.

The models were estimated using data collected from ethanol service stations in Minnesota, a nationwide leader in production and use of ethanol as an additive to gasoline for the last two decades. Prior to 1990, Minnesota provided a tax credit for blending ethanol into gasoline. However, the tax credit was found to negatively influence funding for transportation. The credit was classified as ineffective in increasing ethanol production and was phased out in the mid-1990s. Another state financial support program, started in 1987, provided 20 cents per gallon to in-state ethanol processors for the first 15 million gallons of annual production. Minnesota also provides tax incentives to increase E85 blending by taxing it at a lower rate than E10 or gasoline. Additionally, grants were provided to service station owners for installing E85 dispensing pumps; many of these stations participated in a monthly survey conducted by the Minnesota Department of Commerce and the American Lung Association of Minnesota. By August 2013, the requirement for ethanol blend will be increased to 20% (E20) from the current 10% (E10) blend, conditional on the increase in the current up to 10% ethanol blend restrictions established by the federal government. The combination of these state financial incentives and consumption mandates aims to achieve a broader goal of securing 25% of Minnesota's energy demand from renewable sources by 2025 (Yunker 2009).

RELEVANT LITERATURE

Due to the relatively short period of ethanol availability in the marketplace and consequent data limitations, the literature on ethanol demand estimation is minimal. Anderson (2010) shows that household demand for ethanol as a close substitute for gasoline is sensitive to gasoline/ethanol relative prices. The gasoline price (cross price) elasticity of ethanol demand was estimated to be in the 2.5–3.0 range. The results were applied to study ethanol content standard related policies. A relatively recent study by Bromiley et al. (2008) analyzed factors that influence consumers' use of E85 in Minnesota. The authors concluded that estimating household demand for ethanol for the purposes of understanding their sensitivity to price changes is an important component for economic viability of the emerging ethanol industry.

In contrast, a great deal of attention has been paid to estimating price elasticity of demand for gasoline. Hughes et al. (2008) analyzed U.S. gasoline demand in two time periods—1975 to 1980 and 2001 to 2006. The short-run elasticity varied from 0.31 to 0.34 for the first period, and from 0.034 to 0.077 for the second, thus providing evidence that short-run price elasticity of gasoline demand is more inelastic in recent years. These results are consistent with those of recent meta-analytic studies (Espey 1996, Graham and Glaister 2002), which report 0.27 and 0.23 for the short-term and 0.71 for the long-term price elasticity of demand. Some recent estimates reported in Brons et al. (2008) showed a slightly higher range, varying from 0.34 for short-run to 0.84 for long-run price elasticity.

However, none of these studies explicitly considers spatial attributes and/or provides a county-level geographic comparison for price elasticity, which has important policy implications relating to local governmental regulations for low level versus higher blends of ethanol or distributional impacts from tax policy. For example, subsidizing E85 fueling stations in Minnesota will have different impacts at the sub-state level if the price elasticity is spatially variable. The same can be said about the distributional impacts of tax policies on ethanol. Bernstein and Griffin (2006) use a dynamic demand model to investigate geographic differences in price-demand relationships at regional, state and sub-state levels. Their results showed that there are regional and state differences in energy demand responsiveness to price changes. However, their analyses only covered electricity and natural gas in the residential sector and electricity use in the commercial sector.

Spatial regression techniques are widely used to analyze data that have spatial characteristics (Case 1991), including hedonic house price spatio-temporal autoregressive models (Pace et al. 1998) and transportation spatial demand models (Henrickson and Wilson 2005). Henrickson and Wilson used a moving-window regression to estimate barge transportation demand elasticity. This approach is conceptually relevant to the geographically weighted regression (GWR) approach as it produces spatially varying parameter estimates. However, the moving-window regression introduces so-called edge effects because data points within each local grid are given a weight equal to one (thus, they are included in the regression), while those outside of grid are given a weight of a zero, which imposes limitations on capturing spatial variation between the two (Fotheringham et al. 2002).

One of the specifications considered in the non-spatial model by Anderson (2010) restricted the data to two relationships by including urban and rural dummy variables to observe region effects. However, it is not known if only two dummies for the entire study area is appropriate disaggregation, or if additional sub-regional dummies should be included. Another approach, market segmentation, is used to reformulate data into a small number of mutually exclusive and collectively exhaustive sub-samples (e.g., geographical samples—counties, states; socio-economic samples—income groups, education levels, etc.). Both of these strategies (dummy variables and market segmentation) introduce a problem of discontinuity in data that eliminates the local spatial variations among different locations (for which data are available) in a study area.

Theoretical support for the GWR approach can be found in Schmalensee and Stoker (1999), who argue that household composition, demographic characteristics, and demand preferences change considerably over time and geography, and that it is reasonable to expect that not only temporal but also spatial variations will influence household demand for transportation fuel. Regardless of the importance of demographic changes in preference formation, there is a lack of research investigating the influence of household composition, demographic characteristics, and location on transportation fuel demand (Dahl and Sterner 1991). Additionally, consumers' environmental perceptions regarding biofuels and their attitudes about price and performance relative to imported petroleum-based fuels may vary depending on where they live and purchase fuel—urban versus rural setting (Bromiley et al. 2008).

However, the GWR methodology is not without criticism. Although some previous findings showed that, in some cases, spatial error dependence can be considerably mitigated with the use of GWR (McMillen 2004), it does not explicitly account for spatial dependence in regression residuals (see, for example, Fotheringham et al. [2002], Paez et al. [2002], as cited in Cho et al. [2010]). Cho et al. attempted to address GWR shortcomings by calibrating a weighting scheme bandwidth to minimize spatial dependence in regression residuals. Another study investigated the issue of using time series data in GWR (Crespo et al. 2007). These authors proposed a new spatiotemporal weighting scheme using timedecay and inversevariance bandwidths, which allow interpolating local parameters not only spatially, but also throughout time.

The review of relevant literature shows that there are regional, state or sub-state differences in demand responsiveness to price changes, which exist due to spatially heterogeneous household composition, demographic characteristics and preferences, to name only a few. Meanwhile, to the best of our knowledge, there are no studies that investigate the variability of the price-demand relationship for transportation fuels at a sub-state level. In what follows, we develop a model of ethanol fuel demand, which accounts for spatial heterogeneity in price-demand relationships.

MODEL DESCRIPTION

Basic Model of Consumer Demand for Ethanol

We start with a basic demand model that draws from the works of Anderson (2010), Hughes et al. (2008), and Rask (1998). In particular, the demand for ethanol fuel is modeled as a function of own and gasoline prices (e.g., Hughes et al. 2008, Yatchew and No 2001), income and geographic location (e.g., Schmalensee and Stoker 1999), and the number of vehicles and fueling stations in a county (e.g., Anderson 2010). Given our purpose of extending the basic model of ethanol demand into a spatial model, we also included distance variables. Distances from each fueling station to the closest of five major ethanol blending terminals in the state (e.g., consumers may choose to support the local ethanol terminal), and distances to major highways where there are higher concentrations of vehicles and thus higher demand for ethanol fuels. The logarithmic form presented in equation (1) is used for easy derivation and interpretation of elasticity estimates. Following the model in Anderson (2010)[1], the econometric model for estimating the ethanol demand basic model described above can be specified by the following equation:

$$(1)\quad lnE_{it} = \beta_0 + \beta_1 \ln(PE_{it}) + \beta_2 \ln(PG_{it}) + \beta_3 \ln(INC_{it}) + \beta_4 \ln(VEH_{it}) + \\ + \beta_5 \ln(NSTAT_{it}) + \theta_1 \ln(DISTB_i) + \theta_2 \ln(DISTH_i) + \gamma(TC_t) + \\ + \psi_1(M1) + \cdot\cdot\cdot + \psi_{11}(M11) + \varepsilon_{it}$$

where E_{it} is the monthly ethanol sales for the ith E85 station throughout the period studied, PE_{it} is retail ethanol price, PG_{it} is retail gasoline price, INC_{it} is per-capita income, VEH_{it} is the number of vehicles in each county. $NSTAT_{it}$ is the number of E85 stations in each county in each period (i.e., service stations having E85 dispensers/pumps); $DISTB_i$ represents time-invariant distances from each E85 station to the nearest ethanol blending terminal; $DISTH_i$ is time-invariant distance-to-highway variable representing the distance from each E85 station to the nearest major highway node in the state; TC_t is a regional dummy variable controlling for regional effects for the Twin Cities area; and finally $M1$ through $M11$ are controls for time effects, and ε_{it} is random error term. The estimation of equation (1) allows interpreting the coefficient of ethanol price variable as own price elasticity and the coefficient of gasoline price variable as cross price elasticity of ethanol demand.

Estimating demand functions that include price among the explanatory variables is often subject to endogeneity issues. In this model, the parameter estimates will be biased if the fuel prices are correlated with unobserved characteristics embedded in the error term. As argued in Anderson (2010), many ethanol retail stations in Minnesota price ethanol at a fixed discount relative to gasoline. The fixed discounted price, which sometimes remains over lengthy periods, translates into weak or no correlation between ethanol prices and local and short-term ethanol demand shifts. To empirically test for this, the distances to major highways variable was used to instrument ethanol prices. However, using two-stage least squares (2SLS) estimation did not result in statistically significant estimates. The first-stage statistics had the following results: F(1, 6842)=3.10 p-value=0.078. Tests for endogeneity returned Durbin score $\chi(1)$=31.26, p-value=0.00 and Wu-Hausman score F(1, 6841)=31.32, p-value=0.00. Unfortunately, due to data limitations, it is not possible to examine this issue further. Anderson (2010) used interactions of logged wholesale ethanol and gasoline prices with station brand dummies, the logarithm of distance to ethanol refinery, and the logarithm of the numbers of ethanol and gasoline stations in the same county. While the first-stage summary statistics had favorable results, the overidentification test statistics were not statistically significant. Therefore, it was not possible to rule out the possibility of the instruments being jointly correlated with the error term.

Spatial Non-Stationarity

The existence of spatial non-stationarity in data violates the Gauss-Markov assumption that there is a single linear relationship with constant variance across a sample of data observations (Lesage and Pace 2009). Spatial non-stationarity is typical of any data that include geographic information (e.g., fueling station locations). Schmalensee and Stoker (1999) argued that demographic shift played an important role in increasing overall transportation fuel consumption over the last decades. The same source reports that household structure (number of drivers, household size, and household head age) has a strong effect on gasoline demand. In addition to geographically varying household composition, the existence of spatial patterns in demand can be motivated by consumers' interdependent preferences. Yang and Allenby (2003) introduced a model of interdependent consumer preferences with data on automobile purchases in which they found that preferences for Japanese-made cars are attributed to geographically and demographically defined networks. The approach described in equation (1) above does not incorporate considerations of spatial patterns in household demand into the model. In what follows, the model of ethanol demand is specified such that it captures the influence of local factors.

Spatially Explicit Model of Consumer Demand for Ethanol

In this section, equation (1) is extended to a spatially weighted regression model. The GWR model accounts for spatial non-stationarity in data and allows estimating geographically varying coefficients (Fotheringham et al. 2002). It includes a spatial weighting matrix that assigns higher weights to regressors in the near locations and gradually decreases the weights as the distance from the regression point increases. The GWR model for this study can be represented in the following form (Brundson et al. 1998):

$$(2)\quad y_{it} = \beta_{0t}(\upsilon_i, v_i) + \Sigma_m \beta_{mt}(\upsilon_i, v_i) X_{it} + \Sigma_k \theta_k(\upsilon_i\ v_i) Z_i + \varepsilon_{it},$$

where y_{it} is the dependent variable (monthly ethanol sales volume) for the *i*th fueling station. The matrix X_{it} includes time and location-specific explanatory variables as in equation (1) (e.g., prices for ethanol and gasoline, disposable income, vehicle stock, number of stations in each county), Z_i represents the time-invariant variables (distances to major highways and blending terminals), and ε_i is the error term. The coefficients β and θ are to be estimated for each of the fueling stations at (υ_i, v_i) projected coordinates (i.e., converted from geographic coordinates). The expressions for $\beta(\upsilon_i, v_i)$ and $\theta(\upsilon_i, v_i)$ indicate that the price elasticity of demand of ethanol and the other estimates are location-specific. The estimator for this model has the following form:

$$(3)\quad \hat{\beta}(\upsilon_i, v_i) = (X'W(\upsilon_i, v_i)X)^{-1} X'W(\upsilon_i, v_i)\, y,$$

where $W(\upsilon_i, v_i)$ is a distance-based weighting matrix for expressing potential interaction among spatial units (e.g., fueling stations). One possible way to assign weights to the elements in the weighting matrix is to use a kernel that has a Gaussian shape, as shown below:

$$(4)\quad w_i = \exp[-1/2(d(\upsilon_i, v_i)/h)]^2.$$

In this weighting scheme, the $d_i(\upsilon_i, v_i)$ is of Euclidean distance, as described above, and is bandwidth. The bandwidth parameter for our distance-based weighting matrix is selected using the following cross-validation (CV) procedure:

$$(5)\quad CV = \textstyle\sum_{i=1}^{n} [y_i - \hat{y}{\neq}i(h)]^2,$$

where *n* is the sample size, $\hat{y}_{\neq i}$ denotes the fitted value of y_i with the observation for point *i* omitted from the calibration process (Fotheringham et al. 2002). In the *CV* equation, omitting the *i*th observation is necessary, otherwise the score will be minimized when *h* is zero, i.e., as *h* tends to zero, $\hat{y}_i(h)$tends to y_i, so the *CV* score is minimized when *h* is zero. A value of *h* that minimizes the *CV* score is then used as the distance-weighting bandwidth. If the *i*th observation and the location (υ_i, v_i) in the weighting scheme given by equation (4) coincide, i.e., if the data were observed at the location (υ_i, v_i), the weight for that point will be one. Then the weights of other locations around it will decrease according to a Gaussian curve as the distance between the two increases.

Taking the natural logarithm of both sides of equation (2), we specify the demand for ethanol at each location as follows:

$$
\begin{aligned}
(6)\quad lnE_{it} &= \beta_0(\upsilon_i, \nu_i) + \beta_1(\upsilon_i, \nu_i)\ln(PE_{it}) + \beta_2(\upsilon_i, \nu_i)\ln(PG_{it}) + \\
&+ \beta_3(\upsilon_i, \nu_i)\ln(INC_{it}) + \beta_4(\upsilon_i, \nu_i)\ln(VEH_{it}) + \beta_5(\upsilon_i, \nu_i)\ln(NSTAT_{it}) + \\
&+ \theta_1(\upsilon_i, \nu_i)\ln(DISTB_{it}) + \theta_2(\upsilon_i, \nu_i)\ln(DISTH_{it}) + \varepsilon_{it},
\end{aligned}
$$

where the variables are interpreted as in equation (1). In contrast, however, the coefficients are geographically referenced, and the model provides a "surface" of parameter estimates across the study area (e.g., the coefficient estimates are derived for each location). To estimate the model, we use the GWR tool provided under ArcMap Spatial Statistics Toolbox. The estimates then were visualized on a map using Geographic Information Systems (GIS) software.

DATA SOURCES

Ethanol price information was obtained from a survey conducted by the Minnesota Department of Commerce and the American Lung Association of Minnesota. Initial data included monthly price observations and sale volumes of individual E85 service stations in Minnesota from 1997–2009. Starting with only 10 stations in 1997, the number of E85 service stations steadily increased up to more than 330 by mid-2009. As of mid-2010, with more than 350 stations, Minnesota had the highest number of E85 stations in the nation. This makes up more than 18% of the total number of E85 stations in the U.S. (U.S. DOE Alternative Fuels and Advanced Vehicles Data Center 2009). The distribution of all E85 service stations in the United States is provided in Table 1.

Table 1: The Distribution of E85 Service Stations in the U.S. (as of September 2009)

State	Number of E85 Stations	State	Number of E85 Stations	State	Number of E85 Stations
Minnesota	351	N. Dakota	31	Idaho	5
Illinois	192	Tennessee	29	Connecticut	4
Iowa	123	Arizona	26	Louisiana	4
Wisconsin	121	Florida	26	Mississippi	4
Indiana	112	Pennsylvania	26	Utah	4
Missouri	95	N. Carolina	17	DC	3
Michigan	91	Washington	15	West Virginia	3
S. Carolina	85	Kentucky	14	Massachusetts	2
S. Dakota	80	Maryland	14	Delaware	1
Colorado	76	Nevada	14	Montana	1
Ohio	63	Alabama	11	Alaska	0
Nebraska	48	New Mexico	11	Hawaii	0
California	40	Oklahoma	11	Maine	0
Texas	40	Arkansas	8	New Hampshire	0
Georgia	37	Oregon	8	New Jersey	0
New York	35	Virginia	8	Rhode Island	0
Kansas	33	Wyoming	6	Vermont	0
Total	1928				

Source: U.S. Department of Energy, Alternative Fuels and Advanced Vehicles Data Center. *http://www.afdc.energy.gov/afdc/fuels/stations_counts.html*

Figure 1: Geographic Distribution of E85 Service Stations in Minnesota

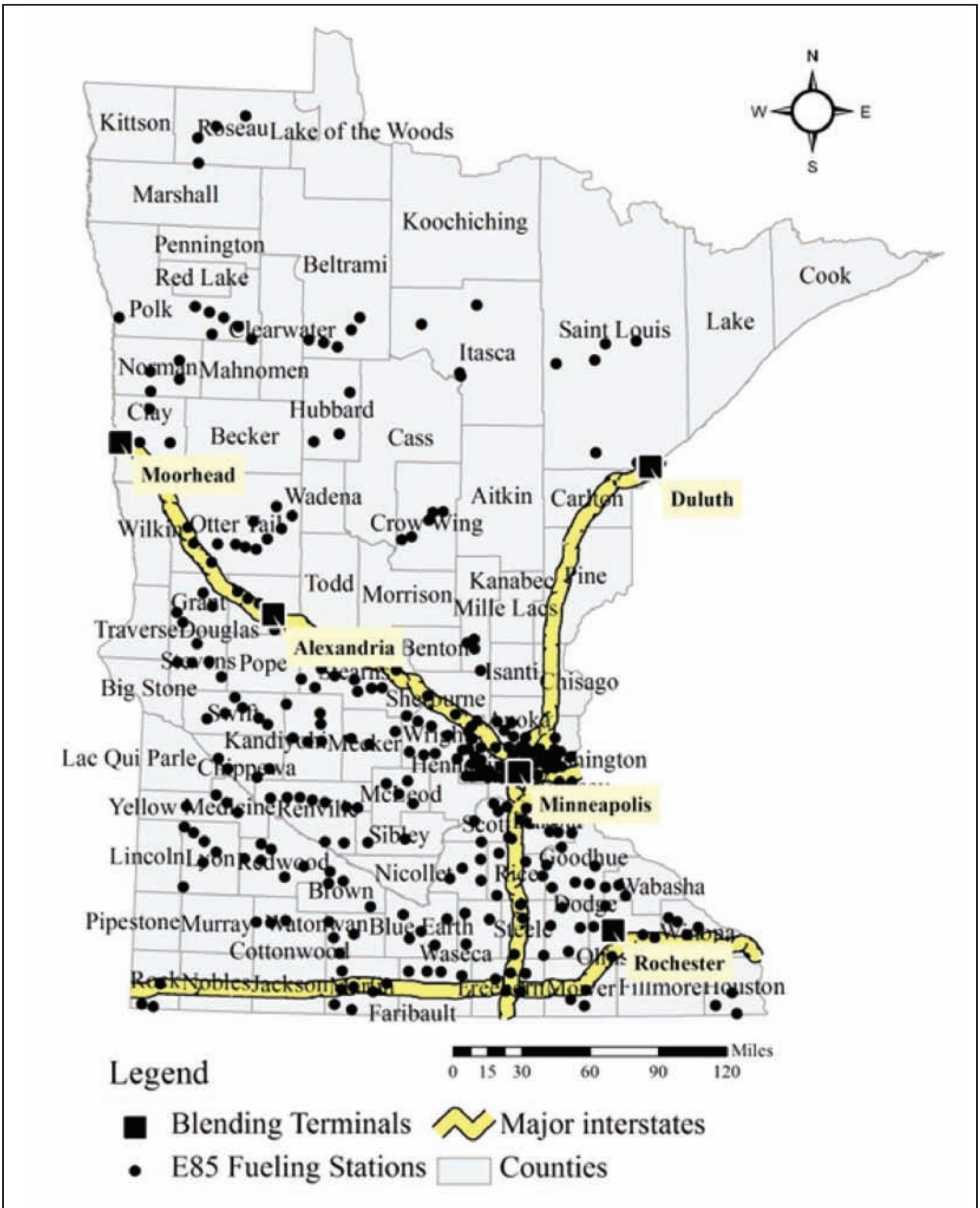


Figure 1 depicts the study area and the spatial distribution of E85 service stations. The number of E85 fueling stations in each county for each period was derived from the E85 sales dataset. Monthly observations for retail gasoline prices were averaged from the Minnesota Weekly Gasoline Retail Price Reports provided by the Energy Information Administration (Energy Information Administration 2009). In contrast to service station-level ethanol sales data, gasoline prices were only available at county-level, and only for 2000–2009. As a result, the number of observations decreased from 13,339 to 8,542.

Per-capita income information was obtained from the Federal Reserve Economic Data (FRED) state/county-level database (Federal Reserve Economic Data 2009). Vehicle stock information per county was obtained from the U.S. Census Bureau (U.S. Census 2000). A small portion of observations were dropped due to missing or not reported prices and sales volumes. The inclusion of income and vehicle stock variables available only for the 2003–2008 period restricted the number of usable observations further. As a result, the number of observations was decreased from 8,542 to 6,860, and data used in this paper are for the 2003-2008 period. Using a historical consumer price index from the Department of Labor, all fuel prices and income were converted into real 2009 prices.

GIS ArcMap software was also utilized to identify E85 fueling stations. The Minnesota road network shapefile (Minnesota Department of Transportation 2009) was overlaid with a station locations map available from the American Lung Association and Clean Air Choice organization (American Lung Association and Clean Air Choice 2008). According to data confidentiality requirements by the American Lung Association and Clean Air Choice, counties containing fewer than three service stations were excluded from the analysis. ArcMap software was used to derive distances between ethanol fueling stations and major highways in the state as well as to five ethanol blending terminals in Minnesota (Minneapolis, Alexandria, Moorhead, Rochester, and Duluth). Fuel blending terminal location information was obtained from the Oil Price Information Service (OPIS) Rack Cities guide (OPIS 2009). Table 2 provides descriptive statistics for the data used in this paper.

Table 2: Descriptive Statistics

Variables	Mean	St.Dev.	Min	Max
Ethanol sales volume (gallons/month)	5,186	4,883	11	37,770
Income ($/per-capita)	39,565	6,783	27,274	49,196
Ethanol price (retail; $/gallon)	2.21	0.47	1.02	3.86
Gasoline price (retail; $/gallon)	2.66	0.60	1.64	3.87
Distance from nearest highway (miles)	22.44	24.51	0.28	144.00
Ethanol pumps in county (number/month)	6	4	1	17
Distance from nearest rack (miles)	34.15	26.32	1.00	100.00
Vehicle stock in county (number/month)	256,533	322,812	10,245	1,115,371

RESULTS

Basic Model Results

Table 3 provides a summary of OLS estimates from the model described above. The model was first estimated by using data for the period after the passage of the Energy Independence and Security Act of 2007 (EISA). For the entire period (2003–2008), the own price elasticity of demand was found to be 3.27, indicating a 10% increase in the price of ethanol leads to a 32.7% decrease in the quantity of ethanol demanded.

Table 3: Basic Model Estimation Results

	All Data		Prior EISA 2007 Data		Post EISA 2007 Data	
ln(PE)	-3.27	***	-2.52	***	-4.07	***
	(0.12)		(0.16)		(0.18)	
ln(PG)	4.41	***	4.73	***	4.35	***
	(0.12)		(0.17)		(0.18)	
ln(INC)	0.11	***	0.12	***	0.006	
	(0.02)		(0.03)		(0.02)	
ln(VEH)	0.29	***	0.23	***	0.43	***
	(0.01)		(0.02)		(0.02)	
ln(NSTAT)	-0.25	***	-0.21	***	-0.46	***
	(0.02)		(0.02)		(0.03)	
ln(DISTB)	0.02	**	-0.003		0.04	***
	(0.01)		(0.01)		(0.01)	
ln(DISTH)	0.01	**	0.06	***	-0.01	
	(0.01)		(0.01)		(0.01)	
Twin Cities Area	2.51	***	2.20	***	2.87	***
	(0.05)		(0.07)		(0.09)	
Greater MN	2.11	***	1.81	***	2.45	***
	(0.06)		(0.08)		(0.09)	
Month Indicators	Yes		Yes		Yes	
N	6860		3164		3696	
Adj. R-squared	0.98		0.98		0.98	

Notes: ***p<0.05, **p<0.1, *p<0.2. Standard errors are in parentheses. Dependent variable is monthly ethanol sales volume in gallons. Prices are in 2009 dollars. Income is the real per capita disposable income in 2009 dollars.

One of the reasons that the change in quantity of ethanol demanded is proportionately larger than the change in price (i.e., demand is elastic) is that consumers have quick access to close substitute fuel—gasoline—at almost zero search cost. In other words, every station that offers E85 also offers gasoline. Imperfect information about the environmental and economic benefits of ethanol fuels is another reason for high demand sensitivity to price increases. Some service stations in the Midwest advertised gasoline as "ethanol free" fuel, emphasizing that E85 results in a reduced range (miles per tank of fuel) and engine problems because of its moisture content (Galbraith 2008). Considering these conditions, consumers may show high sensitivity to small price increases by either decreasing their consumption of ethanol fuel or by switching to gasoline.

For the post EISA period (2007–2008), elasticity was estimated to be -4.07, much higher in absolute value compared to that of the period prior to EISA (2003-2006), which was found to be -2.52. The results of two-sample t-test, ($t = 46.3$, $p < .00$), showed that there is a statistically significant difference between the two samples. One possible reason for increased demand sensitivity after the EISA was passed is that consumers became more aware about the environmental impacts from the production and use of ethanol. Provided that every ethanol station also offers gasoline, the consumers may switch to gasoline at zero search cost. The economic recession, which started in

2008, may be another plausible explanation for overall increased sensitivity to price changes for transportation fuels.

However, the demand responsiveness to gasoline price changes did not vary to the same extent (4.73 for prior, and 4.35 for post-EISA period). For the whole period (2003-2008), the estimate was 4.41, indicating that a 10% increase in the price of gasoline leads to a 44.1% increase in the quantity of ethanol demanded. The estimates for pre- and post-EISA periods (4.73 and 4.35, respectively), suggest relatively stable, sensitive ethanol demand responsiveness to gasoline price changes throughout the study period.

Income elasticity of demand for ethanol was found to be 0.11 for 2003–2008. This estimate is relatively higher than those reported in a recent study by Bromiley et al. (2008). These authors found that the influence of income levels on E85 monthly sales is minimal in magnitude and statistically insignificant. Although not directly comparable, our income elasticity estimates are lower than the estimates for gasoline, ranging from 0.47 to 0.54, as reported by Hughes et al. (2008).

The estimate for the vehicle stock variable (0.29) for 2003–2008 suggests that every 10% increase in vehicle stock will lead to only a 2.9% increase in ethanol sales. However, due to data limitations, the vehicle stock variable is a proxy for flexible fuel vehicle (FFV) stock in this analysis. Therefore, this coefficient may not fully reveal the relationship between increasing FFV stock and E85 sales levels. The estimates for pre- and post-EISA were found to be 0.23 and 0.43, respectively. According to the Minnesota Department of Public Safety registration records, the total number of passenger vehicles in Minnesota reached 3.34 million in 2006, then increased slightly to 3.4 million in 2008. Considering 125,000 FFVs in 2006 in Minnesota, as reported in Bromiley et al. (2008), the proportion of FFVs is less than 5%. Overall, the estimate is in accordance with the expectation of a positive relationship between stock of vehicles and fuel sales.

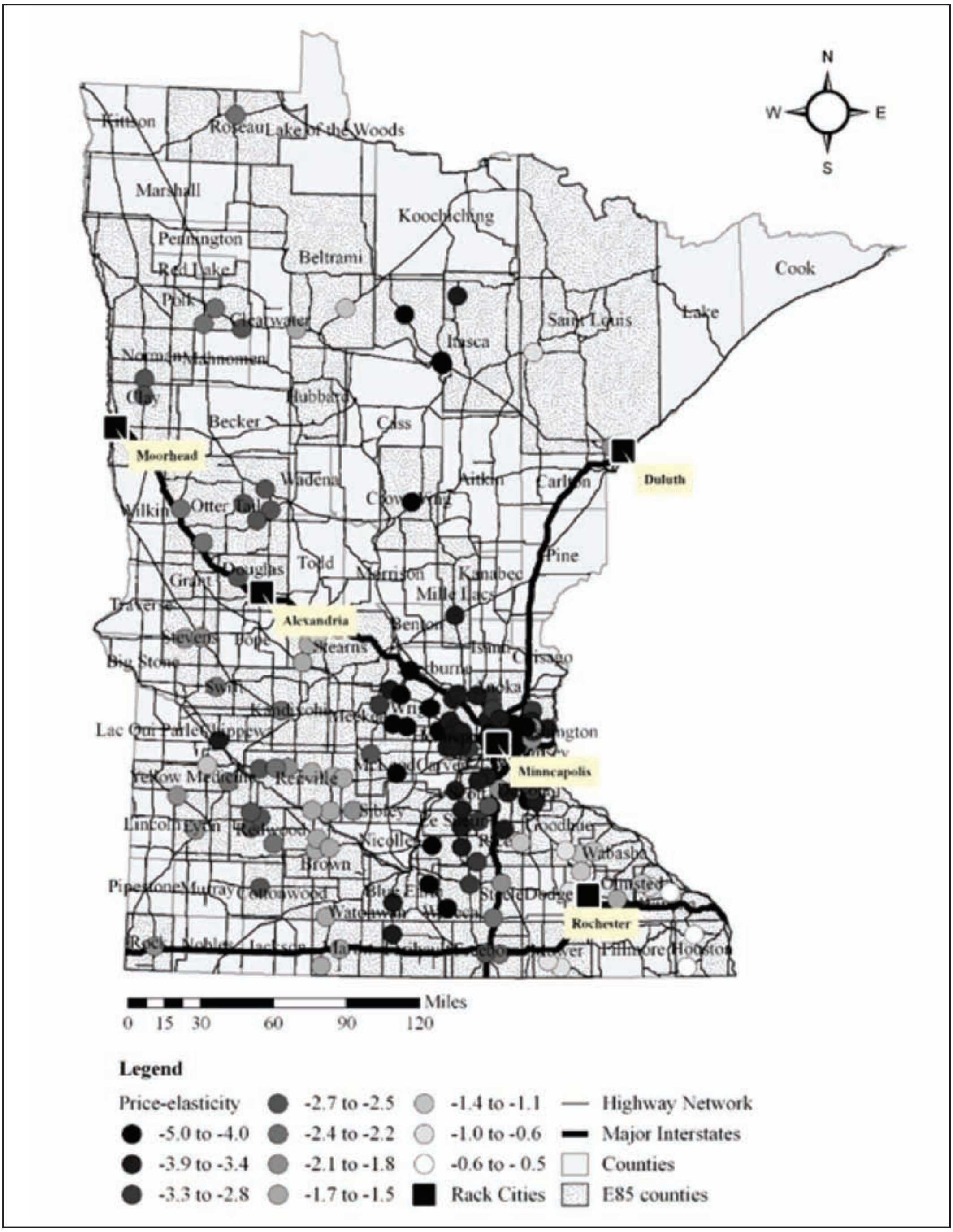
The estimates for the number of ethanol stations per county variable was in -0.25 for 2003–2008, and -0.21 and -0.46 for the pre- and post-EISA periods. The negative sign suggests that a percentage increase in the number of ethanol stations in a county will reduce ethanol sales at an individual station by 0.25% (0.21% and 0.46% for the pre- and the post-EISA periods, respectively). These results have the same negative sign, but not the same statistical significance as the estimates found in Anderson (2010).

The distance to major highways variable showed relatively weak influence on the E85 sales volume. The estimate for 2003–2008 is 0.01, and 0.06 for the pre-EISA period. The influence of distances to blending terminals in Minnesota on E85 monthly sales volume was also found to be weak (0.02 for 2003–2008 , 0.04 for post EISA period). Consumer choice behavior is mainly influenced by fuel prices, which partly reflect distance-related cost increments. This can partially explain the weak relationship of distance-related variables. Influenced by a higher concentration of fuel stations, the estimate for the Twin Cities area dummy variable is positively correlated with ethanol sales. Lastly, monthly dummy estimates (not reported here) reflect expected seasonal variation in transportation fuel demand, indicating relatively increased levels of ethanol sales during summer months.

GWR Model Results

Figure 2 illustrates spatial changes in the magnitude of price elasticity of demand for ethanol. As shown, the relationship between price and quantity demanded varies geographically. (The map includes only statistically significant coefficients.) The distribution of the estimates shows relatively higher price-sensitivity for E85 quantity demanded around the Twin Cities area as well as Itasca, Crow Wing, Nicollet, LeSueur, Blue Earth, Waseca and Faribault counties (-2.2 to -5.0). Most of the estimates in the rural areas vary from -0.5 to -2.7.

Figure 2: Spatial Distribution of Own Price Elasticity for E85 Fuel Demand in Minnesota



Overall, the estimated high elasticity ranges are consistent with our expectations, and are explained by the availability of close substitute, gasoline, at almost zero search cost (since every service station where E85 is available also offers gasoline). However, the main distinction from the first model is that the elasticity is not constant across the study area. The variation in estimates also supports motivation for the existence of spatial heterogeneity in the data structure.

The estimates in the OLS model showed that consumers are generally sensitive to both ethanol and gasoline price changes. However, the findings from the GWR model indicate that consumers' demand sensitivity to price changes varies geographically. In addition to visualizing elasticity estimates on a map, Table 4 provides a summary of estimates for comparing GWR and OLS results side by side, and shows that the OLS cross price elasticity estimate (4.35) is between the upper quartile and maximum values of the GWR results. The own price elasticity estimate from the OLS model (-3.21) falls between the minimum and lower quartile values of the GWR estimates. Spatial distribution of the own price and gasoline price elasticity estimates from the GWR model reveals that the OLS results represent only a portion of the geographic variation in price-demand relationships.

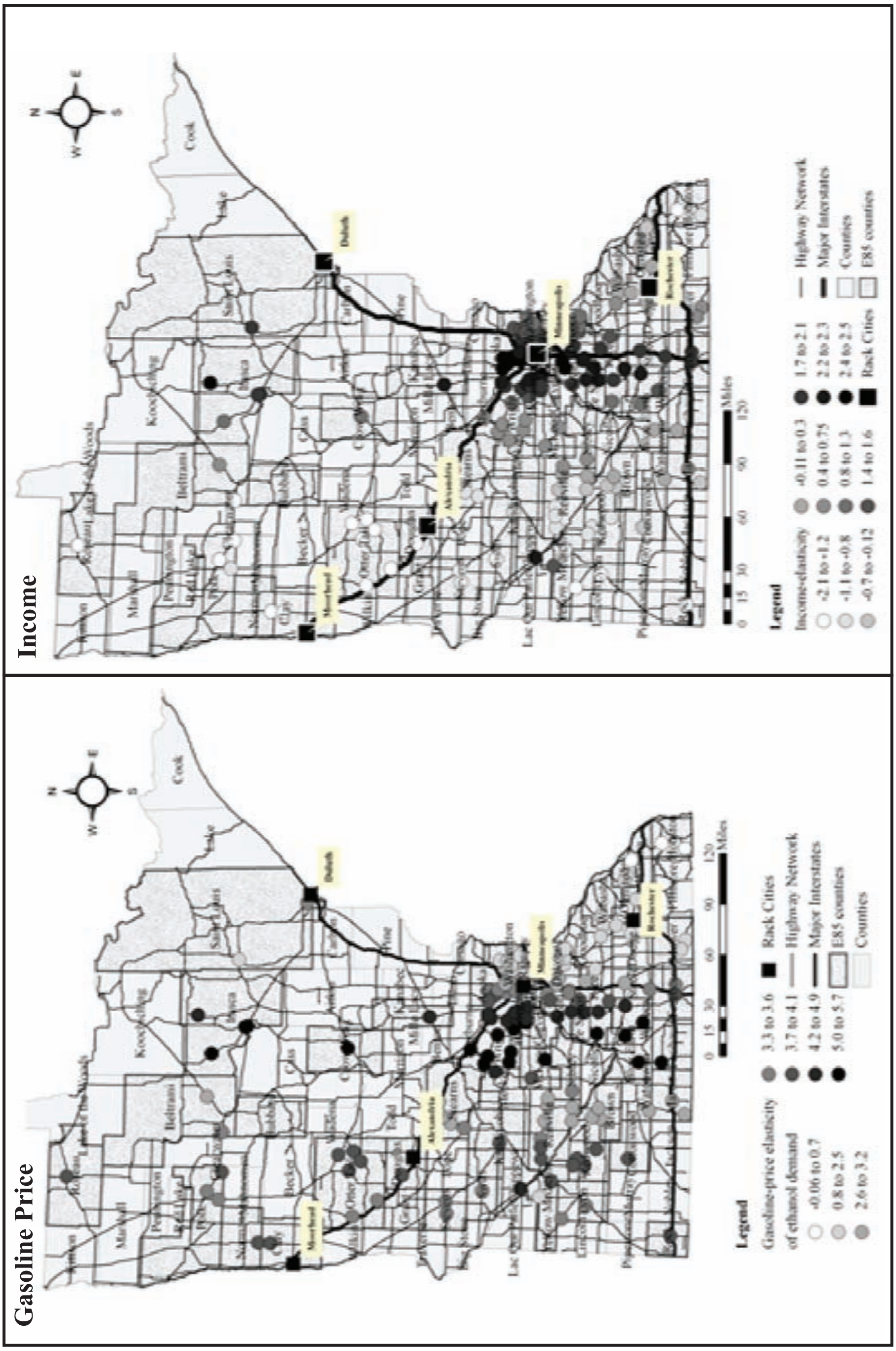
Table 4: GWR Parameter Summary and Comparison With the OLS Model Coefficients

Variables	Min	Lower quartile (25th percentile)	Median quartile (50th percentile	Upper quartile (75th percentile	Max	OLS (2003–2008)	Standard errors–OLS (2003–2008)	GWR coefficients variability statistic ($\sqrt{\rho i}$)
ln(PE)	–5.00	–2.70	–2.08	–1.40	–0.50	–3.21	0.05	1.06
ln(PG)	–0.06	2.49	3.35	3.93	5.70	4.35	0.12	1.11
ln(INC)	–2.10	–0.48	0.95	2.02	2.50	0.41	0.08	1.36
ln(VEH)	–0.21	–0.02	0.13	0.33	0.59	0.29	0.01	0.21
ln(NSTAT)	–0.51	–0.39	–0.26	-0.14	0.06	–0.27	0.02	0.15
ln(DISTB)	–0.19	–0.08	–0.01	0.07	0.75	0.02	0.01	0.14
ln(DISTH)	–0.22	0.07	0.12	0.20	0.64	0.02	0.01	0.09

The statistical significance of the variation in the GWR coefficients was tested based on the following hypothesis: $H_0{:}\beta(\upsilon_i, v_i) = \beta_{OLS}$, where i indexes the fueling station locations, against $H_1{:}\beta(\upsilon_i, v_i) \neq \beta_{OLS}$. To test this hypothesis, Brundson et al. (1998) suggest measuring the variability in the GWR coefficients using the following statistics: $\rho_i = \sum_i(\beta(\upsilon_i, v_i) - \beta_{i\cdot}{}^2 / N$, where a dot in the subscript of the second β coefficient denotes averaging GWR coefficients over locations. The $\sqrt{\rho_i}$ for all variables in the model (the last column of Table 4) is then compared with the standard errors from the OLS model. As shown, all of the variability statistics are greater than the standard errors from the OLS model. Thus, the null hypothesis is rejected in support of the GWR model.

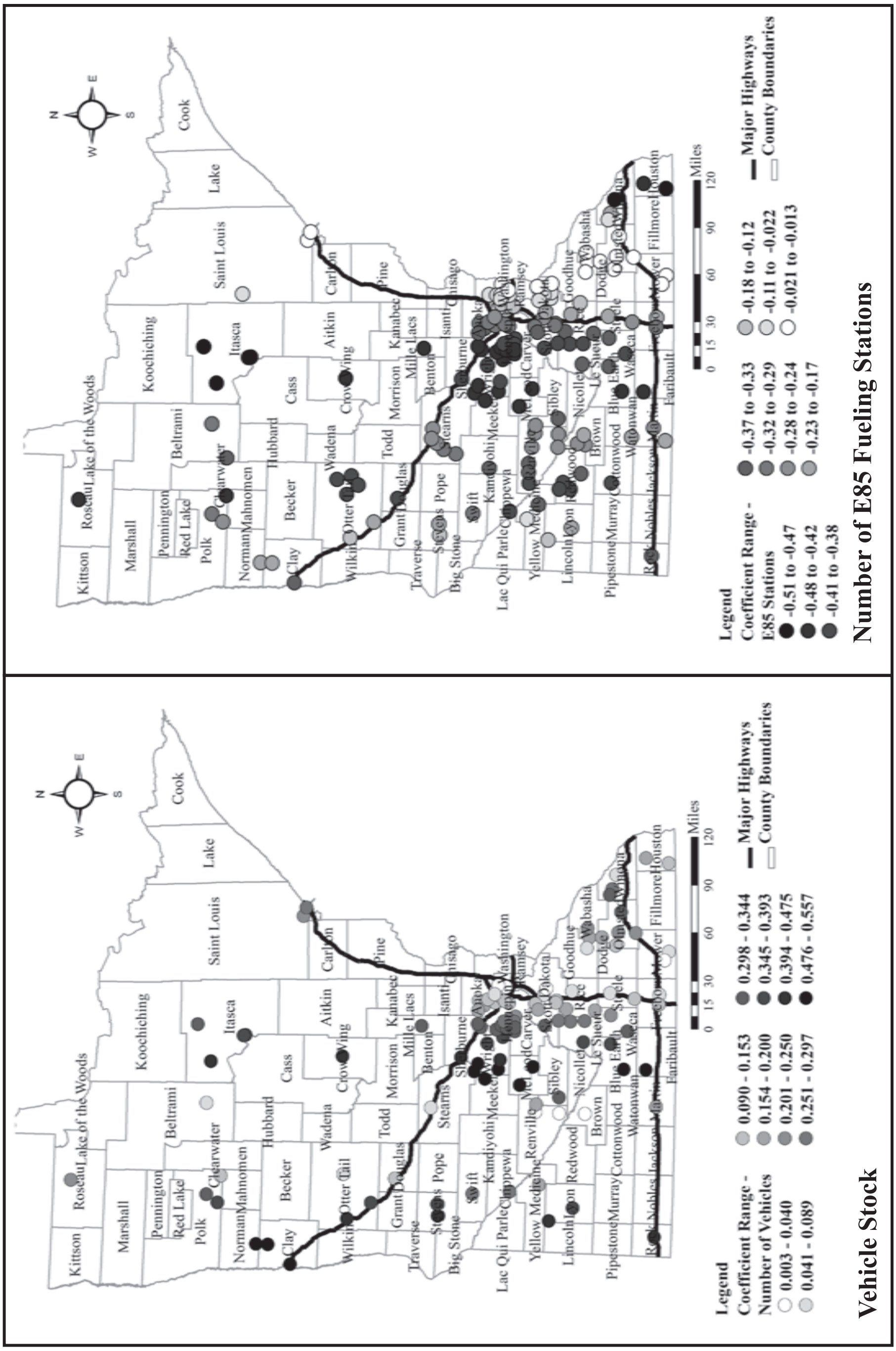
The first part of Figure 3 shows gasoline price (cross) elasticity ranges. The estimates vary from -0.06 to 5.7 across the study area. The areas that revealed high sensitivity to gasoline price changes with respect to quantity demanded for ethanol fuel are similar to those found in Figure 2. Income elasticity estimates for the Twin Cities area were found to be in the 1.4 to 2.5 range, indicating a positive relationship between income levels and ethanol consumption in the urban area. The signs of the estimates for the rest of the regions change from negative to positive, ranging from -2.1 to 1.3. According to the comparison in Table 4, the OLS estimate (0.41) for income elasticity falls between the lower and median quartiles of the GWR estimates.

Figure 3: Spatial Distribution of Gasoline (Cross Price) and Income Elasticity Estimates



The distribution of the elasticity estimates with respect to vehicle stock and the number of neighboring E85 stations is shown in Figure 4. The coefficients for vehicle stock are statistically significant and positive, thus meeting our expectations of a positive influence of vehicle availability in the close proximity to fueling stations on fuel sales. Given a small fraction of E85 compatible vehicles, the negative sign for the number of E85 fueling stations provides the size of local competition among fueling stations.

Figure 4: Spatial Distribution of Vehicle Stock and Number of E85 Fueling Station Estimates



CONCLUSIONS

Minnesota is one of the nation's leaders in per capita use of environmentally cleaner fuel alternatives, such as E85 ethanol, and understanding consumers' demand responsiveness to price changes reveals important policy implications. From the general relationship found in the first model, it was concluded that increasing the price of E85 ethanol by 10% will lead to a 32% decrease in the quantity of E85 demanded. Likewise, increasing the price of gasoline by 10% will increase the quantity of E85 demanded by 43%. These results show fundamental differences between price-demand relationships for ethanol and gasoline. The demand for gasoline is known to be inelastic. However, due to the availability of a substitute fuel in the form of gasoline, consumers are highly sensitive to ethanol price changes and can switch to the alternative at zero search cost. In addition to this general relationship, the resulting price elasticity estimates from the spatial regression model showed significant spatial variation across the study area. The demand for ethanol was found to be elastic, with estimates varying from -5.0 to -2.2 within the Twin Cities area.

Although high elasticity levels were found in a few more areas, the Twin Cities area represents the largest cluster of consumers, whose demand is responsive to price changes. With the exception of the counties described in the results section, most demand elasticities for the rural areas of the state vary from -0.5 to -2.7. Although the OLS model's static estimates showed that consumer demand for E85 is highly sensitive to prices changes, their comparison with the GWR estimates showed that the OLS model results are specific to certain geographic areas and that the coefficients vary geographically. One possible reason for this variation is that the demand function itself does not have a constant elasticity shape and follows the geographic variation in consumer preferences.

In addition to joining several regional biofuel initiative programs (e.g., the Energy Security and Climate Stewardship Platform Plan), several local private-public partnerships in Minnesota (e.g., "E85 Everywhere" campaign) propose to considerably increase E85 availability at retail fueling stations in the state. Understanding consumer demand sensitivity to price changes reveals important insights about the potential impacts of policy decisions. For example, the distributional impacts from a tax or subsidy policy depend on the price elasticity of demand, and knowing the geographic patterns of price-demand relationships indicates that some areas may be more (or less) influenced by statewide policies. The results show that the impacts of E85 tax policy will be stronger in counties with relatively higher price elasticities. Additionally, the results showed that some areas in the state are relatively more sensitive to increasing the number of service stations. This is also relevant to the consideration that the E85 grants and subsidies should vary across the state. The evaluation of these impacts is imperative as the Office of Energy Efficiency and Renewable Energy (under requirements of the Government Performance Results Act) estimates the benefits of the state's portfolio of biofuel promotion programs. The spatially variable estimates may also be useful for alternative fuel policy simulation analysis that requires consideration of a range of price-elasticities to be used in calibration. The outcome of the GWR model allows obtaining more detailed estimates, which can be used in these policy simulations with more certainty. Non-spatial econometric models emphasize similarities or regularities of data being analyzed. In contrast, a spatially disaggregated estimation approach helps to reveal differences across the study area. With this distinction, this approach may be useful for investigating regional differences in the way consumers react to price variations.

Several limitations of this study are worth mentioning. Although this investigation aims to reveal spatial differences in the price-demand relationship, it is geographically bounded. Availability of ethanol fueling stations and price differences outside of Minnesota's borders may influence sales included in these data. Additionally, a portion of E85 sales can be attributed to households not residing in Minnesota since many E85 stations are close to major interstate highways connecting the state with the neighboring states.

Endnotes

1. Following Anderson (2010), the household's utility function in terms of transportation fuels and other goods can be represented as $U = f(Q_e + rQ_g) + X$, where Q_e and Q_g are consumption levels of close substitutes (ethanol and gasoline), r specifies the rate at which the consumer converts gallons of gasoline into ethanol-equivalent gallons, and X represents the composite good. Since gasoline and ethanol are close substitutes, the household demand is at the corner solution, such that the household will purchase ethanol only when $p_e < p_g/r$, where p_e and p_g are per gallon retail prices of ethanol and gasoline, respectively. Therefore, ethanol is purchased when its price is less than ethanol-equivalent fuel price, which is p_g/r. Alternatively, the household will purchase gasoline when $p_e < p_g/r$. In other words, because ethanol has lower energy content (i.e., provides fewer miles per gallon), the fuel type decision is made based on ethanol-equivalent price (Anderson 2010). Relative prices influence households' decisions in choosing between gasoline and ethanol. However, the quantity demanded still depends on the absolute levels. For the consumer who owns a flexible fuel vehicle (FFV that uses both gasoline and ethanol), this approach allows the quantity of ethanol demanded to be expressed as $d(p_e)$. The household demand for ethanol can be aggregated by assuming that out of households that own vehicles, ϕ fraction own FFVs. It is also assumed that each household owns a single vehicle. Further, it is assumed that the fuel-switching price ratio r has differentiable cumulative distribution function $H(r)$, which is defined on $[0,\infty)$. Because $r < p_g/p_e$, i.e., households choose ethanol only when the fuel-switching ratio is less than the relative price, the portion of households that chooses ethanol is the function evaluated at $H(p_g/p_e)$. Given these assumptions, the aggregate demand for ethanol, as represented in Anderson (2010), takes the following form $E(p_e, p_g) = N\phi \int_0^{p_g/p_e} d(p_e) dH(r) = N\phi H\left(\frac{p_g}{p_e}\right) d(p_e)$, where the total number of households, N, is multiplied by the fraction that own FFVs (ϕ), multiplied by the fraction of those FFV owners who choose ethanol (which, as shown in the equation above, is a function of relative prices), multiplied by the level of ethanol consumption by households that choose ethanol, which is a function of absolute price of ethanol (Anderson 2010). Further, the following logarithmic aggregate demand model can be used to derive the price elasticity of demand for ethanol, and gasoline price elasticity (cross price) of demand for ethanol $lnE(p_e, p_g) = lnN\phi + lnH\left(\frac{p_g}{p_e}\right) + lnd(p_e)$.

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Passenger Car Equivalents of Light Duty Trucks and the Costs of Mixed Vehicle Traffic: Evidence from Michigan

by Sarah B. Cosgrove

This study uses naturalistic data from drivers operating instrumented vehicles to estimate the following distance by vehicle type and compute the passenger car equivalents of light duty trucks (LDTs). Unlike most previous studies, this study separates LDTs by vehicle type and produces evidence that cars follow different types of LDTs at different distances. While car drivers follow pickup trucks more closely, they follow SUVs and minivans at a greater distance. The external cost on the transportation system is estimated to be approximately $37 million annually in the Detroit area and $2.05 billion annually for the United States as a whole.

INTRODUCTION

Traffic congestion is a growing problem in urban areas of the United States According to the 2010 Urban Mobility Report (Schrank et al. 2010), traffic congestion levels have worsened in all of the 439 urban areas studied over the past 25 years. More specifically, roads are congested for an increasing portion of the day and more roads are congested. The costs of extra time and fuel due to congestion increased from $24 billion in 1982 to $115 billion in 2009, measured in constant 2009 dollars.

Sport utility vehicles (SUVs), pickup trucks, and minivans, collectively referred to hereafter as light duty trucks (LDTs), comprise a significant proportion of vehicles on the road today and add to the congestion problem because they require more space on the road than passenger cars, hereafter referred to as cars. According to the National Auto Dealers Association, from 2001 through 2009, an average of 52% of new vehicles sold each year were LDTs (AutoExec 2010). Several attributes of LDTs result in them requiring more space on the road than cars. First, LDTs are longer. Specifically, the average SUV is 6.7% longer, the average pickup truck is 28.2% longer, and the average minivan is 9.3% longer than the average car.[1] While LDTs are also significantly heavier and their drivers may perceive them to require more stopping distance, this aspect is conservatively ignored in this research.

In addition to their greater length, LDTs are higher (21% to 30%) and wider (5% to 17%) than cars. Using data from the Automotive News annual Market Data Books (for model years 2003-2006), weighted average characteristics were computed for cars, SUVs, pickup trucks, and minivans, weighted by total sales for the top 10 cars, top five SUVs and pickup trucks, and top three minivans from 2002-2005. The vehicles included in these calculations comprise 34% of new cars and 45% of new light duty trucks sold between 2002 and 2005. Table 1 collects data on the differences in length, height, width, and weight. For all vehicle types, the mean values are provided. In addition, for SUVs, pickup trucks, and minivans, the percentage difference from the mean car value is provided.

The greater height and width causes areas of blocked vision, or “blind spots,” for cars following LDTs. To maintain a consistent level of safety, the driver should allow a greater following distance behind an LDT than behind a car, given the unknown road situation in front of the LDT. In other words, the total road space needed by a vehicle while driving includes not only the length of the vehicle but also the following distance to the next vehicle. If data reveal that car drivers follow LDTs at a greater distance than they follow cars, then LDTs followed by cars require more total road space than cars, both for their longer length and for the greater following distance of the car. This result would lead to important implications for traffic congestion and for the manner in which transportation planners compute road capacity. Cosgrove and Holahan (2010) provide evidence that the traffic flow rate with mixed vehicle types (cars and LDTs) is lower than uniform traffic flow. Thus, congestion time costs are higher than they would be with uniform traffic. Likewise, road capacity is reduced with mixed vehicle traffic compared with uniform traffic.

Table 1: Difference in Specifications by Vehicle Type and Percent Difference from Cars

	Length (in.)	Width (in.)	Height (in.)	Weight (lbs.)
Cars	181.1	70.1	56.9	3100.1
SUVs	193.2 (6.7%)	73.8 (5.3%)	71.7 (26.0%)	5943.7 (91.7%)
Pickup Trucks	232.3 (28.2%)	81.9 (16.8%)	74.3 (30.6%)	8702.8 (180.7%)
Minivans	198.0 (9.3%)	77.6 (10.7%)	69.0 (21.2%)	5729.2 (84.8%)

Note: Values are weighted averages of the specifications for top 10 cars, top five SUVs, top five pickup trucks, and top three minivans sold between 2002 and 2005. The autos included in these calculations comprise 34% of new cars and 45% of new light duty trucks sold between 2002 and 2005. In order of number sold, cars: Toyota Camry, Honda Accord, Honda Civic, Ford Taurus, Chevrolet Impala, Toyota Corolla, Chevrolet Cavalier/Cobalt, Nissan Altima, Ford Focus, Chevrolet Malibu; SUVs: Ford Explorer, Chevrolet Trailblazer, Jeep Grand Cherokee, Chevrolet Tahoe, Jeep Liberty; pickup trucks: Ford F series, Chevrolet Silverado, Dodge Ram, Chevrolet Sierra, Ford Ranger; minivans: Dodge Caravan, Honda Odyssey, Toyota Sienna.

This paper should be of interest to policymakers and transportation professionals because the country is experiencing increasing traffic congestion with little space and funding to expand highway capacity. In the event of highway expansion, the current capacity approach overstates the capacity by not accounting for the effects of mixed vehicle traffic. In the absence of highway expansion, the results of this study can be used to determine appropriate variable pricing by vehicle type to reduce the congestion problem.

This study has several objectives. The first objective is to determine whether car drivers behave differently when following LDTs than when following cars. More specifically, given the ambiguous results of previous work in the field, this study aims to clarify those mixed results and provide a more certain conclusion. Assuming there is a behavioral difference, the next objective is to develop an equation for an appropriate adjustment factor for LDTs to include in the standard capacity calculation in the Highway Capacity Manual (2000). Using that adjustment factor, this study predicts the relationship between the percentage of vehicles that are LDTs and capacity. Finally, a computation of the increased costs from mixed vehicle traffic is included.

The second section discusses the existing literature on the topic. The third section explains the data used in the study. The empirical model is presented in the next section. The fifth section explains the regression results. The sixth section explains the adjustment to the capacity calculation and discusses the relationship between vehicle mix and capacity. The next section discusses congestion costs from mixed vehicle traffic and is followed by the conclusion.

LITERATURE REVIEW

The existing literature on following behavior with mixed vehicle types provides ambiguous results on driver behavior. In an early study on the topic, Evans and Rothery (1976) found that lead vehicle size does not significantly affect following distance. In contrast, Yoo and Green (1999) found that drivers in a simulation followed cars approximately 10% closer than they followed pickup trucks, school buses, and tractor trailers. The authors caution that all headways observed in the study were much greater than those typically reported in on-the-road studies.

Sayer et al. (2000) used instrumented passenger cars to derive naturalistic following data, i.e., driving as they "naturally" would, same speeds, routes, level of aggression, in a 1996-1997 Intelligent Cruise Control Field Operational Test.[2] The authors had 1,698 observations of 70 drivers and observed a vehicle mix of 65% passenger cars, 35% LDTs. They found that cars followed LDTs an average of 5.6 meters or 0.19 seconds in headway time margin more closely than they followed other cars, in contrast to their a priori expectation of driver behavior. The authors speculate that perhaps car drivers ignore the possible dangers in front of the LDTs because they are unable to see them, among other possible explanations.

Kockelman and Shabih (2000) assessed capacity at signalized intersections and found that it is reduced due to greater following distance of cars behind LDTs. They computed an aggregate LDT passenger car equivalency of 1.19, indicating that LDTs require approximately 20% more road space through intersections than cars.

Most recently, Brackstone et al. (2009) studied six subjects driving two test routes in an instrumented vehicle in the United Kingdom. They observed very few LDT following events in some speed categories, thus limiting their analysis to headways at speeds greater than 20 meters per second. They found that, in general, cars follow LDTs more closely than they follow cars and suggested the same reasons offered by Sayer et al. (2000).

Given the mixed results and limited number of observations or drivers in some studies, a current comprehensive analysis is in order. This study includes more current data, more observations, and more subjects than most previous studies. Moreover, subjects have free driving range on their typical daily routes and they were completely unaware that their following behavior by vehicle type would be assessed. Finally, and perhaps most importantly, this study separates the lead vehicle LDT into different types of LDTs and studies corresponding following behavior.

DATA TO ESTIMATE FOLLOWING DISTANCE

The University of Michigan Transportation Research Institute generously shared the rich dataset used for this study. The data were collected for the Road Departure Crash Warning (RDCW) System Field Operational Test from May 2004 through February 2005. Eleven Nissan Altima four-door sedans were equipped with two road departure warning systems, video cameras capturing the forward scene, and data collection systems, which recorded data continuously at 10Hz or higher while the car was being operated. The purpose of the test was to assess the effectiveness of the road departure warning systems; however, the extremely rich behavioral data collected in the test coupled with the videos of what drivers saw are ideal for a vehicle following study. Different from most previous studies on the topic, drivers were completely unaware that any of the data would be used for a vehicle following study because the data were collected for a distinctly different purpose. Therefore, the behavior captured is representative of their normal driving patterns.

Drivers were recruited from the general population in the southeast Michigan area including Detroit, surrounding suburbs, and rural areas and ranged in age from 20 to 70 years old. Each driver was instructed to use the instrumented car in place of their primary vehicle, driving where and how they normally would, for four weeks. The road departure warning systems were inactive during the first week for each driver to provide control data for the primary study and were activated for the remaining three weeks.[3] Of the 87 original drivers, complete data for this study were available for 65 drivers.

To extract the relevant data for this study, a "following event" was defined as the instrumented vehicle maintaining a range rate, or rate of change of range to the lead vehicle, of ± one meter per second (m/s). The observations were restricted to highway driving during daylight hours (defined as solar zenith angle between zero and 90 degrees) when windshield wipers were off to avoid driving in the dark and inclement weather, which may alter decisions about following distance. Because the primary concern of this paper is the effects of any blind spot externality on congestion costs, the observations were further restricted to include only travel during dense traffic conditions when congestion would increase the time cost of travel.[4] Presumably, in uncongested traffic if faced with a blind spot from a lead LDT, a car driver could change lanes with ease to alleviate the blind spot externality, thus the blind spot in uncongested traffic does not impose an external cost. Finally, a driver was excluded from the dataset if there were not at least two observations following a car and following an LDT.

Still video images for each observation were viewed to determine the type of vehicle the driver was following, hereafter, lead vehicle type. Lead vehicles could be accurately classified by type at a maximum of three seconds of headway time at highway speeds. Images were examined for the 4,010 observations that met the criteria specified above. Of these, 40 observations were dropped because the pictures were too bright, too dark, or completely black. Three additional observations were discarded because the road was snow covered, which likely affects driver following distance. Eight more observations were discarded because the lead vehicle type was a motorcycle and motorcycle following behavior may be different than car or LDT following behavior, with an insufficient number of observations to evaluate in its own category in this study. Thus, 3,959 observations remained. Summary statistics for all variables are provided in Table 2.

Table 2: Summary Statistics

Variable Name	Mean	Std Dev	Minimum	Maximum
dist (m)	29.35	15.96	1.69	120.69
secfol	1.17	0.65	0.50	6.30
leadpickup	0.12	0.32	0	1
leadsuv	0.25	0.43	0	1
leadminivan	0.12	0.32	0	1
leadhtruck	0.07	0.25	0	1
male	0.50	0.50	0	1
pickupprimary	0.13	0.33	0	1
suvprimary	0.11	0.32	0	1
minivanprimary	0.13	0.34	0	1
yearsdriving	25.24	14.69	2.5	54
engage	1.81	0.99	1	5
engagemale	0.87	1.06	0	4
speedcat5	0.02	0.15	0	1
speedcat10	0.05	0.21	0	1
bachelors	0.32	0.47	0	1
graduate	0.17	0.38	0	1
logincome	11.02	0.35	10.18	11.76
speedcat15	0.05	0.22	0	1
speedcat20	0.07	0.25	0	1
speedcat25	0.09	0.28	0	1
speedcat30	0.28	0.45	0	1
speedcat35	0.37	0.48	0	1
speedcat40	0.07	0.26	0	1
targets	4.70	2.01	0	12
RDCWdisabled	0.33	0.47	0	1

EMPIRICAL MODEL

To determine whether car drivers follow LDTs and heavy trucks at a greater distance than they follow other cars, an OLS regression model was used with two different dependent variables, following distance and following time. The model, while consistent with the general form of similar research in the field, includes a richer set of explanatory variables to capture the key variables of interest and control for driver characteristics that may affect following behavior. The model is shown in equation 1.

$$(1)\quad dep_{it} = \beta_1\mathbf{LDT}_{it} + \beta_2 Htruck_{it} + \beta_3\mathbf{DEM}_i + \beta_4\mathbf{Speedcat}_{it} + \beta_5 Targets_{it} + \beta_6 RDCWdisabled_{it} + \varepsilon_i$$

where
dep = *dist* or *secfol*
i = individual driver
t = following event
LDT_{it} is a vector of LDT lead vehicle types
DEM_i is a vector of demographic variables
$Speedcat_{it}$ is a vector of speed categories

In addition to the OLS model, a fixed effects model was also estimated in case of endogeneity of driver characteristics for which demographic variables could not control. A comparison of the two models shows no bias in the OLS estimation coefficients. Thus, the OLS model is chosen because it provides some interesting information on the differences in driving behavior by demographics.[5]

Both time and distance are used as dependent variables in this study. Each instrumented vehicle was equipped with forward-looking radars to detect the distance to the lead vehicle. The variable *dist* is the following distance measured in meters. Time is measured as the number of seconds the instrumented vehicle is following behind the lead vehicle, indicated by variable s*ecfol*. Table 3 illustrates the mean values of following distance and following time by lead vehicle type and the comparison to a car following a car. The mean following distance and time are longer for cars following all categories of non-cars, except for pickup trucks.

Table 3: Summary of Dependent Variables by Lead Vehicle Type

Lead Vehicle Type	Following Distance (meters)		Seconds Following	
	Mean	% of Car	Mean	% of Car
Car	27.9	-	1.14	-
Pickup	27.1	-2.9%	1.09	-4.4%
SUV	32.4	16.1%	1.23	7.9%
Minivan	28.9	3.4%	1.16	1.8%
Heavy Truck	32.4	16.1%	1.34	17.5%

The key variable of interest in this empirical work is the lead vehicle type. While most previous studies grouped all LDTs in one category, the data in this study are rich enough to support separating LDTs into pickup trucks, SUVs, and minivans, creating three distinct variables: *leadpickup*, *leadSUV*, and *leadminivan*. This is an important advantage over previous work because following driver behavior may vary by these vehicle types due to their differences in size, window placement, and likelihood of windows being tinted. While there are clearly differences in the sizes of different models of pickup trucks and SUVs, some of the images were not clear enough to determine the exact make and model of the lead vehicle so these categories could not be defined more narrowly. A category for heavy trucks and a corresponding variable, *leadhtruck,* was also included where heavy trucks were defined as those with more than four tires, in accordance with the Highway Capacity

Manual's definition of heavy vehicles (2000). The expected signs on all these variables are positive, indicating that drivers follow LDTs and heavy trucks at a greater distance than they follow cars.

Several demographic variables were collected from the drivers, and are included in the analysis to control for differences in driving behavior. *Male* is an indicator variable for gender, taking a value of one for males and zero for females. Typically, males are considered to be more aggressive drivers than females so the expected sign of *male* is negative indicating that they follow more closely than females. More driving experience is expected to cause drivers to leave a bigger cushion between them and vehicles they follow. Thus, a y*earsdriving* variable is included to account for the number of years a subject has been driving and is expected to be positive. Because this variable is so closely correlated with age, no additional age variable is included. If drivers with higher incomes have a greater value of travel time, they may follow more closely. A *logincome* variable is included to capture this possible effect with an expected negative sign. Finally, categorical education variables for attaining a bachelor's degree, *bachelor*, and a graduate degree, *graduate*, are included to control for the fact that more educated drivers may be more cognizant of the risks of following too closely. If this hypothesis holds, the signs on the education variables will be positive.

In addition, because not all drivers in the study typically drive cars, it is important to consider the type of vehicle they drive on a routine basis. Drivers who typically drive LDTs may exhibit more caution when following LDTs in a car because they are unaccustomed to blocked vision from a lead vehicle. Indicator variables for drivers' primary vehicle type, *pickupprimary*, *suvprimary*, and *minivanprimary*, take a value of one if the driver's primary vehicle is a pickup truck, SUV, or minivan, respectively, zero otherwise. These variables are expected to have a positive sign, indicating greater following distance.

All drivers participating in the study completed a behavioral questionnaire before they were given the instrumented vehicle. One question is particularly relevant to this study. Drivers were asked how often they engage in "tailgating," with responses varying from "never" (1) to "most of the time" (7). Driver responses to this question are indicated in the *engage* variable, which is expected to have a negative sign. Because men reported that they engaged in tailgating less frequently than women, an interaction term, *engagemale*, was included. While these types of self-reported behavioral questions do not tend to be particularly informative, they may serve to differentiate drivers by their degree of risk aversion.

Observation specific variables include speed categories, a measure of relative density, and whether the crash warning system was enabled. Following behavior inherently differs with the rate of traffic flow, thus some measure of speed is essential to the model. To avoid multicollinearity between speed and the dependent variable, either distance or time, speed is converted to a categorical variable in increments of five m/s. The variables are *speedcat* in eight increments and the fastest, *speedcat40*, is used as the base case. Given that the fastest speed is used as the base, the sign on the remaining speed category variables is expected to be negative, indicating that cars follow more closely at slower speeds. The *targets* variable counts the number of other vehicles detected by the radar in front and in the surrounding lanes of the instrumented vehicle and serves as a measure of traffic density. The expectation is that the *targets* variable will have a negative sign because more traffic density leads to following more closely. Finally, the *RDCWdisabled* variable takes a value of one when the Road Departure Crash Warning system is disabled. It may be important to control for the system if having it enabled prompts drivers to behave more cautiously, including following at a greater distance.[6] In this case, the *RDCWdisabled* variable would have a negative sign.

REGRESSION RESULTS

The results of the regressions are presented in Table 4 and summarized below. The key variables tell an interesting story. Ceteris paribus, car drivers follow pickup trucks more closely than they follow cars, but car drivers leave a greater cushion between themselves and SUVs, minivans (insignificant in one model), and heavy trucks than other cars. In detail, cars follow pickup trucks 0.05 seconds and 1.7 meters, about 5%, more closely than cars. However, cars follow SUVs at a mean time of 0.12 seconds and at a mean distance of 3.2 meters, about 9%, farther than they follow cars, and they follow minivans 0.06 seconds and 1.1 meters, about 3%, farther than they follow cars. Likewise, cars follow heavy trucks at a mean time of 0.15 seconds and at a mean distance of 2.9 meters, about 8%, farther than they follow cars. While these magnitudes are small, they may have a large effect on aggregate congestion costs. Two reasons may explain the difference in following time and distance between pickup trucks and other categories of LDTs. First, while most SUVs and minivans have tinted windows on the back of the vehicle, many pickup trucks do not. Clearly, tinted glass creates a greater visual barrier for the following driver. Secondly, pickup trucks without cabs create less of a visual barrier than SUVs and minivans, which have bodies that extend the full height and length of the vehicle.

Table 4: Results from Regression Analysis

Variable	Dist	std error	secfol	std error
constant	83.171*	9.645	3.095*	0.390
leadpickup	-1.672**	0.734	-0.053***	0.030
leadsuv	3.247*	0.559	0.121*	0.023
leadminivan	1.124	0.732	0.059**	0.030
leadhtruck	2.925*	0.939	0.150*	0.038
male	-6.538*	0.988	-0.296*	0.040
pickupprimary	1.553**	0.797	0.075**	0.032
suvprimary	-2.239*	0.842	-0.118*	0.034
minivanprimary	-1.954*	0.784	-0.036	0.032
yearsdriving	0.181*	0.020	0.006*	0.001
engage	-2.116*	0.493	-0.114*	0.014
engagemale	1.651*	0.493	0.096*	0.020
bachelors	2.515*	0.606	0.124*	0.024
graduate	0.324	0.734	0.007	0.030
income	-4.069*	0.919	-0.176*	0.037
speedcat5	-30.578*	1.758	1.464*	0.071
speedcat10	-23.751*	1.326	0.732*	0.054
speedcat15	-17.435*	1.312	0.465*	0.053
speedcat20	-12.515*	1.246	0.331*	0.050
speedcat25	-9.632*	1.138	0.161*	0.046
speedcat30	-4.540*	0.959	0.118*	0.039
speedcat35	-2.925*	0.912	0.023	0.037
Targets	-0.564*	0.122	-0.023*	0.005
RDCWdisabled	-0.001	0.487	0.032	0.020
F	53.07		55.24	
R^2	0.237		0.244	
Adj R^2	0.232		0.239	

*Denotes significance at the 1% level.
**Denotes significance at the 5% level.
***Denotes significance at the 10% level.

Two important outcomes can be drawn from these results. First, drivers following SUVs leave a distance and time cushion about equal to their cushion for tractor-trailers, school buses, and other heavy trucks. While the HCM applies an adjustment factor to heavy trucks when computing capacity, no such adjustment factor is currently applied to SUVs.[7] The second significant outcome is that the results distinguish this study from previous similar studies because previous work did not separate the LDTs by type and, consequently, did not reveal the varying behavior by lead vehicle type. Perhaps this explains the ambiguous results of previous studies. It is likely, given these results, that studies with higher percentages of observations where the lead LDT was a pickup concluded that drivers follow LDTs more closely, while studies with higher percentages of observations where the lead LDT was an SUV concluded that drivers follow LDTs at a greater distance.

Before moving to the capacity implications and congestion costs from mixed vehicle traffic, several additional conclusions can be drawn from the results regarding driving habits. First, male drivers follow more closely than female drivers, ceteris paribus. Also, consistent with expectations, as driving experience increases, following distance increases. In addition, a 1% increase in income results in drivers following 4.1 meters more closely, perhaps indicating their higher time value of money. Interestingly, drivers with a bachelor's degree follow at a greater distance than drivers with a high school diploma and/or some college experience; however, following behavior of drivers with a graduate degree does not differ significantly from drivers with a high school diploma. Perhaps the drivers with graduate degrees have a higher time value of money.

Drivers' primary personal vehicle type influences their following distance. Drivers whose primary personal vehicle is a pickup truck allowed a larger cushion between their car and the lead vehicle than other drivers. Perhaps these drivers felt relatively less secure driving the small car compared with the large truck to which they are accustomed. However, drivers whose primary personal vehicle is an SUV or a minivan followed more closely than other drivers.

Drivers who stated in a questionnaire that they engaged in tailgating behavior frequently did follow more closely than drivers who denied frequently engaging in tailgating behavior. With regard to speed, there is a clear and expected pattern of following at a greater distance at higher speeds, compared with the base speed category of 40 m/s. Likewise, the seconds following are lower at higher speeds than the base speed category. Finally, when more targets, other persistent vehicles moving in the same direction, were present on the road, drivers followed more closely. This result is logical given that cars tend to group more closely with increased traffic.

THE EFFECTS OF VEHICLE MIX ON CAPACITY

The empirical results confirm that driver behavior differs depending on the type of vehicle the driver is following. As a result, it is important to consider the effects of vehicle mix on road capacity. Under conditions of uniform traffic, as additional vehicles are added to traffic flow, those vehicles travel at a free flow speed and incur no time cost of travel until a congestion point is reached, after which each additional vehicle added to the traffic flow increases itss own travel time cost as well as the cost of other drivers on the road. This is shown by the well-known speed-flow curve (Walters 1961). Cosgrove and Holahan (2010) illustrate that the congestion point will be reached at a lower flow rate and the marginal and average time cost will increase more rapidly than with uniform traffic. The next step in this analysis is to compute the effects of mixed vehicle traffic on the traffic flow rate and evaluate consequent changes in time cost.

An adjustment factor, similar to the heavy vehicle factor in the HCM, is needed to evaluate the effect of mixed traffic on capacity. The standard HCM (2000) calculation for peak capacity is

(2) $$PeakCap = BaseCap \times PHF \times N \times f_{HV} \times f_p$$

where:

PeakCap = peak capacity, in terms of vehicles per hour (all lanes, one direction)

BaseCap = base capacity, in terms of passenger cars per hour per lane
PHF = peak hour factor; a variable used to account for variations in flow within the peak hour, U.S. HCM recommends a default value of 0.92 for urban areas.
N = number of lanes in one direction
f_{HV} = adjustment factor for heavy vehicles
f_p = adjustment factor for driver population; value set to 1 on urban freeways indicating that the drivers are familiar with roadway and traffic conditions.

The HCM (2000) heavy vehicle adjustment factor is illustrated in equation (3).

$$(3) \quad f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R\left(E_R - 1\right)}$$

where:
P_T = percentage of traffic that is heavy trucks and buses
E_T = passenger car equivalent for heavy trucks, which is 1.5 on level freeway segments
P_R = percentage of traffic that is recreational vehicles
E_R = passenger car equivalent for recreational vehicles, which is 1.2 on level freeway segments

To create an adjustment factor for LDTs, passenger car equivalents (PCEs) will need to be calculated for each type of LDT. There are several methods for computing PCEs. A form of a mean headway approach is chosen here due to the available data. Typically, headways are computed from the front bumper of the lead vehicle to the front bumper of the following vehicle. Each observation in this study shows following time and distance from the rear bumper of the lead vehicle. Due to the nature of the study, all following vehicles were cars. To accurately reflect the PCE for the different LDT types given the data in this study, the computation must include the length of the vehicle and the lagging headway. Thus, in this case, distances rather than times are used in the calculation, and the average length of the lead vehicle by vehicle type is added to the following distance. Equation (4) was used to compute the mean headways by vehicle type.

$$(4) \quad H_{V,S} = Length_V + Following\text{Distance}_{C,S} + \partial Following\text{Distance}_{\text{V}}$$

where
H = headway
V = vehicle type (cars, pickups, minivans, SUVs)
S = speed category
$FollowingDistance_{C,S}$ = following distance for car-car pairs by speed category
$\partial\, FollowingDistance_V$ = change in following distance by vehicle type

The average lengths by vehicle type are: cars—4.600 meters, pickups—5.900 meters, minivans—5.029 meters, and SUVs—4.907 meters.[8] For a baseline, the car-car headways were computed at each of the eight speed categories using the regression results in Table 4. Next, the LDT-car headways were computed for each of the three LDT types at each of the eight speed categories. A weighted average of the headways by the number of observations from each speed category was taken to arrive at the final headway values for each vehicle type. Finally, equation (5) was used to compute the passenger car equivalencies for each LDT type.

(5) $$E_V = \frac{H_V}{H_C}$$

where:
E_V is the passenger car equivalency for each vehicle type
H_V is the weighted average headway by vehicle type from the front bumper of the lead vehicle to front bumper of the following vehicle
H_C is the mean headway for cars from the front bumper of the car to front bumper of the following car

The PCEs by vehicle type are: pickups—0.99, minivans—1.04, SUVs—.09.

These PCEs can now be incorporated into the standard HCM capacity equation (2000) to adjust for the effects of LDTs in traffic.[9] Equation 6 shows the proposed LDT adjustment factor akin to the existing heavy vehicle adjustment factor from equation 3.

(6) $$f_{LDT} = \frac{1}{1 + P_P(E_P - 1) + P_M\left(E_M - 1\right) + P_S\left(E_S - 1\right)}$$

where:
P_P = percentage of traffic that is pickup trucks
E_P = passenger car equivalent for pickup trucks
P_M = percentage of traffic that is minivans
E_M = passenger car equivalent for minivans
P_S = percentage of traffic that is SUVs
E_S = passenger car equivalent for SUVs

In the sample studied, pickup trucks were the lead vehicle in 12% of the observations. Minivans were the lead vehicle in 12% of the observations and SUVs were the lead vehicle in 25% of the following events. These values are reasonable to use in the adjustment factor calculation as they combine to 49%, which is close to the 52% of new vehicles sold between 2001 and 2009 that were LDTs (AutoExec 2010). As a result, the LDT adjustment factor is 0.975. In other words, ceteris paribus, the presence of this combination of LDTs reduces highway capacity by 2.5%.

CONGESTION COSTS FROM MIXED VEHICLE TRAFFIC

Any estimation of the congestion costs from mixed vehicle traffic must be made and interpreted with caution given the number of variables involved. For a reasonable, albeit conservative, approximation, the 2010 Urban Mobility Report (UMR) data for the Detroit area can be used with the data above to estimate the spillover cost from mixed vehicle traffic. According to the UMR, the annual congestion cost for the Detroit area in 2009 was \$2.032 billion. UMR uses a value of time equal to \$16.01 per hour and a commercial value of time for heavy truck traffic equal to \$105.67 per hour. The report counts 250 working days per year and assumes a vehicle-occupancy rate of 1.25 passengers per vehicle. It is important to note that a disproportionate amount of the cost tallied in the UMR stems from heavy truck traffic, which would be present with or without LDTs. The UMR attributes \$551 million of the total cost for Detroit to heavy truck congestion costs (Schrank and Lomax 2010). The remaining \$1.481 billion results from mixed LDT and car traffic.

The relationship between capacity and delay costs is nonlinear. However, without a complex simulation that is outside of the scope of this paper, it is difficult to apply this nonlinear relationship to link the capacity reduction to delay costs. As a result, a linear relationship is assumed. This assumption could present two problems. The first would result in an overstatement of costs associated with mixed vehicle traffic while the second would result in an understatement of these costs. First, when demand is relatively low, a reduction in capacity may not cause any delay at all. This problem does not affect the computations included in this paper because the UMR only accumulates costs when delay is occurring. Therefore, there is no overstatement of costs associated with mixed vehicle traffic. Second, when demand is relatively high, a reduction in capacity is likely to result in a much greater than proportional increase in delay. Assuming a linear relationship smoothes the exponential increase in the speed-flow curve (Walters 1961) and, thus, understates the true costs of LDTs in the traffic mix. While this approach is suboptimal, it provides a conservative estimate of the effects of LDTs on delay costs.

Using the UMR data and the adjusted highway capacity level computed above, a comparison can be made between the costs when traffic comprises only cars and heavy trucks and when LDTs are added to the traffic mix. Compared with the mixed vehicle scenario, 2.5% more capacity would exist if only cars and heavy trucks were in traffic. Assuming a linear relationship between capacity and delay costs, $37 million annually in congestion costs could be avoided without LDTs in the traffic mix.

Care must be taken in applying the estimates from Detroit to the remainder of the country because of potential differences in driving behavior, composition of traffic, and congestion levels. However, a rough estimate of the nationwide annual congestion cost from delay attributable to the mix of cars and LDTs can be derived in the same format described above. UMR estimates $115 billion in annual congestion costs nationally, of which $33 billion is attributed to heavy trucks (Schrank and Lomax 2010). Applying the 2.5% reduction in capacity found in the Detroit area, the additional congestion cost from LDTs in the vehicle mix is $2.05 billion annually for the United States. It is important to point out that these conservative calculations account for congestion costs only. There are documented safety effects of vehicle mismatch and corresponding accident costs. The computation of those costs is outside the scope of this paper.

CONCLUSION

This analysis results in several interesting conclusions. For the first time in a study of mixed vehicle traffic, LDTs are divided into categories, and the estimates reveal that following behavior differs dramatically by these categories. Car drivers follow pickup trucks more closely than they follow cars, and car drivers leave a cushion behind SUVs about equal to the distance they leave behind heavy trucks. The additional following distance behind SUVs results in a PCE of 1.09, while pickup trucks are nearly equivalent to cars with a PCE of 0.99. The capacity of a highway computed using the standard HCM equations is overstated by 2.5%, given the percentages of each type of LDT present in this study. The external cost on the transportation system is estimated to be approximately $37 million annually in the Detroit area and $2.05 billion annually for the United States as a whole.

While the reduction in capacity and corresponding external time cost from mixed vehicle traffic is not huge, there are policy implications from these results. First, the effects of the blind spot externality could be internalized with a toll that varied by vehicle type. For a discussion of this approach, see Cosgrove and Holahan (2010). Moreover, transportation planners should incorporate the PCE for SUVs when computing expected capacity from lane additions or extensions so that they do not overstate the benefits of an expansion project.

Endnotes

1. Values are weighted averages of the specifications for the top 10 cars, top five SUVs, top five pickup trucks, and top three minivans sold between 2002 and 2005.

2. The cars were outfitted with cameras, radars, and computers to record extensive data every time the vehicle was being operated.

3. For additional details on the RDCW Field Operational Test, please see LeBlanc et al. (2006).

4. A density value was determined by computing a smoothed three-minute moving average of the number of persistent vehicles moving in the same direction as the instrumented vehicle. Traffic was classified as dense when the smoothed average was greater than four.

5. Results from the fixed effects model are available from the author by request.

6. The RDCW system alerts drivers when they are drifting from their lane and when they are approaching a curve too rapidly. As a result, there is no reason to think observations of following distance with the system enabled will be unduly biased. Still, the variable will be tested.

7. Following distance is one of several factors that should be considered in computing a passenger car equivalency (PCE) for heavy trucks. SUVs should not be counted as heavy trucks for capacity calculations, nor should they be considered identical to cars. The details of the recommended PCE for SUVs are discussed in the sixth section.

8. These are the values found in the first section converted to meters.

9. Including the E_S equation in the HCM capacity equation and examining the relationship between flow rate and vehicle mix reveals an asymmetric U-shaped curve where capacity is lowest with 75% SUVs.

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Pre-Determining Performance-Based Measures for Managed Lanes

by Mark W. Burris, Chao Huang, Tina Geiselbrecht, Ginger Goodin, Matthew MacGregor

The operational decisions facing managed lanes can be highly politicized and difficult to make quickly. For example, changing the operating parameters such that a user class can no longer access the lanes may require extensive public debate and ignite controversy. This research examined managed lanes across the country and found that none had developed plans on how to deal with such situations as they arise in the future. We found there are significant potential benefits for agencies if they use operational goals for their managed lane facilities to guide decision making prior to the point it becomes critical. In addition, the policies developed act as a performance promise to managed lane users.

INTRODUCTION

Over the past several years, transportation agencies around the United States have implemented many transportation innovations to meet the mobility needs of a growing population and the economy. These innovations have included High Occupancy Vehicle (HOV) lanes, High Occupancy Toll (HOT) lanes, managed lanes (ML) and toll roads. HOV lanes are those which restrict access to vehicles with multiple occupants (often two or more people per car, HOV 2+). Similar to HOV lanes, HOT lanes allow free access to vehicles with multiple occupants, and allow single occupancy vehicles (SOVs) to use it for a toll. Managed lane is a more general term that encompasses both HOV lanes and HOT lanes, plus other facilities/lanes that limit/regulate access to improve facility performance. Whenever these projects are considered, there are a range of policy decisions that must be addressed, some of which can be controversial. Moreover, the operating characteristics of a project are likely to change over time, requiring additional policy decisions to adjust operating strategies to match the new operating characteristics. A literature review indicated that very little research has been conducted specifically related to using performance measures to set toll rates, other than what is implicit in toll rate settings as a part of typical pre-project traffic and revenue analyses. As regions, areas, cities, and states further their operations to include pricing, it will be important to have thought through the process of change in advance. Doing this provides more time to actually discuss and evaluate pre-approved approaches to achieve mobility with pricing in a more efficient manner. This study reviewed the state-of-the-practice in operational performance management of tolled and managed lane facilities and captured the methods that agencies use to set tolls to manage performance. This information was used to develop a multi-faceted framework to aid in operational decisionmaking over the life of a managed lane facility.

Though a specific procedure or methodology is not required for states to determine if the operational performance of an HOV facility is degraded, the Federal Highway Administration (FHWA) suggests a minimum average operating speed for HOT facilities (FWHA 2008a). According to this source, speed should be maintained at 45 mph for HOT facilities with a speed limit of 50 mph or greater, and not more than 10 mph below the speed limit for a facility with a speed limit of less than 50 mph. Section 166(d)(2)(B) of this source provides that a facility is considered degraded if it fails to maintain a minimum average operating speed at least 90% of the time over a consecutive 180-day period during morning or evening weekday peak periods (or both for a reversible facility).

According to the FHWA (2008a), the vehicle-occupancy requirements for carpools have evolved over time from initially a three or more (3+) occupancy level used in many projects to a two-person per vehicle (2+) carpool designation currently on some facilities. Currently, 185 of the

HOV facilities in this country (54%) use purely two or more people (2+) per vehicle requirement, and there are 14 facilities that use purely three or more people per vehicle occupancy requirement (Chang et al. 2008). There are some instances in which changes in the designated vehicle-occupancy restrictions occurred over the life of an HOV facility. For instance, on both the I-10 West and U.S. 290 HOV lanes in Houston, the HOV lanes using the two or more people per vehicle occupancy requirement have experienced congestion resulting in reductions in trip time reliability and slower travel times. As a result, the vehicle-occupancy requirements were increased to three or more (3+) during the morning and afternoon peak-hours (morning only on U.S. 290). Facilities like the El Monte Busway on I-10 in Los Angeles, Nimitz Highway in Honolulu, Hawaii and the U.S. 290 and I-10 West HOV lanes in Houston require three or more occupants during specific peak hours and a two or more people per vehicle requirement at other times (Burris and Stockton 2004). Studies have shown that in changing from HOV2 to HOV3+, vehicle demand may be reduced by 75% to 85% (California Department of Transportation 2003). Such adjustments may be too severe if only a moderate reduction in demand is necessary to maintain free-flow conditions.

Though the FHWA has provided recommendations on vehicle occupancy requirements and performance standards for HOT lane projects in the United States, the operating characteristics of a project are determined by local factors that are likely to change over time as well. The following sections present a brief literature review and describes existing and future operating policies of several facilities.

LITERATURE REVIEW

Texas has a long-standing tradition of using variable operating strategies to meet the needs for mobility. Toll roads were first initiated in the Dallas-Fort Worth area with the completion of the Dallas-Fort Worth Turnpike in 1957. This facility and others are operated by the North Texas Toll Authority. The toll roads in Houston, operated by the Harris County Toll Road Authority and the Central Texas Turnpike Project in the Austin area and Loop 49 in Tyler operated by the Texas Department of Transportation (TxDOT), are traditional toll roads with a toll rate determined by vehicle type regardless of occupancy or time of day. The advantage of this methodology is its simplicity; it is easy to communicate with the user. However, it does not manage congestion on the facility and does not fully utilize the limited capacity of the facility (Goodin et al. 2011).

To address urban freeway congestion, transportation planners have looked to HOV lanes for the past three decades. Beginning with the I-45 Contraflow Demonstration Project in Houston, HOV facilities in Texas have proven to be an effective mobility strategy by offering a reliable high-speed option with travel time savings for bus riders, carpoolers, or vanpoolers. Texas has also had unique experience in addressing operational concerns by modifying vehicle eligibility requirements in HOV lanes and evaluating the impacts, particularly on the Katy HOV lane in Houston. When the Katy HOV lane was opened in 1984, only authorized buses and vanpools were allowed. Gradually between 1984 and 1987, 4+ carpools, then 3+ carpools, and then 2+ carpools were allowed, and with each step the change was evaluated from an operational standpoint.

When congestion worsened on the Katy Freeway HOV lane, the occupancy restriction was shifted back to carpools with three or more occupants (HOV3+) during the peak periods. Houston is the only location where HOV2+ lanes have been successfully converted to HOV3+ lanes (note that I-95 in Miami recently converted from HOV2+ to HOT3+). There are many congested HOV lanes across the country in cities such as Los Angeles, Seattle, Long Island, and Atlanta, where life-cycle operating frameworks were not put in place to identify the performance thresholds that would trigger a change from two or more to three or more occupants per vehicle. As a result, one of the most pressing issues facing HOV operators today is how to address growing congestion in HOV lanes through increasing occupancy requirements given the absence of an operating policy framework.

One step beyond HOV lanes are HOT lanes, which use both occupancy and pricing restrictions as a strategy for meeting multiple performance objectives in congested urban freeway corridors. Operational HOT lanes use both variable pricing and dynamic pricing to manage SOV demand for the HOT lane. Variable pricing, where the price of access for SOVs varies based on time of day and day of week, is currently in operation on four HOT lanes (I-25 near Denver, SR-91 near Los Angeles, I-10 in Houston, and U.S. 290 in Houston [HOV2 pays on U.S. 290]). Dynamic pricing, where the price of access for SOVs varies based on current traffic conditions, is currently in operation on seven HOT lanes (SR 167 in Seattle, I-95 in Miami, I-394 and I-35 in Minneapolis, I-15 in San Diego, I-680 in Alameda County, California, and I-15 in Salt Lake City).

Pricing (variable and dynamic) has been demonstrated in practice as the only strategy that has the ability to truly manage demand on a real-time basis (Goodin et al. 2011). Take for example, the operating policy of the I-394 MnPass express lane in Minnesota. The dynamic pricing on this lane is designed to ensure continuous free flow in the lanes by adjusting the toll up or down depending upon the amount of traffic in the lanes (Burris and Goel 2009). SOVs must pay the variable per-trip fee to use the lanes during peak hours. The amount of the fee is posted on changeable message signs located just before the entrances to the MnPASS lanes. The fee can be adjusted as often as every three minutes to keep traffic at free-flow levels. This works well as a short-term method to keep traffic at free-flow levels on this lane, and it is working well on all HOT lanes. In the long term, it is possible to have too many HOVs to allow SOVs access to the lane at any price. However, there is no predetermined level when this change would occur or a policy regarding how it would happen. Without these policies and thresholds in place, adjustments to the operating procedures can be a difficult and time-consuming process.

DATA COLLECTION

A state-of-practice review through phone interviews of key personnel in agencies with operational projects plus website exploration of individual managed lanes projects across the country were used to obtain data for this study. Data and information were collected to answer the questions in the Appendix. These questions related to the goals and objectives of the projects, changes in toll rates, the presence of a policy framework for the facility and changes in that framework, how changes in the policy framework were communicated to stakeholders, and stakeholder reaction to changes in policy. Additional information was gathered on the types of performance data used and how they are collected. The study gathered this information from randomly selected 20 projects, which included HOT lanes, express lanes, a priced queue jump, conversions from HOV to HOT, and traditional toll roads. Information on 12 of the projects was collected via phone interview and the rest through exploration of project websites and other sources. Because of space limitations, we discuss in detail six projects in this paper.

RESULTS

SR167 HOT Lanes Pilot Project

Washington State's first HOT lanes opened on State Route 167 (SR 167) on May 3, 2008. The HOT lanes were converted from existing HOV lanes and now offer SOVs the option to pay a toll to use the lanes. Two general purpose lanes remain toll-free and open to all traffic in each direction. Carpools of two people or more, vanpools, transit, and motorcycles use the HOT lanes toll free (Washington Department of Transportation 2010). To ensure traffic in the HOT lane always flows smoothly, the toll paid by the SOVs is adjusted every five minutes and ranges from $0.50 to $9.00 based on real-time traffic data, including vehicle speed and traffic volumes, which are collected by loops underneath the pavement. The toll rate varies with traffic such that it is higher when traffic slows down and it is lower when traffic is moving at a high speed. In addition to testing the HOT lane concept, the goals of the project included gauging public interest, gathering data, improving freeway efficiency (speed and traffic volumes), and safety (crashes, etc.) plus the ability to finance improvements (reconstruction and operations costs) through tolls. Performance data, speed in this case, are collected by loops located every half mile, and tolls are used to finance the construction, operation, and improvement costs in this corridor.

The Washington Department of Transportation (WSDOT) proposed an initial toll range with a price cap of $9.00. Once the cap is reached, the HOT lanes will be reverted to HOV-only lanes. The $9.00 price cap was partially selected by looking at Minneapolis' I-394 price range. The Washington State Legislature (WSL) requires the Transportation Commission to review the toll charges periodically to determine appropriate toll rates, which maintain travel time, speed, and reliability on the highways (WSL 2005). WSDOT annually reports to the Transportation Commission and the legislature on operations and findings. The report includes data regarding facility use, a review of the impacts of the HOT lanes on several areas—including freeway efficiency and safety, effectiveness of transit, throughput, and vehicle movement by mode, if collected toll revenue is sufficient to finance improvements and transportation services, and the impacts on all highway users (WSL 2005). As stated in the Revised Code of Washington (RCW 47.56.403) (WSL 2005), the commission may offer a toll discount to inherently low-emission SOVs. The department is also responsible for, through modifying the pilot project, addressing identified safety issues and mitigating the negative impacts to HOV lane users. The pricing algorithm used by this project was designed to maintain speeds of at least 45 mph for 90% of the time during rush hour in the HOT lanes. If deemed appropriate, the Commission may vary the toll by time of day, level of congestion, vehicle occupancy, and other criteria. Combining the traffic volume and lane speed, the pricing algorithm software calculates the corresponding toll rates every five minutes to manage the number of single occupant vehicles entering the HOT lanes.

After the first year of operation, WSDOT stated that the HOT lanes were working by saving people time, providing commuters with more options, and improving the use of SR 167 (WSDOT 2010). For example, commuters in the HOT lanes typically save three to eight minutes on each trip, depending on direction. During the first year of operation, the project did not have adverse effects on safety. In fact, from May 2009 through December 2009 there was a 17% reduction in monthly collisions. Despite this finding, additional data are needed to corroborate it.

Express Toll Lanes on I-30/Tom Landry in Dallas

In Dallas, the express toll lanes on I-30 are managed HOV lanes in the median of a general purpose freeway. The I-30 corridor serves as the region's test bed for value pricing so that potential strategies can be examined and adjusted before being applied in other corridors. The MLs have been established to serve several objectives such as "reduce SOV travel by providing travel-time and pricing incentives to HOVs and transit passengers; make available high-speed reliable travel to all users in the corridor (>50 mph); and create revenue generation to pay for the MLs' ongoing operation and maintenance" (Macias et al. 2009). In accordance with approved regional policies, SOVs are allowed to use the managed HOV lanes by paying a fee. The facility initially opened as HOV-only lanes in the first phase and is proposing to shift into "Express Lanes" later once installations of tolling equipment are completed (currently anticipated to open sometime after 2012).

During the HOV-only phase, HOV2+, vanpools, motorcycles, and transit vehicles will be allowed to use the facility free. Variable pricing will be applied in the second phase and certain users (HOVs and motorcycles carrying a valid transponder) will receive a discount during peak hours (6:30 a.m.–9:00 a.m. and 3:00 p.m.–6:30 p.m.). The current HOV-only mode is being operated by the Dallas Area Rapid Transit (DART), which is responsible for lane opening/closing, incident management, lane communications, operational enforcement, occupancy enforcement, and performance data collection. Performance data are collected on a regular basis and help in developing the pricing algorithms for the project.

During the value pricing phase, two stages are planned: fixed schedule mode and dynamic mode. Poe and MacGregor (2008) indicated that "a fixed-fee schedule will be applied during the first six months of operation; dynamic pricing will be applied thereafter. The toll rate will be set up to a $0.75 per mile cap during the fixed-schedule phase. Toll rates will be updated monthly during the fixed-schedule phase and single-occupant vehicles will pay the full rate. During the dynamic-pricing phase, tolls will be rebated if the average speed drops below 35 miles per hour." In the fixed schedule mode, the toll rate schedule is manually calibrated to maintain the desired level of service (average speeds greater than 50 mph) (Macias et al. 2009). The frequency of the calibration cannot be more than once every 30 days. The dynamic mode will start operating after the initial 180 days of operation in the fixed schedule mode. It is anticipated that the initial use of the collected revenue will be to pay for toll collection, and operational and maintenance costs of the managed lane. Depending on the extent and funding of the pricing infrastructure, there may be a need to use any excess revenue to offset capital expenditures.

SR 91 Express Lanes in Orange County

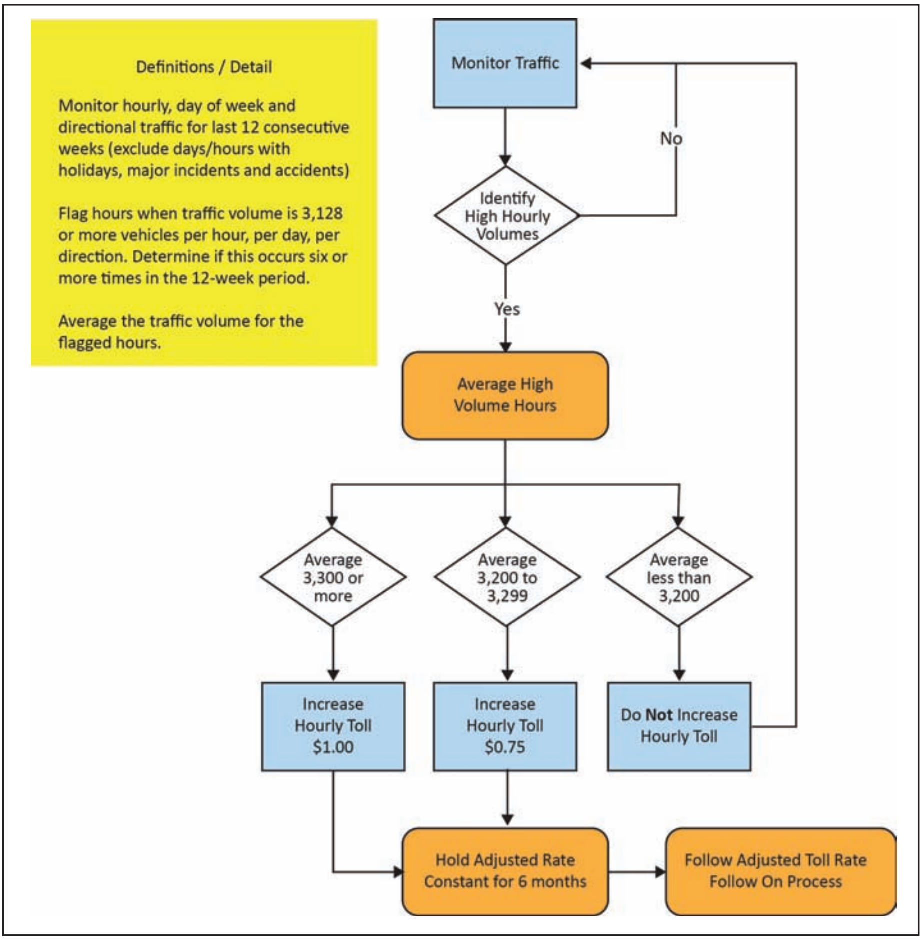
The SR 91 Express lanes began as California's first modern, privately owned toll road. The facility is 10-miles long with two lanes in each direction and all tolls are paid electronically. The road was purchased by the Orange County Transportation Authority (OCTA) in 2003. As the operating agency, the OCTA sets toll policies to optimize traffic at free-flow speeds. This toll adjustment serves several goals such as: a) reducing congestion by diverting traffic to non-peak period, b) maintaining free-flow speed on the express lanes and offering travel time savings, c) meeting increasing travel demand in the future, and d) generating sufficient revenue for the operations and maintenance of the express lanes. The performance data collected are hourly, daily, and directional traffic volumes. This project defines a "super peak" as the hourly period per day and per direction when traffic volumes meet or exceed a designated trigger point defined as 92% of the maximum optimal capacity of the lanes (3,400 vehicles per hour [vph] per direction).

The toll rates for the SR 91 express lanes are determined following OCTA toll policies (OCTA 2003). To implement these policies, the operating agency continually monitors hourly traffic volumes in the SR 91 express lanes. Traffic volumes greater than 3,128 vehicles per hour per direction are flagged for further review. If the average directional volume of flagged traffic exceeds 3,300 vehicles per hour, the toll is increased by $1.00. If the average directional volume of flagged traffic is between 3,200-3,299 vehicles per hour, the toll is increased by $0.75. If directional volumes are less than 3,200 vehicles per hour, then the toll is not changed (see Figure 1). The current minimum toll is $1.00 ($0.10/mile) and the maximum is $9.90 ($0.99/mile). A review is conducted six months after a toll increase that examines the most recent 12 consecutive weeks of traffic volumes. Weeks that a major traffic anomaly occurred due to a holiday or an accident/incident are not counted. If traffic volumes have dropped by a large amount (see Figure 2), the toll is reduced by $0.50 to encourage more demand and subsequently better use of the SR 91 Express Lanes. There is at least a 10-day notice to the OCTA's Board of Directors and customers prior to a toll adjustment becoming effective. Tolls outside "super peak" hours are adjusted to account for annual inflation.

To encourage carpooling, there are discounts for vehicles with three or more persons (HOV3+). Such vehicles can ride free in the SR 91 express lanes during most hours, except from 4:00 p.m. to 6:00 p.m. weekdays in the eastbound direction when they pay 50% of the toll. This exception will remain in effect unless the debt service coverage ratio is projected to be 1.2 or greater for a six-month period. In that case, HOV3+ will travel completely free every day (OCTA 2003).

The SR 91 Express Lanes 2009 Annual Report (OCTA 2009) indicated that the "Three Ride Free" trips accounted for 22% of the total SR 91 express lanes trips, and this Three Ride Free policy turned out to be effective in encouraging "more people to ride together and cut their travel time and

Figure 1: Toll Policy Decision Process



Source: OCTA (www.91expresslanes.com)

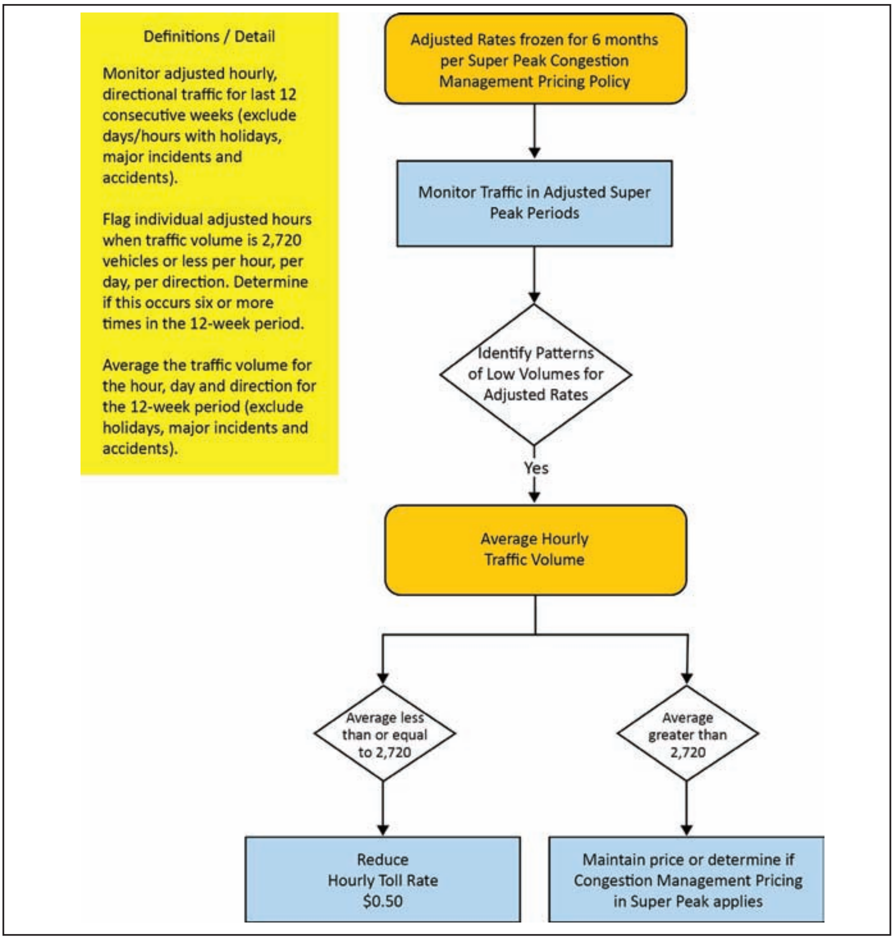
save money during tough economic conditions." The report also states that apart from being used for operations, maintenance, and debt payments, excess revenues will be used for improvements along the SR 91 corridor.

MnPASS Express Lanes on I-394 in Minneapolis, Minnesota

The conversion of the original I-394 HOV lanes to HOT lanes in Minneapolis was authorized by the Minnesota Legislature in 2003, and the first phase of the project opened in May 2005. The HOT lanes were the first of their kind in Minnesota. These lanes are known as the MnPASS Express Lanes and allow SOVs to pay a toll to access the HOV lanes. However, carpools and buses have priority and use the HOV lanes toll-free.

As stated in the provisions of the toll lane legislation (MnDOT 2003), the Commissioner of Transportation is responsible for the implementation of user fees on HOV lanes. The commissioner could also adjust the occupancy requirements to HOV3+ to ensure traffic flows freely. However, it is likely that the legislature would want to be involved in that decision. The goals of the HOT lane are to improve operating efficiency in trunk highway corridors and provide travelers with more options. Moreover, the legislation defines the way collected fees are to be used: "1) repay trunk highway fund or other fund source for cost of equipment and modifications in the corridor, 2) cover the costs of implementing and administering the fee collection system" (MnDOT 2003), and excess

Figure 2: Adjusted Toll Rate Follow On Process (Super Peak Adjusted Rates Only)



Source: OCTA (www.91expresslanes.com)

revenues shall be spent half on capital improvement in this corridor and the other half transferred to the Metropolitan Council for expansion and improvement of bus transit services in this corridor. The I-394 project goals are: “1) to improve the efficiency of I-394 by increasing the person- and vehicle-carrying capabilities of HOV lanes, 2) to maintain free flow speeds for transit and carpools in the Express Lanes, 3) use excess revenue to make transit and highway improvements in the I-394 corridor, 4) to use electronic toll collection and 5) to employ new Intelligent Transportation System (ITS) technologies such as dynamic pricing and in-vehicle electronic enforcement” (Minnesota Department of Transportation 2004). The use of the toll revenue is directed by the authorizing legislation: first to cover operating costs, then if there is any excess revenue, to make transit and highway improvements in the I-394 corridor.

The I-394 project is designed for better use of the capacity in the corridor. Traffic speeds are maintained at or near posted limits by a dynamic pricing strategy which adjusts the toll rates based on demand and use of the lanes. Information on travel speeds and traffic density in the lanes are collected by loop detectors located every half mile on the highway. According to the legislation, the toll rates may adjust by time of day or vary with congestion. The express lanes remain free to HOVs and motorcyclists during peak hours and to all users in off-peak periods. The toll rates are dynamically adjusted every three minutes to manage the traffic at free-flow speed. The average peak period toll varies between $1.00 and $4.00 depending on the level of congestion in the MnPASS express lanes, and the rates are set between $0.25 per segment up to a maximum of $8.00

for traveling the entire corridor. This ensures that traffic in the MnPASS express lanes continues to flow at 50 to 55 mph.

Since the conversion of the I-394 HOV lanes to HOT lanes in 2005, the performance of the entire facility has improved significantly and it has received wide public satisfaction and support (URS Corporation 2008). The amount of traffic on the MnPASS lanes has increased by 33%, peak hour volumes have increased by 5%, while the HOT lane still maintains targeted levels of service. The goal of maintaining 50-55 mph on the MnPASS lanes at least 95% of the time has been achieved. A comparison of crash rates over the last three years shows there has been a 12% decline since MnPASS began.

Also, the operators have the authority to override the current state of the HOT lane. The three override states are: "Closed to all traffic in either direction; Open to HOV traffic only northbound or southbound ($0.00 rate for HOV, all others are violations); Open to all traffic ($0.00 rate for all, no violators)" (MnDOT 2008). In emergencies or special situations, the override state reflects the 'state' of a lane and independent of the rate information.

Express Lanes on Interstate 15 (I-15) in San Diego: Previous and Current Policy

Previous Policies (Prior to March 2009). The "FasTrak" pricing program in San Diego was implemented in April 1998. This program allows SOVs to pay a toll each time they use the express lanes and the toll rates vary with time of day and traffic flow in the I-15 express lanes. These express lanes extend from SR 56 in the north to the SR 163 and the I-15 split in the south. It is currently (July 2011) open as a two-lane reversible facility but is being widened and will be four lanes in 2012. Fees are adjusted in $0.25 increments as frequently as every six minutes to help maintain free-flow traffic conditions on the express lanes. The toll varies between $0.50 and $4.00, and it could be as high as $8.00 during very congested periods. Pricing is based on maintaining a level of service (LOS) "C" for the express lane facility (Wilbur Smith Associates 2009). This LOS of "C" equates to nearly a free-flow traffic condition. The primary goals of the project are to maximize the use of the existing I-15 express lanes and to fund new transit and HOV improvements in this corridor. According to the Value Pricing Project Quarterly Report (FHWA 2008b), approximately 75% of the traffic on the I-15 express lanes travel for free during weekdays (HOV2 or more for free) and the rest are SOV paying customers. Collected tolls are used to pay for express bus service in the corridor, HOV enforcement, and operations, and maintenance costs of the Electronic Toll Collection (ETC) system, and the customer service center. In 2002, about $2.2 million in toll revenues were collected; approximately 50% was used to fund the Inland Breeze Express Bus Service operating in the corridor and the other 50% to the enforcement activities of the California Highway Patrol, the operation of the ETC system, and the customer service center (FHWA 2008b). Survey results of public responses to the concept indicate that both users and non-users of the dynamically priced express lanes strongly support the use of price as a strategy to improve traffic (FHWA 2008b).

Supernak et al. (2001) evaluated the I-15 pricing project using a wide range of quantitative data, including traffic volumes, travel modes, vehicle speeds, travel times, and violations, and found that it made better use of the express lanes, increased subscriber vehicles, and generated sufficient revenue to fund transit improvements in the corridor. Also they found that it did not negatively affect the number of carpools on the express lanes and there were substantial increases in HOV volumes during its implementation. In addition, due to its good performance in redistributing traffic from the middle of the peak to the peak shoulders, FasTrak is capable of maintaining free-flow conditions at all times, as required by California law, despite steadily increasing volumes on the express lanes.

Current Policies (Post March 2009). The extension of the I-15 express lanes from SR 56 to Del Lago opened in March 2009 and with it, all express lanes (SR 163/I-15 split to Del Lago) now operate as described. The lanes are designed to provide a platform for new technology, including electronic sensors monitoring the traffic flow, a sophisticated congestion pricing system that adjusts the toll rate based on the level of congestion in the express lanes, and a moveable barrier allowing for directional expansion during the morning and afternoon peaks. All these innovations provide sufficient flexibility to meet current traffic demand and accommodate projected growth in the future. Although there are no written goals, our survey revealed that maximizing throughput and efficiency of the system was paramount. Carpools, vanpools, and transit have priority to use the express lanes, and the remaining capacity is sold to SOVs. The collected tolls are used in maintenance of back office operations, customer service, operations and maintenance of the facility, including moving the reversible barrier, and excess revenues that go to a reserve account. The survey respondent also indicated that the transit operator receives $500,000 per year from excess revenue if available.

Contrary to the previous volume-based pricing system, in 2009 the I-15 express lanes started a distance-based pricing strategy that dynamically varies the per-mile toll rate every few minutes based on the level of traffic in the express lanes to maintain free-flow traffic. The initial rates were developed by Wilbur Smith Associates (2009) and approved by the legislature and the San Diego Association of Governments (SANDAG) Board. The SANDAG Board of Administration has the authority to set toll rates between $0.50 and $8.00. The current pricing approach on the reversible express lanes ensures level of service “C” by measuring actual volume and comparing it to the facility’s design capacity. Density is measured at four toll plazas and it is also used as performance data. The toll-setting algorithm considers density at downstream plazas to make adjustments to the current toll rates.

HNTB Corporation (2006) indicates that Caltrans has installed vehicle detectors at strategic locations along the express lanes and adjacent to the general purpose lanes to collect congestion data. Vehicle location, speed, and volume data are collected through inductive loop detectors for all lanes and segments in both directions and are transmitted to the Traffic Management Center (TMC). With these data, operators in Caltrans TMC can compare the performance of the I-15 corridor between the express lanes and the general purpose lanes, and then make effective traffic management decisions.

The express lanes provide all travelers with a reliable travel option. HOVs, motorcycles, transit, and approved hybrid vehicles continue to use the lanes free. However, SOVs now have the option to pay to use the lanes and receive a reliable trip. Statistics from SANDAG show that the average traffic volume on the entire I-15 facility ranges from 170,000 to 295,000 vehicles a day and vehicles on the general purpose lanes (GPLs) usually are subject to 30 to 45 minutes delay at peak periods. Traffic in the corridor is projected to be approximately 380,000 vehicles a day by 2020 (San Diego Association of Governments 2010), which necessitates improvements in pricing strategies to meet growing demand.

Interstate 95 (I-95) Express (Miami). In December 2008, the northbound express lanes on I-95 between I-195/SR 112 and NW 151st Street on I-95 were opened for tolling in Miami-Dade County. Carpools (HOV3+), hybrid vehicles, and South Florida Vanpools drive toll-free after registering with South Florida Commuter Services. Motorcycles and emergency vehicles can use the express lanes toll-free and do not need to register. The goals of the project are to maximize throughput, improve operations of HOV lanes which were over capacity during peak periods, increase HOV restrictions from four hours to 24 hours daily, and utilize the surplus capacity of the HOV lanes when available by making SOV drivers pay a toll. Other goals are to maintain free-flow speed and travel time savings on the express lanes, increase trip reliability, and provide incentives for transit and carpooling. Still others are to reduce congestion by diverting traffic to non-peak periods, meet increasing travel demand in the future, and facilitate trip-reducing carpool formations.

To achieve the goal of maintaining free-flow speed on the express lanes, traffic equilibrium was found between the target of maintaining 45 mph speed for most of the time and not setting the toll so high that this speed is achieved 100% of the time. To maintain free-flow conditions (45 mph) along the express lanes, the operating agency used an algorithm guided by project-specific rules, which enabled the software (Express Lanes Watcher) to recommend toll changes every 15 minutes. The software collects real-time traffic data from the express lanes, compares it to historical data, and analyzes this information to dynamically generate tolls based on traffic density within the express lanes. The toll rates were set by the Florida Legislature on recommendations from the Florida Department of Transportation (FDOT). The congestion-priced tolls vary from $0.25 to $3.50 between the Golden Glades Interchange to downtown Miami, and they can increase to $7.10 when traffic experiences extreme conditions to offer trip reliability similar to those choosing the express lanes. The rates are equivalent to a minimum $0.03/mile to a maximum $1.00/mile (FDOT 2010). A minimum $0.25 toll is collected for each segment travelled. Toll rates are set based primarily on speed, though there are other affecting factors such as density and occupancy. Slight changes to operations are under the jurisdiction of FDOT. However, significant deviations to operating policies have to be approved by the Florida Legislature. There have been no changes to date.

Performance data (speed, volume, and occupancy) are collected every 0.33 mile on the freeway, including the express lanes and general purpose lanes. The operating speeds and LOS in the express lane and adjacent GPLs are collected via microwave sensors (WaveTronix and Electronic Integrated System Incorporated [EIS]) and loops on ramps. Tolls are the sole source of revenue and are used in priority order for operation and maintenance of the lanes, repaying the contractor who put up advance funding, transit, and any state road.

DISCUSSION

The study found that most surveyed agencies had some written goals and objectives (see Table 1). In addition, pricing is frequently used as a tool to meet these goals. However, in the long term, most express lanes must confront more than just pricing (for example, occupancy requirements) will need to change to meet the goals of the facility. No agencies contacted have an advance policy to address changes in the number of passengers required for free travel in a HOT lane. This difficult decision is always left to a future governing body.

Also, the study found that most agencies operating express lanes have preferred vehicles, including buses, carpools, motorcycles, and sometimes low emission vehicles. Although the express lanes may be operating with a set of high priority user groups in mind, it may be useful to rank the groups to ensure that operational or policy changes are accommodated and decisions made based on the groups most preferred. The survey revealed that the preferred vehicles for express and other managed lanes are transit, HOV3+, HOV2, SOVs, low emission/"green" vehicles, fuel efficient vehicles, motorcycles, off- and on-duty law enforcement/ambulance/fire vehicles, and trucks. Low-income travelers were mentioned but not explicitly given any priority or discount.

The goals, performance measures, change triggers and preferred user groups, if available, are shown in Table 2. Notice that the SR 91 Express Lanes in California are the only example where specific traffic volumes, and therefore congestion levels, result in specific price changes. This project had the most clearly defined triggers and actions to ensure performance. Originally built by a public-private partnership, the OCTA bought out the franchise eight years after its initial opening (Corridor Watch 2007).

> "One of the challenges faced when OCTA bought the SR 91 Express Lanes was how to design and implement a congestion management toll policy administered by a board of publicly elected officials. OCTA implemented a Toll Policy that adjusted toll rates based on the number vehicles on the SR 91 Express Lanes and based on its stated goal to maintain a "free flow" commute at all times. As a result, toll adjustments do not need a Board vote each time ... To date, OCTA has adjusted 18 peak period hours based upon traffic volumes" (The International Bridge Tunnel and Turnpike Association 2010).

It is difficult to imagine a public agency going to its board of directors 18 times over nine years for a change (usually an increase) in toll rates.

All the HOT/Express/MLs projects recognize that varying the toll rate for the least preferred user group (SOVs in most of these cases) is necessary to ensure the free flow of traffic. For some lanes, this policy effectively manages demand for many years due to the capacity of the lanes and

Table 1: Summary of Typical Goals and MOEs of Investigated Projects

General Goal	Project Goals	Measures of Effectiveness
• High-speed travel	• Improving freeway efficiency • Maintain desired level of service • Save travel time • Maintain free flow speed • Maintain a speed for 90% of the peak periods • Congestion reduction	• Average speed • LOS
• Optimize revenue	• Generate revenue • Fund new transit and HOV improvements • Generate revenue to pay off bonds	• Revenue • Violation rate
• Optimize throughput	• Increase person- and vehicle-carrying capabilities of HOV lanes • Maximize the use of the existing Express Lanes • Effectively use the excess capacity of the Express Lane and the whole freeway • Maintain a "quality throughput" • Optimize traffic flow (throughput) • Maximize throughput and efficiency	• Person throughput per hour • Persons in HOVs + Buses per hour
• Safe travel	• Safety • Reduce serious crashes from trucks	• Number of Crashes • Incident clearance time
• Reliable travel	• Reduce congestion	• 95th % travel times • Buffer index

low usage from toll-free (HOV2+ and transit) vehicles. However, there are other facilities where usage by toll-free vehicles will soon eliminate the excess capacity sold to SOVs. This is particularly true in high growth states, like Texas, and where the managed lane is a single lane per direction. At that point, policy makers will be faced with the difficult decision of what changes are required to once again meet their performance objective.

This decision is politically difficult as it will require eliminating some groups' toll-free status. The challenge is how to identify which group(s) and at what point (based on how much performance has degraded) should they be eliminated. If such decisions are made when the project is initiated, then user groups would know well in advance what changes will occur to keep a performance promise on the facility. For example, when an HOV lane becomes a HOT lane and allows SOVs for a toll, the SOVs would know that when average speeds drop to a certain point they would no longer be given tolled access to that lane. Therefore, decision makers should consider these complex issues long before the situations on their facilities become critical. They should also provide policy guidance for many years into the future.

The benefits of such a policy include a clear performance promise to users that the lane will not fall below a certain minimum acceptable standard. If it were to get close to that trigger point, then measures to fix the problem are already set. As well, the implications of poor facility performance are known well in advance. As an example, the user group to be removed from a lane knows this well in advance and will not be surprised by it. The literature review revealed no HOT lanes with set policies on how to deal with SOVs once the volume of HOVs reaches the capacity of the lane. Likely, SOVs will be restricted from using the lane during peak periods, but this decision will be

Table 2: Summary of Goals, MOEs, and Preferred User Groups of Investigated Projects

Project	Specific Goals	MOEs	Preferred user groups
SR167 HOT Lanes Pilot Project	• Maintain travel time, speed, and reliability on the facility	• Speeds • Volume	• HOV2+ (with exceptions requiring HOV3+), vanpools, transit, and motorcycles toll free • SOVs pay toll
Express Toll lanes on I-30 in Dallas	• Maintain average speeds greater than 50 mph	• Maintain average speeds greater than 50 mph	*HOV-only phase*: • HOV2+, vanpools, motorcycles, and transit toll free *Variable pricing phase*: • HOVs and motorcycles carrying a valid transponder receive discount
SR 91 Express Lanes in Orange County	• Reduce congestion through diverting traffic to non-peak period • Maintain free flow speed on the Express Lanes and travel time savings • Meet increasing travel demand in the future • Generate sufficient revenue for the operations and maintenance of the toll lanes	• Hourly, daily, and directional traffic volume • Travel Time • Trigger point: 92% of the maximum optimal capacity	• HOV3+ free (50% off during peak hours) • HOV3+ free during peak hours if debt service coverage ratio is ≥ 1.2 for a 6-month period
MnPASS Express Lanes on I-394 in Minneapolis	• Improve the efficiency of I-394 by increasing the person- and vehicle-carrying capabilities of HOV lanes • Maintain free flow speeds for transit and carpools • Use excess revenue to make transit and highway improvements in I-394 corridor • Use electronic toll collection • Employ new Intelligent Transportation System technologies	• Traffic density • Travel speed	• Carpool and buses free • HOVs and motorcycles free during peak hours • All users free during off-peak periods
MnPASS I-35W Corridor in Minneapolis	• Allow the unused capacity of the HOV lanes to be used by SOV drivers paying a toll • Maintain the service (free flow traffic at 55 mph) to carpools and transit on the managed lanes	• Traffic speed • Volume • LOS determined by traffic density	• Transit • Carpools

Table 2 (continued)

Project	Specific Goals	MOEs	Preferred user groups
Express Lanes on I-15 (San Diego)	*Previous policies*: • Maximize the use of the existing I-15 Express Lanes • Fund new transit and HOV improvements in this corridor *Current Policies*: • Maximize throughput and efficiency of the system	*Previous policies:* • LOS *Current Policies*: • Volume • Density	• Carpools and vanpools • Transit • Remaining capacity sold to SOVs
Express Lanes on I-15 (Salt Lake City)	• Effectively use the excess Express Lane capacity and support the effective use of the capacity of I-15 as a whole • Maintain 55 mph for 90% of the peak periods on weekdays by limiting the number of permits purchased by SOVs • Clearly define toll rates to the driver	• Volume (transponder reads) • Speed	Toll Free: • HOV2+ • Motorcycles • Emergency vehicles • Transit • Clean-fuel vehicles (with C plate from DMV)
95 Express (Miami)	• Maximize throughput • Improve operations of HOV lanes which were over capacity during peak periods • Increase HOV restrictions from four to 24 hours/day and utilize surplus capacity of the HOV lanes, when available, by SOV drivers paying a toll • Maintain free flow speed on the Express Lanes and travel time savings • Increase trip reliability • Incentivize transit and carpooling • Reduce congestion through diverting traffic to non-peak period • Meet increasing travel demand in the future, and • Facilitate trip-reducing carpool formations (as opposed to “fampools”)	• Speed • Traffic density • Volume • Occupancy	Toll Free: • HOV3+ • Hybrid vehicles • Motorcycles • Emergency vehicles • South Florida vanpool
SR 73 Toll Road in Orange County	• Generate revenue to pay off bonds • Optimize traffic flow (throughput)		• All vehicles pay the toll

Table 2 (continued)

Project	Specific Goals	MOEs	Preferred user groups
C-470 Tolled Express Lanes	• Minimize congestion • Reduce traveler delay • Improve reliability on C-470 between I-25 and Kipling		• All vehicles pay the toll
Queue jumps in Lee County	• Maximize throughput	• Speed	• All vehicles pay the toll
Toll Roads in Illinois	• Divert non-essential truck traffic from peak periods of travel • Reduce congestion • Improve safety, such as reduce crashes from trucks	• Volume/ throughput	• Will likely begin as HOV2+ • Passenger vehicles: constant rate • Commercial vehicles: varying rate by time of day
Regional System of Variable-Priced Lanes in the Washington, DC Region	• Manage traffic in reasonably free-flow conditions through adjusting toll rates • Maximize not only number of vehicles but also throughput via integrating transit service as part of the variably-priced lanes system		• HOV2+ facility
Pennsylvania Turnpike	• Raise revenue		
Inter County Connector (ICC) and Express Toll Lanes (ETL) on I-95 in Maryland	• Goals of ICC & ETL Optimize revenue • Optimize traffic Goals of ICC Encourage travelers to cancel or postpone their trips when congestion levels are higher • Generate revenue Goals of ETLs • Maintain relatively free-flow traffic conditions in the ETLs by encouraging travelers to use the GPLs or to shift travel to a less congested time	• LOS • Target revenue	• All vehicles pay the toll

Table 2 (continued)

Project	**Specific Goals**	**MOEs**	**Preferred user groups**
Express Toll Lanes on I-75 in Atlanta	• Increase throughput as well as number of vehicles in the corridor • Maintain free-flow speeds in the managed lanes • Increase trip reliability • Provide travel alternatives by accommodating transit and/or carpools		• HOV free (cars only)
Conversion of HOV lanes to HOT Lanes on I-85 in Atlanta	• Provide users in HOT lanes reliable travel times in this corridor by effective use of the managed lanes along I-85 north of Atlanta through dynamic pricing • Maintain average speeds 45 mph or more for 90% of the peak period		Toll free: • HOT3+ • Transit • On-call emergency vehicles • Motorcycles • Vehicles with alternative-fuel vehicle (AFV) license plate
ELDP Projects in Texas	• Goals of ELDP • Manage high levels of congestion Optimize traffic • Reduce emissions in a non-attainment or maintenance area • Finance added Interstate lanes for the purpose of reducing congestion • Performance Goals of IH635, I-30, and I-35E • Address the effects on travel, traffic, and air quality • Address the distribution of benefits and burdens • Address the use of alternative transportation modes • Address the use of revenues to meet transportation or impact mitigation needs	• Average speed • Traffic volume and changes • Number of incidents • 95th and 80th petcentile travel times	• HOV • Vanpool • Transit

made when congestion becomes critical and may come as an unwelcome surprise to SOV users of the facility. Therefore, a policy set in advance removes the need for difficult policy decisions at multiple points in the facility's life, most of which would be likely done in haste due to the failing performance of the facility and the critical need for a decision. Finally, it guides the data collection needs for measuring the performance of the facility.

CONCLUSION

In conducting this state-of-practice review, many organizations from around the country were investigated for any "performance promises" they might have on any of their facilities. Although many verbally expressed interest in the idea, only one had clearly defined triggers and actions to ensure performance. This was the SR-91 Express Lanes in California, where specific traffic volumes, and therefore congestion levels, result in specific price changes. Others, particularly the dynamically priced HOT lanes, had something similar where they raise their tolls to ensure smooth traffic flow every few minutes. However, none had a plan where, if the price consistently rose to a certain threshold on a daily basis, the lane would stop accepting paying customers at that time of day.

Similar to a performance promise is the federal legislation that requires traffic speed on HOT lanes to exceed 45 mph for 90% of the time during peak periods. Frequently failing to meet this requirement may force the removal of SOVs from a facility. Fortunately, all HOT lanes have used pricing to avoid this problem. This was the closest any facility came to pre-determined vehicle occupancy adjustments based on performance measures.

Finally, the goals and objectives for the many projects proved interesting and insightful. However, how a facility would meet the goals when traffic congestion rises to a point where price alone is not the answer is unknown. This is a difficult decision left to future policy makers and would possibly "surprise" the facility users.

APPENDIX

Survey Questions

- Are there specific project goals/objectives?
- How do projects address toll rate changes?
- Is there a policy framework for the operation of the facility? How was it developed? Who was involved?
- Have there been changes in policy? If so, what caused them?
- How are the changes communicated to the public and other stakeholders?
- What is the reaction to policy or toll rate changes?
- What performance data are collected?
- How are performance data collected?

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Incorporating Energy-Based Metrics in the Analysis of Intermodal Transport Systems in North America

by John Zumerchik, Jack Lanigan Sr., and Jean-Paul Rodrigue

As both regulators and operators strive toward energy, security, sustainability, and carbon accounting goals, establishing a consistent approach in monitoring and comparing intermodal freight transportation becomes essential. Current freight performance tools focus on capacity, speed, throughput, productivity, or emissions and tend to be segregated within individual transportation modes. These tools are neither holistic enough for supply chains striving to eliminate waste, nor for transportation planners trying to prioritize public funding. This paper argues that evaluating intermodal quantitatively within an energy-based freight sustainability framework ensures that funding results in lower cost per ton of reduction of carbon, oxides of nitrogen or particulate matter emissions than from the practice of focusing on new engines, retrofits, or electrification.

INTRODUCTION

Supply chain managers face many competitive choices when deciding how best to minimize costs in the processing, staging, and transportation of goods. In recent years, the introduction of better practices have helped logistics costs decline significantly from 17.9% of U.S. GDP in 1980 to 8.3% by 2010 (CSCMP 2011), allowing U.S. businesses to more effectively compete in the global economy. Yet since transportation costs annually account for $768 billion of the $1.2 trillion total cost of logistics (CSCMP 20111), and energy is a major component of those transportation costs, the prospects for future gains are limited. Future challenges include the high likelihood of rising energy costs, longer supply chains that require more fuel, and more stringent safety and security requirements (delays consuming more fuel as well as negatively impacting labor productivity). Nevertheless, there is great potential to reduce freight energy consumption in North America with higher utilization levels of intermodal rail, as well as niche applications for barges and short sea shipping. Improving rail intermodal on-dock and near-dock efficiency are particularly critical. In 2005, congestion resulting from port landside access was estimated to cost up to $200 billion annually, which includes 2.3 billion gallons of fuel and 3.7 billion man-hours wasted (USDOT MARAD 2005). Moreover, wasted fuel and man-hours are only likely to worsen as a growing number of larger ships—off-loading and loading many more containers per port call—are put into service.

Historically, U.S. rail infrastructure has been private and not publicly funded like port, highway, and airport infrastructure. This outlook changed in recent years with the funding of projects such as the Alameda, Heartland, Crescent, and National Gateway Corridor projects through public/private partnerships (Chase 2009). Public funding of intermodal rail is now looked at favorably as a means to increase freight capacity as well as reduce highway congestion, diesel truck emissions, and highway maintenance costs. But in light of capital scarcity, the question is how to evaluate the merits of public investment in intermodal versus other freight projects. While comprehensive methodologies have been developed for energy-based sustainability analysis of freight moved by a single mode (e.g., IFEU Heidelberg et al. 2010), these methodologies do not take into account the full complexity of North American intermodal transits. Thus, there is a critical need for energy-based sustainability methodologies, particularly at the terminals where the modal transfers take place. Studies comparing intermodal to truck freight (ICF Consulting 2009) have been using estimates of limited value because energy use per container throughput significantly varies by terminal design, operational practices, and volumes in relation to capacity.

This paper contends that energy-based analysis per individual intermodal transit can be determined, and that objective energy measures can be compared and tied to improvements in costs, reliability, and congestion. Therefore, this paper evaluates the applicability of current intermodal measures for freight efficiency, introduces new terminal efficiency metrics, and presents methodologies for terminals so that intermodal movements can be compared to truck-only movements. Before analyzing current measures, the dimensions of intermodal fuel consumption need to be identified, along with other freight efficiency factors (economic and social) that affect modal decisions.

FREIGHT EFFICIENCY

For freight moving through the supply chain—whether taking place on a single mode or through an intermodal sequence—a measure of economic efficiency and sustainability relates to the minimization of energy use, which is best measured in British Thermal Units (BTUs) to better account for terminal and storage operations becoming electrified, and the different energy contents of fuels. Energy-based analysis of intermodal freight has three aspects: line haul, modal transfer, and storage components.

- **Line Haul Energy** is the fuel needed to transport goods (ton-miles/BTU) so that comparisons can be made across different modes. Additional energy for equipment repositioning and temperature control need to be accounted for as well. Finally, drayage miles per intermodal transit are needed to calculate complete trip energy usage. Naturally, the higher the ratio of drayage to rail mileage, the less the energy advantage of intermodal.
- **Modal Transfer Energy** pertains to all freight transfer points. Whereas truck freight usually involves only origin and destination facilities, intermodal entails multi-transfer points, encompassing the fuel used in the terminal for modal transfer by cranes, drayage trucks, yard tractors, service vehicles, as well as energy use for switching.
- **Storage Energy** relates to warehousing operations, including loading, unloading, storing and cross-docking (moving cargo from one transport vehicle directly into another). Temperature-sensitive products require additional energy to operate the mechanical equipment to insure the integrity of the goods being carried, and therefore, their commercial value.

Although supply chains naturally tend to strive toward minimizing energy use since it is a major operating cost for all modes, there are other important overriding economic efficiency factors impacting intermodal decisions. For transportation providers, these include labor productivity and equipment life cycles, and for shippers and receivers, major concerns include inventory carrying costs and cash flow (e.g., shortening the in-transit times shortens the period between when goods are paid for and sold).

APPLICABILITY OF CURRENT PERFORMANCE MEASURES

Energy usage in intermodal freight transportation can be evaluated in four areas: line-haul, equipment utilization/repositioning, temperature control, and terminal transfer operations.

Line-Haul

Approximately 71% of U.S. petroleum consumption is used by the transportation sector. Rail uses only 2.13% of this total while accounting for 40% of all domestic freight movements (U.S. Senate 2010). This rail energy advantage is reflected in Table 1, which shows rail to be around 10 times more energy efficient than truck (Davis et. al. 2009). This advantage continues to improve with advances in locomotive technology, tribology (friction, wear, lubrication), and material science making possible lighter and more durable rolling stock. For example, a five-unit articulated double stack well car sharing axles and wheels with other car units results in the highest ratio of freight weight to total train weight than any other rail rolling stock.

Table 1: Comparative Freight Mode Energy Efficiency

Transportation Mode	BTU per short ton mile	kJ per ton kilometer
Class I Railroads	341	246
Heavy Trucks	3,357	2,426

Source: Davis et al., 2009.

Despite double stack well cars being the most energy efficient means to move freight over land, intermodal includes other factors that have a profound impact on overall fuel usage. Additional line haul mileage from less direct rail routes (e.g., built alongside winding rivers), drayage mileage at the origin and destination, terminal energy consumption, and gradients for the rail route all contribute to diminish the estimated energy efficiency advantage of intermodal rail down to a multiple of 2.75 to 5.5 times greater than trucking (ICF Consulting 2009).

Though barges have been advocated as an efficient means of moving intermodal containers, any barge energy efficiency advantage is primarily attributable to very slow speeds. Thus, from an energy sustainability and economic efficiency perspective, using barges to transport containers is only appropriate for low value and non-time sensitive freight, or for inland ports that are relatively close to the port terminal.

Energy measures for intermodal services also must account for the reality of equipment weight relative to freight weight. In particular, trailer loads have a significant tare weight advantage over the heavier container and chassis combination. This means that drayage fuel economy will be slightly lower for any given weight of freight, and the freight weight that can be carried will be less. However, this drayage operation disadvantage is often partially offset by the weight of the over-the-road sleeper berth.

Another freight network inefficiency is that overweight roadway limits for the drayage leg puts a cap on the ton-miles per gallon advantage that can be achieved on rails. This has been mitigated in some states by systems allowing overweight drayage trucks to haul freight to and from intermodal terminals and combination trucks of two or more trailers. Raising weight limits for all trucks improves trucking efficiency, but would negatively affect freight efficiency because it will cause a modal shift away from rail. On the other hand, permits that allow overweight trucks only on routes to and from intermodal terminals positively affect both rail efficiency in terms of increasing returns to density and freight efficiency.

As supply chain management continues to make strides in reducing the size and weight of packaging, an increasing percentage of loads are “cubing out,” implying that a load exhausts a container’s volume well before exceeding its weight limit. It is likely that more ship lines will offer greater quantities of 53-foot containers to match the standard truck length in the United States. This is a more efficient strategy than the practice of transloading near the port (e.g., the contents of three ISO 40s transferred into two domestic 53-foot containers). In 2007, the ship line APL began offering 53-foot container service in Los Angeles for high-value and time-dependent loads to be quickly trucked from the ports to their final local destinations. Despite demand from the supply chain (Journal of Commerce 2011), the usage of 53-foot containers remains very limited since container ship holding cells are designed to accommodate 20- or 40-foot containers.

Equipment Utilization and Repositioning

Better equipment utilization permits smaller and more productive fleets, which lowers capital costs and the energy required to manufacture the materials used in chassis and containers. Chassis utilization is a perplexing problem for the industry (Zumerchik et. al. 2009). While a small number of chassis results in an inability to support modal transfers, too many result in increasing marginal costs (storage, rehandling, and damage costs). Industry sources estimate the North American fleet to be around 820,000 (Mitchell 2007, Prince 2008), indicating a very low utilization rate. For 38 to 39 million chassis moves per year the mean chassis utilization rate would be less than four trips per month (Intermodal Association of America 2011).

Aside from utilization, containers face an empty repositioning problem. Containers are either not available, or when they are, the cost of repositioning and drayage costs are prohibitive. Moreover, because of the considerably higher container rates imposed on inbound trips, which are trade imbalance driven, ship lines often reposition their empty containers back to Asian export markets immediately instead of waiting for the availability of an export load. The performance measure of average container dwell at the terminals gives some indirect insight into container and chassis utilization. Extended free container time before demurrage charges, up to 10 days at some marine terminals, obviously works against better container and chassis utilization. Both the container and chassis are effectively unproductive transportation units when serving as a warehouse on wheels at terminals and receiver facilities.

Improving motor carrier efficiency is critical since motor carriers must interface with both shippers and receivers, and represent the critical first and last mile of every intermodal trip. Even though the percentage and mean distance of empty backhauls are considerably greater for over-the-road freight than for intermodal (ICF Consulting 2009), intermodal has a greater potential to reduce empty mile energy consumption with better container repositioning strategies, strategically positioned empty container depots, more intermodal terminals, more chassis and container pick up locations, and more efficient drayage operations (e.g., reducing chassis-related delays and costs).

Temperature Protection in Transit

Typically, 0.4 to 1.7 gallons per hour of diesel fuel are burned to control product temperature in transit (Shurepower LLC 2005), which must be added to the energy for transport. For a standard refrigerated container, energy efficiency is impacted by the added weight of the equipment and fuel, or the reduced internal volume because of the insulation in the floor, ceiling, and sidewalls. Although over 12% of tractor and trailer load originations use refrigerated containers (ACT Research 2007), the number of products requiring some form of temperature protection, depending on seasonal conditions and length of transit, is considerably greater. Protection classes include frozen, chilled, conditioned, protected, and ambient, with either large or small recommended or required temperature variance. For shorter transits or for products with less stringent required temperature variances, passively protecting temperature-sensitive products in dry containers saves significant energy compared with climate controlled containers. Unfortunately, dark painted containers, favored for the cleaner more presentable look, makes providing passive heat protection more difficult. During a static field test, when the daytime high temperature reached 25°C, the internal air temperature of a high albedo (reflective) white painted container rose to 38°C (52% greater than daytime high), while that of a low albedo (absorptive) brown-painted container rose much more to 50°C (100% greater than daytime high) (DWD 1989). Without the additional weight of climate control equipment and fuel, shipping passively in high albedo containers also can allow for more cases per container. Further, passively shipping temperature-sensitive products addresses the reality of a shortage of refrigerated containers, and allows for consolidation of loads to achieve more cases per load by mixing classes of freight.

Climate controlled trailers and containers parked dockside for use as additional warehousing are often a part of the supply chain warehousing decision. This affords greater flexibility, but it is the most energy intensive option and reduces intermodal equipment utilization. At the other extreme is underground storage such as Subtropolis outside of Kansas City. Subtropolis, a former limestone mine that spans 4.5 square kilometers, retains an ambient temperature in the range of 18 to 21 degrees Celsius year round. For the warehousing of temperature controlled products, energy costs at the Subtropolis are about 50%-70% less than they are for conventional warehousing (Hunt Midwest 2008). Although supply chains have effective tools to account for advanced carbon reductions strategies, there exists no widely accepted methodologies for temperature-controlled product transportation and storage, which are considerably more energy intensive than shelf stable product shipments.

Modal Transfers

Despite many states claiming intermodal connections as an important criterion of their freight transportation system, McMullen and Monsere (2010) found that few evaluate the performance of their intermodal rail or port facilities. Barber and Grobar (2001) looked at performance measures at the San Pedro Ports, but the measures were to determine capacity, throughput, and productivity. Productivity is the only measure that can have energy implications. For example, crane productivity can be increased by operating cranes more hours each day (utilization), or achieving more lifts per operating hour (efficiency), fewer moves per container transfer, or the distance moved per container for transfer. However, only the latter two, involving terminal operation and design, have energy implications.

Determining transfer energy consumption is, in its simplest form, about determining the amount of handling during the transfer process: the number of times a container is handled, the number of operations involved in interchange, the distance over which a container is handled within a terminal, and the handling of chassis and hostler usage to bring containers trackside or to storage areas. Better terminal designs result in energy conservation benefits, which provide far greater savings than energy efficiency gains by eliminating handling processes altogether, as opposed to continuing the same processes, but with more energy efficient equipment. The European EcoTransit methodology for intermodal, which assigns a universal value of 4.4 kWh per intermodal transfer (IFEU Heidelberg et al. 2010), is of limited utility because of the wide variations in container handling operations. For example, a hoist height of 30 feet (atop containers stacked three-high) requires significantly more energy than for 10 feet. The same is true for a container requiring several rehandling lifts compared to a transfer requiring none. Beyond lifts, there is tremendous potential to conserve energy by eliminating or reducing the need for yard tractors, concentrating all rail transfer activities under widespan gantry cranes instead of at remote storage areas, and terminal designs that eliminate switching, and railroad grade conflicts, minimize within terminal drayage mileage, and direct all roadway traffic moves in one direction (idling and safety benefit).

Intermodal terminals consist of three interactive operations: gate, transferring (ramp/berth), and storage. The storage function can be "stacked," which uses remote and the center row (rail) to store containers, or "wheeled" with containers stored on chassis. Generally, small volume rail terminals use primarily wheeled operations, and higher volume terminals use wheeled and stack storage. The minimally mechanized wheeled operation transfers containers with one lift, not requiring multiple lifts like a stack terminal, but requires much more land to store chassis and park containers on chassis.

None of the current terminal metrics gives a direct insight into energy conservation and efficiency. However, these can be calculated. For yard tractors and vehicles that move and stack containers, the energy profile for a terminal can be determined by the distance traveled per transfer, along with idling time per transfer waiting on a crane (yard tractor), or the time needed for a container crane (crane spreader) to engage a container's four corner castings. Likewise for cranes, an energy profile can be determined by the mean lifts per modal transfer, mean distance per lift, and whether the operation involves single cycling or double cycling.

Significant potential exists for crane productivity and energy conservation gains with double cycling to reduce the number of cycles required to turn a vessel or train. Rail terminal modeling by

Goodchild et al. (2011) showed that cycles could be reduced by almost 50% and crane gantry travel by 75% to turn a train. The faster and more reliable trains are turned around, the fewer locomotives and well cars are needed to service a particular corridor, and the fewer loading tracks are needed in the terminal. For shipping lines, port turnaround times tend to be more significant to maintain schedule integrity than the number of vessels allocated to a maritime route. Turnaround times are a function of the cranes available, utilization (container lifts per crane), and cycle times. Cycle times in lifts per container gantry crane-hour are usually 25-40 moves per hour for quay cranes, and 40-60 for rail cranes (Tioga 2010).

Another important factor is the concept of immediate selectivity, which is the unloading and loading of containers in a manner so that cranes, trucks, and yard tractors do not have to wait on each other. The cranes unloading and loading vessels and trains require significant synchronization with yard tractors to minimize waiting, and the same holds for cranes servicing drayage trucks for container yards. The enormous amount of time in the terminal that trucks consume fuel while the engines idle, estimated to be about 0.82 gallon/hour (US EPA 2002), can be dramatically curtailed by terminals that provide immediate selection. Since terminals are optimized for crane productivity, the lack of immediate selectivity resulting in diesel engine idling is predominantly a problem for drayage trucks.

Lack of immediate selectivity is not reflected in current terminal freight efficiency metrics that primarily focus on land use productivity and capacity. The most common is throughput density expressed in TEU per acre per year. It is the annual throughput divided by the size of the terminal, which is not a meaningful measure to compare wheeled operations, stacking operations, and terminals that do both. For example, the port of Singapore handles over 24,000 TEU per acre per year compared with only around 4,500 at the San Pedro ports (Tioga Group 2010). Stacking reduces land costs while increasing handling costs. This metric also cannot account for the unique operations of each port. Again, while Singapore is a transshipment hub with about 95% of its traffic ship-to-ship, the San Pedro ports are gateways with the bulk of the traffic bound to their hinterland, and include acreage devoted to on-dock rail. Singapore can thus contend with much higher stacking densities since the containers are transferred between ships. On the other hand, lower TEU per acre for wheeled terminals is often justified because of lower handling costs. Though a wheeled terminal requires fewer lifts and cranes, the downside is that sprawling wheeled terminals are more labor, time, and energy intensive, especially when compared with stack operations that move all chassis storage outside of the gates, eliminating maintenance, repair, racking, inspections, and chassis flips (transfer a container from a bad chassis to a good chassis).

Throughput density is a function of average container dwell time, which has significant freight efficiency implications. The shorter the average container dwell time, the higher the throughput density of a given terminal. Reducing the average container dwell time from seven to four days can increase terminal capacity from 4,500 to 7,900 TEUs per acre (Sisson 2003). More importantly, this reduces the number of rehandling lifts required for stack terminals, and the size of the chassis fleet for wheeled terminals. However, reducing free dwell time before demurrage charges can put pressure on terminal gates and local access roads since customers have fewer options to pick up their cargo.

The standard practice of not charging for container storage at terminals is inefficient and the more extended free time before demurrage charges begin could add to freight inefficiency. The problem is similar to employer-provided free parking for passenger vehicles. Studies have found that employer-provided free parking subsidies are one of the greatest impediments to commuting and carpooling (Shoup and Breinholt 1997). Use of the container yard as a supply chain buffer is effectively giving something away free that has a significant cost to the provider, not only the opportunity cost of using the land for some other productive use, but also the cost of constructing, gating, monitoring, and maintaining the container yard. Nevertheless, this practice is likely to continue as ports with excess capacity offer longer free dwell times as a competitive advantage.

Terminals without excess capacity must find solutions. A general assumption is that the freight inefficiencies associated with stacking and the multitude of chassis costs and utilization problems of wheeled operations (Zumerchik et al. 2009) are unavoidable. One technology that will positively address these major equipment and labor productivity weaknesses of both wheeled and stack operations is the Automated Transfer Management Systems (ATMS) in Figure 1 (Zumerchik et al. 2009). As an interim step, ATMS in combination with appointments would be effective for a wheeled terminal or a mixed wheeled and stack terminal. Wheeled containers would be loaded into the stack side ATMS by the yard tractor drivers before the dray appointment time (Huyhn and Zumerchik 2010). In essence, the appointment would initiate the chassis flip by completing half the chassis flip operation before the driver arrives. The objective would be for dray firms to make appointments so that the container is transferred into an ATMS for immediate selection before the driver's arrival. Terminals with ATMS also would reduce the fuel wasted idling while waiting for a chassis to flip a few minutes instead of up to two hours at some terminals (Harrison et al. 2009). Further, if ATMS systems are vessel or track side, terminals achieve much lower operating costs as well as decreasing marginal costs. Although the authors know of no average and marginal cost curves for intermodal terminals to date, every current terminal experiences increasing marginal costs well before reaching their design capacity.

Except for drayage mileage per intermodal transit, metrics for comparing energy implications of terminal location alternatives, in conjunction with terminal efficiency, have yet to be developed. There is also the drayage driving distance picking up and dropping off equipment within the terminal to consider, which will vary by terminal design and chassis requirements. For example, the drayage driver who arrives at the Port Elizabeth terminal (New Jersey) dropping off and picking up a chassis can travel up to 1.7 more miles in the terminal than drivers coming and going with their own chassis. Thus, replacing a conventional terminal with a well-designed modern terminal can eliminate millions of truck and yard tractor in-terminal miles annually.

Figure 1: A 2-High ATMS Positioned Perpendicular to the Tracks, with WSG Crane and Loading Tracks in the Background

The design of the rail freight network itself holds enormous potential as the largely point-to-point network evolves toward more of a hub-and-spoke model. When freight requires interchange between an eastern and western railroad for transcontinental rail freight flows, high-value and/or time-dependent containers are trucked across town, which effectively doubles terminal processes. In the Chicago area alone there are about 20,000 cross-towns a day (Butler 2010). Thus, better coordination between rail systems would result in enormous energy savings (Rodrigue 2008, Lanigan et. al. 2007).

New Terminal Metrics

For comparative analysis of terminal efficiency, Mi-Jack has developed two new metrics—container capacity per acre (CCPA) and container handling efficiency factor (CHEF)—to measure a terminal's capacity in relation to handling efficiency. CCPA is the annual transfer capacity for inbound and outbound transfers divided by the total acres of land required for the transfer operation. For a one million annual transfer terminal on 450 acres, the CCPA is 2,222 (1 million/450). Higher CCPAs indicate more efficient use of terminal land. For example, sprawling primarily wheeled operations with large areas dedicated to chassis storage will have a much lower CCPA than primarily stacking operations requiring a smaller chassis fleet, or a fleet located outside the terminal gates. Whereas CCPA is a land productivity measure, CHEF measures the number of lifts and internal handlings to perform one million modal transfers. It captures all handling for inbound or outbound completion of the modal transfer, all activities to and from storage from the well cars or sea vessel, and rehandling lifts required for the delivery of outbound and loading of inbound containers to the truck carrier.

Historically, the initial criterion for designing rail or port terminals is the number of transfers per year for inbound and outbound shipments. The number of internal lifts and handling was not a major consideration because technology limited terminal design choices. However, new technology like ATMS can result in major efficiency gains through reductions in handling. For terminals, the maximum efficiency is one lift per modal transfer. In other words, each container transferred is handled once with no internal handling and lifts.

Assuming no live lifts directly onto a truck carrier's chassis, conventional wheeled terminals require a minimum of two internal handlings per container to complete the modal transfer (e.g., a yard tractor to bring the chassis to trackside followed by moving the chassis and/or container to a storage area). This results in three million total handlings annually for one million modal transfers:

1 million transfers/450 acres = 2,222 CCPA
2 million internal handlings
3 million transfers and handlings/450 acres = 6,667 CHEF

Because each transfer also includes a minimum of two internal handlings, the maximum efficiency for this wheeled terminal operation is a CHEF of 6,667. This also indicates that the maximum efficiency ATMS terminal is three times more efficient than conventional wheeled terminals.

CHEF can track handling efficiency for whatever are the actual total internal handlings and lifts needed for modal transfers. When a terminal runs out of chassis and must start grounding or stacking containers, this adds a minimum of two additional lifts per transfer (yard tractor-stack, and stack-truck carrier), making a minimum of five. This would raise the CHEF to 11,111 as shown below.

1 million transfers/450 acres = 2,222 CCPA
4 million internal handlings and lifts
5 million/450 acres = 11,111 CHEF

The lift total also must include rehandling lifts to reach containers at the bottom of stacks. If the terminal needed 800,000 rehandling lifts annually, the following calculations show the total would be 5.8 million lifts for one million modal transfers, resulting in a CHEF of 12,889:

1 million transfers/450 acres = 2,222 CCPA
4.8 million internal handlings and lifts
5.8 million/450 acres = 12,889 CHEF

To confirm the usefulness of CCPA and CHEF for energy-based sustainability analysis, Table 2 compares the lifts and internal handling for an emerging inline ATMS rail terminal design on 71 acres to a primarily wheeled (650 acres) and 60% stacked (350 acres) terminals for one million modal transfers annually. For the 60% stacked terminal, replacing rubber tire gantry cranes with widespan cranes to reduce the need for yard tractor shuttling would significantly improve CHEF.

By keeping all terminal activities concentrated under the widespan cranes, the inline ATMS terminal significantly reduces energy consumption from 510,417 to 168,750 gallons (67% less) for stacked terminals, and from 837,000 to 168,750 gallons (80% less) for wheeled terminals, and can be located on only 71 acres of land for a very high CCPA and CHEF of 14,085:

1 million transfers/71 acres = 14,085 CCPA
0 internal handlings and lifts
1 million/71 acres = 14,085 CHEF

Whereas it is well-known that wheeled operations are the most energy intensive (i.e., the higher the volume of drayage and yard tractor trips the greater the distance per trip), few realize they also entail the highest operating costs. Wheeled operations are often presented more favorably than in reality (e.g., Tioga Group 2010) when the analysis ignores land costs and chassis storage that may take up to 35% of a terminal's land (Kelly 2010). Similarly, a favorable presentation may occur if the analysis ignores the increasing marginal costs of maintenance and repair of chassis fleets (e.g., racking and stacking damage), the large chassis fleet required, and the costs assumed by other parties. From a staging of container cost perspective, shuttling containers between storage and trackside is considerably more costly than stack-well car lifts of widespan cranes. By allowing the truck carrier self-service staging, a major benefit of the inline ATMS terminal is container staging for train loading at no cost to the railroad. This efficiency benefit, and the sequencing delay time savings benefit associated with fewer phases/events/movements for the inline ATMS terminal, are additional operational cost benefits not captured by CHEF and CCPA.

With the collection and tracking of lift and handling activity, the CHEF and CCPA effectively can capture efficiency gains from new operations, designs, and technology, including information technology designed to limit rehandling lifts. A secondary benefit of this measure is that by focusing efforts on reducing the number of times a container is handled, the terminal is improving safety and reducing the risk of damaging the container and freight inside it.

OPERATION AND SUPPLY CHAIN MITIGATING FACTORS

Although reducing energy costs is of paramount importance, often economic efficiency factors, such as equipment and labor costs, inventory carrying costs, and cash flow considerations, are a higher priority than capturing energy-based advantages. For example, rail and water shipments require cost analysis to determine whether line-haul economies, which include fuel savings, warrant the resulting operational and energy-related diseconomies. The introduction of double stack trains generated tremendous economies of density benefits without any additional tracks, which more than offset the diseconomies associated with the effective doubling of container volume at the terminals. However, mega containerships may be another matter. Railways and highways are not an open ocean. This raises the question if the benefits of transit fuel efficiency and economies of scale more than offset the energy cost and the cost of landside diseconomies mega ships require. These ships also require longer periods to load and unload, greater container handling, longer container dwell times, greater road and rail congestion, and major new investments that are required for new berths, larger cranes, higher clearance bridges, and channel dredging. Unless container handling is efficient, and most of the containers arrive and depart quickly and efficiently by on-dock or near-dock railway, servicing mega containerships will increase energy consumption per container throughput on the

Table 2: One Million Annual Transfers (500,000 Truck-Rail Inbound; 500,000 Rail-Truck Outbound)

	Wheeled*	60% Stacked	Inline ATMS
Acres	650	350	77
Yard Tractors (YT)			
Trips to/from Storage (no "live" or "direct" lifts)[1]	2,000,000	2,000,000	WSG; not applicable
Mean Distance/Trip (miles)[2]	1.5	0.75	WSG; not applicable
Mileage	3,000,000	1,500,000	WSG; not applicable
Fuel Consumption (6 mpg)[3]	500,000	250,000	-
Crane Lifts/Transfers[4]			
Unloading Wellcars	500,000	500,000	500,000
Inbound (Import) Storage (YT-Stack, Stack-Truck)[5]		600,000	not applicable
Outbound (Export) Storage (Truck-Stack, Stack-YT)[6]	-	600,000	not applicable
Rehandling Lifts and Flips[7]	50,000	300,000	
Loading Wellcars	500,000	500,000	500,000
Total Lifts	1,050,000	2,500,000	1,000,000
Fuel Consumption (40 lifts/hr; 6 g/hr)[8]	4,375	10,417	4,167
Double Cycling Fuel Savings 50%[9]	-	-	2,083
Total Fuel Consumption of Cranes	4,375	10,417	2,083
Total Lifts and Handling	3,050,000	4,500,000	1,000,000
CCPA	1,538.46	2,857.14	14,062.72
CHEF	4,846.15	12,857.14	14,062.72
Drayage Trucks			
Trips	1,000,000	1,000,000	1,000,000
Mean Miles In-Terminal[10]	2.0	1.5	1
Fuel Consumption[11]	333,333	250,000	166,667
Total (gallons)	837,708	510,417	168,750
Carbon Emissions lbs. (22.384 lbs./gallon)	18,751,263	11,425,167	3,777,300
Carbon Emissions (Metric Tons)	8,505	5,182	1,713
Fuel Cost ($3.25 gallon)	$ 2,722,552	$ 1,658,854	$ 548,438

*Assumption of no chassis shortages requiring containers to be grounded/stacked.
[1] 1M empty chassis/bobtail + 1M chassis/container = 2M trips; when chassis dropped trackside for next inbound train, it requires bobtail move.
[2] Mean mileage to and from trackside and the storage area; more real estate requires more miles: Wheeled > Stacked.
[3] Idling fuel consumption to connect/disconnect chassis not included.
[4] Assumes no chassis lifts; if chassis storage is limited, it would require adding stacking/racking lifts.
[5] 10% stacked for Wheeled (run out of chassis) and 10% wheeled for Stacked Terminal (e.g., reefers left wheeled).
[6] For Wheeled terminals, all outbound containers are left on chassis.
[7] Flips and rehandling lifts vary significantly by terminal; here 10% for Wheeled and 40% for Stacked.
[8] Lifts/hour and gallons/hour for diesel RTG; other container handling equipment performance/fuel consumption will vary.
[9] Not possible current terminals; double cycling: no empty moves, 50% fewer cycles, 50% less operating time (Goodchild,2010).
[10] Estimate of respectively 1 and 0.5 greater miles for chassis processes at Wheeled and Stacked (port of NYNJ it is 1.7 miles).
[11] ATMS automated communication, less idling, lugging, and delays (one way traffic, no grade crossings) ensures even less fuel use.

Source: Calculated by the authors.

hinterland side. Yet, since the total line haul cost, including interest payments, depreciation, fuel, crewing, and maintenance per TEU, is 14% less on a 10,000 TEU vessel than a 5,000 TEU vessel (Smil 2010), many major ports are planning to accommodate the greater container surges expected as more mega containerships start calling at North American ports.

LABOR PRODUCTIVITY AND EQUIPMENT LIFE CYCLE CONCERNS

In the movement of freight from origin to destination, labor productivity can be measured in man-hours per trip. Aside from line haul time, all truckload, less than truckload, and intermodal freight involve time at the origin and destination, which varies depending on how quickly trucks are processed. While this time is comparable for trucking and intermodal, a container traveling in a 100 well car-double stack train requires far fewer line-haul man-hours than 200 tractor-trailers traveling by highway. But some of this intermodal line-haul labor advantage is offset at the terminals. For example, rail terminals require gate processors, crane operators, yard tractor drivers, ramp workers, searchers for misplaced containers, maintenance and repair personnel, and chassis and container inspectors. For intermodal rail, the fewest man-hours per intermodal transit can be achieved with longer unit trains over greater distances, faster train and truck turn times, and shorter drayage distances. Gross labor productivity at intermodal rail or marine terminals is measured by the number of moves per man-hour. Given the standard full-time work for one employee of 2000 man-hours per year, marine terminals generally achieve somewhere between 800-1500 TEUs per full-time employee per year, or 0.4 to 0.75 TEUs per man-hour (USDOT MARAD 1998).

In terms of miles driven per hour, it is far less for drayage drivers than for over-the-road drivers because of shorter trips, terminal congestion, and delays. For a wheeled terminal, it can take well over two hours to disconnect one chassis, connect another, hook up the lights and brakes, inspect the equipment, and fill out a Driver Vehicle Inspection Report (DVIR) for both the chassis being dropped off and the one picked up. Although experienced drivers with knowledge of a terminal's operation usually endure short turn times (Harrison et al. 2009), there is great potential to improve drayage productivity (Transportation Research Board 2011).

Because of the long expected life cycles of container handling equipment (often over 25 years), energy sustainability improvements, which also would be improving terminal labor productivity, will be incremental within current terminal designs and operations. Moreover, there are widely varying capital costs, productivity (lift cycles/hour), and operating costs that entail complex tradeoffs. For example, the capital cost of a double-engine vehicle used to move and stack containers (straddle carriers), is less than the cost of a rubber tired (RTG) and a rail-mounted (RMG) gantry crane, but requires significantly more maintenance. Because the combination of container handling equipment is often dictated by operational design, transitioning to an energy conserving terminal design is problematic since the change involves replacing existing equipment.

THE SUPPLY CHAIN AND SPEED EFFICIENCY

Freight shipping decisions are based on total logistics costs, which include the costs of inventory, warehousing, and transportation. The trend has been toward more just-in-time, and a shift from a demand-driven instead of a supply-driven supply chain. Characterizing a firm's decisions is difficult since shippers are not a homogeneous group. There are varying business models, and the market is dynamic with the introduction of new technologies, and continual changes in customer requirements and supply-chain strategies affecting inventory levels and distribution strategies such as transloading, point-of-sale distribution, direct shipments, and load consolidation. For example, while transloading is a less energy efficient strategy for intermodal containers headed to hinterland distribution centers than the norm, collaborative distribution involving multiple shippers consolidating and combining their shipments to create truckloads and direct ship strategies that bypass distribution centers, result in significant energy savings.

Because energy is a major cost of transporting freight, supply-chain managers will choose more energy efficient rail and water alternatives, but only when total logistics costs warrant those choices. For instance, intermodal transits sometimes take more days than trucked freight, so there is a "speed lag" cost to consider in determining the total logistics costs of a supply chain. Intermodal rail also carries the risk of missing train cut-off times, which can increase transit times. Based on the average value per volume or average value per ton, it is possible to calculate per-day inventory carrying costs to the receiver and the cash-flow costs to the supplier from delayed payment so that the "speed lag" costs can be determined. Terms of payment, whether shipping is controlled or arranged by the shipper or receiver, and whether freight is being transported for pre-sold orders versus replenishment of inventory, also have implications for desired speed.

Of related importance is greater accountability and transparency in meeting customer commitments for multi-modal transit moving through multiple terminals. The Canadian National Railway addressed this issue in 2010 by instituting a supply-chain scorecard that specifies performance targets and service measures, and calls for balanced accountability among supply-chain participants to provide better end-to-end transportation solutions that would help mutual customers compete more effectively in end markets (Morgeau 2010).

PUBLIC COST: MEASURING INFRASTRUCTURE EFFICIENCY

The social costs of truck emissions, congestion and safety, and highway and bridge repair are enormous and make it difficult to quantify the social benefits from public-private partnerships designed to divert more freight to more energy efficient rail than to greater highway capacity, dedicated truck lanes, and highways.

Emissions

Public funding of transportation projects are often judged by attaining environmental goals of reducing gaseous or particulate matter emissions by focusing on comparing the replacement technology to the current technology. Taking this approach often does not translate into freight efficiency improvements. For example, Table 2 shows that an intermodal terminal design that conserves energy by reducing handling will result in a better return on investment in terms of energy savings and emission reductions (e.g., lower cost per ton of particulate matter or reductions in nitrogen oxide emissions) than a technology replacement or retrofits that provide cleaner and more energy efficient equipment.

Congestion and Safety

Congestion, as an inefficiency factor, is not easily measured, but can be indirectly assessed with average speeds along highways or rail corridors, and the percentage of time that freight is not moving. Increasingly, this has been captured by the supply chain with equipment tracking technology more so for over-the-road trailers than for intermodal containers. Although North American railroads have invested heavily to upgrade their intermodal networks for higher speeds, sharing access with slower freight trains, Amtrak, and local passenger trains results in a considerable amount of idle time waiting along rail sidings or inside or outside terminals for traffic to clear. Not surprisingly, a tracked container moving from California to Atlanta was found to be in motion for less than 50% of the time (Elango et al. 2008). Because performance along corridors varies widely, information on idle time and average speed while in motion broken down by corridor would be helpful to better understand congestion-related delays along rail intermodal corridors.

Intermodal rail infrastructure investments are being considered to improve roadway safety and reduce highway fatalities because the fatality rate associated with the movement of intermodal containers by rail has been estimated to be nine times safer than moving similar containers by truck (U.S. Department of Transportation 2010). Despite the safety benefit of greater volumes of freight moving intermodal, measures do not exist that quantify the benefits of a public investment in intermodal in terms of less energy wasted, reduced accidents, and fatalities.

Highway and Bridge Maintenance

Shifting 50 million of the 300 million long-distance truck originations of more than 300 miles (ACT Research 2007) to intermodal has the potential to dramatically reduce the wear and tear on bridges and highways. Since fuel taxes and fees cover only about 50% of the costs of highways and bridge maintenance and repair (Dutzik et al. 2011), any increase in intermodal market share will simultaneously increase freight energy efficiency while shrinking the difficult to quantify deficit between highway tax/fee revenue from trucks and the maintenance/repair costs caused by trucks.

CONCLUSIONS

Up until recently, the focus in assessing the performance of intermodal transportation was mostly on modal and terminal capacity and throughput. While these assessments remain entirely valid, economic and environmental considerations are primarily being used to assess investments such as raising bridge and tunnel clearances for double stack service, double tracking congested corridors, adding more and longer rail sidings, and new or retrofitted terminals. Largely by default, emissions have developed into one of the primary quantitative criteria used in analyzing public-private partnership funding of intermodal freight investments. This is an understandable development. Unlike other criteria such as safety, congestion, and highway maintenance, emission reductions can be quantified and objectively compared. Unfortunately, emission reductions are a poor indicator of freight efficiency. Thus, in an era of limited availability of public funding, maximizing returns on investment is even more salient.

Energy-based freight efficiency analysis ensures the best public and private return on investment in reaching the national goal of getting a much greater share of freight off the highways and on the railways. Whether freight efficiency is evaluated strictly in terms of energy-based sustainability, or includes economic efficiency and social factors as well, additional metrics like CCPA and CHEF, which can be applied to any rail or port terminal in North America to determine its efficiency, are clearly valuable. All aspects of intermodal freight transportation need to be analyzed so that robust carbon accounting methodologies and tools can be developed.

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***Jack Lanigan, Sr.**, Chairman of the Board, Mi-Jack Products Inc. Since founding Mi-Jack in 1954, Mr. Lanigan has been credited with collaborating with the railroads on many important intermodal innovations. Mr. Lanigan introduced the first Drott reliable overhead rubber tire gantry crane in 1963 for TOFC (trucks on flat cars), now called intermodal. Working with the Santa Fe in the mid-1960s, Lanigan helped convince the shipping industry to standardize container lengths and corner castings so that the railroads (Santa Fe, Union Pacific, and the Southern Pacific) could accommodate all the ship lines' containers, which made the landbridge feasible. In 1967, Mi-Jack delivered the first crane with the twist lock top pick for the new standardized container, but because Matsen, APL, and Sealand all had different corner castings and container sizes, Lanigan developed a corner side latch as a temporary top pick for the nonstandard containers during the transition. In the late 1970s, Lanigan worked with the Southern Pacific Railroad and APL on the top spreader that would accommodate the high side wall double stack car, and at the same time encouraged the development of the low side wall so that any type of side loader or overhead crane could load or unload double stack cars. Aside from equipment innovation, Mr. Lanigan is credited with developing the 2 for 1 terminal design (now the standard), and establishing one of the largest rail and port terminal operations in the nation, culminating in the 1997 Mi-Jack/Kansas City Railway Company joint venture to rebuild and operate the Panama Canal Railway to significantly reduce the volume of trucks transporting containers across the Isthmus highway. Lanigan was awarded the Intermodal Association of North America's Silver King Award (1989) and Intermodal Achievement Award (1992 on behalf of Mi-Jack) in acknowledgement of his contributions. David DeBoer in "Piggyback and Containers: A History of Rail Intermodal on America's Steel Highway" states that intermodal pioneers like Lanigan "cared so deeply about improving the business that they went substantially beyond the normal manufacturer-customer relationship. They often became missionaries for improvements that were only indirectly related to their primary products." www.mi-jack.com*

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A Strategic Variance Analysis of the Profitability of U.S. Network Air Carriers

by Paul Caster and Carl A. Scheraga

Airlines, as part of their strategic planning process, articulate positions with regard to cost leadership, product differentiation, and growth. Decisions implemented are dynamic and inter-temporal in nature. Therefore, it is often difficult to assess the effectiveness of changes in strategies, particularly since such effectiveness is often a function of the confounding forces of organizational strategy and market conditions. Managers thus need a multi-period methodology to evaluate the implementation of strategic positions. One such approach is the strategic variance analysis of operating income.

Horngren et al. (2000, 2006, 2012) demonstrate a methodological template for decomposing operating income into three components: (1) growth, (2) price recovery, and (3) productivity. It is suggested that the price recovery component assesses a firm's product differentiation strategy and that the productivity component assesses a firm's low-cost strategy. Thus, this framework is very much in the spirit of Porter's (1980) seminal work.

This study examines U.S. network airlines in the post-9/11 environment. Utilizing the above methodology, it first identifies comparative strategic positions across airlines and then assesses the implementation efficacy of these positions.

INTRODUCTION

The decade from 2000-2010 was a tumultuous one for the U.S. airlines industry. This has been particularly so for network carriers (as classified by the U.S. Department of Transportation) Alaska, American, Continental, Delta, Northwest, United, and US Airways. Since the upheaval of 9/11, United, Delta, US Airways (twice), and Northwest have all filed for bankruptcy. American and Continental reorganized outside of bankruptcy. Not including regional affiliates, these airlines account for a 58% share of the U.S. market (Herbst 2009).

In comparing 2008 with 2000, Herbst (2009) details some dramatic statistics for the so-called legacy carriers—American, Continental, Delta, Northwest, United, and US Airways.[1] Total operating revenue decreased by $2.3 billion, falling from $89.2 billion to $86.9 billion. Fuel cost went from $11.3 billion to $36 billion (an increase of 218%). More specifically, the fuel cost for the average one-way passenger fare increased by 304%, going from $23 to $93. Capacity as measured by available seat miles (ASMs) decreased by 14.3%. At the same time, employee wage/salary expense decreased by 33.5%. The average one-way passenger fare increased by 22%, going from $162 to $198. While the average air fare increased by $36, the labor wage cost for the average air fare decreased by 36% to $41. Since 9/11, over 155,000 jobs for just the legacy carriers have been lost, falling from 428,000 to 272,000 (a decrease of 36%) total employees. The average passenger ratio to airline employee increased from 1,139 passengers per employee to 1,413. As employees worked more for less, the average revenue generated per employee increased by 53%, going from $209,000 per employee to over $319,000.

Data from the Security and Exchange Commission (10K Reports) and the Bureau of Transportation Statistics show a similar pattern for Alaska Airlines for this time period. While operating revenues increased 83%, operating income declined by 82%. Average fuel cost increased by 232%, although available seat miles increased by 25%. The average passenger fare increased by 34%. From 2002 to 2008, the average number of passengers per employee increased from 1,396 to

1,746, the average revenue per employee increased by 63%, the number of employees decreased by 5%, and wages and benefits as a percentage of operating income decreased by 5.9%.

This study utilizes strategic variance analysis to investigate how changes in network airlines' strategies, in the post-9/11 environment, have impacted operating income. The analysis will not only allow for the examination of the impact of a carrier's strategic actions with regard to managing growth, price-recovery, productivity, and capacity, but will also allow for a benchmarking of the efficacy of a carrier's strategies against those of its rivals. As noted below, this kind of analysis is particularly useful in a dynamic environment such as that faced by the network carriers, where strategic actions by rivals are simultaneous and interactive (Mudde and Sopariwala 2008b).

Several recent articles have applied strategic variance analysis to analyze a given airline's profitability (Mudde and Sopariwala 2008a and Bailey et al. 2009) or to examine a given airline's cost structure (Dikolli and Sedatole 2004). However, none of these articles provides a comprehensive and strategic analysis of airline profitability by comparing each carrier to similar airlines in their sector of the industry, nor has any study been conducted over an extended period of time.

STRATEGIC VARIANCE ANALYSIS

In his seminal work, Michael Porter (1980) developed the paradigm of three generic strategies for creating a competitive advantage. A firm pursuing a position of cost leadership will emphasize efficiency in order to lower costs, thus being able to under-price competitors. The focus of such a strategy is one of low margins and high volume. A firm with a strategic orientation toward differentiation seeks to produce a product or service that embodies distinctive qualities for which customers are willing to pay a premium price. The third strategy is a niche-seeking one. This strategy seeks to identify a small part of the market not served by direct competitors of the firm. The firm is able to charge a premium price for a high quality product desired by this small market segment, that is, volume of sales will be low but margins high.

Banker and Johnston (2002) argue that in increasingly dynamic business environments, in the context of Porter's strategy framework, "it has become increasingly important for managers to develop coherent, internally and logically consistent business strategies and to have tools and models which provide useful information to support strategic decision-making, planning and control." One development, in response to this strategic mandate, has been the emergence of strategic variance analysis (SVA). Shank and Churchill (1977) note that variance analysis is the term applied to the process of specifying the reasons as to why actual operating income, for a given period, is different from the expected or planned level of operating income. Operating income is decomposed into components (and their associated measures) that logically relate to a firm's business strategy as described by Porter above. The variances are differences in the component measures of budgeted versus actual operating income.

Specifically, Shank, and Govindarajan (1993) decompose variances in operating revenues into mutually exclusive sub-variances in order to separate out the impacts of key underlying causal factors. They define the notion of corporate mission in terms of profitability and the orientation/perspective of build, hold, or harvest. They further define the notion of strategy in terms of Porter's low cost leadership and product differentiation. They then argue that by analyzing the sub-variances with reference to a firm's mission and strategy, one can determine the extent to which variances between actual and budgeted performance are consistent, or not consistent, with the above mission and strategy. Furthermore, these variances can suggest the dimensions of performance that need improvement. The framework of Horngren et al. (2012) provides the specification of the components of operating revenues utilized in this study.

THE FRAMEWORK OF THIS STUDY

Horngren et al. (2000, 2006, 2012) provide a framework for analyzing a manufacturer's change in operating income from one period to *any* future period by decomposing company performance into cost leadership, product differentiation, and growth components. Sopariwala (2003) extends the SVA model in Horngren et al. (2000) to include underutilization of capacity as a fourth factor in the analysis. Capacity utilization is an important consideration, particularly in the airline industry, where carriers make strategic decisions about grounding existing airplanes or purchasing new airplanes and expanding their fleets. Mudde and Sopariwala (2008b) adapt the Horngren et al. (2000) framework to include factors unique to the airline industry. They also choose cost drivers, such as RPMs and ASMs, that are more suitable to airlines as compared with those that would be used by manufacturers. The individual components described in Mudde and Sopariwala (2008b) are as follows:

Growth Components

The growth component for an airline measures the change in operating income caused by variations in revenue-passenger miles (RPMs) (holding sales prices, input costs, and input-output relationships constant) that are due to either changes in market share or in market size.

Price-Recovery Component

The price-recovery component measures the change in operating income caused by variations in sales prices and unit input costs (holding sales units, for example RPMs or ASMs, and input-output relationships constant). Horngren et al. (2012) suggest that the price-recovery component assesses a firm's *product differentiation strategy*. A positive value for this component implies that the firm's product differentiation strategy provided sufficient pricing power to the firm so that its customers were induced to reimburse the firm by an amount greater than the increase in costs experienced by the firm.

Productivity Component

The productivity component measures the change in operating income caused by variations in input-output relationships (holding RPMs, sales prices, and unit input costs constant). Horngren et al. (2012) suggest that this component assesses a firm's *low-cost strategy*. A positive value for this component implies that operating income increased because of gains in the firm's efficiency.

Capacity Underutilization Component

The capacity underutilization component measures the change in operating income caused by a variation in the cost of unused capacity over the time period being considered. Sopariwala (2003) suggests that this component assesses a firm's ability to manage the critical tradeoff between used and unused capacity.

The empirical specifications of each of these components are provided in the appendix. The specifications utilized are those provided in Mudde and Sopariwala (2008b), who show the variances were normalized by dividing by revenue-passenger miles in billions.

PURVIEW OF THIS STUDY

Mudde and Sopariwala (2008b) performed an SVA on Southwest Airlines for the year 2005 relative to 2004. They showed that the $266.5 million increase in operating income in 2005 was primarily the result of Southwest's productivity gains during the period. Southwest has a reputation in the industry as a cost leader, and during the period, they reduced fuel usage costs, decreased costs due to increases in passenger load factor, and decreased costs due to increases in miles flown per passenger, all consistent with their strategy as a low cost leader.

Mudde and Sopariwala (2008a) used this SVA of Southwest Airlines for the year 2005 as a benchmark for United Airlines for the same year. Their analysis illustrated that an SVA of a single company, taken by itself, may produce misleading results. For example, when examining the growth component, United Airlines appeared to be doing better in 2005 due to an increase in the size of the market. But that increase was negligible when compared with Southwest. However, it is not obvious that Southwest Airlines is an appropriate benchmark for United Airlines (see Tsoukalas et al. 2008). In an unpublished working paper, Mudde and Sopariwala (2010) use industry averages taken from the U.S. Department of Transportation, Bureau of Transportation Statistics to benchmark the performance of American Airlines for the year 2009. We believe this may be an improvement over benchmarking against a single competitor. However, we question the choice of the entire U.S. airline industry as an appropriate benchmark. We suggest that, for the present study, a composite based on using just the U.S. network airlines would make a more appropriate benchmark.

TIMEFRAME OF THIS STUDY AND ASSOCIATED DATA SET

The data needed to calculate the variances for SVA are collected from the International Civil Aviation Organization, *Financial Data: Commercial Air Carriers, Series F* and *Traffic: Commercial Air Carriers, Series T*, as well as the U.S. Department of Transportation, Bureau of Transportation Statistics, *TranStats Aviation Database* for the relevant years.

We examine two, three-year time periods: 2004 to 2006 and 2007 to 2009. A three-year window is utilized because of the need to allow time for changes in strategic choices to impact logistical, technological, and capacity configurations that impact operational efficiency. Precedence for measuring the impact of such strategic choices from one end point of a multi-year period to the other can be found in Greer (2006) and Scheraga (2011). We chose 2004 as the starting point of the analysis because the airline industry was severely disrupted in the aftermath of 9/11 and the industry did not return to pre-9/11 levels until July 2004 (Bureau of Transportation Statistics 2005).

The analysis for the time period 2004-2006 included all seven of the network airlines—Alaska, American, Continental, Delta, Northwest, United, and US Airways. However, US Airways was not included in the latter time period. US Airways and America West merged in September of 2005 (although actual integration was not implemented until 2007), with unconsolidated financial and operating data for these two airlines not being available after 2007. For purposes of benchmarking, we constructed a composite in each time period from all the airlines being examined in that particular time period.

The data set includes both U.S. and international flights of each airline. The data set excludes flights of regional airlines that may have partnerships with network airlines. Regional airlines have a different profile and would not be comparable to network airlines.

RESULTS OF THE STRATEGIC VARIANCE ANALYSIS

First we illustrate the calculation of SVA using data for Delta Airlines. As shown in Table 1, Delta Airlines had a $1.157 billion operating loss in 2003, but three full years later, by the end of 2006, it recorded a $30.84 million operating profit. Thus, for the three-year period ending in 2006, operating profitability increased by $1.188 billion. In 2009, Delta was back in the red with a $604.8 million operating loss. Thus, for the three-year period ending in 2009, operating profits decreased by $635.6 million. Examining individual lines in the income statements is not very meaningful to gauge what happened during these two, three-year periods, or which aspects of Delta's strategies were more or less successful.

Table 1: Example: Delta Airlines – Financial Data ($)

	2003	2006	2009
Operating Revenues	14,203,030,000	17,339,136,000	18,046,578,000
Operating Expenses	15,360,195,000	17,308,296,000	18,651,424,000
Flying Operations	4,328,788,000	5,642,667,000	6,130,117,000
Maintenance	1,168,779,000	1,133,176,000	1,294,256,000
Depreciation and amortization	1,099,559,000	1,194,253,000	961,664,000
User charges	302,370,000	319,343,000	413,798,000
Station expenses	2,103,243,000	1,786,841,000	1,815,537,000
Aircraft and traffic servicing	2,405,613,000	2,106,184,000	2,229,335,000
Passenger services	1,416,162,000	1,114,511,000	1,313,133,000
Promotion and sales	1,219,397,000	1,190,751,000	1,174,798,000
General & Administrative	953,176,000	925,343,000	1,112,997,000
Transport related expenses	2,768,721,000	4,001,411,000	4,435,124,000
Operating profit	-1,157,165,000	30,840,000	-604,846,000

Data Source: International Civil Aviation Organization, *Financial Data: Commercial Air Carriers Series F*, Montreal, Quebec, Canada, 2003, 2006, and 2009

Table 2 provides the operational data for Delta Airlines needed to perform the SVA, and Table 3 provides the fuel data. Table 4 reclassifies the financial data into the categories used by Mudde and Sopariwala (2008a, 2008b), namely fuel costs, flight-related costs, and passenger-related costs. Flight-related costs include flying operations less fuel costs, plus maintenance, passenger service, general and administrative costs, depreciation and amortization, and transport-related costs. Passenger-related costs include aircraft and traffic servicing expenses and promotion and sales-related expenses. Finally, Table 5 calculates the data used to perform the SVA based on the reclassified financial data in Table 4 combined with the operational data in Table 2 and the fuel data in Table 3. Finally, variances are calculated using the formulas in Appendix A and the data are normalized based on revenue-passenger-miles (RPMs) in billions. This results in the SVA presented in Tables 6a and 6b, in addition to the other network air carriers in this study.

Table 2: Example: Delta Airlines – Operational Data

	2003	2006	2009
Revenue passenger enplanements	84,076,432	73,524,956	67,744,784
Revenue passenger miles	89,135,332,782	98,748,194,606	100,582,412,275
Available seat miles	119,886,312,311	125,073,038,393	122,149,414,544

Data Source: International Civil Aviation Organization, *Traffic: Commercial Air Carriers, Series T*, Montreal, Quebec, Canada, 2003, 2006, and 2009

Table 3: Example: Delta Airlines – Fuel Data

	2003	2006	2009
Total gallons used	2,009,322,668	1,932,690,482	1,934,723,833
Total fuel costs	1,594,053,782	4,069,259,987	4,663,250,851
Average fuel cost per gallon ($)	0.79	2.11	2.41

Data Source: U. S. Department of Transportation, Research and Innovative Administration, Bureau of Transportation Statistics, *TranStats Database*, Washington, D. C., 2003, 2006, and 2009

Table 4: Example: Delta Airlines – Reclassified Financial Data ($)

	2003	2006	2009
Total operating revenues	14,203,030,000	17,339,136,000	18,046,578,000
Less: Total operating expenses	15,360,195,000	17,308,296,000	18,651,424,000
Fuel costs	1,594,053,782	4,069,259,987	4,663,250,851
Flight-related costs	10,141,131,218	9,942,101,013	10,584,040,149
Passenger-related costs	3,625,010,000	3,296,935,000	3,404,133,000
Operating income/(loss)	-1,157,165,000	30,840,000	-6,0484,6000

	2003	2006	2009
Flying operations	4,328,788,000	5,642,667,000	6,130,117,000
Less: Fuel cost	1,594,053,782	4,069,259,987	4,663,250,851
Flying operations (excluding fuel cost)	2,734,734,218	1,573,407,013	1,466,866,149
Maintenance	1,168,779,000	1,133,176,000	1,294,256,000
Passenger service	1,416,162,000	1,114,511,000	1,313,133,000
General and administrative	953,176,000	925,343,000	1,112,997,000
Depreciation and amortization	1,099,559,000	1,194,253,000	96,1664,000
Transport related	2,768,721,000	4,001,411,000	4,435,124,000
Total flight-related costs	10,141,131,218	9,942,101,013	10,584,040,149

	2003	2006	2009
Aircraft and traffic servicing	2,405,613,000	2,106,184,000	2,229,335,000
Promotion and sales	1,219,397,000	1,190,751,000	1,174,798,000
Total passenger-related costs	3,625,010,000	3,296,935,000	3,404,133,000

Data Sources: 1) Data Source: International Civil Aviation Organization, *Financial Data: Commercial Air Carriers, Series F*, Montreal, Quebec, Canada, 2003, 2006, and 2009 and 2) U. S. Department of Transportation, Research and Innovative Administration, Bureau of Transportation Statistics, *TranStats Database*, Washington, D. C., 2003, 2006, and 2009.

The SVA of Delta clearly shows how Delta achieved profitability by the end of 2006. During the three-year period, productivity improvements resulted in almost $1.5 billion in increased operating profits. Cost cutting occurred across the board, but particularly in passenger-related activities. Delta's annual reports filed with the Securities and Exchange Commission (SEC) reveal some specific examples of cost-cutting measures taken. Delta eliminated approximately 6,000 non-pilot jobs, reduced pay and benefits for non-pilot employees, and simplified the fleet by retiring four different fleet types. Additionally, it redesigned hubs in Atlanta and elsewhere to improve reliability and thereby reduce costs (SEC 2004, 2005).

The price-recovery component indicates an almost $1 billion decrease in profitability. The analysis indicates that increases in Delta's airfares were not sufficient to cover increased fuel costs during the period. Management of capacity resulted in approximately $510 million in increased profitability for the three-year period. The Delta Annual Report indicated that existing capacity was shifted in part from certain underperforming domestic flights to more profitable international flights (SEC 2006). The growth component indicates a modest $154 million improvement.

For the three years ending in 2009, the SVA of Delta shows a similar pattern to the earlier period, except that productivity gains were far smaller and not nearly sufficient to cover tremendous losses in the price-recovery component. The price-recovery component shows a loss of over $1.3 billion. The small increase in airfares was overwhelmed by large increases in fuel costs, flight-related costs, and passenger-related costs, holding all else equal. Productivity gains were more modest than in the prior three-year period. Delta achieved savings of $359 million in passenger-related costs and almost $200 million in fuel used per available seat mile. Capacity management contributed $222.3 million in profitability and the growth component shows an increase of $39.3 million. Nonetheless, the large loss in the price-recovery component resulted in an overall decrease in profitability of $635.7 million for the three years.

The SVA for Delta is insightful and interesting, but it is an incomplete analysis without taking into consideration what was happening with its closest competitors. For this reason, we conduct a relative SVA by ranking each of the network carriers on the four components of SVA. Table 7a shows the rankings for the three-year period ending in 2006, after normalizing the data using RPMs in billions. The domestic airline business finally reached pre-9/11 levels in July 2004, and continued to grow during this period. Thus, six of the seven network airlines saw positive contributions to operating income based on growth of the business, but Continental and Alaska led the way by far, while Northwest and United were laggards. US Airways actually experienced a decline during this time period.

The price-recovery component indicates the extent an airline increases its fares relative to related increases in costs, holding all else equal. It is an indicator of product differentiation. As seen in Table 7a, US Airways experienced very positive contributions to profitability, followed by United and Northwest, while all other airlines were unable to raise fares in an amount sufficient to cover increased costs. Alaska ranked last in this category during this period, followed by Delta.

The productivity component was positive for all seven carriers. Delta led the way in this category, followed by Alaska, with Northwest and United ranking sixth and seventh respectively. Examining the price-recovery and productivity components together suggests that Northwest and United followed a product differentiation strategy while Delta and Alaska led the way in cost cutting to improve productivity. Finally, US Airways ranked first in improved profitability through management of capacity, and all but Continental showed increased profitability related to capacity changes.

Table 7b shows the rankings (now with US Airways excluded) for the three-year period ending in 2009, after normalizing the data using RPMs in billions. The growth component rankings are similar during this period. Continental again ranked first of the six airlines while Alaska slipped to third place from second in the earlier period. Northwest and United were at the bottom, though in reverse order from the earlier period. But notably, changes in the overall market resulted in decreases in profitability for Northwest, United, and also American.

Table 5: Example: Delta Airlines – Data Used in Strategic Variance Analysis

	2003	2006	2009
Total operating revenues ($)	14,203,030,000	17,339,136,000	18,046,578,000
Revenue passenger miles (RPMs)	89,135,332,782	98,748,194,606	100,582,412,275
Average revenue per RPM	0.159	0.176	0.179
Revenue passenger miles (RPMs)	89,135,332,782	98,748,194,606	100,582,412,275
Available seat miles (ASMs)	119,886,312,311	125,073,038,393	122,149,414,544
Passenger load factor (%)	74.35%	78.95%	82.34%
Hence, budgeted available seat miles	121,619,209,417	132,815,534,864	127,396,232,026
Revenue passenger miles (RPMs)	89,135,332,782	98,748,194,606	100,582,412,275
Revenue passenger enplanements	84,076,432	73,524,956	67,744,784
Average revenue passenger miles per passenger ($)	1060.17	1343.06	1484.73
Hence, budgeted revenue passenger enplanements	87,386,930	93,143,713	74,890,660
Number of gallons used	2,009,322,668	1,932,690,482	1,934,723,833
Available seat miles (ASMs)	119,886,312,311	125,073,038,393	122,149,414,544
Average number of gallons per ASM	0.0167602	0.0154525	0.0158390
Total flight-related costs ($)	10,141,131,218	9,942,101,013	10,584,040,149
Available seat miles (ASMs)	119,886,312,311	125,073,038,393	122,149,414,544
Average flight-related cost per ASM ($)	0.085	0.079	0.087
Total passenger-related costs ($)	3,625,010,000	3,296,935,000	3,404,133,000
Revenue passenger enplanements	84,076,432	73,524,956	67,744,784
Average cost per revenue passenger ($)	43.12	44.84	50.25
Revenue passenger (RPMs)	89,135,332,782	98,748,194,606	100,582,412,275
Available seat miles (ASMs)	119,886,312,311	125,073,038,393	122,149,414,544
Idle or unused capacity (ASMs)	30,750,979,530	26,324,843,787	21,567,002,269
Hence, budgeted idle capacity (ASMs)	32,483,876,636	34,067,340,258	26,813,819,751

Data Sources: 1) International Civil Aviation Organization, *Financial Data: Commercial Air Carriers, Series F*, Montreal, Quebec, Canada, 2003, 2006, and 2009, 2) International Civil Aviation Organization, *Traffic: Commercial Air Carriers, Series T*, Montreal, Quebec, Canada, 2003, 2006, and 2009, and 3) U.S. Department of Transportation, Research and Innovative Administration, Bureau of Transportation Statistics, *TranStats Database*, Washington, D.C., 2003, 2006, and 2009.

The price-recovery component indicates a dramatic change in the rankings for Alaska, going from last to first, while United maintained its second place ranking. Alaska was also the only airline of the six to increase fares in sufficient amount to cover related increases in costs. American and Continental, which were fourth and fifth respectively in the earlier period, slipped to fifth and sixth during the latter period.

Alaska ranked first in productivity for the three years ending 2009, while Delta slipped from first to fourth place. The results for Alaska are impressive, as it not only ranked first in price-recovery, but also first in productivity. Alaska was successful in cutting costs and also in raising fares rather than passing along the cost savings to its customers. American slipped to last place in productivity, but all six airlines experienced increases in profitability through productivity gains.

Delta, United, and Continental improved profitability through capacity management, while American, Alaska, and Northwest saw profitability decreases during the period related to capacity management.

STAGE LENGTH, DOMESTIC VERSUS FOREIGN OPERATIONS, AND SVA RANKINGS

Stage or average flight length is a concept that captures economies of distance. It has been suggested that there is a correlation between average flight length and unit cost. This occurs because for a given aircraft size, increasing the distance of a flight results in larger output volume as measured in RPMs. However, it must be noted that, empirically, this posited effect has been shown to be ambiguous (Caves et al. 1981 and Tretheway 1984).

The ratio of domestic scheduled revenue passenger-miles to international schedule passenger-miles captures the international focus of an airline. A priori, the impact of this measure is not unambiguous, although there are arguments to suggest a potential negative influence on operational efficiency. Fethi et al. (2002) suggest that an increase in the international focus of an airline exposes it to spatial disparities in its operating environment. In structuring bilateral agreements, the international air transport system has tended to focus on individual or small sets of routes between countries. This has impeded the achievement of high levels of efficiency over global networks of air services. There are unresolved issues with regard to ownership and control, cabotage and the right of establishment (the setting up and management of companies). There is still divergence across geographic regions with regard to competition law and policy in air transport. There are differences in fiscal policies with air transport being subjected to many taxes, which is finance general governmental expenditure, while customs clearance can impede both speed and reliability. Finally, airport infrastructure constraints can significantly affect the level of competition in particular markets.

Pearson correlation coefficients were calculated between an airlines' ranking on each component of the SVA analysis and their corresponding rankings for stage length and the ratio of domestic scheduled revenue passenger-miles to foreign scheduled revenue passenger-miles. There were no statistically significant correlations for either the 2004-2006 time period or the 2007-2009 time period.

FURTHER ANALYSIS OF THE GROWTH COMPONENT AND CONCLUSIONS

The domestic airline industry was rocked by the 9/11 tragedy and in the years following 9/11. This was coupled with a general economic downturn that lasted approximately three years. As traffic increased to pre-9/11 levels, the industry began to experience tremendous increases in fuel costs that threatened the very existence of many airlines. The industry was again severely hit, beginning in mid-2008, by the worst economic recession since the 1930s. Particularly hard hit were the legacy or network carriers. Management of these airlines was tasked with developing strategies to deal with dramatic changes in growth and the cost of inputs.

Table 6a: Strategic Variance Analysis 2004-2006

	Alaska	American	Continental	Delta	Northwest	United	US Airways	Composite
GROWTH COMPONENT 2004-2006								
Revenue effect	453,691,878	2,811,775,915	2,496,491,053	1,531,735,627	553,888,048	1,727,294,826	-66,291,108	9,855,630,117
Fuel cost effect	-66,403,583	-388,327,209	-358,212,552	-171,911,836	-84,464,216	-248,461,285	7,094,394	-1,317,325,858
Flight-related cost effect	-175,151,540	-1,375,345,063	-1,061,955,929	-813,147,817	-227,598,043	-890,324,602	33,377,004	-4,780,185,949
Passenger-related effect	-139,294,499	-768,232,901	-728,649,836	-390,941,719	-191,634,632	-514,421,314	17,788,048	-2,820,943,581
TOTAL	**72,842,256**	**279,870,742**	**347,672,736**	**155,734,255**	**50,191,158**	**74,087,625**	**-8,031,663**	**937,174,729**
PRICE-RECOVERY COMPONENT 2004-2006								
Revenue effect	211,439,122	2,278,247,085	3,180,486,947	1,604,370,373	2,817,239,952	4,208,835,174	1,380,200,108	15,333,774,883
Fuel cost effect	-471,710,024	-3,828,438,185	-1,853,965,777	-2,920,895,535	-2,246,447,729	-2,841,063,847	-1,007,233,236	-15,222,020,603
Flight-related cost effect	-133,242,925	865,320,879	-1,671,102,977	503,537,331	-700,464,092	-1,029,314,359	-158,519,829	-2,032,146,563
Passenger-related effect	59,044,396	436,067,853	25,400,970	-160,708,624	353,833,643	687,418,915	217,983,665	1,493,693,325
TOTAL	**-334,469,432**	**-248,802,368**	**-319,180,837**	**-973,696,455**	**224,161,774**	**1,025,875,882**	**432,430,708**	**-426,698,958**

Table 6a (continued)

	Alaska	American	Continental	Delta	Northwest	United	US Airways	Composite
_PRODUCTIVITY COMPONENT 2004-2006								
Fuel cost effect	50,035,532	481,709,093	204,174,231	365,698,506	194,445,736	87,427,468	56,814,411	1,508,342,435
Fuel (ASM) cost effect	67,859,727	560,049,736	212,520,098	251,902,660	313,814,762	340,760,327	105,158,016	1,842,933,707
Passenger-related effect	48,306,103	246,734,048	268,723,866	879,725,343	8,554,989	269,628,399	168,608,287	2,121,185,256
TOTAL	**166,201,363**	**1,288,492,877**	**685,418,195**	**1,497,326,509**	**516,815,487**	**697,816,193**	**330,580,715**	**5,472,461,399**
CAPACITY UNDERUTILIZATION COMPONENT 2004-2006								
Unused capacities	-40,752,430	214,467,764	-378,268,935	134,235,787	-125,392,998	-224,154,281	-44,119,994	-481,362,397
Available capacities	-131,982,297	-649,794,077	-1,016,842,088	-438,742,912	164,855,537	-459,679,021	335,692,238	-2,470,754,722
Used capacities	175,151,540	1,375,345,063	1,061,955,929	813,147,817	227,598,043	890,324,602	-33,377,004	4,780,185,949
TOTAL	**2,416,813**	**940,018,750**	**-333,155,094**	**508,640,691**	**267,060,581**	**206,491,299**	**258,195,240**	**1,828,068,830**

Table 6b: Strategic Variance Analysis 2007-2009

	Alaska	American	Continental	Delta	Northwest	United	Composite
GROWTH COMPONENT 2007-2009							
Revenue effect	76,392,142	-2,746,117,173	247,721,124	322,069,175	-1,788,986,906	-2,792,013,981	-6,782,251,227
Fuel cost effect	-20,341,412	681,059,676	-54,221,482	-75,585,266	459,271,131	662,631,241	1,631,023,084
Flight-related cost effect	-30,956,254	1,101,536,116	-111,433,874	-145,802,625	669,969,292	1,274,484,766	2,898,030,959
Passenger-related effect	-18,566,661	590,939,477	-49,027,225	-61,239,564	428,428,256	512,292,668	1,390,268,958
TOTAL	**6,527,814**	**-372,581,904**	**33,038,544**	**39,441,720**	**-231,318,227**	**-342,605,306**	**-862,928,226**
PRICE-RECOVERY COMPONENT 2007-2009							
Revenue effect	237,099,858	151,015,173	-896,725,124	385,372,825	97,349,906	-182,607,019	-107,178,773
Fuel cost effect	103,408,138	5,602,930	114,270,960	-600,032,058	595,433,020	522,238,504	669,748,078
Flight-related cost effect	-202,025,261	-1,440,766,152	-39,062,189	-719,963,590	-868,515,032	-363,159,189	-3,749,230,763
Passenger-related effect	-9,109,301	-377,711,018	-272,718,665	-405,034,217	-373,895,922	-227,871,310	-1,598,991,366
TOTAL	**129,373,433**	**-1,661,859,067**	**-1,094,235,018**	**-1,339,657,040**	**-549,628,027**	**-251,399,014**	**-4,785,652,825**

Table 6b (continued)

	Alaska	American	Continental	Delta	Northwest	United	Composite
PRODUCTIVITY COMPONENT 2007-2009							
Fuel cost effect	85,057,117	8,308,068	141,677,759	-118,679,257	227,211,753	50,184,026	544,457,269
Fuel (ASM) cost effect	19,440,806	31,884,475	28,810,763	200,305,717	-24,843,792	-9,110,740	188,753,647
Passenger-related effect	81,661,963	23,640,541	223,950,890	359,075,781	386,617,666	178,274,642	1,198,430,408
TOTAL	**186,159,886**	**63,833,084**	**394,439,412**	**440,702,242**	**588,985,628**	**219,347,928**	**1,931,641,323**
CAPACITY UNDERUTILIZATION COMPONENT 2007-2009							
Unused capacities	-52,444,574	-345,352,446	-8,320,470	-154,375,462	-168,581,670	-80,286,845	-828,939,806
Available capacities	11,477,186	1,439,083,450	-57,020,340	232,399,916	729,066,589	1,527,048,003	4,017,372,492
Used capacities	30,956,254	-1,101,536,116	111,433,874	145,802,625	-669,969,292	-1,274,484,766	-2,898,030,959
TOTAL	**-10,011,134**	**-7,805,112**	**46,093,063**	**223,827,079**	**-109,484,373**	**172,276,392**	**290,401,727**

Table 7a: Normalized Strategic Variance Analysis 2004-2006

	Alaska	American	Continental	Delta	Northwest	United	US Airways	Composite
GROWTH COMPONENT 2004-2006	**2**	**3**	**1**	**4**	**5**	**6**	**7**	
Revenue effect	25,473,465	20,175,983	32,747,227	15,511,530	7,632,226	14,735,230	-1,774,916	17,621,381
Fuel cost effect	-3,728,366	-2,786,454	-4,698,782	-1,740,911	-1,163,863	-2,119,577	189,949	-2,355,314
Flight-related cost effect	-9,834,244	-9,868,830	-13,929,997	-8,234,559	-3,136,157	-7,595,193	893,655	-8,546,737
Passenger-related effect	-7,820,977	-5,512,478	-9,557,920	-3,958,976	-2,640,604	-4,388,432	476,267	-5,043,708
TOTAL	**4,089,879**	**2,008,221**	**4,560,528**	**1,577,085**	**691,602**	**632,028**	**-215,044**	**1,675,622**
PRICE-RECOVERY COMPONENT 2004-2006	**7**	**4**	**5**	**6**	**3**	**2**	**1**	
Revenue effect	11,871,685	16,347,631	41,719,408	16,247,086	38,819,781	35,904,788	36,954,265	27,416,033
Fuel cost effect	-26,485,131	-27,471,074	-24,319,029	-29,579,230	-30,954,626	-24,236,586	-26,968,237	-27,216,222
Flight-related cost effect	-7,481,199	6,209,136	-21,920,362	5,099,205	-9,651,951	-8,780,889	-4,244,300	-3,633,378
Passenger-related effect	3,315,169	3,129,018	333,192	-1,627,459	4,875,603	5,864,243	5,836,419	2,670,650
TOTAL	**-18,779,475**	**-1,785,289**	**-4,186,791**	**-9,860,398**	**3,088,807**	**8,751,556**	**11,578,146**	**-762,917**

Note: Numbers in shaded areas are rankings, from 1 to 7, of the effect of a component on operating income.

Table 7a (continued)

	Alaska	American	Continental	Delta	Northwest	United	US Airways	Composite
PRODUCTIVITY COMPONENT 2004-2006	**2**	**3**	**4**	**1**	**6**	**7**	**5**	
Fuel cost effect	2,809,348	3,456,518	2,678,215	3,703,344	2,679,339	745,827	1,521,181	2,696,842
Fuel (ASM) cost effect	3,810,124	4,018,654	2,787,690	2,550,960	4,324,169	2,906,963	2,815,561	3,295,075
Passenger-related effect	2,712,246	1,770,448	3,524,932	8,908,774	117,882	2,300,150	4,514,414	3,792,575
TOTAL	**9,331,718**	**9,245,620**	**8,990,837**	**15,163,077**	**7,121,390**	**5,952,940**	**8,851,157**	**9,784,491**
CAPACITY UNDERUTILIZATION COMPONENT 2004-2006	**6**	**2**	**7**	**3**	**4**	**5**	**1**	
Unused capacities	-2,288,129	1,538,920	-4,961,868	1,359,375	-1,727,836	-1,912,218	-1,181,294	-860,652
Available capacities	-7,410,418	-4,662,617	-13,338,225	-4,443,047	2,271,605	-3,921,436	8,988,015	-4,417,588
Used capacities	9,834,244	9,868,830	13,929,997	8,234,559	3,136,157	7,595,193	-893,655	8,546,737
TOTAL	**135,697**	**6,745,133**	**-4,370,096**	**5,150,886**	**3,679,926**	**1,761,539**	**6,913,067**	**3,268,497**

Note: Numbers in shaded areas are rankings, from 1 to 7, of the effect of a component on operating income.

Table 7b: Normalized Strategic Variance Analysis 2007-2009

	Alaska	American	Continental	Delta	Northwest	United	Composite
GROWTH COMPONENT 2007-2009	**3**	**4**	**1**	**2**	**6**	**5**	
Revenue effect	4,170,858	-22,445,070	3,188,719	3,202,043	-28,747,399	-27,838,296	-14,086,888
Fuel cost effect	-1,110,600	5,566,562	-697,950	-751,476	7,380,071	6,606,888	3,387,672
Flight-related cost effect	-1,690,150	9,003,278	-1,434,400	-1,449,584	10,765,800	12,707,488	6,019,276
Passenger-related effect	-1,013,703	4,829,975	-631,089	-608,850	6,884,454	5,107,909	2,887,620
TOTAL	**356,406**	**-3,045,255**	**425,279**	**392,133**	**-3,717,074**	**-3,416,010**	**-1,792,321**
PRICE-RECOVERY COMPONENT 2007-2009	**1**	**5**	**6**	**4**	**3**	**2**	
Revenue effect	12,945,178	1,234,305	-11,542,836	3,831,414	1,564,325	-1,820,717	-222,613
Fuel cost effect	5,645,877	45,795	1,470,920	-5,965,576	9,568,069	5,207,076	1,391,082
Flight-related cost effect	-11,030,175	-11,775,935	-502,817	-7,157,947	-13,956,250	-3,620,946	-7,787,237
Passenger-related effect	-497,350	-3,087,177	-3,510,492	-4,026,889	-6,008,169	-2,272,033	-3,321,141
TOTAL	**7,063,531**	**-13,583,012**	**-14,085,225**	**-13,318,999**	**-8,832,025**	**-2,506,621**	**-9,939,909**

Note: Numbers in shaded areas are rankings, from 1 to 6, of the effect of a component on operating income.

Table 7b (continued)

Table 7b (continued)

	Alaska	American	Continental	Delta	Northwest	United	Composite
PRODUCTIVITY COMPONENT 2007-2009	1	6	3	4	2	5	
Fuel cost effect	4,643,948	67,905	1,823,706	-1,179,921	3,651,087	500,369	1,130,850
Fuel (ASM) cost effect	1,061,429	260,604	370,858	1,991,459	-399,217	-90,840	392,046
Passenger-related effect	4,458,580	193,223	2,882,743	3,569,966	6,212,596	1,777,521	2,489,167
TOTAL	**10,163,957**	**521,732**	**5,077,308**	**4,381,504**	**9,464,466**	**2,187,049**	**4,012,063**
CAPACITY UNDERUTILIZATION COMPONENT 2007-2009	5	4	3	1	6	2	
Unused capacities	-2,863,369	-2,822,698	-107,103	-1,534,816	-2,708,955	-800,515	-1,721,727
Available capacities	626,631	11,762,182	-733,978	2,310,542	11,715,440	15,225,717	8,344,173
Used capacities	1,690,150	-9,003,278	1,434,400	1,449,584	-10,765,800	-12,707,488	-6,019,276
TOTAL	**-546,588**	**-63,794**	**593,320**	**2,225,310**	**-1,759,315**	**1,717,714**	**603,171**

Note: Numbers in shaded areas are rankings, from 1 to 6, of the effect of a component on operating income.

Horngren et al.'s (2012) SVA analysis provides a useful technique to understand how management of these airlines developed strategies to deal with these challenges. In terms of productivity, during the three-year period from 2004 to 2006, all seven airlines were successful in cutting costs, with Delta and Alaska leading the way. This trend continued in the three-year period from 2007 to 2009, with Alaska and Northwest leading the way. In terms of price recovery, management of US Airways, United, and Northwest were successful in differentiating their service, as they were the only airlines able to raise fares in amounts sufficient to cover increased costs in the earlier period. Alaska showed dramatic improvement in raising fares during the latter period in an amount sufficient to cover increased costs.

Horngren et al. (2012) suggest that some changes in profitability may be exogenous to a company, such as an overall improvement in the economy. Other changes may be endogenous, such as improvements that result from management's strategic decisions to increase productivity or raise selling prices. They also explain that companies that successfully implement a cost leadership strategy will generally exhibit favorable growth and favorable productivity. In contrast, companies that successfully implement a product differentiation strategy will generally exhibit favorable growth and favorable price-recovery. Implicit is an assumption that management will choose exclusively either a productivity-based strategy or a product differentiation strategy.

We believe the assumption of one exclusive strategy is too strong, and that management may choose a blended strategy. For example, even though management may decide upon a strategy of product differentiation, which often means they can successfully raise selling prices, it doesn't preclude them from also trying to increase productivity. In terms of the SVA, the importance of this relates to adjustments made to the variances calculated to take into consideration industry-wide or exogenous factors. Horngren et al. (2012) assume, a priori, a cost leadership strategy when they illustrate SVA. Thus, they make market adjustments to the growth component and the productivity component. Since we do not know, a priori, management's choice of strategy, and since management may follow a blended strategy at that, we only adjust the growth component for industry-wide factors.

In Tables 8a and 8b, we calculate the percentage change in RPMs for each network carrier. We also calculate a composite change for the network carriers in total. Table 8a is for the three-year period ending in 2006, and Table 8b is for the three-year period ending in 2009. Using Delta Airlines as an example, in the three-year period ending in 2006, Delta's RPMs increased by 10.60%. Taken by itself, this appears to be impressive growth. However, the composite for the network carriers grew by 13.63%. If one assumes that Delta should have met the composite growth rate, then the net effect on Delta's income for the period would be approximately $198 million. However, as shown in Table 6a, the net effect of growth on income for Delta was only approximately $154 million. Therefore, adjusting for the market impact, Delta actually fell short by approximately $44 million, in terms of the growth component.

The market adjustment to the growth component is also very revealing in the three-year period ending in 2009. Table 6b shows that Delta experienced a modest increase in net income of approximately $39 million due to growth. However, Table 8b shows that the composite for the network carriers was a decrease in RPMs of 7.64%. Delta's increase in RPMs during this period was 1.84%. Compared with all network carriers, this represents a 515% improvement in performance. If one assumes that Delta should have equaled the composite decrease in growth, then the net effect on Delta's income for the period would be a loss of approximately $163 million. Since Delta in fact produced an increase in income due to growth of approximately $39 million, it is as if it overcame a loss of $163 million to do so. Viewed in that perspective, it is equivalent to an increase of approximately $202 million ($39 million minus a loss of $163 million).

SVA is a useful management tool for analyzing strategies used to improve profitability. In the airline industry, many strategic decisions are made that, when implemented, may take several years to reach their full effect on company profits. This includes long-term fuel hedges and changes in capacity (adding planes, deleting routes, and reconfiguring seating). This paper illustrates that SVA may be performed for longer-term time frames to analyze strategic decisions. Further, the analysis shows the benefits of benchmarking performance against a peer group of companies, in this case the U.S. network airlines. The analysis indicated that Alaska Airlines in particular made great strides in improving profitability by not only cutting costs to improve productivity, but also increasing fares sufficiently to more than cover increases in fuel costs, which had risen dramatically during the period.

Table 8a: Impact of Endogenous Strategies - Growth Component, 2004-2006

	RPMs 2004	RPMs 2006	%Δ2004-2006	ENDOGENOUS
Alaska	14,553,539,641	17,822,404,781	22.46	39.31%
American	120,299,948,302	139,420,782,629	15.89	14.22%
Continental	57,577,384,885	76,302,518,293	32.52	58.09%
Delta	89,412,207,707	98,887,497,017	10.60	-28.58%
Northwest	68,746,644,596	72,674,331,902	5.71	-138.70%
United	104,371,719,160	117,445,990,416	12.53	-8.78%
US Airways	37,774,319,226	37,357,913,286	-1.10	-1339.09%
Composite	492,735,763,516	559,911,438,325	13.63	

Endogenous Effect = $[\%\Delta RPMs(2004\text{-}2006)_{\text{Airline i}} - \%\Delta RPMs(2004\text{-}2006)_{\text{Market}}] / |\%\Delta RPMs(2004\text{-}2006)_{\text{Airline i}}|$

Table 8b: Impact of Endogenous Strategies - Growth Component, 2007-2009

	RPMs 2007	RPMs 2009	%Δ2007-2009	ENDOGENOUS
Alaska	17,822,404,781	18,361,670,904	3.03	352.15%
American	139,420,782,629	122,391,483,735	-12.21	-37.43%
Continental	76,302,518,293	77,768,332,936	1.92	497.92%
Delta	98,887,497,017	100,711,842,838	1.84	515.22%
Northwest	72,674,331,902	62,941,173,546	-13.39	-42.94%
United	117,445,990,416	100,453,973,793	-14.47	-47.23%
Composite	522,553,525,039	482,628,477,752	-7.64	

Endogenous Effect = $[\%\Delta RPMs(2007\text{-}2009)_{\text{Airline i}} - \%\Delta RPMs(2007\text{-}2009)_{\text{Market}}] / |\%\Delta RPMs(2007\text{-}2009)_{\text{Airline i}}|$

APPENDIX – Calculation of Strategic Variances from Year i to Year j

The Growth Component

1. **Airline Revenues**
   [*Revenue effect of the Growth Component (i.e., lower expected revenue due to lower RPM)*]
   Variance = {Year i revenue/RPM} * {Year j RPMs – Year i RPMs}

2. **Fuel Costs**
   [*Fuel cost effect of the Growth Component (i.e., lower expected fuel costs due to lower RPMs)*]
   Variance = {Year i fuel cost/gallon} * {Year i gallons used per ASM} * {Year i actual ASMs – Year j budgeted ASMs}

3. **Flight-related Costs**
   [*Flight-related cost effect of the Growth Component (i.e., lower expected flight-related costs due to lower RPMs)*]
   Variance = {Year i cost/ASM} * {Year i passenger load factor} * {Year i actual ASMs – Year j budgeted ASMs}

4. **Passenger-related Costs**
   [*Passenger-related cost effect of the Growth Component (i.e., lower expected passenger-related costs due to lower RPMs)*]
   Variance = {Year i cost/passenger} * {Year i revenue passengers – Year j budgeted revenue passengers}

The Price-Recovery Component

1. **Airline Revenues**
   [*Revenue effect of the Price-Recovery Component (i.e., higher revenue due to higher airfares)*]
   Variance = {Year j RPMs} * {Year j revenue/RPM – Year i revenue/RPM}

2. **Fuel Costs**
   [*Fuel cost effect of the Price-Recovery Component (i.e., higher costs due to higher fuel prices)*]
   Variance = {Year j budgeted ASMs} * {Year i gallons used/ASM} * {Year i fuel cost/gallon – Year j fuel cost/gallon}

3. **Flight-related Costs**
   [*Flight-related cost effect of the Price-Recovery Component (i.e., higher costs due to higher flight-related costs per ASM)*]
   Variance = {Year j passenger load factor} * {Year j actual ASMs} * {Year i cost/ASM – Year j cost/ASM}

4. **Passenger-related Costs**
   [*Passenger-related cost effect of the Price-Recovery Component (i.e., higher costs due to higher costs per passenger)*]
   Variance = {Year j budgeted revenue passengers} * {Year i cost/passenger – Year j cost/passenger}

The Productivity Component

1. **Fuel Costs (a)**
   [*Fuel cost effect of the Productivity Component (i.e., lower costs due to lower fuel usage per gallon)*]
   Variance = {Year j fuel cost/gallon} * {Year j budgeted ASMs} * {Year i gallons used /ASM – Year j gallons used/ASM}

2. **Fuel Costs (b)**
   [*Fuel (ASM) cost effect of the Productivity Component (i.e., lower costs due to higher passenger load factor)*]
   Variance = {Year j fuel cost/gallon} * {Year j gallons used/ASM} * {Year j budgeted ASMs – Year j actual ASMs}

3. **Passenger-related costs**
   [*Passenger-related cost effect of the Productivity Component (i.e., lower costs due to higher miles per passenger)*]
   Variance = {Year j cost/passenger} * {Year j budgeted revenue passengers – Year j revenue passengers}

The Capacity Underutilization Component

1. **Flight-related costs (a)**
   [*Changes in flight-related costs relating to unused capacities (i.e., higher unit costs to acquire capacity that is unused)*]
   Variance = {Year j actual ASMs – Year j RPMs} * {Year i cost/ASM – Year j cost/ASM}

2. **Flight-related costs (b)**
   [*Changes in flight-related costs of available capacities (i.e., lower underutilization due to decrease in available capacity)*]
   Variance = {Year i cost/ASM} * {Year i actual ASMs – Year j actual ASMs}

3. **Flight-related costs (c)**
   [*Changes in flight-related costs of used capacities (i.e., higher underutilization due to decrease in capacity used)*]
   Variance = {Year i cost/ASM} * {Year j RPMs – Year i RPMs}

Endnotes

1. It wasn't possible to have data for a year later than 2009 since the study would have lost Northwest Airlines, which by 2010 had been fully assimilated into Delta Airlines. Full and separate non-consolidated data were available for Northwest through 2009. However, this was not the case for US Airways as unconsolidated data were available only through 2007, after which US Airways and America West data are both consolidated.

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